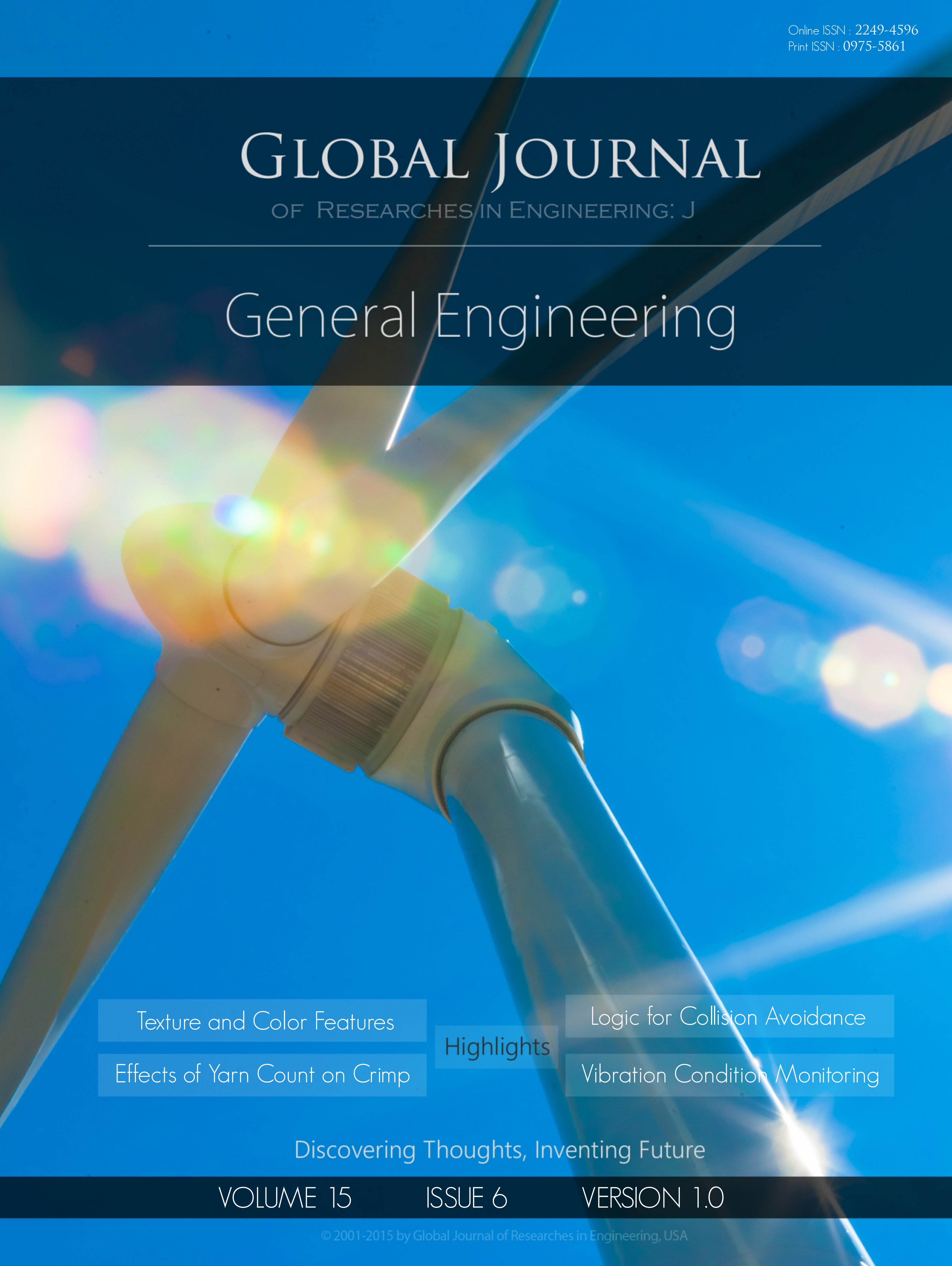

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OF RESEARCHES IN ENGINEERING: J

General Engineering

Highlights

Texture and Color Features

Effects of Yarn Count on Crimp

Logic for Collision Avoidance

Vibration Condition Monitoring

Discovering Thoughts, Inventing Future

VOLUME 15 ISSUE 6 VERSION 1.0

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Texture and Color Features based Color Image Retrieval using Canonical Correlation

By K. Seetharaman & Bachala Shyam Kumar

Pondicherry Engineering College, India

Abstract- This paper proposes a novel technique, based on Canonical correlation analysis, and the Chi-square test is employed to test the significance of the correlation coefficients. If it is significant, then it is concluded that the input query and target images are same or similar; otherwise, it is inferred that the two images are significantly different. In order to experiment the proposed canonical correlation method, a database is designed and constructed with the help of different types of images and their feature vectors. The F_β-measure is applied to evaluate the performance of the proposed method. The obtained results expose that the proposed technique yields better results than the existing.

Keywords: canonical correlation, query images, target images, F-measure, Chi-square test.

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K. Seetharaman α & Bachala Shyam Kumar σ

Abstract- This paper proposes a novel technique, based on Canonical correlation analysis, and the Chi-square test is employed to test the significance of the correlation coefficients. If it is significant, then it is concluded that the input query and target images are same or similar; otherwise, it is inferred that the two images are significantly different. In order to experiment the proposed canonical correlation method, a database is designed and constructed with the help of different types of images and their feature vectors. The F_β-measure is applied to evaluate the performance of the proposed method. The obtained results expose that the proposed technique yields better results than the existing.

Keywords: canonical correlation, query images, target images, F-measure, Chi-square test.

I. Introduction

The proliferation of digitizing the functions of private and public sectors, governmental organizations impetus to increase the repository capacity of the devices as well as the speed of accessing and retrieving the data through the internet. Owing to awareness and usage of the Internet and World Wide Web (WWW), a number of Internet users increased exponentially. Perhaps, a number of approaches have been developed with a consideration of the internet users and the difficulties in accessing the data available on the Internet and the WWW, they are not completely fulfilling the users' requirements. Specifically, images demand large amount of space and consume more time to retrieve from the image repository.

At the earlier stage, the text annotation based image retrieval method has been developed which is time consuming (Yap and Wu, 2015), and also it is not effective and efficient because it retrieves the images based on the text annotated manually by the user. Then, the content-based image retrieval (CBIR) method has been developed, which attracted a number of researchers. Most of the techniques have been developed based on the contents of the images, namely low-level global visual features, viz. colour properties, shape, texture, spatial orientation, etc., which are used as a query for the retrieval process (Huang et al., 1997; Stricker and Orengo, 1995; Pentland et al., 1994; Fuh et al., 2000). Liu, et. al. (2011) propose micro-structure descriptor, which extracts and integrates colour, texture, shape and colour layout information for image retrieval. The authors claim that it has only 72 dimensions for full colour image. But this is too large compared to those of the methods proposed by (Seetharaman, 2015; Krishnamoorthi and Sathiya Devi, 2013). The work proposed in (Murala et al., 2012) encodes the relationship between reference pixel and its surrounding neighbors by comparing gray-level values, and it extracts the edge information on local extreme in different angles. Though, a number of works have been developed based on the statistical distributional approaches and parametric tests of hypothesis, most of them are not effective and efficient, since there is no guarantee that all the images are distributed as independent and identical to Gaussian random process. The statistical parametric tests can be applied on an image, if it is distributed to Gaussian process. Otherwise, it does not lead to a good result. Generally, the parametric tests can be used if the data are quantitative and are distributed as independent and identical to Gaussian process. This motivated to develop the proposed method.

This paper adopts the idea of Canonical correlation analysis (CCA) for image retrieval. It is an effective and efficient technique for both textured and structured images, since it does not strictly rely on the distributional process. The Correlation analysis is dependent on the co-ordinate system, in which the variables are described, so even if there is a very strong linear relationship between two sets of multidimensional variables, this relationship might not be visible as a correlation. The CCA seeks a pair of linear transformation for each set of variables such that when the set of variables are transformed, the corresponding co-ordinates are maximally correlated. It is one of the valuable multi-data processing methods (Sun, et al. 1994; Zhang, et al. 1999). In recent years, CCA has been applied to several fields such as signal processing, computer vision, neural network and speech recognition.

In recent years, there has been a vast increase in the amount of multimedia content available both in off-line and online, though it is unable to access or make use of this data unless it is organized in such a way as to allow efficient browsing. To enable content based image retrieval with no reference to labeling, this paper attempts to learn the semantic representation of the

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images, and their associated text. This paper presents a general approach using KCCA that can be used for content based (David and John, 2003) as well as region based retrieval (Fyfe and Lai, 2001; David and John, 2003). In both cases, the KCCA approach and the Generalized Vector Space Model (GVSM) are compared, which aims at capturing some term to term correlations by looking at co-occurrence information.

The canonical correlation is the most general multivariate form, because multiple regression, discriminant function analysis and MANOVA are the special cases of the Canonical correlation analysis. Thus, it yields better results. The one more advantage of using canonical correlation is that there is no specific requirement for the data that should follow the normality conditions, if it is a descriptive analysis.

II. PROPOSED RETRIEVAL METHOD

Considering a multivariate random vector of the form (x, y). Suppose it is given a sample of instances $S = [(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)]$ of (x, y), Let S_x denote $(x_1, \ldots, x_n)$, and similarly S_y denote $(y_1, \ldots, y_n)$. It can be considered for defining a new co-ordinate for 'x' by choosing a direction I_q, and projecting x onto that direction

$$x \rightarrow \langle I_q, x \rangle$$

Similarly, by choosing a direction I_t it is obtained a sample of the new 'x' co-ordinate as

$$S_{x,I_q} = [\langle I_q, x_1 \rangle, \langle I_q, x_2 \rangle, \ldots, \langle I_q, x_n \rangle]$$

with the corresponding values of the new 'y' co-ordinate being

$$S_{y,I_t} = [\langle I_t, y_1 \rangle, \langle I_t, y_2 \rangle, \ldots, \langle I_t, y_n \rangle]$$

The linear combination of the feature vectors x_i of the query image is

$$I_q = f_1 x_1 + f_2 x_2 + \ldots + f_m x_m \qquad (1)$$

and the linear combination of the feature vectors y_i of the target image is

$$I_t = f_1 y_1 + f_2 y_2 + \ldots + f_n y_n \qquad (2)$$

The first canonical correlation is the maximum among the correlation coefficients between the variates I_q and I_t that is considered as the canonical correlation coefficient between the query and target images.

The function to be maximized is

$$\rho = \max_{I_q, I_t} corr(S_x I_q,\ S_y I_t)$$

$$\rho = \max_{I_q, I_t} \frac{\langle S_x I_q,\ S_y I_t \rangle}{\| S_x I_q \| \, \| S_y I_t \|}$$

If $E[f(x, y)]$ denote the empirical expectation of the function, $f(x, y)$, then

$$E[f(x, y)] = \frac{1}{N} \sum_{i=1}^{N} f(x_i, y_i)$$

Now, the correlation expression can be rewritten as in equation (3)

$$\rho = \max(I_q, I_t) \frac{\hat{E}[\langle I_q, x \rangle \langle I_t, y \rangle]}{\sqrt{\hat{E}\left[\langle I_q, x \rangle^2 \hat{E} \langle I_t, y \rangle^2\right]}} \qquad (3)$$

$$\rho = \max(I_q, I_t) \frac{\hat{E}[I_q' x y' I_t]}{\sqrt{\hat{E}[I_q' x x' I_q] \hat{E}[I_t' y y' I_t]}} \qquad (4)$$

Follows that

$$\rho = \max(I_q, I_t) \frac{I_q' \hat{E}[x y'] I_t}{\sqrt{I_q' \hat{E}[x x'] I_q I_t' \hat{E}[y y'] I_t}} \qquad (5)$$

Where, I' represents the transpose of a vector or matrix I. The covariance matrix of (x, y) is

$$C(x, y) = \hat{E}\left[\begin{pmatrix} x \\ y \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}'\right] = \begin{bmatrix} Cxx & Cxy \\ Cyx & Cyy \end{bmatrix} = C \qquad (6)$$

The total covariance matrix C is a block matrix, where the within-sets covariance matrices are C_{xx} and C_{yy}, and the between-sets covariance matrices are $C_{xx} = C_{yx}'$.

Thus, we can rewrite the function, ρ as

$$\rho = \max(I_q, I_t) \frac{I_q' C_{xy} I_t}{\sqrt{I_q' C_{xx} I_q I_t' C_{yy} I_t}} \qquad (7)$$

The maximum canonical correlation is the maximum of ρ with respect to I_q and I_t.

Significance of the canonical correlation coefficient, ρ, is examined by employing the Chi-squared test expressed in equation (8).

Statistical hypothesis:

$$H_0 : \rho(I_q, I_t) = 0$$

$$H_\alpha : \rho(I_q, I_t) \neq 0$$

$$\chi 2 = -\left(p - 1 - \frac{1}{2}(m + n + 1) \right) \mathit{ln} \prod_{j=1}^{\min(m,n)} (1 - \hat{\rho}_j^{\,2}) \qquad (8)$$

Which is asymptotically distributed as a Chi-squared with $(m - i + 1)(n - i + 1)$ degrees freedom for large sample size, N. If $\rho(I_q, I_t) < \chi^2_\alpha$, then the two images belong to the same class; otherwise, the two images are different, where α is the level of significance (Kanti et al., 1979).

III. Image and Feature Databases Settings

To experiment the proposed CCA method, an image database is constructed using 1, 27,167 images, which have been collected from different sources, and that are subjected to experiments. Among them, 1932 colour images of size 512×512 pixels have been collected from various sources such as 4676 images from CalTech image database (Coral database); 695 images from Corel image database; 3336 images from INRIA Holidays image database (CalTech Holiday Database); 682 images from VisTex image database; 558 images with size 128×128 that are photographed by a digital camera; 537 images with size 128×128 that have been downloaded from various websites. The texture images collected from Corel and VisTex image databases are divided into 16 non-overlapping sub-images of size 128×128. To evaluate the proposed method is invariant for rotation and noise, the images are rotated through 90°, 180° and 270° degrees. In addition to that 524 multi-spectral satellite images such as tropical depression and cyclone images, and wetland images are incorporated in the image database. Therefore, totally there are [1932 (actual image) + ((16 × (695+682)) + (4676 + 3336 + 558 + 537)) × 3 (rotated through 90°, 180° and 270°) +30,289 (scaled) + 626 (satellite)] = 1, 28, 482 images. Based on these image collections, an image database and FV database are constructed.

IV. Measure of Performance

In order to measure the performance of the proposed method, the F_β-measure is adopted, which is a harmonic mean of precision (P) and recall (R) values, and that are given in equations (9), (10) and (11). The F_β, measures the effectiveness of retrieval with respect to a user who attaches β times as much importance to recall as precision (Van Rijsbergen, 1979). The β value is decided with respect to weight which is given to the P and R. In the context of the proposed research work, the β is considered as 0.5, since more weight is given to the precision. Thus, equation (9) is rewritten as in equation (12).

$$F_\beta \text{ measure} = (1 + \beta^2) \times \frac{(P) \cdot (R)}{(\beta^2 \times P) + (R)} \qquad (9)$$

Where,

$$P = \frac{|\{\text{Relevant Images}\} \cap \{\text{Retrieved } \mathit{Images}\}|}{|\text{Retrieved } \mathit{Images}\,|} \qquad (10)$$

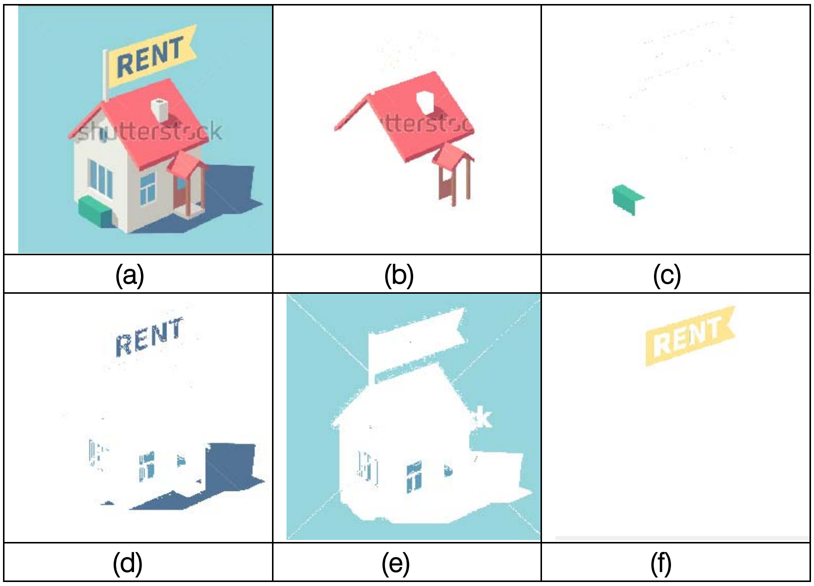
$$R = \frac{|\{\text{Relevant Images}\} \cap \{\text{Retrieved } \mathit{Images}\}|}{|\text{Relevant } \mathit{Images}\,|} \qquad (11)$$

In the context of the proposed research, the β is considered as 0.5 since more weight is given to the precision. Thus, equation (9) can be written as in equation (12).

$$F_{0.5} \text{ measure} = (1 + 0.5^2) \times \frac{(P) \cdot (R)}{(0.5^2 \times P) + (R)} \qquad (12)$$

V. Experiments and Results

A colour image is given as input key image to the system, and the shapes in the image are segmented; the segmented image is modelled to HSV colour space. The texture features are extracted from the V component of the HSV colour space. The colour features, such as H, S and V, and the texture feature are considered as observation and used in the CCA method expressed in equation (7). For a sample, due to space constraints, a shape segmented colour image is presented in Fig.1.



(a) (b) (c)

(d) (e) (f)

Figure 1: Segmented Shapes: (a): actual image; (b): red component shape; (c): green component shape; (d): blue component shape; (e): combination of green and blue; (f): combination of red and green.

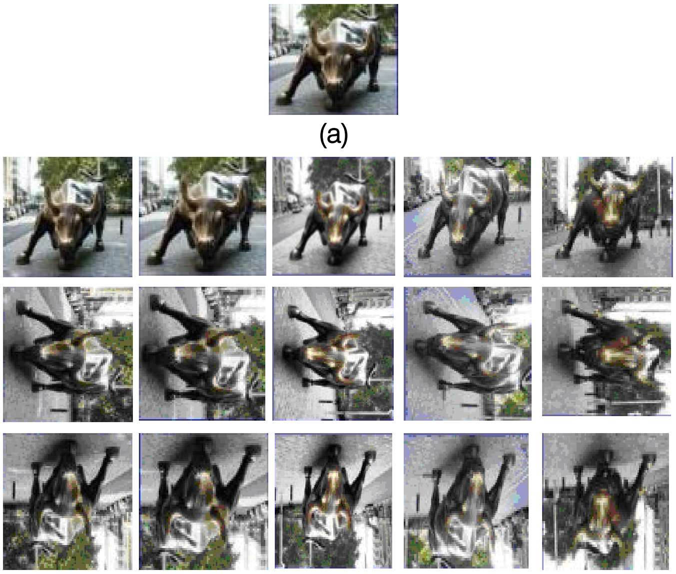
In order to experiment the CCA method discussed in section 2, the expression in equation (7) is implemented with the image and their feature databases constructed and discussed in section 4 that measures the correlation between both query and target images. Due to space constraints, for a sample, some of the images considered from the image database are presented in this paper that have been included during the experiments.

The target images are identified and marked in the image database, based on the results obtained by experiments. According to the users' requirements, the user can fix the level of significance of the tests by which the user can retrieve a number of same or similar images. The proposed system matches and retrieves the same image (target and query images are the same) from the image feature database at the level of significance 0% or 0.001 (100% accuracy – same images); almost the same images for 1% to 2% (99% to 98% accuracy) level of significance; similar images for the level of significance from 3% to 5%; related images for the level of significance from 6% to 8%. The selected images are indexed (ranked) from lowest to highest, i.e. in an ascending order based on the test statistic values obtained. The image which corresponds to the first value in the indexed list is marked as target image and it is retrieved from the image database.

The canonical correlation coefficient ρ is computed, based on the equation (8), on the input query image. The query and target images are considered in various combinations, and the computed ρ values are tested using the Chi-squared test statistic given in equation (9) of the section 2.

In order to validate the proposed system, the image in column 1 of Figure 1(a) is given as input query image, for which the system retrieves the images in row against them. The retrieved output images show that the proposed CCA method is robust for scaling and rotation for both textured and structured images. Since the proposed system serves same as the distributional approach, the proposed system acts as invariant for rotation and noise.

The experiment is conducted at various levels of significance on the input query Wall Street Bull image given in Figure 2(a). The images in column 2 of the Figure 2(b) are retrieved at 2% level of significance; images in columns 3, 2 and 1 are retrieved at 5% level of significance; at 8% and 12% level of significance, the system retrieves the images in columns 4, 3, 2, 1 and 7 respectively; at 15% level of significance, all the images presented in Figure 2(b) are retrieved. The number of shapes in both query and target images are compared, if it matches, then it is emphasized that both the images are same or similar.



(a)

(b)

Figure 2 : Wall Street Bull – (a): actual image with size 75 × 100; row 2 of (b): actual image with size 96 × 128; row 3 of (b): images in row 2 are rotated clockwise through 90 degrees; row 4 of (b): images in row 2 are rotated clockwise through 180 degrees.

The obtained output of the experiments, based on the canonical correlation, is tabulated in Table 1; it can be observed from the output that the proposed CCA yields 0.9982 for the images Wall Street Bull-1 versus Wall Street Bull -1, i.e. the query and target images are same. Similarly, the canonical correlation coefficients are obtained for different combinations of the Bull images are presented in Table 1. The computed canonical correlation coefficient matrix is a symmetric. The main advantage of the proposed system is that it facilitates the user to retrieve only the required number of images by fixing the level of significance, whereas the existing methods retrieve a number of similar images. Thus, in the existing methods, the user has to expend time to select the required image from the set of retrieved same or similar images. In addition to that the proposed system retrieves a set of similar images by fixing the level of significance at a desired level.

Table 1: Canonical Correlation Coefficient for Wall Street Bull images

Vs.	Bull-1	Bull-2	Bull-3	Bull-4	Bull-5
Bull-1	0.9999	0.9881	0.7506	0.7457	0.6152
Bull-2	0.9881	0.9998	0.7561	0.7389	0.5896
Bull-3	0.7506	0.7561	0.9999	0.7931	0.6856
Bull-4	0.7457	0.7389	0.7931	0.9998	0.7953
Bull-5	0.6152	0.5896	0.6856	0.7953	1.0000

Furthermore, to prove the efficacy of the proposed method, a number of structured images are considered for the experiment. For a sample, a few of them are presented in Figure 3. The image given in Figure 3(a) is fed as input query to the system, and the level of significance is fixed at 0.08 (i.e. 8 percent); for which the system retrieves the images presented in row 1. The images in row 2 are retrieved, while the level of significance is fixed at 0.12 or lesser (i.e. 12 percent or lesser), whereas it retrieves the images in rows 3 and 4 at the level of significance 0.15

Figure 3 : Structure images downloaded from Internet – (a): input key image; (b): retrieved output images

Moreover, to emphasis that the system works well for the textured or semi-structured images, a number of images are considered from the Corel-10K and 5K image databases; and the obtained retrieved images are present in Figure 4. The system retrieves the images in columns 2-6 for the input key images in column 1. Images in in column 2 are retrieved at the level of significance 0.01 (i.e. 1%); the images in column 3 are retrieved while the level of significance is fixed at 0.08 or lesser (8% or lesser); while the level of significance is at 0.15 or lesser (i.e. 15% or lesser), the images in columns 4 and 5 are retrieved; images in column 7 are retrieved at the level of significance, 0.18 (i.e. 18% or lesser).

Figure 4 : Corel 5K and 10K images – Texture or Semi-structured images.

Column 1: input query images; columns 2-5: retrieved output images

A comparative study is performed to measure the efficiency of the proposed method with the existing methods: Orthogonal Polynomial (OP) (Krishnamoorthi and Sathiya Devi, 2013), Bhattacharyya distance (BD) (Yang and Newsam, 2013), and Mahalanobis distance (MD) (Hoi, et al., 2010) in terms of average of the precision and recall values of the retrieved results. The average of the precision and recall values are obtained at the level of significance (α) 0.12 percent and above.

The obtained results reveal that the proposed method outperforms the existing systems. But, this paper takes account of texture and structure images. Averages of the precision and recall values are calculated for various methods: OP, BD and MD measures, and the results are presented in Table 2. Bar chart is plotted for the observed results, and is presented in Figures 5.

Table 2 : Performance of the Proposed System with Other Existing Methods
(Average values of the Precision and Recall)

Image Database	Proposed system (α is at 0.12 and above)			OP			BD			MD		
	R	P	$F_{0.5}$	R	P	$F_{0.5}$	R	P	$F_{0.5}$	R	P	$F_{0.5}$
CalTech	0.9585	0.7952	0.8233	0.9015	0.7631	0.7873	0.8523	0.6937	0.7205	0.8252	0.6817	0.7063
Corel	0.9098	0.8585	0.8683	0.9255	0.8039	0.8256	0.7829	0.7736	0.7754	0.8095	0.6912	0.7120
Structure Images	0.9681	0.7852	0.8160	0.8762	0.7729	0.7916	0.8139	0.6483	0.6758	0.8069	0.6275	0.6567

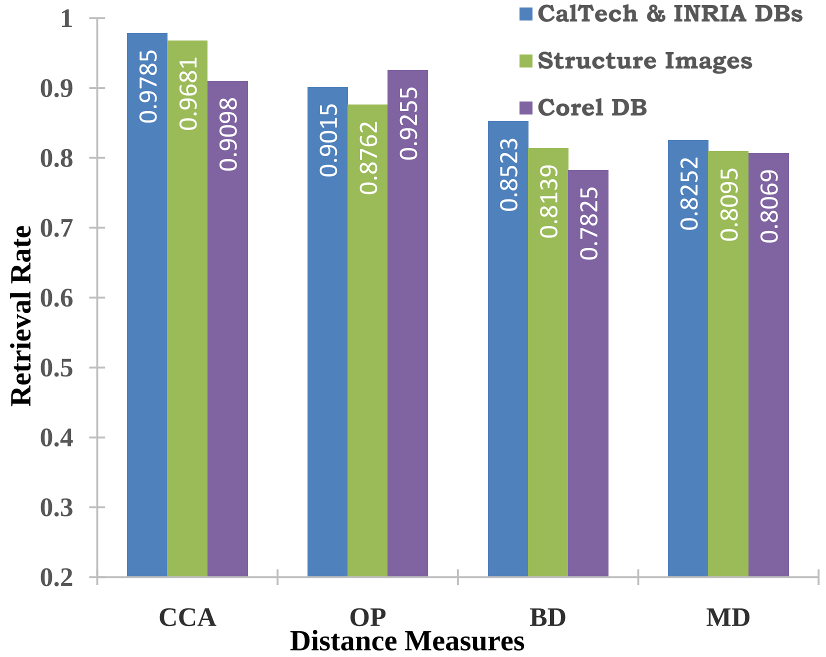


Figure 5 : Bar Chart: Comparison of Retrieval Rates of Different Methods

Time Complexity

The performance of the proposed system is compared with the existing systems: OP method, BD and MD distance measures in terms of computational time complexity. The system is implemented using Java SE 7 compiler with the system specification, Intel Core i5-4440 processor based PC with 4GB DDR3 RAM. The time consumed by the proposed system for feature extraction, matching and retrieving the images is measured in terms of seconds after a rigorous experimentation, and the obtained results are presented in Table 3. The proposed system demands lesser time compared to that of the existing systems, and also the proposed system yields better retrieval results.

Table 3 : Comparison of Computational Time Complexities

Time Consumption	Proposed System	OP	BD	MD
Feature extraction time	0.485 sec	0.798 sec	0.975 sec	0.852 sec
Searching time	0.0581 sec	0.072 sec	0.070 sec	0.069 sec

VI. Conclusion

In this paper a novel technique, Canonical correlation analysis and the Chi-square test are employed. The Chi-square test tests the correlation coefficient between the query and target images that whether it is significant or not. The canonical correlation coefficient extracts the spatial relationship among the pixels in the image, by which the spatial orientation of the texture properties are extracted; and the properties between the query and target images are tested. If it is significant, then it is concluded that the input query and target images are same or similar; otherwise, it is inferred that the two images differ significantly. It is observed from the results that the proposed technique yields better results than the existing techniques

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Detection and Parameter Extraction of Low Probability of Intercept Radar Signals using the Hough Transform

By Daniel L. Stevens & Stephanie A. Schuckers

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Abstract- Digital intercept receivers are currently moving away from Fourier-based analysis and towards classical time-frequency analysis techniques, such as the Wigner-Ville distribution, Choi-Williams distribution, spectrogram, and scalogram, for the purpose of analyzing low probability of intercept radar signals (e.g. triangular modulated frequency modulated continuous wave and frequency shift keying). Although these classical time-frequency techniques are an improvement over the Fourier-based analysis, they still suffer from a lack of readability, due to cross-term interference, and a mediocre performance in low SNR environments. This lack of readability may lead to inaccurate detection and parameter extraction of these radar signals. In this paper, the use of the Hough transform, because of its ability to suppress cross-term interference, separate signals from cross-terms, and perform well in the presence of noise, is proposed as an improved signal analysis technique. With these qualities, the Hough transform has the potential to produce better readability and consequently, more accurate signal detection and parameter extraction metrics.

Keywords: radar detection, hough transform, low probability of intercept.

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Detection and Parameter Extraction of Low Probability of Intercept Radar Signals using the Hough Transform[1]

Daniel L. Stevens α & Stephanie A. Schuckers σ

Abstract- Digital intercept receivers are currently moving away from Fourier-based analysis and towards classical time-frequency analysis techniques, such as the Wigner-Ville distribution, Choi-Williams distribution, spectrogram, and scalogram, for the purpose of analyzing low probability of intercept radar signals (e.g. triangular modulated frequency modulated continuous wave and frequency shift keying). Although these classical time-frequency techniques are an improvement over the Fourier-based analysis, they still suffer from a lack of readability, due to cross-term interference, and a mediocre performance in low SNR environments. This lack of readability may lead to inaccurate detection and parameter extraction of these radar signals. In this paper, the use of the Hough transform, because of its ability to suppress cross-term interference, separate signals from cross-terms, and perform well in the presence of noise, is proposed as an improved signal analysis technique. With these qualities, the Hough transform has the potential to produce better readability and consequently, more accurate signal detection and parameter extraction metrics. Two different triangular modulated frequency modulated continuous wave low probability of intercept radar signals and two different frequency shift keying low probability of intercept radar signals (4-component and 8-component) were analyzed. The following metrics were used for evaluation of the analysis: percent error of chirp rate, percent detection, number of cross-term false positives, and lowest signal-to-noise ratio for signal detection. Experimental results demonstrate that the qualities of suppressing cross-term interference, separating signals from cross-terms, and performing well in a low SNR environment did lead to improved readability over the classical time-frequency analysis techniques, and consequently, provided more accurate signal detection and parameter extraction metrics (smaller percent error from true value) than the classical time-frequency analysis techniques. In addition, the Hough transform was utilized to detect, extract parameters, and properly identify a real-world low probability of intercept radar signal in a low signal-to-noise ratio environment, where the classical time-frequency analysis failed. In summary, this paper provides evidence that the Hough transform has the potential to outperform the classical time-frequency analysis techniques. Future work will include automation of the metrics extraction process, analysis of additional low probability of intercept radar waveforms of interest, and analysis of other real-world low probability of intercept radar signals utilizing more powerful computing platforms.

Keywords: radar detection, hough transform, low probability of intercept.

I. INTRODUCTION

In order to perform their functions properly, many of today's radar systems must be able to 'see without being seen' [PAC09], [WIL06]. This necessitates that they be low probability of intercept (LPI) radars. These radars typically have very low peak power, wide bandwidth, high duty cycle, and power management, making them difficult to be detected and characterized by intercept receivers.

Fourier analysis techniques using the FFT have been employed as a tool of the digital intercept receiver for detecting and extracting parameters of LPI radar signals [PAC09]. When a practical non-stationary signal (such as an LPI radar signal) is processed, the Fourier transform cannot efficiently analyze and process the time-varying characteristics of the signal's frequency spectrum, because time and frequency information cannot be combined to tell how the frequency content is changing in time [XIE08], [STE96]. The non-stationary nature of the received radar signal mandates the use of some form of time-frequency analysis for signal detection and parameter extraction [MIL02].

Some of the more common classical time-frequency analysis techniques include the Wigner-Ville distribution (WVD), Choi-Williams distribution (CWD), spectrogram, and scalogram. The WVD exhibits the highest signal energy concentration [WIL06], but has the worse cross-term interference, which can severely limit the readability of a time-frequency representation [GUL07], [STE96], [BOA03]. The CWD is a member of Cohen's class, which adds a smoothing kernel to help reduce cross-term interference [BOA03], [UPP08]. The CWD, as with all members of Cohen's class, is faced with a trade-off between cross-term reduction and time-frequency localization. The Spectrogram is the magnitude squared of the short-time Fourier transform [HLA92], [MIT01]. It has poorer time-frequency localization but less cross-term interference than the

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WVD or CWD, and its cross-terms are limited to regions where the signals overlap [ISI96]. The Scalogram is the magnitude squared of the wavelet transform, and can be used as a time-frequency distribution [COH02], [GAL05], [BOA03]. Like the Spectrogram, the Scalogram has cross-terms that are limited to regions where the signals overlap [ISI96], [HLA92].

Though classical time-frequency analysis techniques, such as those described above, are a great improvement over Fourier analysis techniques, they suffer in general from cross-term interference and a mediocre performance in low SNR environments, as described above. This may result in degraded readability of time-frequency representations, potentially leading to inaccurate LPI radar signal detection and parameter extraction metrics.

A promising avenue for overcoming these shortfalls is the utilization of the Hough Transform, which is very similar to the Radon transform, and is used, for the detection of straight lines and other curves [BAR95], [BEN05], [ZAI99], [INC07]. The Hough transform of a particular time-frequency representation is found by computing the integral of the time-frequency representation along straight lines at different angles. The presence of a 'spike' in the Hough transform representation reveals the presence of high positive values concentrated along a line in the time-frequency representation – whose parameters (such as chirp rate) correspond to the coordinates of the spike (theta and rho values) [BAR92], [YAS06], [BAR95]. Detection can be achieved by establishing a threshold value for the amplitude of the Hough transform spike. Therefore the Hough transform can be used to convert a difficult global detection problem in the time-frequency representation into a more easily solved local peak detection problem in the Hough transform representation.

Since cross-terms have amplitude modulation, the integration implicit in the Hough transform reduces the cross-terms, while the useful contributions, which are always positive, are correctly integrated [TOR07], [BAR92], [BAR95]. Likewise, in the presence of noise, the integration carried out by the Hough transform produces an improvement in SNR [INC07], [YAS06], [NIK08]. These qualities make the Hough transform a viable candidate for analyzing LPI radar signals.

In related work, [WON09] performed research using the WVD followed by the Hough transform as one of their detection and parameter estimation algorithms, but this was utilized for a single chirp signal, which presents no cross-term interference like the triangular modulated FMCW and FSK waveforms that are examined in this paper. [GUL08] utilized the pseudo Wigner-Ville distribution followed by the Radon transform, but used it only for parameter extraction, and not for signal detection. This paper utilized the Hough transform for both parameter extraction and signal detection. [GER09] used an algorithm similar to the WVD followed by the Hough transform, called the periodic Wigner-Ville Hough transform. This algorithm was used on a sawtooth FMCW waveform, which is a viable LPI radar waveform. Their research assumed that phase is coherent from on LFM ramp to the next which is not always the case. Also, for their research, one needed to search for the right repetition period, the right starting frequency and the right slope. Overall, it appears that little research has been done in the area of using the Hough transform for the analysis of triangular modulated FMCW LPI radar signals and FSK LPI radar signals.

In this paper, the Hough transform is evaluated as a technique for improving the readability of the classical time-frequency analysis representations by suppressing cross-term interference, separating signals from cross-terms, and performing well in a low SNR environment. This approach is assessed using 2 triangular modulated FMCW LPI radar signals and 2 FSK LPI radar signals (4-component and 8-component). Metrics designed include: percent error of chirp rate, percent detection, number of cross-term false positives, and lowest SNR for signal detection.

The rest of this paper is organized as follows: Description of the proposed methodology is presented in section II. Experimental results comparing the reassignment method and classical time-frequency analysis techniques are presented in section III, followed by discussion and conclusions.

II. METHODOLOGY

The methodologies detailed in this paper describe the processes involved in obtaining and comparing metrics between the classical time-frequency analysis techniques and the Hough transform for the detection and parameter extraction of LPI radar signals.

The tools used for this testing were: MATLAB (version 7.7), Signal Processing Toolbox (version 6.10), Wavelet Toolbox (version 4.3), Image Processing Toolbox (version 6.2), Time-Frequency Toolbox (version 1.0) (http://tftb.nongnu.org/).

All the testing was accomplished on a desktop computer (HP Compaq, 2.5GHz processor, AMD Athlon 64X2 Dual Core Processor 4800+, 2.00GB Memory (RAM), 32 Bit Operating System).

Testing was performed for 4 different waveforms (2 triangular modulated FMCWs and 2 FSKs), each waveform representing a different task (Task 1 through Task 4). For each waveform, parameters were chosen for academic validation of signal processing techniques. Due to computer processing limitations they were not meant to represent real-world values. The number of samples for each test was chosen to be either 256 or 512, which seemed to be the optimum size for the desktop computer. Testing was performed at three different SNR levels: 10dB, 0dB, and low SNR (the lowest SNR at which the signal could be detected). The noise added was white Gaussian noise, which best reflected the thermal noise present in the IF section of an intercept receiver [PAC09]. Kaiser windowing was used, when windowing was applicable. 25 runs were performed for each test, for statistical purposes. The plots included in this paper were done at a threshold of 5% of the maximum intensity and were linear scale (not dB) of analytic (complex) signals; the color bar represented intensity. The signal processing tools used for each task were:

Classical time-frequency analysis techniques: WVD, CWD, spectrogram, scalogram

Hough transform method: Hough transform of WVD and Hough transform of CWD

Task 1 consisted of analyzing a triangular modulated FMCW signal (most prevalent LPI radar waveform [LIA09]) whose parameters were: sampling frequency=4KHz; carrier frequency=1KHz; modulation bandwidth=500Hz; modulation period=.02sec.

Task 2 was similar to Task 1, but with different parameters: sampling frequency=6KHz; carrier frequency= 1.5KHz; modulation bandwidth=2400Hz; modulation period=.15sec. The different parameters were chosen to see how the different shapes/heights of the triangles of the triangular modulated FMCW would affect the cross-term interference and the metrics.

Task 3 consisted of analyzing an FSK (prevalent in the LPI arena [AMS09]) 4-component signal whose parameters were: sampling frequency=5KHz; carrier frequencies=1KHz, 1.75KHz, 0.75KHz, 1.25KHz; modulation bandwidth=1000Hz; modulation period=.025sec.

Task 4 was similar to Task 3, but for an FSK 8-component signal whose parameters were: sampling frequency=5KHz; carrier frequencies=1.5KHz, 1KHz, 1.25KHz, 1.5KHz, 1.75KHz, 1.25KHz, 0.75KHz, 1KHz; modulation bandwidth=1000Hz; modulation period=.0125sec. The different number of components and different parameters between Task 3 and Task 4 were chosen to see how the different number/lengths of FSK components would affect the cross-term interference and the metrics.

Because of computational complexity, the WVD tests and the Hough transform of WVD tests for 512 samples, SNR=0dB and 512 samples, SNR=low SNR – were not able to be performed for any of the 4 waveforms. It was noted that a single run was still processing after more than 8 hours. The WVD is known to be very computationally complex [MIL02].

After each particular run of each test, metrics were extracted from the time-frequency representation and the Hough transform plot. The metrics extracted were as follows (TF=time-frequency representation; HT=Hough transform):

a) Percent detection

HT: percent of time signal was detected – signal was declared a detection if any portion of each of the signal components exceeded the noise floor threshold (see Figure 1).

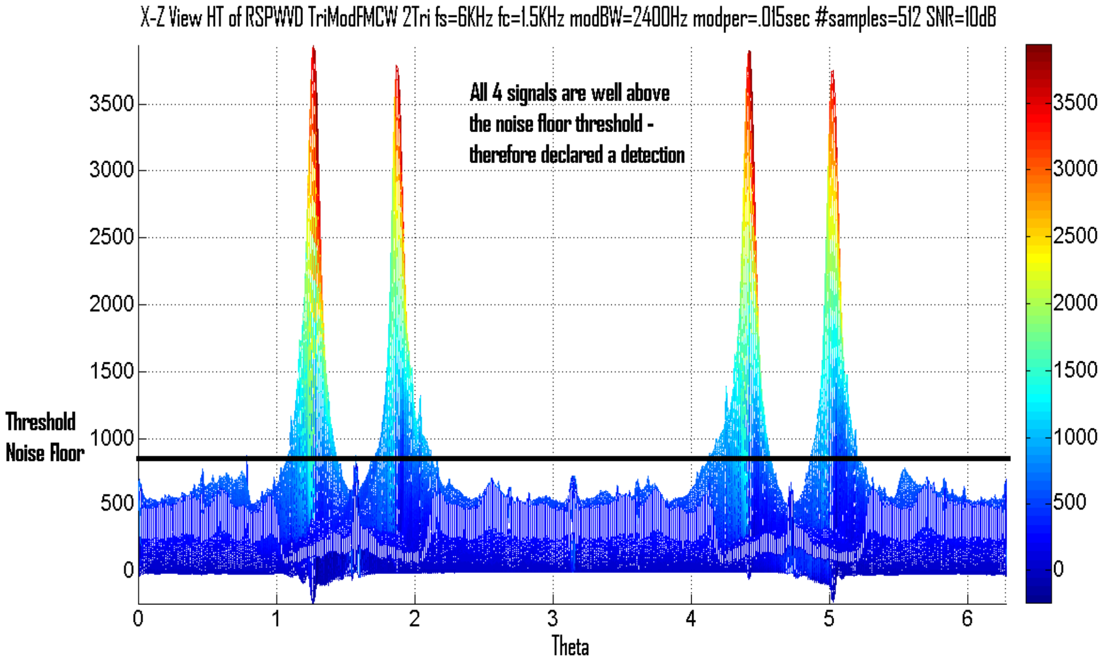


Figure 1 : Percent detection (Hough transform). This plot is a theta-intensity (x-z view) of the HT of an RSPWVD (512 samples, SNR=10dB). Signal declared a (visual) detection because at least a portion of each of the signal components exceeded the noise floor threshold.

TF: percent of time signal was detected - signal was declared a detection if any portion of each of the signal components (4 chirp components for triangular modulated FMCW, and 4 or 8 signal components for FSK) exceeded a set threshold (a certain percentage of the maximum intensity of the time-frequency representation).

Threshold percentages were determined based on visual detections of low SNR signals (lowest SNR at which the signal could be visually detected in the time-frequency representation) (see Figure 2).

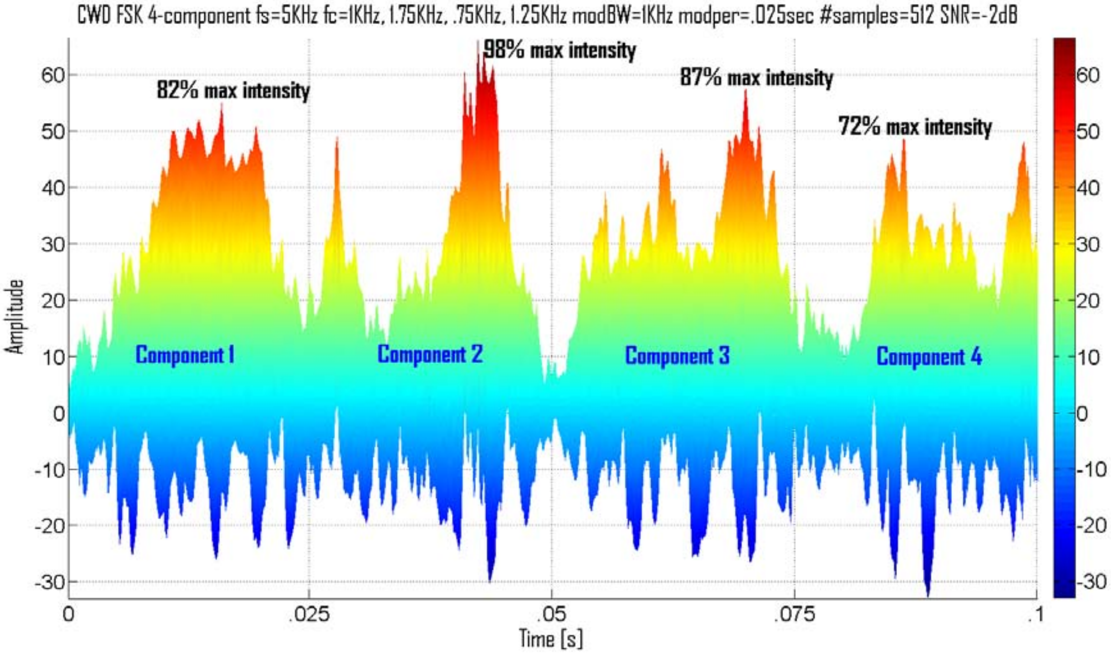


Figure 2 : Threshold percentage determination. This plot is an amplitude vs. time (x-z view) of CWD of FSK 4-component signal (512 samples, SNR= -2dB). For visually detected low SNR plots (like this one), the percent of max intensity for the peak z-value of each of the signal components was noted (here 82%, 98%, 87%, 72%), and the lowest of these 4 values was recorded (72%). Ten test runs were performed for each time-frequency analysis tool, for each of the 4 waveforms. The average of these recorded low values was determined and then assigned as the threshold for that particular time-frequency analysis tool. Note - the threshold for CWD is 70%.

Thresholds were assigned as follows: CWD (70%); spectrogram (60%); scalogram, WVD (4-component FSK) (50%); WVD (triangular modulated FMCW) (35%); WVD (8-component FSK) (20%).

For percent detection determination, these threshold values were included in the time-frequency plot algorithms so that the thresholds could be applied automatically during the plotting process. From the threshold plot, the signal was declared a detection if any portion of each of the signal components was visible (see Figure 3).

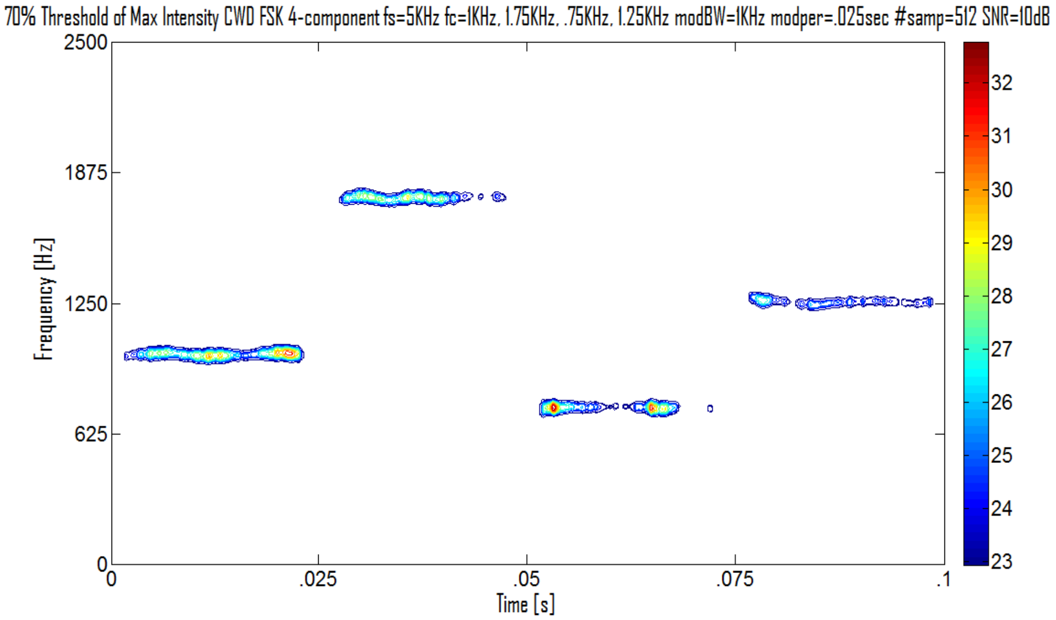


Figure 3 : Percent detection (time-frequency). CWD of 4-component FSK (512 samples, SNR=10dB) with threshold value automatically set to 70%. From this threshold plot, the signal was declared a (visual) detection because at least a portion of each of the 4 FSK signal components was visible.

Automatically applying a threshold value to the time-frequency plot algorithms for percent detection determination can be seen as a first step towards the future work of automating the metrics extraction process.

b) Cross-term false positives (XFPs)

The number of cross-terms that were wrongly declared as signal detections. For the time-frequency representation, the XFP detection criteria is the same as the time-frequency signal detection criteria listed in the percent detection section above. For the HT, the XFP detection criteria is the same as the HT signal detection criteria listed in the percent detection section above. Figure 4 shows a WVD plot with 4 true signals and 6 cross-terms, all 6 of which were XFPs.

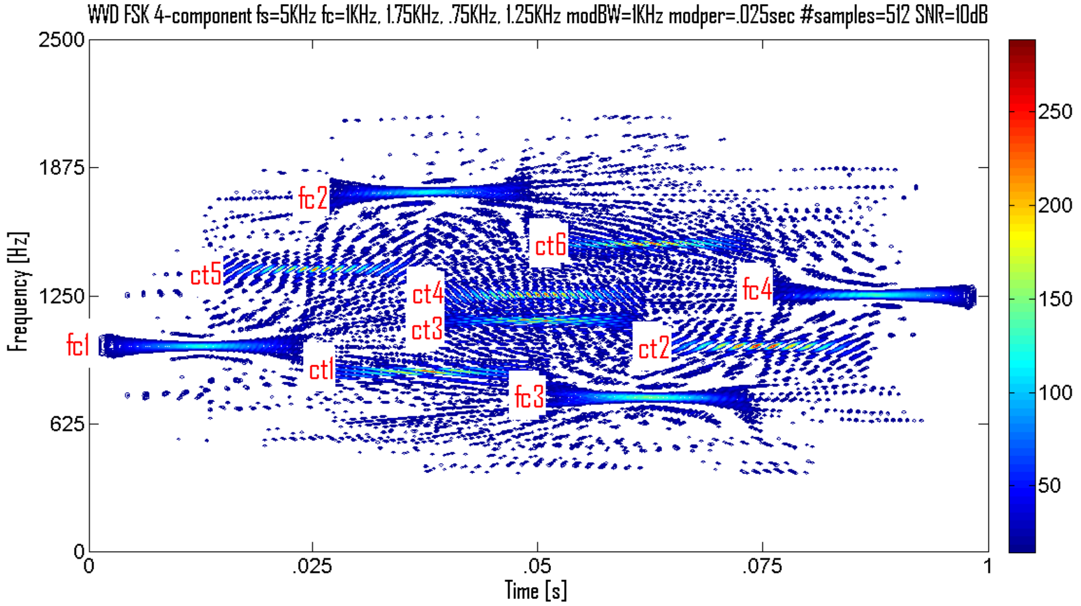


Figure 4 : Example of cross-term false positives (XFPs). WVD of a 4-component FSK signal at SNR=10dB (512 samples). There are 4 true signals (fc1=1KHz, fc2=1.75KHz, fc3=0.75KHz, fc4=1.25KHz) and 6 XFPs (cross-terms that were wrongly declared as signal detections because they passed the signal detection criteria listed in the percent detection section above) (ct1=0.875KHz, ct2=1KHz, ct3=1.125KHz, ct4=1.25KHz, ct5=1.375KHz, ct6=1.5KHz).

c) Chirp rate

HT: $chirprate = (-\tan\theta)\left(\frac{\max\ valueofY\ -axisofTFplot}{\max\ valueofX\ -axis\ ofTFplot}\right)$ – (for Task 1 and Task2 only).

TF: (modulation bandwidth/modulation period) – (for Task 1 and Task 2 only).

d) Lowest detectable SNR

HT: the lowest SNR level for which each signal component exceeded the noise floor threshold (see Figure 5).

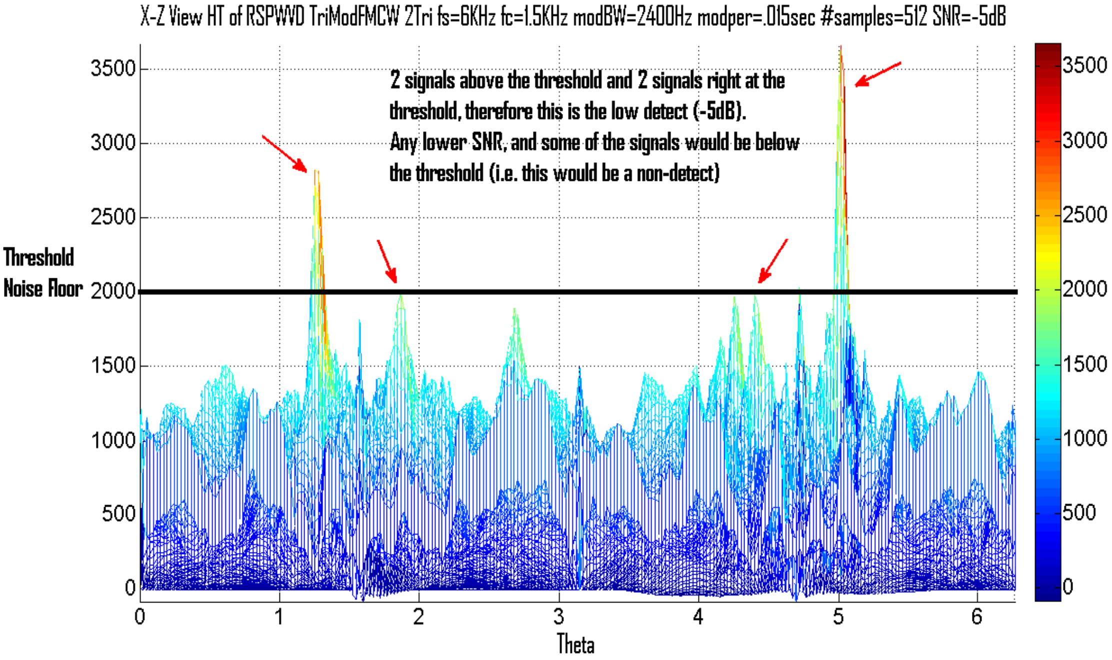


Figure 5 : Lowest detectable SNR (Hough transform). This plot is a theta-intensity (x-z view) of the HT of an RSPWVD (512 samples, SNR=-5dB). Signal declared a (visual) detection because at least a portion of each of the signal components exceeded the noise floor threshold. For this case, any lower SNR would have been a non-detect. Compare to Figure 1, which is the same plot, except that it has an SNR level equal to 10dB.

TF: the lowest SNR level at which at least a portion of each of the signal components exceeded the set threshold listed in the percent detection section above.

For lowest detectable SNR determination, these threshold values were included in the time-frequency plot algorithms so that the thresholds could be applied automatically during the plotting process. From the threshold plot, the signal was declared a detection if any portion of each of the signal components was visible. The lowest SNR level for which the signal was declared a detection is the lowest detectable SNR (see Figure 6).

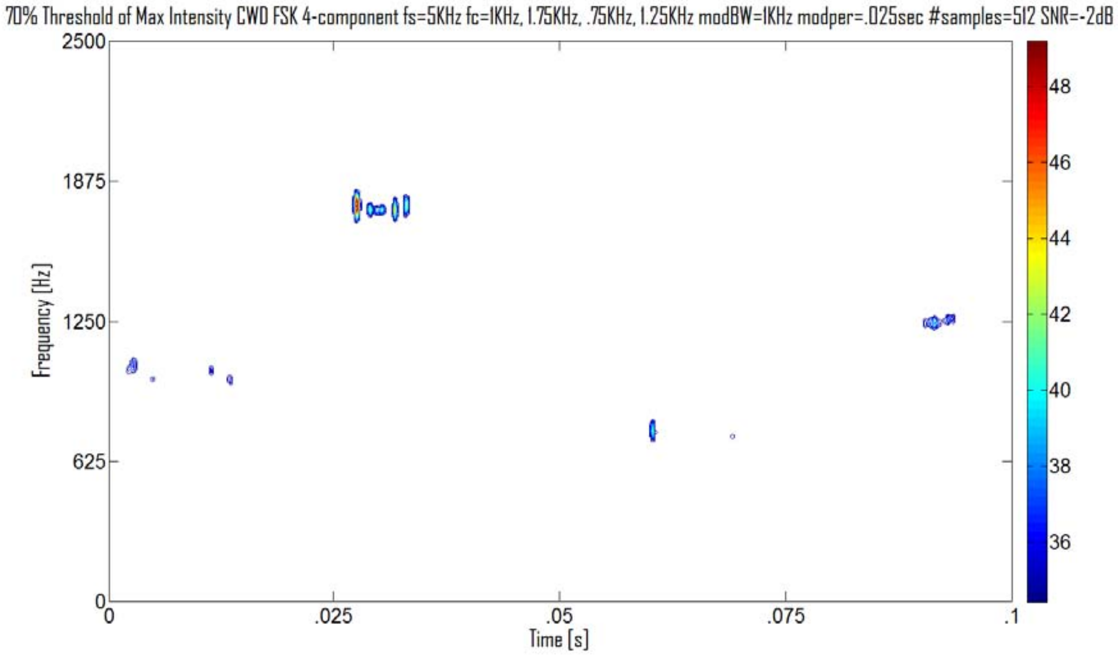


Figure 6 : Lowest detectable SNR (time-frequency). CWD of 4-component FSK (512 samples, SNR=-2dB) with threshold value automatically set to 70%. From this threshold plot, the signal was declared a (visual) detection because at least a portion of each of the 4 FSK signal components was visible. For this case, any lower SNR would have been a non-detect. Compare to Figure 3, which is the same plot, except that it has an SNR level equal to 10dB.

Automatically applying a threshold value to the time-frequency plot algorithms for the determination of the lowest detectable SNR can be seen as a first step towards the future work of automating the metrics extraction process.

The data from all 25 runs for each test was used to produce the mean, standard deviation, variance, actual, error, and percent error for each of these metrics listed above.

The metrics from the classical time-frequency analysis techniques were then compared to the metrics from the Hough transform. By and large, the Hough transform outperformed the classical time-frequency analysis techniques, as will be shown in the results section.

For Task 5, data from a CD was analyzed, with the only a priori knowledge being that the data contained an LPI radar signal in a low SNR environment (between -5dB and -10dB), and that the data was collected at a sampling frequency of 4GHz. The data (19 megabytes) was first processed using the Spectrogram (because it is the fastest time-frequency analysis tool). The signal was not visible in the Spectrogram time-frequency representation, due to low SNR. The data was then processed with the Hough transform of the Spectrogram, and the signal was detected, but had almost zero slope (like an FSK (tonal) signal). A MATLAB script was written which allowed for decimation of the Y-axis for the receiver IF bandwidth (~750MHz to 1250MHz), and then the data was re-processed with the Hough transform of the Spectrogram, this time for the purpose of determining if the signal had slope or if it was tonal. From the Hough transform plot it was observed that the signal had slope (i.e. was a chirp signal). The Hough transform plot allowed for not only detection of the chirp signal, but also for extraction of the chirp rate. A back-mapping from the Hough plot to the time-frequency representation was then performed. The signal was located in the time-frequency representation, and the modulation bandwidth and modulation period (and consequently the chirp rate) were extracted from the time-frequency representation. From these metrics, the type/source of the signal was identified. Additional details/results of Task 5 testing are addressed later in this chapter.

III. Results

Some of the graphical and statistical results of the testing are presented in this section.

Table 1 presents the overall test metrics (signal processing tool viewpoint) for the 4 time-frequency analysis techniques and the 2 Hough transform methods used in this testing.

Table 1 : Signal Processing Tool viewpoint of the overall test metrics (average percent error) for the 4 classical time-frequency analysis techniques (WVD, CWD, spectrogram, scalogram) along with their combined average (TF) and for the 2 Hough transform methods (WVD + HT, CWD + HT), along with their combined average (HT). The parameters extracted are listed in the left-hand column: chirp rate (cr), percent detection (% det), # of cross-term false positives (#XFP), lowest detectable SNR (low snr).

params	wvd	cwd	spectro	scalo	TF	wvd+ht	cwd+ht	HT
cr	5.29%	11.49%	16.25%	28.5%	15.4%	5.40%	2.74%	4.07%
% det	94.6%	92.5%	96.4%	90.4%	93.4%	100%	98.7%	99.4%
# XFP	25	0	0	0	25	4	4	8
low snr	-2db	-2.4db	-3db	-2.8db	-2.5db	-3db	-4.4db	-3.7db

From Table 1, the WVD had the best percent error of chirp rate (5.29%) of any of the classical time-frequency analysis tools, but performed the poorest out of all of the 6 signal processing techniques in the areas of number of cross-term false positives (25) and low SNR (-2dB). Figure 7(left-hand side) shows the cross-term interference problem that the WVD has.

The CWD performed 'middle-of-the-road' in every category (cr=11.49%; % det=92.5%; #XFP=0; low snr= -2.4dB) , as compared to the other classical time-frequency analysis techniques.

The spectrogram had the best low SNR (-3dB) and percent detection (96.4%) of the classical time-frequency analysis techniques, but had a poor percent error of chirp rate (16.25%).

The scalogram had the worst percent detection (90.4%) and percent error of chirp rate (28.5%) of the classical time-frequency analysis techniques, but did well in low SNR (-2.6dB).

The WVD + HT had a good percent error of chirp rate (5.40%) that was on par with that of the WVD (5.29%), and also had the best percent detection (100%) of all the 6 signal processing techniques. In addition, the WVD + HT had a low SNR value (-3dB) that equaled the best low SNR value of the classical time-frequency analysis techniques (spectrogram), and its number of cross-term false positives (4) was lower thanthat of the WVD (25) (see Figure 7 for comparison).

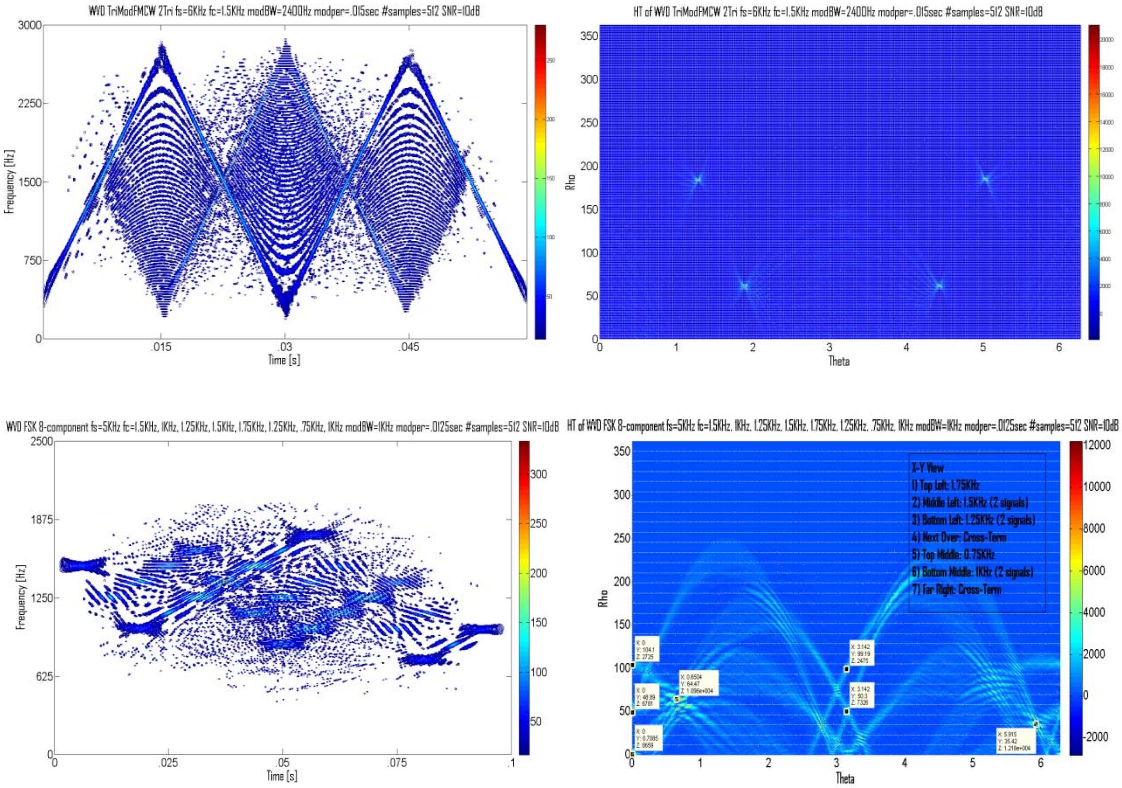


Figure 7 : Cross-term comparison between classical time-frequency analysis techniques (left) and the Hough transform (right). Top left: WVD of a triangular modulated FMCW signal (512 samples, SNR=10dB) (left). Top right: the Hough transform of the WVD of a triangular modulated FMCW signal (512 samples, SNR=10dB). Bottom left: WVD of an FSK (8-component) signal (512 samples, SNR=10dB). Bottom right: the Hough transform of theWVD of an FSK (8-component) signal (512 samples, SNR=10dB). Upper 2 plots – the Hough transform (right) has

eliminated the cross-term interference that the WVD (left) displays, making it easier to see the signal (better readability) in the Hough transform plot (the four bright spots which represent the four legs of the triangular modulated FMCW signal). The WVD appears to have another triangle signal between the outer two triangle signals. Lower 2 plots - In the WVD plot (left) there are 8 signal components and 9 cross-term components that appear to be signal components, all melded in together with one another. The 8 signal components are located at 5 distinct frequencies (one at 0.75KHz, two at 1KHz, two at 1.25KHz, two at 1.5KHz, and one at 1.75KHz). In the Hough transform plot (right) there are 8 signal components (located at 5 different frequencies (3 on the left-hand side of the plot and 2 in the middle of the plot)) plus 2 cross-term components, clearly separated from the signal components. The Hough transform plot makes it easier to see the signal components (better readability) as compared to the WVD plot.

The CWD + HT performed the best of all the 6 signal processing techniques in the areas of percent error of chirp rate (2.74%) and low SNR (-4.4dB) (see figure 8 (right-hand side)). It also performed very well for percent detection (98.7%).

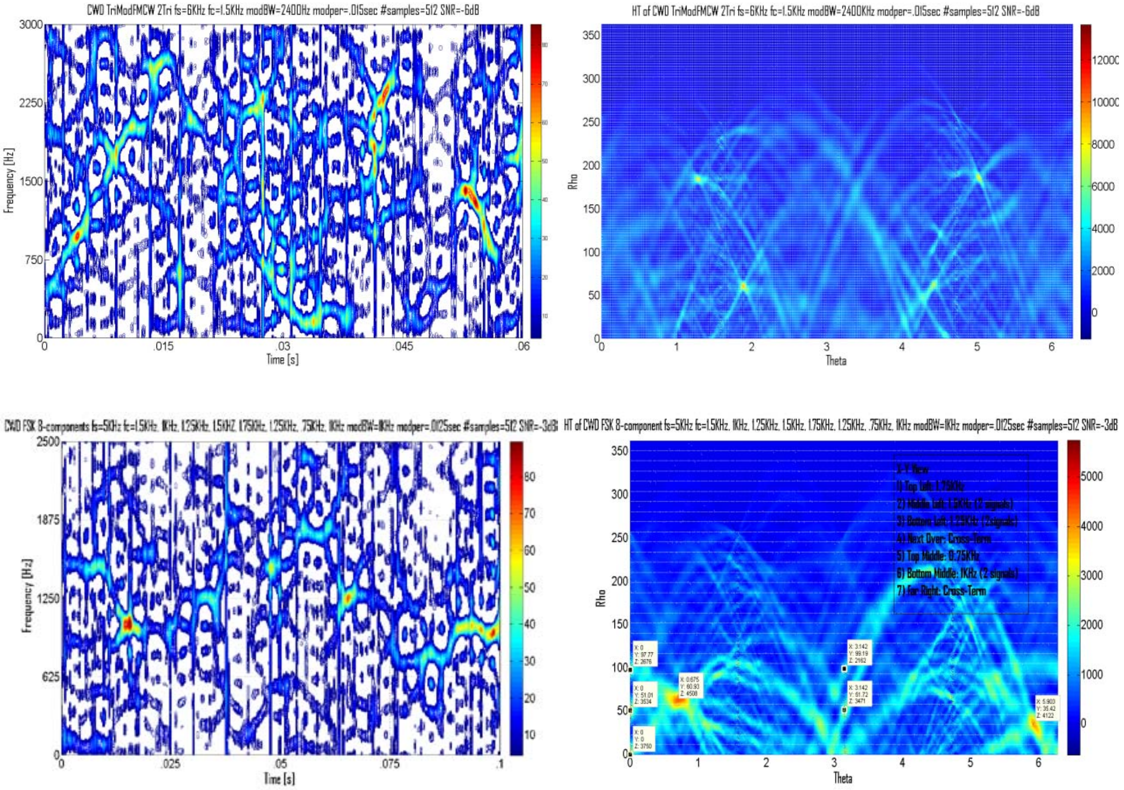


Figure 8 : Low SNR comparison between classical time-frequency analysis techniques (left) and the Hough transform (right). Top left: CWD of a triangular modulated FMCW signal (512 samples, SNR=-6dB) (left). Top right: the Hough transform of the CWD of a triangular modulated FMCW signal (512 samples, SNR=-6dB). Bottom left: CWD of an FSK (8-component) signal (512 samples, SNR=-3dB). Bottom right: the Hough transform of the CWD of an FSK (8-component) signal (512 samples, SNR=-3dB). Upper 2 plots - Though the signal is not visible in the CWD plot (left) (due to the low SNR (-6dB)), the four bright spots that represent the four legs of the triangular modulated FMCW signal are clearly seen in the Hough transform of the CWD plot (right). Each bright spot has a unique rho and theta value that can be used to back-map to the time-frequency representation (here CWD) and find the location of the 4 (non-visible) chirps that make up the triangular modulated FMCW signal. Lower 2 plots - Though the signal components are not visible in the CWD plot (due to the low SNR (-3dB)), the 5 bright spots (3 on the left and 2 in the middle) corresponding to the 5 different frequencies of the 8 FSK components are clearly visible in the Hough transform of the CWD plot (as are 2 cross-term components). The Hough transform does a good job of detecting the signal components and separating the signal components from the cross-term components, all in a low SNR environment.

Overall from Table 1, the Hough transform methods outperformed the classical time-frequency analysis techniques in percent error of chirp rate (4.07% to 15.4%), percent detection (99.4% to 93.4%), number of cross-term false positives (8 to 25), and low SNR (-3.7dB to -2.5dB).

Table 2 presents the overall test metrics (SNR viewpoint) for the testing performed in this paper.

Table 2 : SNR viewpoint of overall test metrics (average percent error) for the classical time-frequency analysis techniques (TF) and for the Hough transform methods (HT) for SNR=10dB, 0dB, and lowest detectable SNR (low SNR). The parameters extracted are listed in the left-hand column: chirp rate (cr), percent detection (% det), number of cross-term false positives (#XFP).

params	TF 10dB	TF 0dB	TF low snr	HT 10dB	HT 0dB	HT low snr
cr	13.73%	14.51%	17.04%	4.0%	6.23%	3.24%
% det	100%	82.4%	N/A	100%	98.7%	N/A
# XFP	21	2	2	2	0	4

Table 2 shows that the percent error of chirp rate and percent detection tended to worsen with lowering SNR values (see Figure 9) for both the classical time-frequency analysis techniques and the Hough transform (except for HT low SNR). The XFP numbers in Table 2 are representative of the fact that, due to computational complexity, there was no WVD testing accomplished at lower than 10dB (except for the 256 sample cases).

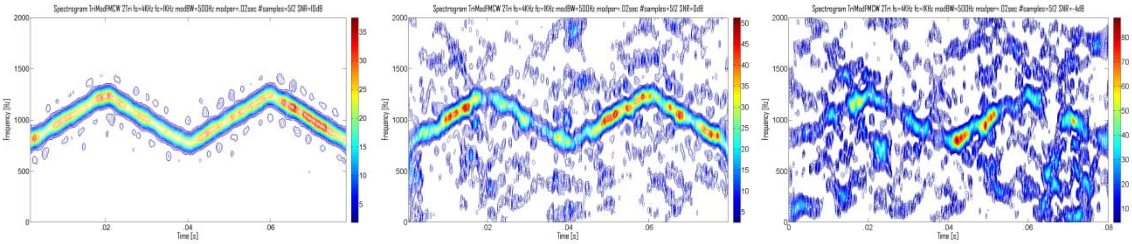


Figure 9 : Readability degradation due to reduction in SNR. Spectrogram, triangular modulated FMCW, modulation bandwidth=500Hz, 512 samples. SNR=10dB (left), 0dB (center), -4dB (left). Readability degrades as SNR decreases, negatively affecting the accuracy of the metrics extracted, as per Table 2.

Table 3 presents the overall test metrics (Task 1, 2, 3, and 4 view point) for the testing performed in this paper.

Table 3 : Task 1, 2, 3, and 4 viewpoint of overall test metrics (average percent error) for the classical time-frequency analysis techniques (TF) and for the Hough transform (HT). Task1=triangular modulated FMCW signal (modulation bandwidth=500Hz), Task2=triangular modulated FMCW signal (modulation bandwidth=2400Hz), Task 3=FSK (4-component) signal, Task 4=FSK (8-component) signal. The parameters extracted are listed in the left-hand column: chirp rate (cr), percent detection (% det), number of cross-term false positives (#XFP), lowest detectable SNR (low snr).

params	TF Task1	TF Task2	TF Task3	TFTask4	HTTask1	HTTask2	HTTask3	HTTask4
cr	12.09%	5.47%	N/A	N/A	3.68%	0.31%	N/A	N/A
% det	88%	93.7%	100%	100%	99.27%	100%	99.27%	100.0%
# XFP	8	2	6	9	0	0	4	4
low snr	-2.8db	-3.3db	-2.67db	-1.67db	-4.4db	-6.0db	-3.5db	-3.5db

Table 3 shows that the percent error of chirp rate, percent detection, and low SNR were all better for Task 2 (triangular modulated FMCW, modulation bandwidth=2400Hz) than for Task 1 (triangular modulated FMCW, modulation bandwidth=500Hz) for both the classical time-frequency analysis techniques and the Hough transform (see Figure 10). Also, the low SNR was lower for Task 3 (4-component FSK signal) than for Task 4 (8-component FSK signal).

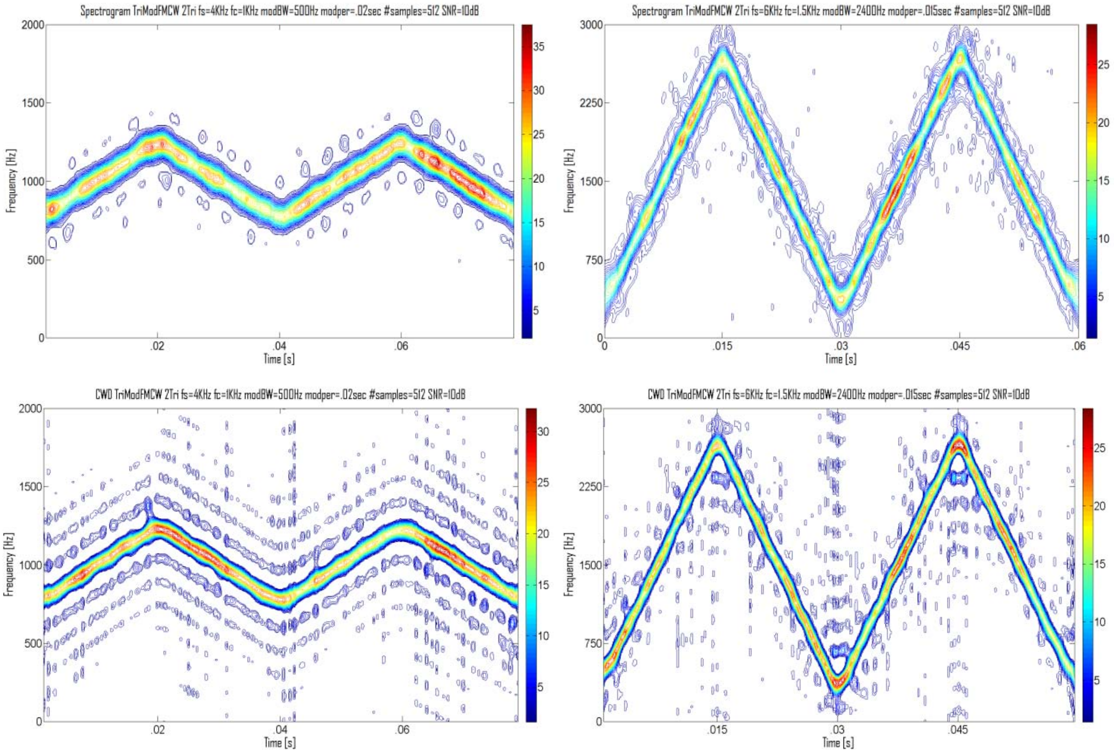


Figure 10 : Comparison between Task 1 (left) and Task 2 (right). The uppper two plots are both spectrogram plots of a triangular modulated FMCW signal (512 samples, SNR=10dB), Task 1 (modulation bandwidth=500Hz) is on the left and Task 2 (modulation bandwidth=2400Hz) is on the right. The lower two plots are CWD plots of the same signals. The Task 2 plots (right) have a larger modulation bandwidth than Task 1 plots, therefore the signals appear taller and more upright than the Task 1 signals.

Figure 11 shows a Spectrogram plot (left) of the area where the Task 5 real-world signal was located, though the signal was not visible in the Spectrogram plot (yellow area is in-band portion, and orange areas are out-of-band portion of band pass filter). The Hough transform of the Spectrogram (right) was performed, and the signal became visible, despite the low SNR environment (-5dB to -10dB). The Hough transform plot showed that the signal values were near theta=0 (or pi) and rho=0, which back-mapped to a nearly flat signal (i.e. tone) which was located near the center (frequency-wise) of the time-frequency representation. For this case, either the signal was a tonal (perhaps an FSK component), or the signal was a chirp; but because the bandwidth of the Spectrogram was so wide (2GHz) compared to the modulation bandwidth of the chirp, the chirp signal appeared 'flat'. For this case, the bandwidth of the Spectrogram needed to be reduced so that the slope of the signal (given that it is a chirp) would become apparent.

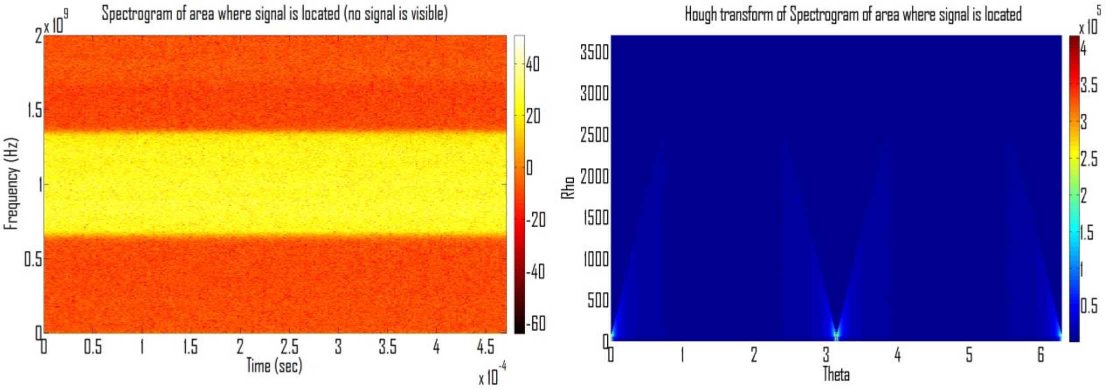
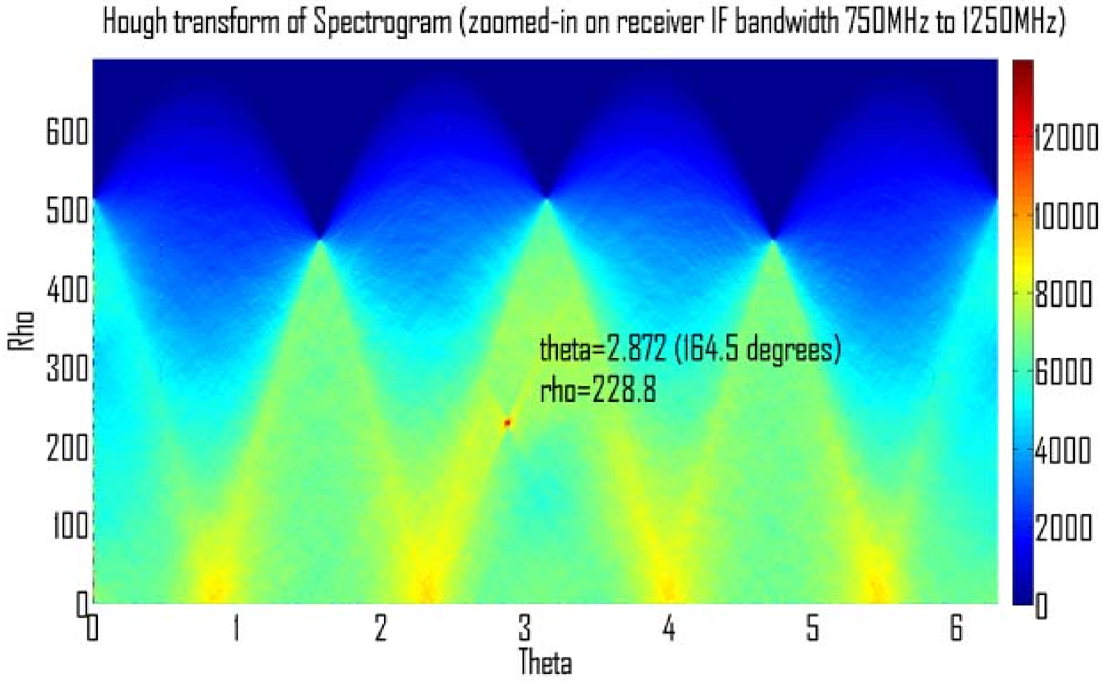


Figure 11 : Spectrogram (left) and Hough transform of Spectrogram (right) of area where Task 5 real-world signal was located. Signal was not visible in the spectrogram, but was visible in the Hough transform, due to the Hough transform's ability to extract signals from low SNR environments.

To investigate this further, a MATLAB script was utilized that that allowed for 'zooming-in' on the receiver IF bandwidth (representing the yellow portion of the Spectrogram in Figure 11 (~750MHz to 1250MHz)) (Y-axis zoom-in only). The data was processed again using the Hough transform of the Spectrogram (Figure 12). The signal appeared at theta=2.872 and rho=228.8, which indicatedthat the signal was indeed a chirp signal, with a chirp rate of

$$chirprate = (-\tan\theta)\left(\frac{\max valueofY - axisofTFplot}{\max valueofX - axis\,ofTFplot}\right)$$

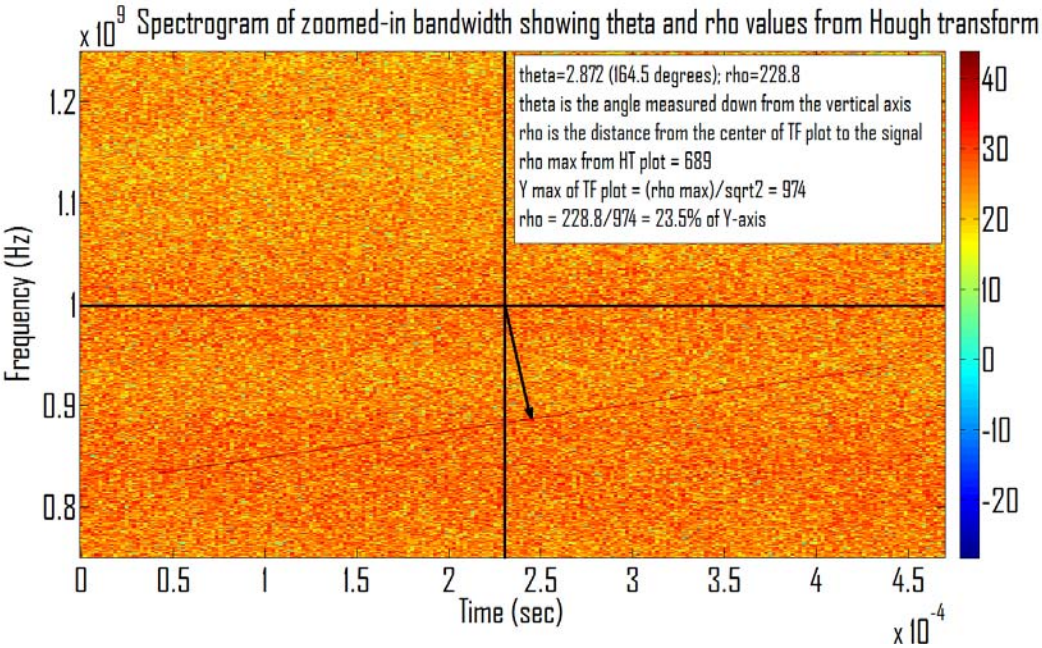
or (-tan (2.872*57.3)(500MHz/471usec) = 0.28MHz/usec.



theta=2.872 (164.5 degrees)
rho=228.8

Figure 12 : Hough transform of Spectrogram (zoomed-in on receiver IF bandwidth (~750MHz to 1250MHz)) of area where Task 5 real-world signal was located. Signal is clearly visible at theta=2.872 and rho=228.8

Using these theta and rho values, back-mapping was performed from the Hough transform to the time-frequency representation (Spectrogram), which allowed the signal to be located (see Figure 13).



theta=2.872 (164.5 degrees); rho=228.8
theta is the angle measured down from the vertical axis
rho is the distance from the center of TF plot to the signal
rho max from HT plot = 689
Y max of TF plot = (rho max)/sqrt2 = 974
rho = 228.8/974 = 23.5% of Y-axis

Figure 13 : Spectrogram (zoomed-in on receiver IF bandwidth (~750MHz to 1250MHz)). Shows how the Hough transform theta and rho values back-map to the time-frequency representation for signal location.

Once the chirp signal was detected in the Spectrogram, the modulation bandwidth (103MHz) and modulation period (389.34usec) metrics were extracted. The chirp rate (modulation bandwidth/modulation period) was then calculated to be 0.264 MHz/usec (very close to the chirp rate of 0.28MHz/usec obtained from the Hough transform plot).

Based on these parameters, it was determined that the signal was the front-end chirp of a particular LPI radar device, which was confirmed by the personnel who supplied the CD for testing.

IV. DISCUSSION

This section of the paper will elaborate on the results from the previous section.

From Table 1 (signal processing tool viewpoint of overall test metrics), the performance of each of the 6 signal processing tools will be summarized, including strengths, weaknesses, and generic scenarios in which a particular tool might be used.

The WVD had the best percent error of chirp rate (5.29%) of all of the classical time-frequency analysis tools, but performed the poorest of all the 6 signal processing techniques in the areas of number of cross-term false positives (25) and low SNR (-2dB). Chirp rate can be seen as directly related to time-frequency localization. As per the methodology section, chirp rate is proportional to the modulation bandwidth. Since modulation bandwidth is a measure from the highest frequency value of a signal to the lowest frequency value of a signal, then the 'thinner' the signal (i.e. good time-frequency localization) the more accurate the modulation bandwidth (and therefore the more accurate the chirp rate), and the 'thicker' the signal (i.e. poor time-frequency localization) the less accurate the modulation bandwidth (and therefore the less accurate the chirp rate). Based on this, it can be said that the WVD's excellent chirp rate is due to its excellent time-frequency localization. This can be attributed to the fact that the WVD exhibits the highest signal energy concentration in the time-frequency plane [GUL07], [PAC09] and is totally concentrated along the instantaneous frequency [CIR08], [GUA06]. The WVD's cross-term interference problem, which is well-known [GUL07], makes it very difficult to see the actual signal [DEL02], [GUA06], [WON09], reducing the readability of the time-frequency distribution. Figure 7 clearly shows the cross-term interference problem that the WVD has. The cross-terms produced a false positive (XFP) triangle in the middle of the two-triangle signal (upper-left plot), and also produced 9 XFPs in the FSK 8-component signal (lower-left plot). Cross-terms are located half-way between signal components [DEL02], [WON09]. Though the WVD is highly concentrated in time and frequency, it is also highly non-linear and non-local, and is therefore very sensitive to noise [AUG95], [FLA03], which accounts for its poor low SNR performance (-2dB). The WVD might be a good tool to use if excellent chirp rate (time-frequency localization) is a requirement, but readability and low SNR environments are not an issue, such as in a scenario where off-line analysis is performed, without any time constraints (because of the WVD's slow plot time). The readability issue can be alleviated if a single-component signal is used, which would eliminate the cross-term interference, but which is unrealistic for LPI radar signals.

The CWD performed 'middle-of-the-road' in every category, as compared to the other classical time-frequency analysis techniques. Its decent performance for percent error of chirp rate (11.49%) (time-frequency localization) can be attributed to the fact that the CWD is part of the Cohen's class of time-frequency distributions, which use a smoothing kernel to smooth out cross-term interference, but at the expense of time-frequency localization [CHO89], [WIL92]. In this sense, the CWD is seen as a mid-point between the WVD (good localization, poor cross-term interference) and the spectrogram (poor localization, good cross-term interference). The fact that it doesn't smooth out all of the cross-term interference allows for decent localization (and therefore decent chirp rate). The CWD might be used in a scenario where above average localization (chirp rate) is required (i.e. somewhere between the WVD and the spectrogram). The goal of such a scenario would be to obtain above average signal metrics in a short amount of time (due to the CWD's fairly quick plot time).

The spectrogram had the best low SNR (-3dB) and percent detection (96.4%) of the classical time-frequency analysis techniques, but had a poor percent error of chirp rate (16.25%). It is known that the spectrogram suffers in time-frequency localization (and therefore chirp rate)[ISI96], [COH95], [HLA92]. The results of these 3 metrics can be attributed to the spectrogram's extreme reduction of cross-term interference, which accounts for good low SNR, and percent detection, but at the expense of poor time-frequency localization (chirp rate). The spectrogram might be used in a scenario where a short plot time is necessary (since it is the fastest time-frequency technique), in a fairly low SNR environment, and where time-frequency localization (chirp rate) is not an issue. Such a scenario might be a 'quick and dirty' check to see if a signal is present, without precise extraction of its parameters.

The scalogram had the worst percent detection (90.4%) and percent error of chirp rate (28.5%) of the classical time-frequency analysis techniques, but did well in low SNR (-2.8dB). The scalogram suppresses almost all cross-terms [GRI07], [LAR92], accounting for its good low SNR performance. Because of this cross-term reduction, it is surprising that the scalogram did not perform better in the area of percent detection. This could be due to its bad time-frequency localization (chirp rate), or to the fact that a wavelet/scalogram performs better on signals that change rapidly in frequency over time, vice the triangular modulated FMCW and FSK signals used in this paper. Like the spectrogram, the scalogram might be used in a scenario where short plot time is necessary (the scalogram has a very fast plot time), in a fairly low SNR environment, and where time-frequency localization (chirp rate) is not an issue, or in a scenario that detects/analyzes signals that change rapidly in frequency over time.

The WVD + HT and the CWD + HT both had good percent error of chirp rates (5.40%/2.74%), that were on par with or better than that of the WVD (5.29%). In addition, the WVD + HT and the CWD + HT both had good percent detections (100%/98.7%) and low SNRs (-3dB/-4.4dB) (see Figure 8). In the presence of noise, the integration carried out by the Hough transform produces an improvement in SNR [INC07], [YAS06], [NIK08]. The WVD + HT and the CWD + HT both had a lower number of cross-term false positives (4/4) than did the WVD (25) (see Figures 7 and 8 for comparison).Since cross-terms have amplitude modulation, the integration implicit in the Hough transform reduces the cross-terms, while the useful contributions, which are always positive, are correctly integrated [TOR07], [BAR95].

Overall from Table 1, the Hough transform methods outperformed the classical time-frequency analysis techniques in percent error of chirp rate (4.07% to 15.4%), percent detection (99.4% to 93.4%), number of cross-term false positives (8 to 25), and low SNR (-3.7dB to -2.5dB).

From Table 2, it was seen that in general, the percent error of chirp rate and percent detection metrics tended to worsen with lowering SNR values, for both the classical time-frequency analysis techniques and the Hough transform (except for HT low SNR). Figure 9shows how readability is degraded as the SNR level is lowered. It is noted that the for the chirp rate metrics, the classical time-frequency analysis techniques experienced a 17.4% degradation of metrics while going from 0dB to low SNR, while the HT experienced a 48% improvement in metrics while going from 0dB to low SNR. This highlights the classical time-frequency analysis techniques mediocre performance in a low SNR environment, and also highlights the Hough transform's robust performance in a low SNR environment. This translates to improved readability of the Hough transform plot over the classical time-frequency analysis representation in low SNR environments. As noted previously, the XFPs in Table 2 are representative of the fact that, due to computational complexity, there was no WVD testing accomplished at lower than 10dB (except for the 256 sample cases). Had testing been able to be accomplished at lower than 10dB SNR levels for the 512 sample cases, the XFP numbers would have likely increased as the SNR level decreased. Table 2 shows by-and-large that the Hough transform's metrics were more accurate than the classical time-frequency analysis techniques' metrics at every SNR level.

From Table 3, it was seen that the percent error of chirp rate, percent detection, and low SNR are all better for Task 2 (triangular modulated FMCW, modulation bandwidth=2400Hz) than for Task 1 (triangular modulated FMCW, modulation bandwidth= 500Hz) for both the classical time-frequency analysis techniques and the Hough transform. As per Figure 10, the modulation bandwidth is a measure from the highest frequency point of a signal to the lowest frequency point of a signal. Therefore, the 'thickness' of a signal will affect the modulation bandwidth measurement of a 'shorter' signal (Task 1 – left-hand side of Figure 10)) more than that of a 'taller' signal (Task 2 – right-hand side of Figure 10)). Because of this, the modulation bandwidth percent error will be lower for Task 2 (the 'taller' signal) than for Task 1 (the 'shorter' signal). Since chirp rate is proportional to modulation bandwidth, then chirp rate percent error will be lower for Task 2 (the 'taller' signal) than for Task 1 (the 'shorter' signal). As mentioned previously, chirp rate is proportional to time-frequency localization; therefore time-frequency localization will be better for Task 2 than for Task1. Better time-frequency localization translates to better readability, which in turn makes for better percent detection and low SNR values, which accounts for Task 2 having better metrics for these 2 parameters than Task 1. For the Hough transform, the 'longer', 'tighter' signal of Task 2 translates to a 'higher' (greater accumulator value) and 'tighter' spike in the Hough transform plot. The 'higher' spike accounts for the better percent detection and low SNR values of Task 2, because the signal (spike) is that much higher than the noise floor. The 'tighter' signal makes for a more accurate theta value extraction, which in turn makes for a more accurate chirp rate (since chirp rate is proportional to theta per the methodology section). It was also noted that for the classical time-frequency analysis techniques, the low SNR value was lower for Task 3 (4-component FSK signal) than for Task 4 (8-component FSK signal). This may be due to the fact that the Task 3 signal has only 4 components, each of which is twice as long as the Task 4 signal's 8-components. This means that at low SNR levels, the Task 3 signal has a better chance of at least a portion of each of its 4 (longer) signal components exceeding the low SNR threshold than does the Task 4 signal with its 8 (shorter) components. Table 3 shows by-and-large that the Hough transform's metrics were more accurate than the classical time-frequency analysis techniques' metrics for each of the 4 Tasks.

Figure 11 shows that the Spectrogram, though the fastest classical time-frequency analysis technique

[HLA92], did not have the ability to detect the signal in a low SNR environment (-5dB to -10dB). However, in the presence of noise, the integration carried out by the Hough transform produces an improvement in SNR [INC07], [YAS06], [NIK08], and therefore the Hough transform was able to 'dig' the signal out of the noise. The ability to back-map from the Hough transform to the time-frequency representation, based on theta and rho values of the signal, allowed for a quick deduction that the signal (in the time-frequency representation) was nearly 'flat' and that it was located near the middle of the plot (frequency-wise). The ability to zoom-in (Y direction only) on the receiver IF bandwidth (the yellow portion of the Spectrogram of Figure 11) and then perform a Hough transform of the Spectrogram (Figure 12) made possible the detection and chirp rate extraction (0.28MHz/usec) of the signal, and also the determination that the signal was a chirp and not a tone. Back-mapping once again allowed for the signal location to be found in the time-frequency representation. Once the modulation bandwidth (103MHz) and modulation period (389.34usec) values were extracted, and the chirp rate (modulation bandwidth/modulation period) was calculated (0.264MHz/usec, very close to the Hough transform calculated value of 0.28MHz/usec), then identification of the LPI radar device that emitted the signal was straight-forward.

Recapping, the metrics data backs up the following introductory assumptions:

The classical time-frequency analysis techniques are deficient in the areas of cross-term interference and mediocre performance in low SNR environments, making for poor readability and consequently, inaccurate detection and parameter extraction of LPI radar signals.

The Hough transform's qualities of cross-term reduction, separating signals from cross-terms, and good performance in low SNR environments make for better readability and consequently, for more accurate signal detection and parameter extraction of LPI radar signals.

V. Conclusions

It was noted that digital intercept receivers are currently moving away from Fourier-based analysis and towards classical time-frequency analysis techniques, such as the Wigner-Ville distribution, Choi-Williams distribution, spectrogram, and scalogram, for the purpose of analyzing low probability of intercept radar signals (e.g. triangular modulated FMCW and FSK). Though these classical time-frequency techniques are an improvement over the Fourier-based analysis, it was shown through the testing plots that they suffer from a lack of readability, due to cross-term interference, and a mediocre performance in low SNR environments, as brought out in the discussion section of this chapter. It was shown through testing metrics that this lack of readability led to inaccurate detection and parameter extraction of the LPI radar signals, which would undoubtedly make for a less informed (and therefore less safe) intercept receiver environment. Simulations were presented that compared time-frequency representations of the classical time-frequency techniques with those of the Hough transform. Two different triangular modulated FMCW LPI radar signals and two different FKS LPI radar signals (4-component and 8-component) were analyzed. The following metrics were used for evaluation of the analysis: percent error of chirp rate, percent detection, number of cross-term false positives, and lowest signal-to-noise ratio for signal detection. Experimental results demonstrated that the Hough transform's ability to suppress cross-term interference, separate signals from cross-terms, and perform well in the presence of noise did indeed lead to improved readability over the classical time-frequency analysis techniques, and consequently, provided more accurate signal detection and parameter extraction metrics (smaller percent error from true value) than the classical time-frequency analysis techniques. In summary, this paper provided evidence that the Hough transform has the potential to outperform the classical time-frequency analysis techniques. In addition, the Hough transform was utilized to detect, extract parameters, and properly identify a real-world LPI radar signal in a low signal-to-noise ratio environment where classical time-frequency analysis failed. Future plans include automation of the metrics extraction process, analysis of additional low probability of intercept radar waveforms of interest, and analysis of other real-world low probability of intercept radar signals utilizing more powerful computing platforms.

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Ship Handling when the Environmental Parameters Varied as the Function of the Way

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Abstract- The paper devotes the algorithm of ship handling when the environmental parameters varied as the function of the way. In nautical practice, when the ships sail in the channel, they often arrange as the convoy with the leader ship. In order to ensure the maritime safety, the mariner should establish the algorithm for control of ship engine system and steering gear complex. In this research, the author uses the maximum principle of Pontryagin L.S to establish the similar control. However, in order to obtain these ranges of numerical solutions like this, sometimes it's difficult to use the maximum principle. Because, there is not enough the initial condition for using of the auxiliary vector that is the quantity to define the time of control variation. These obstacles shall be cleared by the selection of the transversal conditions. The problems are solved under Maier's and G. Kelly's condition as well as the Hamiltonian operator and Cardano's formula.

Keywords: function of way, maier's condition, G. kelly's condition, hamiltonian operator.

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SHIPHANDLINGWHENTHEENVIRONMENTALPARAMETERSVARIEDASTHEFUNCTIONOFTHEWAY

Strictly as per the compliance and regulations of:

Ship Handling when the Environmental Parameters Varied as the Function of the Way

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Abstract- The paper devotes the algorithm of ship handling when the environmental parameters varied as the function of the way. In nautical practice, when the ships sail in the channel, they often arrange as the convoy with the leader ship. In order to ensure the maritime safety, the mariner should establish the algorithm for control of ship engine system and steering gear complex. In this research, the author uses the maximum principle of Pontryagin L.S to establish the similar control. However, in order to obtain these ranges of numerical solutions like this, sometimes it's difficult to use the maximum principle. Because, there is not enough the initial condition for using of the auxiliary vector that is the quantity to define the time of control variation. These obstacles shall be cleared by the selection of the transversal conditions. The problems are solved under Maier's and G. Kelly's condition as well as the Hamiltonian operator and Cardano's formula.

Keywords: function of way, maier's condition, G. kelly's condition, hamiltonian operator.

I. Introduction

In order to control the navigation of ship in following the object in the sub-system of higher order, example in the coastal system, there should be the unique complex of the programs (or algorithm) for controlling of power system and steering complex in normal and emergency situation. Basing on these programs, the mariner evaluates the situation and the context around the ship and obtains the objective information that he can make the good decision and give the proper solution. In necessary case, it can be transferred the program control to the diesel system. These programs like this can help the mariner estimate the controlled movement of ship as the time.

Those algorithms should be considered as the evaluation and auxiliary. Their objective is to help obtaining the proper controls that are not compulsory to use directly on board the vessel. Also, they can be used as the initial information for maneuvering of the specified vessel to escape from the emergency and critical situation.

These algorithm creations are carried out by the way how the classes of limited condition are used for imposing on the control action and phase co-ordinate. Also, it may be easily extended for the limitations that applied for the speed of variable control or acceleration, where the general form of obtained algorithm is fully preserved. That property of them is to help the mariner using the given algorithms to synthesize the systems of engine complex control and ship steering gear that is for purpose of safety and economical navigation.

II. Literature Review

In this subject, there are researches of authors such as Krasovsky A.A. (1999), Peshekhonov V.G (2000), Kolesnikov A.A. (2002), Astana Y.M (2002), V.S Medvedev et al. (2005), Hecht-Nielsen r. (2007), Stone M. (2009), Weierstrass K. (2010). Their works are based on the classical methods of construction of automatic control systems and in particular the ship's course allows classifying the type of techniques used by the mathematical model of the vessel, processed information, methods of adaptation, design features. In some cases, the sufficient condition purely is the evaluation of the proposal algorithm that is to create the exactly controls. But, it is often required the more detail solutions that means the numerical ones.

In this research, the author uses the maximum principle of Pontryagin L.S to establish the similar control. However, in order to obtain these ranges of numerical solutions like this, sometimes it's difficult to use the maximum principle. Because, there is not enough the initial condition for using of the auxiliary vector that is the quantity to define the time of control variation. These obstacles shall be cleared by the selection of the transversal conditions.

III. Method of Research

It's assumed that the external environment is changing its characteristics as the function of the way. This happens when the parameters are considered as characteristic of the depth, width, and tortuosity of the channel[1, 2, 3 and 4], then

$$\psi = \psi(s) \tag{1}$$

Equations of the ship complex in this case will be:

$$\left.\begin{aligned} \frac{dv}{dt} &= -\frac{1}{T_c}v + \frac{K_c^{\omega}}{T_c}\omega - \frac{K_c^{\psi}}{T_c}\psi(s), \\ \frac{d\omega}{dt} &= -\frac{1}{T_g}\omega + \frac{K_g^h}{T_g}h + \frac{K_g^v}{T_g}v, \\ \frac{dG_m}{dt} &= K_g^{\omega}K_g^h\omega h,\ \frac{ds}{dt} = v. \end{aligned}\right\} \tag{2}$$

And the restricted conditions that applied on the control action hare

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$$0 \le h \le h_{max} \qquad (3)$$

It's necessary to find the control law for the given complex in the dynamic condition:

$$h = h(t)$$

Which the function can be minimized in the sailing time T:

$$\Delta G_m = G_m(v,s) \qquad (4)$$

Basing on the principle of maximum, it's developed and solved the problem of optimal control in the form of Mayer [6, 7, 8 and 11]. The problem relates to the problem of fixed right and left ends.

The boundary conditions are written:

$$\left.\begin{array}{l} \text{at the left end } t=0, v_0=\omega_0=G_{T_0}=s_0=0; \\ \text{at the right end } t=T, v_T,\ \omega_T - \text{free quantities}, s=s_T \end{array}\right\}$$

The Hamiltonian of equation (2) is:

$$H=\left[-\frac{1}{T_c}V+\frac{K_c^{\omega}}{T_c}\omega-\frac{K_c^{\psi}}{T_c}\psi(S)\right]\alpha_1+ \qquad (5)$$
$$+\left[-\frac{1}{T_g}\omega+\frac{K_g^h}{T_g}h+\frac{K_g^h}{T_g}V\right]\alpha_2+\left[K_g^{\omega}\omega K_g^h h\right]\alpha_3+V\alpha_4$$

The function for finding the vector **α** will be:

$$\left.\begin{array}{l} \dfrac{d\alpha_1}{dt}=\dfrac{1}{T_c}\alpha_1-\dfrac{K_g^v}{T_g}-\alpha_2-\alpha_4, \\ \dfrac{d\alpha_2}{dt}=-\dfrac{K_c^{\omega}}{T_c}\alpha_1+\dfrac{1}{T_g}\alpha_2-K_g^{\omega}K_g^h h\alpha_3, \\ \dfrac{d\alpha_3}{dt}=0,\ \dfrac{d\alpha_4}{dt}=\dfrac{K_c^{\psi}}{T_c}\dfrac{d\psi(s)}{ds}\alpha_1. \end{array}\right\} \qquad (6)$$

The transversal conditions are:

$$[(1+\alpha_3)\delta G_m - H\delta t+\alpha_1\delta v+ \qquad (7)$$
$$+\alpha_2\delta\omega+\alpha_4\delta s]_0^T=0$$

Then the above problem has the 1st order integral form:

$$\left[-\frac{1}{T_c}v+\frac{K_c^{\omega}}{T_c}\omega-\frac{K_c^{\psi}}{T_c}\psi(s)\right]\alpha_1+$$
$$+\left[-\frac{1}{T_g}\omega+\frac{K_g^h}{T_g}h+\frac{K_g^v}{T_g}v\right]\alpha_2+ \qquad (8)$$
$$+\left[K_g^{\omega}\omega K_g^h h\right]\alpha_3+v\alpha_4=c$$

The equality (8) is only relied on the contingent selection of variations δG_m, δv, $\delta\omega$ when:

$$\left.\begin{array}{c} \alpha_{3T}=-1, H=c=0, \\ \alpha_{1T}=0, \alpha_{2T}=0, \alpha_{4T}=0 \end{array}\right\} \qquad (9)$$

The structure of resulted control action is investigated:

$$\frac{\partial H}{\partial h}=\frac{K_g^h}{T_g}\alpha_2+K_g^h K_g^{\omega}\omega\alpha_3 \qquad (10)$$

Thence, there is the variable law of the control action as:

$$\left.\begin{array}{l} h=h_{max} \text{ at } \dfrac{K_g^h}{T_g}\alpha_2+K_g^h K_g^{\omega}\omega\alpha_3>0, \\ h=0 \text{ at } \dfrac{K_g^h}{T_g}\alpha_2+K_g^h K_g^{\omega}\omega\alpha_3<0 \end{array}\right\} \qquad (11)$$

From the equation (6), it is obtained the solution of component vector:

$$\alpha \quad \alpha_3=c_3^{\alpha}$$

Because of the transversal condition, it implies that

$$\alpha_{3T}=-1,$$

Consequently

$$c_3^{\alpha}=-1 \text{ and } \alpha_3=-1$$

Basing on this, the control will be varied as following law:

$$\left.\begin{array}{l} h=h_{max} \text{ at } \dfrac{K_g^h}{T_g}\alpha_2-K_g^h K_g^{\omega}\omega>0, \\ h=0 \text{ at } \dfrac{K_g^h}{T_g}\alpha_2-K_g^h K_g^{\omega}\omega<0 \end{array}\right\} \qquad (12)$$

Now, it is going to integrate the equations of the problem. From the equation:

$$v=\frac{ds}{dt},$$

it's found:

$$ds=vdt$$

and

$$s=\int_0^T vdt.$$

Therefore the equations of α_4 (equation 6) can be rewritten as following:

$$\frac{d\alpha_4}{dt}=\frac{K_c^{\psi}}{T_c}\frac{1}{v}\frac{d\psi\left(\int_0^T vdt\right)}{dt}\alpha_1,$$

Or

$$\frac{d\alpha_4}{dt}=\frac{K_c^{\psi}}{T_c}\frac{1}{v}\frac{d\psi(t)}{dt}\alpha_1 \qquad (13)$$

So the given task can be converted to the problem of variable external conditions that change as the function of time [14, 15, 16 and 19].

On the basis of the equation (13), it should be integrated the following differential equations with the control action $h = h_{max}$ on the interval time $0 \div t^*$, it means the time where:

$$\left.\begin{array}{l}
{K_g^h}/{T_g} - \alpha_2 + K_g^h K_g^\omega \omega \alpha_3 : \\
\dfrac{dv}{dt} = -\dfrac{1}{T_c} v + \dfrac{K_c^\omega}{T_c}\omega - \dfrac{K_c^\psi}{T_c}\psi(v,t), \\
\dfrac{d\omega}{dt} = -\dfrac{1}{T_g}\omega + \dfrac{K_g^h}{T_g} h_{max} + \dfrac{K_g^v}{T_g} v, \\
\dfrac{dG_m}{dt} = K_g^\omega K_g^h \omega h_{max}, \ \dfrac{ds}{dt} = v, \\
\dfrac{d\alpha_1}{dt} = \dfrac{1}{T_c}\alpha_1 - \dfrac{K_g^v}{T_g}\alpha_2 - \alpha_4, \\
\dfrac{d\alpha_2}{dt} = -\dfrac{K_c^\omega}{T_c}\alpha_1 + \dfrac{1}{T_g}\alpha_2 - K_g^\omega K_g^h h_{max}\alpha_3, \\
\dfrac{d\alpha_3}{dt} = 0, \ \dfrac{d\alpha_4}{dt} = \dfrac{K_c^\psi}{T_c}\dfrac{1}{v}\dfrac{d\psi(t)}{dt}\alpha_1.
\end{array}\right\} \qquad (14)$$

And, it's continuously integrated that equation in range of t* ÷ T until:

$${K_g^h}/{T_g}\,\alpha_2 + K_g^h K_g^\omega \omega \alpha_3 < 0 .$$

When the actions control h = 0:

$$\left.\begin{array}{l}
\dfrac{dv}{dt} = -\dfrac{1}{T_c} v + \dfrac{K_c^\omega}{T_c}\omega - \dfrac{K_c^\psi}{T_c}\psi(v,t), \\
\dfrac{d\omega}{dt} = -\dfrac{1}{T_g}\omega + \dfrac{K_g^v}{T_g} v, \ \dfrac{ds}{dt} = v, \\
\dfrac{d\alpha_1}{dt} = \dfrac{1}{T_c}\alpha_1 - \dfrac{K_g^v}{T_g}\alpha_2 - \alpha_4, \\
\dfrac{d\alpha_2}{dt} = -\dfrac{K_c^\omega}{T_c}\alpha_1 + \dfrac{1}{T_g}\alpha_2, \ \dfrac{d\alpha_3}{dt} = 0, \\
\dfrac{d\alpha_4}{dt} = \dfrac{K_c^\psi}{T_c}\dfrac{1}{v}\dfrac{d\psi(t)}{dt}\alpha_1.
\end{array}\right\} \qquad (15)$$

The initial conditions about the solution of the equations (15) will be the values ofthe phase coordinate calculated by the solution of the equation (14) at time t*.

The solutions of the equations (14) and (15)can be numerical. In order to consider the structure of the control action and the switching functions (11) and (12), it should be rewritten the equations (6):

$$\left.\begin{array}{l}
\dfrac{d\alpha_1}{dt} = a_{11}\alpha_1 - a_{12}\alpha_2 - a_{14}\alpha_4, \\
\dfrac{d\alpha_2}{dt} = -a_{21}\alpha_1 + a_{22}\alpha_2 - a_{23}\alpha_3, \\
\dfrac{d\alpha_3}{dt} = 0, \ \dfrac{d\alpha_4}{dt} = a_{41}\alpha_1.
\end{array}\right\} \qquad (16)$$

Where:

$$\left.\begin{array}{l}
a_{11} = {1}/{T_c}, \ a_{12} = {K_g^v}/{T_g}, \ a_{21} = {K_c^\omega}/{T_c}, \ a_{14} = -1, \\
a_{22} = {1}/{T_g}, \ a_{23} = K_g^h K_g^\omega h, \ a_{41} = \dfrac{K_c^\psi}{T_c}\dfrac{d\psi(s)}{ds}.
\end{array}\right\} \qquad (17)$$

The typical determinant of the given equations is:

$$\begin{vmatrix}
a_{11} - p & a_{12} & 0 & -a_{14} \\
-a_{21} & a_{22} - p & -a_{23} & 0 \\
0 & 0 & -p & 0 \\
a_{41} & 0 & 0 & -p
\end{vmatrix} = 0$$

Based on the above determinant, it can be written the typical equations as following:

$$p^4 - q_1 p^3 + q_2 p^2 - q_3 p = 0 \qquad (18)$$

That typical equation is invariable for the action control, because of:

$$\left.\begin{array}{c}
q_1 = a_{22} + a_{11}, \ q_2 = a_{14}a_{41} + a_{11}a_{22} - a_{12}a_{21}, \\
q_3 = a_{14}a_{41}a_{22}
\end{array}\right\} \qquad (19)$$

Now, it is continuously found the solutions of equation (16) in the form:

$$\left.\begin{array}{l}
\alpha_1 = c_1\gamma_1^{(1)} l^{p_1 t} + c_2\gamma_1^{(2)} l^{p_2 t} + c_3\gamma_1^{(3)} l^{p_3 t} + \\
+ c_4\gamma_1^{(4)} l^{p_4 t}, \\
\alpha_2 = c_1\gamma_2^{(1)} l^{p_1 t} + c_2\gamma_2^{(2)} l^{p_2 t} + c_3\gamma_2^{(3)} l^{p_3 t} + \\
+ c_4\gamma_2^{(4)} l^{p_4 t}, \\
\alpha_3 = c_1\gamma_3^{(1)} l^{p_1 t} + c_2\gamma_3^{(2)} l^{p_2 t} + c_3\gamma_3^{(3)} l^{p_3 t} + \\
+ c_4\gamma_3^{(4)} l^{p_4 t}, \\
\alpha_4 = c_1\gamma_4^{(1)} l^{p_1 t} + c_2\gamma_4^{(2)} l^{p_2 t} + c_3\gamma_4^{(3)} l^{p_3 t} + \\
+ c_4\gamma_4^{(4)} l^{p_4 t}.
\end{array}\right\} \qquad (20)$$

Wherein γ_i^k is constant factor that specified for each solution k of the typical equation (18) in the following systems:

1. $P_1 = 0$

$$\left.\begin{array}{r}
a_{11}\gamma_1^{(1)} - a_{12}\gamma_2^{(1)} - a_{14}\gamma_4^{(1)} = 0, \\
-a_{21}\gamma_1^{(1)} + a_{22}\gamma_2^{(1)} - a_{23}\gamma_3^{(1)} = 0, \ a_{41}\gamma_1^{(1)} = 0.
\end{array}\right\} \qquad (21)$$

Basing on (21), it's obtained $\gamma_1^{(1)} = 0$ and $\gamma_2^{(2)} = 1$, there are:

$$\gamma_4^{(1)} = -{a_{12}}/{a_{14}}, \quad \gamma_3^{(1)} = {a_{22}}/{a_{23}}.$$

2. $P = P_2$

$$\left.\begin{array}{c}
(a_{11} - p_2)\gamma_1^{(2)} - a_{12}\gamma_2^{(2)} - a_{14}\gamma_4^{(2)} = 0, \\
-a_{21}\gamma_1^{(2)} + (a_{22} - p_2)\gamma_2^{(2)} - a_{23}\gamma_3^{(2)} = 0, \\
-p_2\gamma_3^{(2)} = 0, \ a_{41}\gamma_1^{(2)} - p_2\gamma_4^{(2)} = 0.
\end{array}\right\} \qquad (22)$$

Basing on the equation (22), it's obtained:

$$\left.\begin{aligned} &\gamma_1^{(2)}=1,\ \gamma_2^{(2)}=\frac{a_{11}-p_2}{a_{12}}-\frac{a_{14}a_{41}}{a_{12}p_2},\\ &\gamma_3^{(2)}=0,\ \gamma_4^{(2)}=\frac{a_{41}}{p_2}. \end{aligned}\right\} \qquad (23)$$

3. P = P_3

$$\left.\begin{aligned} &(a_{11}-p_3)\gamma_1^{(3)}-a_{12}\gamma_2^{(3)}-a_{14}\gamma_4^{(3)}=0,\\ &-a_{21}\gamma_1^{(3)}+(a_{22}-p_3)\gamma_2^{(3)}-a_{23}\gamma_3^{(2)}=0,\\ &-p_3\gamma_3^{(3)}=0,\ a_{41}\gamma_1^{(3)}-p_3\gamma_4^{(3)}=0. \end{aligned}\right\} \qquad (24)$$

From that, there'll be:

$$\left.\begin{aligned} &\gamma_1^{(3)}=1,\ \gamma_2^{(3)}=\frac{a_{11}-p_3}{a_{12}}-\frac{a_{14}a_{41}}{a_{12}p_3},\\ &\gamma_3^{(3)}=0,\ \gamma_4^{(3)}={}^{a_{41}}\!/_{p_3}. \end{aligned}\right\} \qquad (25)$$

4. P = P_4

$$\left.\begin{aligned} &(a_{11}-p_4)\gamma_1^{(4)}-a_{12}\gamma_{12}^{(4)}-a_{14}\gamma_4^{(4)}=0,\\ &-a_{21}\gamma_1^{(4)}+(a_{22}-p_4)\gamma_3^{(4)}-a_{23}\gamma_3^{(4)}=0,\\ &-p_4\gamma_3^{(4)}=0,\ a_{41}\gamma_1^{(4)}-p_4\gamma_4^{(4)}=0. \end{aligned}\right\} \qquad (26)$$

Basing on equation (26), it's obtained:

$$\left.\begin{aligned} &\gamma_1^{(4)}=1,\ \gamma_2^{(4)}=\frac{a_{11}-p_4}{a_{12}}-\frac{a_{14}a_{41}}{a_{12}p_4},\\ &\gamma_3^{(4)}=0,\ \gamma_4^{(4)}={}^{a_{41}}\!/_{p_4}. \end{aligned}\right\} \qquad (27)$$

Analyzing of solutions of typical equation (18), there is:

$$p(p^3-q_1p^2+q_2p-q_3)=0$$

Substituting the below - mentioned into the given equation:

$$p=y+{}^{q_1}\!/_{3}$$

It's obtained the following equation:

$$y^3+by+c=0 \qquad (28)$$

Where:

$$b=q_2-\frac{q_1^2}{3},\ c=\frac{9q_2q_1-2q_1^3}{27}-q_3$$

The equation (28) will be solved by Cardano formula:

$$\begin{aligned} y&=\sqrt{-\frac{c}{2}+\sqrt{\left(\frac{c}{2}\right)^2+\left(\frac{b}{3}\right)^3}}+\\ &+\sqrt{-\frac{c}{2}-\sqrt{\left(\frac{c}{2}\right)^2+\left(\frac{b}{3}\right)^3}}. \end{aligned} \qquad (29)$$

Understanding that each of three roots:

$$\delta=\sqrt{-\frac{c}{2}+\sqrt{\left(\frac{c}{2}\right)^2+\left(\frac{b}{3}\right)^3}}$$

It should be chosen one value of solution:

$$\eta=\sqrt{-\frac{c}{2}-\sqrt{\left(\frac{c}{2}\right)^2+\left(\frac{b}{3}\right)^3}}$$

In which, the following condition should be carried out:

$$\delta\eta=-\frac{b}{3}$$

On the basis of that condition, it can be written the root of the typical equation as following:

$$\left.\begin{aligned} &p_2=(\delta_1+\eta_1)-\frac{q_1}{3},\\ &p_3=-\frac{1}{2}(\delta_1+\eta_1)+i\frac{\sqrt{3}}{2}(\delta_1-\eta_1)-\frac{q_1}{3},\\ &p_4=-\frac{1}{2}(\delta_1+\eta_1)-i\frac{\sqrt{3}}{2}(\delta_1-\eta_1)-\frac{q_1}{3} \end{aligned}\right\} \qquad (30)$$

It is clarified a matter of the obtained structure of control.

$$\frac{\partial H}{\partial h}=\frac{K_g^h}{T_g}\alpha_2+K_g^hK_g^\omega\omega\alpha_3$$

From there, there will be:

$$\left.\begin{aligned} &h=h_{max}\ \text{khi}\ \frac{K_g^h}{T_g}\alpha_2+K_g^hK_g^\omega\omega\alpha_3>0,\\ &h=0\ \text{khi}\ \frac{K_g^h}{T_g}\alpha_2+K_g^hK_g^\omega\omega\alpha_3<0. \end{aligned}\right\} \qquad (31)$$

On the basis of symbol (27), roots of equations (20), (21), (22), (23), (24), (25), (26), (27) and the expression solutions of the typical equation, it can be affirmed that:

$$\left.\begin{aligned} &p_2=p_2[A,\frac{d\psi}{ds}];\quad p_3=p_3[A,\frac{d\psi}{ds}];\\ &p_4=p_4[A,\frac{d\psi}{ds}];\quad \gamma_2^{(2)}=\gamma_2^{(2)}[A,\frac{d\psi}{ds}];\\ &\gamma_4^{(2)}=\gamma_4^{(2)}[A,\frac{d\psi}{ds}];\quad \gamma_2^{(3)}=\gamma_2^{(3)}[A,\frac{d\psi}{ds}];\\ &\gamma_4^{(3)}=\gamma_4^{(3)}[A,\frac{d\psi}{ds}];\quad \gamma_2^{(4)}=\gamma_2^{(4)}[A,\frac{d\psi}{ds}];\\ &\gamma_4^{(4)}=\gamma_4^{(4)}[A,\frac{d\psi}{ds}]. \end{aligned}\right\} \qquad (32)$$

In the function (32), A is vector of parameters of equation (16). The given expressions will be right for the constant case of value A and $d\psi/ds$ (method of freezing factor) [16, 17, 18 and 21].

It is necessary to find p_j and γ_i in correspondence with the new values of A and $d\psi/ds$, and define the subsequent roots of the differential equation.

On the basis of (20÷27) and (32),it can be written:

$$\left.\begin{aligned}
&\alpha_2 = c_1 + c_2\left\{\gamma_2^{(2)}\left[A,\frac{d\psi}{ds}\right]\right\}\exp\left\{p_2\left[A,\frac{d\psi}{ds}\right]\right\}+\\
&+c_3\left\{\gamma_2^{(3)}\left[A,\frac{d\psi}{ds}\right]\right\}\exp\left\{p_3\left[A,\frac{d\psi}{ds}\right]\right\}t+\\
&+c_4\left\{\gamma_2^{(4)}\left[A,\frac{d\psi}{ds}\right]\right\}\exp\left\{p_4\left[A,\frac{d\psi}{ds}\right]\right\}t,\\
&\alpha_3 = c_2\frac{1}{T_g K_g^{\omega}}
\end{aligned}\right\} \qquad (33)$$

The integral constants of the given case are defined in correspondence with the obtained edge conditions (9).

The above problem of the optimal control when the external environment is function of way is required for the practical implementation of the algorithm found by measuring the magnitude $\frac{d\psi}{ds}$ and hence the value $\psi = \psi(s)$. As a rule, this information is available especially on canals and rivers. The main difficulty is to find the ways of formalizing this information. Such methods must be simple in structure, and at the same time provide a minimum amount of information loss in finding the controls. For these purposes, it may be proposed a method described in previously.

It's analyzed the possibility of existing of special control in the systems (2) and (6) and transformed the Hamiltonian (5):

$$\begin{aligned}
H = &\left[-\frac{1}{T_c}v\alpha_1 + \frac{K_c^{\omega}}{T_c}\omega\alpha_1 - \frac{K_c^{\psi}}{T_c}\psi(s)\alpha_1 + \right.\\
&\left.+\frac{K_g^{v}}{T_g}\alpha_2 + v\alpha_4\right] + \left[\frac{K_g^{h}}{T_g}\alpha_2 + K_g^{\omega}K_g^{h}\omega\alpha_3\right]h
\end{aligned} \qquad (34)$$

It's marked:

$$\left.\begin{aligned}
&H_0 = -\frac{1}{T_c}v\alpha_1 + \frac{K_c^{\omega}}{T_c}\omega\alpha_1 -\\
&-\frac{K_c^{\psi}}{T_c}\psi(s)\alpha_1 + \frac{K_g^{v}}{T_g}\alpha_2 + v\alpha_4,\\
&H_1 = \frac{K_g^{h}}{T_g}\alpha_2 + K_g^{\omega}K_g^{h}\omega\alpha_3.
\end{aligned}\right\} \qquad (35)$$

In correspondence with the result in [5, 20], it is found:

$$\frac{d}{dt}H_1 = \frac{K_g^{h}}{T_g}\frac{d\alpha_2}{dt} + K_g^{\omega}K_g^{h}\frac{d\omega}{dt}\alpha_3. \qquad (36)$$

The given expression is obtained from the condition $\alpha_3 = \text{const}$. The special control may be existed in (35) only if the derivative H_1 is even order, so it can be found:

$$\frac{d^2}{dt^2}H_1 = \frac{K_g^{h}}{T_g}\frac{d^2\alpha_2}{dt^2} + K_g^{\omega}K_g^{h}\alpha_3\frac{d^2\omega}{dt^2} = 0. \qquad (37)$$

In which:

$$\left.\begin{aligned}
&\frac{d^2\alpha_2}{dt^2} = -\frac{K_c^{\omega}}{T_c}\frac{d\alpha_1}{dt} + \frac{1}{T_g}\frac{d\alpha_2}{dt} - K_g^{\omega}K_g^{h}\alpha_3\frac{dh}{dt},\\
&\frac{d^2\omega}{dt^2} = -\frac{1}{T_g}\frac{d\omega}{dt} + \frac{K_g^{h}}{T_g}\frac{dh}{dt} + \frac{K_g^{v}}{T_g}v.
\end{aligned}\right\} \qquad (38)$$

Substituting (38), respectively, (2) and (6), it's obtained:

$$\left.\begin{aligned}
&\frac{d^2\alpha_2}{dt^2} = -\frac{K_c^{\omega}}{T_c}\left(\frac{1}{T_c}\alpha_1 - \frac{K_g^{v}}{T_g}\alpha_2 - \alpha_4\right)+\\
&+\frac{1}{T_g}\left(\frac{K_c^{\omega}}{T_c}\alpha_1 + \frac{1}{T_g}\alpha_2 - K_g^{\omega}K_g^{h}h\alpha_3\right)-\\
&-K_g^{\omega}K_g^{h}\alpha_3\frac{dh}{dt},\\
&\frac{d^2\omega}{dt^2} = -\frac{1}{T_g}\left(-\frac{1}{T_g}\omega + \frac{K_g^{h}}{T_g}h + \frac{K_g^{v}}{T_g}v\right)+\\
&+\frac{K_g^{h}}{T_g}\frac{dh}{dt} + \frac{K_g^{v}}{T_g}v.
\end{aligned}\right\} \qquad (39)$$

On the basis of (39), it can be rewritten (37) in the developed form, as following:

$$\begin{aligned}
&\frac{d^2}{dt^2}H_1 = b_1^{H}\alpha_1 + b_2^{H}\alpha_2 + b_3^{H}\alpha_4 -\\
&-b_4^{H}h + c_1^{H}v + c_2^{H}\omega - c_3^{H}h = 0.
\end{aligned} \qquad (40)$$

In which:

$$\left.\begin{aligned}
&b_1^{H} = \frac{K_c^{\omega}K_g^{h}}{T_g T_c^2} - \frac{K_c^{\omega}K_g^{h}}{T_g^2 T_c}, \quad b_2^{H} = \frac{K_g^{h}}{T_g^3}+\\
&+\frac{K_g^{v}K_c^{\omega}K_g^{h}}{T_g^2 T_c}, b_3^{H} = \frac{K_c^{\omega}K_g^{h}}{T_g T_c},\\
&b_4^{H} = K_g^{\omega}K_g^{h}\alpha_3\frac{K_g^{h}}{T_g^2},\\
&c_1^{H} = -K_g^{\omega}K_g^{h}\alpha_3\frac{K_g^{h}}{T_g^2} + K_g^{\omega}K_g^{h}\alpha_3\frac{K_g^{v}}{T_g},\\
&c_2^{H} = K_g^{\omega}K_g^{h}\alpha_3\frac{1}{T_g^2}, \quad c_3^{H} = K_g^{\omega}K_g^{h}\alpha_3\frac{K_g^{h}}{T_g^2}.
\end{aligned}\right\} \qquad (41)$$

From the expression (40), it is found the special control:

$$h=\frac{b_1^H\alpha_1+b_2^H\alpha_2+b_3^H\alpha_4+c_1^Hv+c_2^H}{b_4^H+c_3^H} \qquad (42)$$

It's rechecked the optimum of the special control (42) under the G. Kelly's condition [5, 20] as following:

$$\frac{\partial}{\partial h}\frac{d^2}{dt^2}H_1=-(b_4^H+c_3^H)$$

In correspondence with the conditions of transversal action (7), (9), and equation (6), as well as the signs inserted into (41), it's obtained:

$$\alpha_3=-1$$

and

$$b_4^H<0, c_3^H<0\,,$$

therefore:

$$\frac{\partial}{\partial h}\frac{d^2}{dt^2}H_1>0 \qquad (43)$$

The G. Kelly's condition is satisfied and the special controls are optimal.

Now, it's re-examined the answer of the given problem with the less dimension of the model of the mobile system. This less dimension is carried out by excluding of the diesel equation from the equations (32). The problem setting is done as same as [9, 10, 12 and 13], the differential equations are following:

$$\left.\begin{aligned}&\frac{dv}{dt}=-\frac{1}{T_c}v+\frac{K_c^\omega}{T_c}\omega-\frac{K_c^\psi}{T_c}\psi(s),\\&\frac{dG_m}{dt}=K_g^\omega\omega^2,\\&\frac{ds}{dt}=v.\end{aligned}\right\} \qquad (44)$$

The limitation that is necessarily imposed for the control action (Frequency of diesel rotation) will be:

$$0\le\omega\le\omega_{max}$$

It's necessarily found the control law in dynamics $\omega=\omega(t)$ to ensure that at the interval T, the given movement time is reached to minimum for the function:

$$\Delta G_m=G_m(v,s) \qquad (45)$$

The problem is defined under Maier's condition and solved by the maximum principle [18, 22 and 23]. The edge condition is rewritten as following:

At the left end:

$$t=0, v_0=\omega_0=G_{T_0}=s_0=0$$

At the rights end:

$$t=T, v_T, \omega_T \text{ at free } s=s_T$$

The Hamiltonian of the equations (44) is:

$$\begin{aligned}H=&\left[-\frac{1}{T_c}v+\frac{K_c^\omega}{T_c}\omega-\frac{K_c^\psi}{T_c}\psi(s)\right]\alpha_1+\\&+\left[K_g^\omega\omega^2\right]\alpha_2+v\alpha_3.\end{aligned} \qquad (46)$$

The transversal conditions are:

$$[(1+\alpha_2)\delta G_m-c\delta t+\alpha_1\delta v+\delta s\alpha_3]_0^T=0 \qquad (47)$$

The considered problem is 1st order integral:

$$\begin{aligned}&\left[-\frac{1}{T_c}v+\frac{K_c^\omega}{T_c}\omega-\frac{K_c^\psi}{T_c}\psi(s)\right]\alpha_1+\\&+K_g^\omega\omega^2\alpha_2+\alpha_3v=K=0.\end{aligned}$$

The equality (47) can be only existed at the arbitrary selection of variation of $\delta G_m,\delta_v$,when

$$\alpha_{1T}=0, \alpha_{2T}=-1, \alpha_{3T}=0\,.$$

The structure of control is obtained as following:

$$\frac{\partial H}{\partial\omega}=\frac{K_c^\omega}{T_c}\alpha_1+2K_g^\omega\omega\alpha_2=0 \qquad (48)$$

$$\left.\begin{aligned}&\omega=\omega_{max}\text{ when }\frac{K_c^\omega}{T_c}\alpha_1+2K_g^\omega\omega\alpha_2>0,\\&\omega=0\text{ when }\frac{K_c^\omega}{T_c}\alpha_1+2K_g^\omega\omega\alpha_2<0.\end{aligned}\right\} \qquad (49)$$

The equations for finding the vector α are:

$$\left.\begin{aligned}&\frac{d\alpha_1}{dt}=\frac{1}{T_c}\alpha_1-\alpha_3,\\&\frac{d\alpha_2}{dt}=0,\\&\frac{d\alpha_3}{dt}=\frac{K_c^\psi}{T_c}\frac{d\psi(s)}{ds}\alpha_1\end{aligned}\right\} \qquad (50)$$

Understanding that $\alpha_2=c_c^\alpha$, in correspondence with the transversal condition, there's $c_2^\alpha=-1$.The 2nd equation doesn't relate to the remained tasks, thence it's found the solution of equation (50). Excluding α_3 from equation (50), it's obtained:

$$\frac{d^2\alpha_1}{dt^2}-a_1^\alpha\frac{d\alpha_1}{dt}+a_2^\alpha\alpha_1=0 \qquad (51)$$

In which:

$$a_1^\alpha=\frac{1}{T_c},\quad a_2^\alpha=\frac{K_c^\psi}{T_c}\frac{d\psi(s)}{ds}.$$

The typical equation will be:

$$p^2-a_1^\alpha p+a_2^\alpha=0 \qquad (52)$$

And it's obtained the solution as form:

$$p_{1,2}={a_1^\alpha}\!\left/{2}\right.\pm\sqrt{(a_1^\alpha)^2-a_2^\alpha}$$

For the ship complex, the below-expression is always right [24, 25 and 26]:

$$\left(a_1^\alpha\right)^2 << a_2^\alpha$$

Therefore the solutions of the equation (52) will be synchronization with the real positive part. On that basis, the quantity $\alpha_1=\alpha_1(t)$ will be changed the sign for one more time. In order to find the analytic expression for the commutative function (49):

$$\alpha_1=c_1^\alpha e^{p_1t}+c_2^\alpha e^{p_2t} \tag{53}$$

It's defined c_1^α and c_2^α from the transversal condition $\alpha_{1T}=0$ and from the 1st order integral of the problem. The 1st order integral at all the control interval 0 ÷ T when t = T is defined that is equal 0.Applying the edge condition at the left end and $\omega=\omega_{max}$, it can be written the integral as following:

$$-\frac{K_c^\omega}{T_c}\psi(s)\alpha_{10}+\alpha_{10}\frac{K_c^\omega}{T_c}\omega_{max}+K_g^\omega\omega_{max}^2\alpha_{20}=0 \tag{54}$$

Or with the condition at the interval 0 ÷ T, **α_2** = constant = -1, it's obtained:

$$\alpha_{10}\left(\frac{K_c^\omega}{T_c}\omega_{max}-\frac{K_c^\psi}{T_c}\psi(s)\right)=K_g^\omega\omega_{max}^2 \tag{55}$$

$$\alpha_{10}=\frac{T_cK_g^\omega\omega_{max}^2}{K_c^\omega\omega_{max}-K_c^\psi\psi(s)} \tag{56}$$

At time t = 0, there is the algebraic equation as:

$$c_1^\alpha+c_2^\alpha=0$$

And at time t = T, there is:

$$c_1^\alpha e^{p_1t}+c_2^\alpha e^{p_2t}=0$$

Therefore, in order to define c_1^α and c_2^α, it should be necessarily used the following set of equations:

$$\left.\begin{aligned}c_1^\alpha+c_2^\alpha&=\alpha_{10}\\ c_1^\alpha e^{p_1t}+c_2^\alpha e^{p_2t}&=0.\end{aligned}\right\} \tag{57}$$

Those constant quantities are:

$$\left.\begin{aligned}c_1^\alpha&=\left(1-\frac{e^{p_1T}}{e^{p_1T}-e^{p_2T}}\right)\alpha_{10},\\ c_2^\alpha&=\frac{e^{p_1T}}{e^{p_1T}-e^{p_2T}}\alpha_{10}.\end{aligned}\right\} \tag{58}$$

The given problem has the analytic solution. In order to analyze the particular navigational condition, it should be known the function $\psi=\psi(s)$.

Now, it will be examined the appearance possibility of the special control in the set of equation (44), it is shown the Hamiltonian as following [27, 28 and 29]:

$$\begin{aligned}H=&\left[-\frac{1}{T_c}v\alpha_1-\frac{K_c^\psi}{T_c}\psi(s)\alpha_1+v\alpha_3\right]+\\ &+\omega\left[\frac{K_c^\omega}{T_c}\alpha_1+K_g^\omega\omega\alpha_2\right]\end{aligned} \tag{59}$$

It's marked:

$$\left.\begin{aligned}H_0&=-\frac{1}{T_c}v\alpha_1-\frac{K_c^\psi}{T_c}\psi(s)\alpha_1+v\alpha_3,\\ H_1&=\frac{K_c^\omega}{T_c}\alpha_1+K_g^\omega\omega\alpha_2.\end{aligned}\right\} \tag{60}$$

Because of $\alpha_2=-1$ at the interval $0\div T$, so there is:

$$H_1=\frac{K_c^\omega}{T_c}\alpha_1-K_g^\omega\omega. \tag{61}$$

It's found:

$$\frac{d}{dt}H_1=\frac{K_c^\omega}{T_c}\frac{d\alpha_1}{dt}-K_g^\omega\frac{d\omega}{dt} \tag{62}$$

And

$$\frac{d^2}{dt^2}H_1=\frac{K_c^\omega}{T_c}\frac{d^2\alpha_1}{dt^2}-K_g^\omega\frac{d^2\omega}{dt^2}=0 \tag{63}$$

Applying the equation (53), it's found:

$$\frac{d^2\alpha_1}{dt^2}=c_1^\alpha p_1^2e^{p_1t}+c_2^\alpha p_2^2e^{p_2t}$$

From the equation (63), there is:

$$\frac{d^2\omega}{dt^2}=\frac{K_c^\omega c_1^\alpha p_1^2}{T_cK_g^\omega}e^{p_1t}+\frac{K_c^\omega c_2^\alpha p_2^2}{T_cK_g^\omega}e^{p_2t} \tag{64}$$

It's integrated respectively the equations (64), it's obtained the special controls:

$$\left.\begin{aligned}\frac{d\omega}{dt}&=\frac{K_c^\omega c_1^\alpha p_1}{T_cK_g^\omega}e^{p_1t}+\frac{K_c^\omega c_2^\alpha p_2}{T_cK_g^\omega}e^{p_2t}+c_3,\\ \omega&=\frac{K_c^\omega c_1^\alpha}{T_cK_g^\omega}e^{p_1t}+\frac{K_c^\omega c_2^\alpha p_2}{T_cK_g^\omega}e^{p_2t}+c_3t+c_4\end{aligned}\right\} \tag{65}$$

Now, it is re-examined the optimum of the special control, particularly:

$$\frac{d^2}{dt^2}\frac{\partial H}{\partial\omega}=\frac{K_c^\omega}{T_c}\frac{d^2\alpha_1}{dt^2}-K_g^\omega\frac{d^2\omega}{dt^2}=0$$

And the G. Kelly's condition is:

$$\frac{\partial}{\partial\omega}\frac{d^2}{dt^2}H_1=0 \tag{66}$$

And it's seen that the special control is optimal.

IV. Discussion

The above problem of the optimal control when the external environment is function of way is required for the practical implementation of the algorithm found by measuring the magnitude $\frac{d\psi}{ds}$ and hence the value $\psi = \psi(s)$. As a rule, this information is available especially on canals and rivers. The main difficulty is to find the ways of formalizing this information. Such methods must be simple in structure, and at the same time provide a minimum amount of information loss in finding the controls. For these purposes, it may be proposed a method described in previously.

V. Conclusion

The research is obtained the results:

It's proposed the establishing method of extremum principle control on the basis of the selection of the transversal condition that helps us to obtain not only the quality solutions but also the quantitative solution.

It's obtained the control algorithms of engine system that allow the following vessel approaching to the leader ship.

It's researched the programs of control for the steering complex that ensures the meeting movement of ships.

It's obtained the programs of control for engine system and steering complex that is solved the problem of head-on navigation in the confined water.

It's established the programs of control for engine system when the parameters of external environment are varied as function of time, way, and the parameters of ship's sailing are nonlinear variation.

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Implementation of Human Perception in Mobile Robots with Fuzzy Logic for Collision Avoidance

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Abstract- With ever increasing complexities and associated dangers of Industrial processes and activities, a major endeavor have been focused in automating the industrial process and activities and reduce human interactions and thus eradicating the associated dangers. Ever since, a heuristic effort have been concentrated in replacing human with robots due to their ability to perform tasks repeatedly, quickly, accurately and without fatigue. Autonomous Mobile Robots, for a long time, have remained in the spotlight of researches due to its potentials in multifunctional applications and its suitability in such industrial applications. However, the key features like path planning and motion planning of Autonomous Mobile Robots needs to have further development before they can be effectively and successfully used in highly dynamic environments, such as, Industrial Environments. This paper addresses the collision avoidance problem within Motion Planning and provides an innovative way, by implementing Human Perception using Fuzzy Inference System, for tackling this problem. The viability and acceptability of the design have been demonstrated by carrying out MATLAB simulations in 2D environments. And to verify the credibility, simulation results have been provided which further ensures the design meets its desired goals.

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IMPLEMENTATIONOFHUMANPERCEPTIONINMOBILEROBOTSWITHFUZZYLOGICFORCOLLISIONAVOIDANCE

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Bashra Kadhim Oleiwi [α], Asif Mahfuz [σ] & Hubert Roth [ρ]

Abstract- With ever increasing complexities and associated dangers of Industrial processes and activities, a major endeavor have been focused in automating the industrial process and activities and reduce human interactions and thus eradicating the associated dangers. Ever since, a heuristic effort have been concentrated in replacing human with robots due to their ability to perform tasks repeatedly, quickly, accurately and without fatigue. Autonomous Mobile Robots, for a long time, have remained in the spotlight of researches due to its potentials in multifunctional applications and its suitability in such industrial applications. However, the key features like path planning and motion planning of Autonomous Mobile Robots needs to have further development before they can be effectively and successfully used in highly dynamic environments, such as, Industrial Environments. This paper addresses the collision avoidance problem within Motion Planning and provides an innovative way, by implementing Human Perception using Fuzzy Inference System, for tackling this problem. The viability and acceptability of the design have been demonstrated by carrying out MATLAB simulations in 2D environments. And to verify the credibility, simulation results have been provided which further ensures the design meets its desired goals.

Keywords: multi-robot motion planning, multi objective optimization, obstacle avoidance, genetic algorithm, a search algorithm, fuzzy logic, mamdani fuzzy logic inference system, dynamic environments.*

I. INTRODUCTION

As Mobile Robots are becoming popular and their wide range of probable applications are being explored, more and more researches are being carried out to eradicate the incapability of Mobile Robots and make them suitable for different situations and applications. Mobile Robots can have multidimensional functionalities or might be used in various different applications. Different application will demand different application specific functionalities, however one of the most basic and important functionality and fundamental requirement of all Mobile Robots would be to safely navigate from one location to another and then perform its respective tasks. Thus, one of the key fields of research now-a-days has been the path planning of mobile robots, which would ensure the Mobile Robots to safely navigate from its initial location to its final location. However, the word "SAFELY" is of great significance as it encompasses complex collision avoidance strategies and many other complex algorithms for various features. Therefore, the task of Mobile Robots to successfully navigate through the environments depends largely upon how much effective and flexible path planning and collision avoidance algorithm it uses.

On the other hand, a parallel field of interest for many researchers around the world has been the understanding of the human mind and its intelligence. This is because unraveling the mystery of human intelligence, which encompasses complex reasoning, problem solving, decision making and knowledge processing, can be the panacea to the sea of complex problems which are hindering the technological advances. Introducing perceptual judgement, intelligent decision making or experience based learning to robots, vehicle or any other devices can give them the intelligence to overcome complex hurdles. The aim of this work is to mimic human perceptual judgment with a Fuzzy Inference System in Mobile Robots for a robust collision avoidance algorithm.

II. PROBLEM FORMULATION

The current work is an improvement of the approach proposed in the work [1]. The scope of the work is strictly restricted to environments with known static obstacles and more than one (two) Mobile Robots. In addition, the work is based on the following assumptions, firstly, a continuous metric map of the environment is available to the Mobile Robots, and secondly, each Mobile Robots have the exact location information of itself and the other Mobile Robot. This work of motion planning and control basically comprised of two phases. In the first phase, individual multi-objective optimized paths were generated with specific cost functions for individual Mobile Robots the consideration of the other Mobile Robots in the environment, with.

Modified Genetic Algorithm with A* [2]. Although, neglecting the other Mobile Robots reduced complexity of the task of individual path planning for the Mobile Robots, but it generated paths which would intersect with the paths of the other Mobile Robots. This as a result increased the probability of collisions. Thus, if such a situation occurs, an algorithm was needed to avoid collisions of the Mobile Robots. The second phase of the work therefore, was to design a method to avoid such collisions. In the second phase, a Fuzzy

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Inference System was designed to safely avoid the collision by slowing down the low prioritized Mobile Robot. Although this approach provided successful outcomes and was appropriate for some applications, but it also had an inflexibility. In worst cases, if the prioritized robot breaks down in the intersection point for any technical or other problems, the second, low prioritized Mobile Robot, will also stop keeping a safe distance from the other Mobile Robot and does not have the intelligence to drive around the broken Mobile Robot to avoid the collision and complete its due tasks.

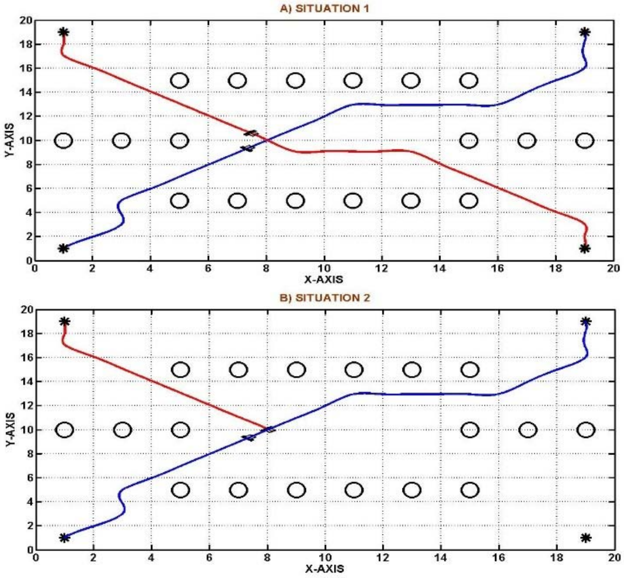


Fig.1 : A) "Situation 1" where both Mobile Robots approach the intersection at the same time and B) "Situation 2" where the prioritized Mobile Robot breaks down in its path.

Figure 1 above depicts the two situations where the Mobile Robots have possibilities of collision. The earlier designed approach was able to tackle "Situation 1" and both Mobile Robots can effectively carry out their respective tasks. However, in "Situation 2" the low prioritized Mobile Robot would stop keeping a safe distance from the prioritized Mobile Robot, but was unable to independently carry out its task unless and until the prioritized Mobile Robot was moved out of its track. This inflexibility demanded an improved strategy, which would help the Mobile Robot to avoid collisions and as well as overcome such situations and carry out its task independent of the state of the prioritized Mobile Robot. The alternative design approach proposed in this paper, is the implementation of mimicked human perceptual judgments with the help of a Fuzzy Inference System for collision avoidance. However, to facilitate the mapping of human mind reasoning in to computation processes would require the understanding of step-by-step formulation of human perceptual judgments. So, to apprehend the design process and the design, the next section gives a narrowed down and general description of human path planning and perceptual judgements specific to our application.

III. Understanding of the Human Mind

Although the process of decision making and perceptual judgment might seem very simple, as human use it instinctively, but to understand the process behind it can be equally complex and hectic. Thus, to decrease the degree of complexity in understanding the human mind, the scope of human intelligence is narrowed down to the interpretation of perceptual judgement within our specific application. Therefore, in other word, we would try to investigate deeply how humans plan their path to safely move from one location to another. Figure 2 shows a simple block diagram to describe the process of how human mind works when people make up their mind to go from one location to another.

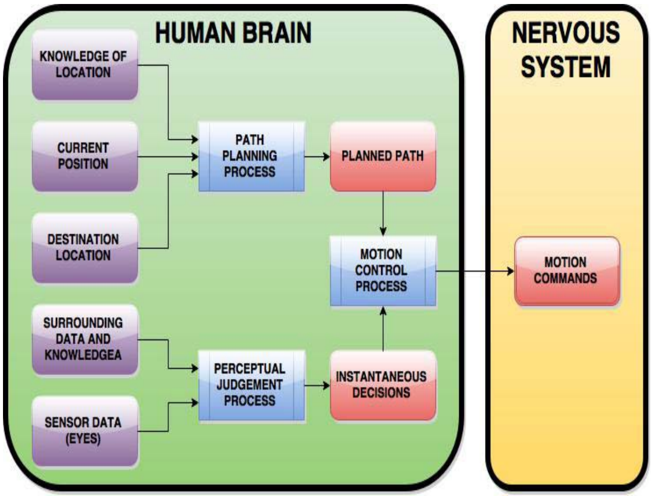


Fig. 2 : Block Diagram of Path Planning by Human Brain.

As soon as people make up their mind, the human mind takes into account, its current position, destination location, knowledge and experience of the place and curves out a path to reach the destination location. So, if the situation remains as it was planned, the preplanned path is taken to reach the destination location. However, if there are any problems or obstacles in the planned path human mind based on perceptual judgements, make instantaneous decisions to take an alternative route or to avoid the obstacle. Since the focus of this is based on collision avoidance with dynamic obstacles, a deeper effort is taken to understand how human perceives an object to be an obstacle in its way.

Firstly, the simplest case can be an object stranded on the preplanned path, which has to be avoided. Second case can be a moving object in the proximity of human vision. As soon as the moving object is noticed, based on individual perception and not precise or accurate data, human mind decides about the proximity of the object, in other words their distance from the object is defined with perceptual judgment as, for instance, far, very far, near or very near etc. However, this degree of perceptual judgment is unique and subjective to individuals. Simultaneously, the human mind also figures out if the object is approaching or moving away. And if it is approaching, again based on perception, human mind decides how fast or slow it is moving. Based on such perceptual judgments (for the case of simplicity, the measure of the individual's physical ability has been ignored to reach the perceptual judgments), the human mind finds out an appropriate way of avoiding the collision with object. And once the object is avoided, and if there are no further distractions, the individual carries on following the preplanned path.

The proposed approach is designed keeping an analogy to the human mind. Figure 3 illustrates a simple block diagram representation of the design.

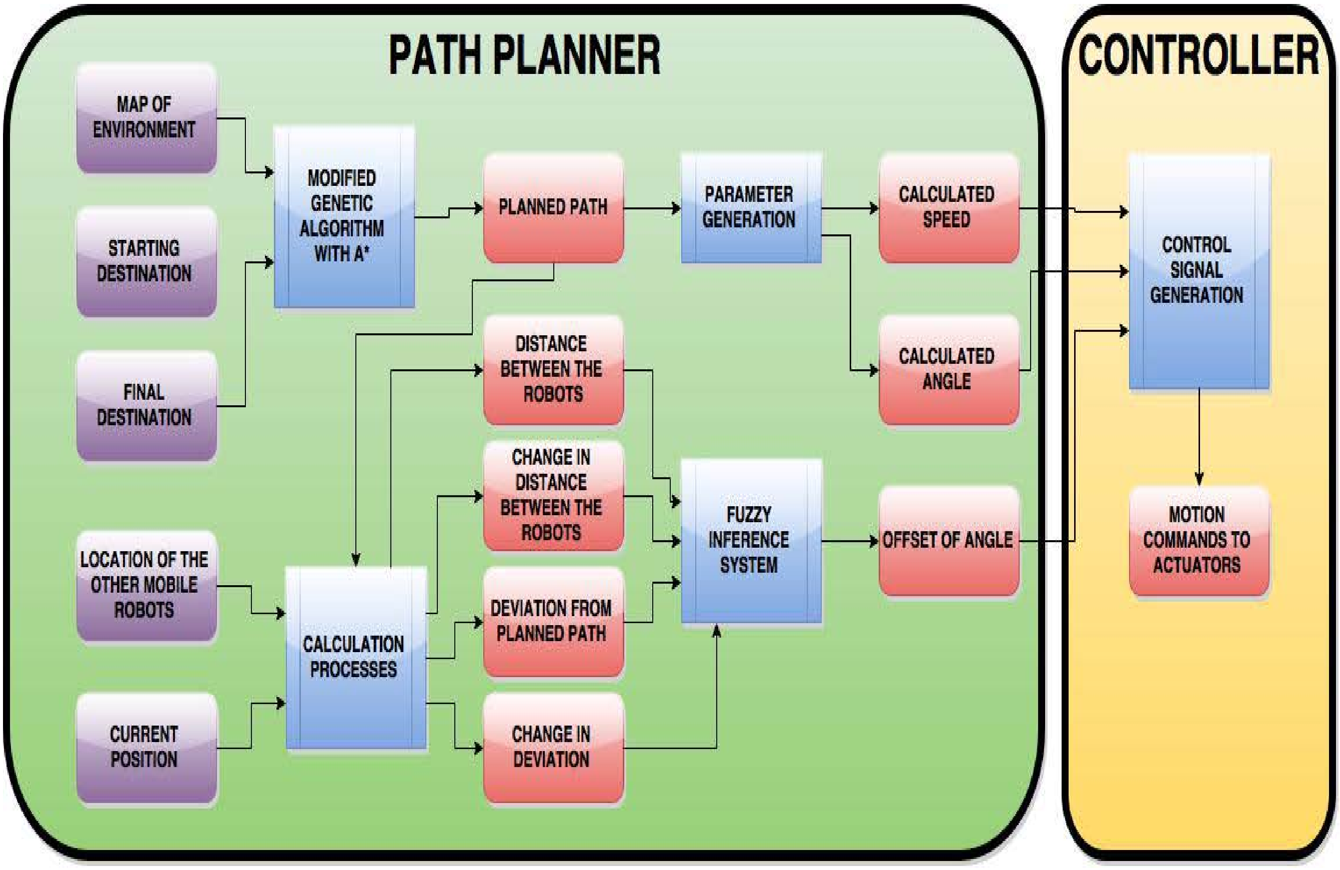


Fig.3 : The Block Diagram representation of the Complete Motion Planner.

As illustrated in the block diagram above, an initial set of parameters such as, speed and angle are calculated for the Mobile Robot based on the preplanned path and forwarded as the input to the Motion Controller. However, these are not the only inputs to the Motion Controller, based on the perceptual situation of the obstacle robot, an offset to the angle is also calculated by the Fuzzy Inference System and forwarded as an input to the controller. Therefore, the offset, generated by the Fuzzy Inference System, acts as the analogous instantaneous decision for the Mobile Robots to deviate from its original preplanned path and take an alternative way to avoid the solution. The proceeding section describes in details the design of the Fuzzy Inference System and how it calculates the offset value.

IV. FUZZY INFERENCE SYSTEM

The Fuzzy Inference System designed, comprises of four inputs and one output. The inputs are **Distance** (distance between the two robots), **CD** (change in distance between the two robots), **S** (deviation from the preplanned path), and **CS** (change in deviation), and the output is Offset (amount of angle needed to be changed). Figure 4 below illustrates the block diagram of the Fuzzy Inference System.

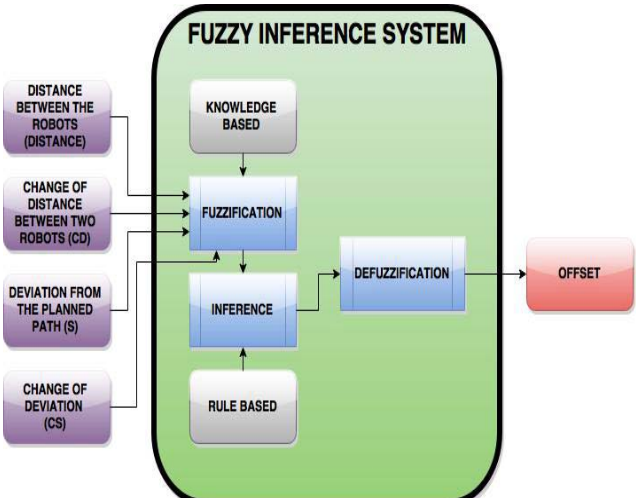


Fig.4 : Block Diagram of the Fuzzy Inference System.

The four inputs shown above, helps the Fuzzy Inference system to develop the perceptual judgment from the situation and thus produce an output based on its perception of the situation. The inputs namely are; **Distance** (Distance between the two Robots), **CD** (Change of distance between the two robots), **S** (Deviation from the planned path) and finally **CS** (Change in deviation from the planned path). Figure 5 below conveys the idea of how the inputs Distance and CD are calculated.

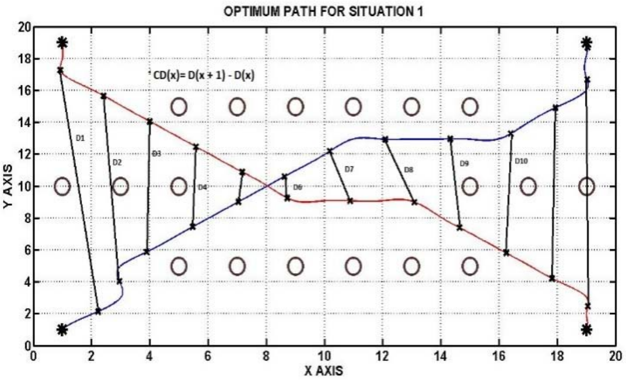


Fig.5 : Process of calculating the inputs **Distance** and **CD**.

As already depicted in Figure 5, the distance between the two robots are calculated at each time instants. The figure also gives an idea that the distance between the two Mobile Robots changes as the Mobile Robots move along their planned path. This change is calculated simultaneously and forwarded to the FIS as an input. This particular input helps the Mobile Robot to perceive whether, the other Mobile Robot (Robot 2) is approaching or retreating it. When **CD** is negative, the Mobile Robot (**Robot** 1) perceives the other Mobile Robot (**Robot** 2) to be approaching it, and on the other hand when **CD** is positive, the Mobile Robot (**Robot** 1) perceives the other Mobile Robot (**Robot** 2) to be retreating it. In addition, the two other inputs **S** and **CS**are also calculated in a similar way. The input **S** is the deviation of its current position from the planned position. This helps the particular Mobile Robot to perceive, how far it has currently deviated from its planned path. Finally the input **CS** helps the Mobile Robot to perceive, whether it is currently moving away or approaching towards its planned path. These four inputs of the FIS altogether, contributes in perceiving the current situation around the Mobile Robot and thus, based on the perceptual judgment, it produces an output **OFFSET**. The output as the name suggests, is the offset which is added to the angle calculated and thus helping the Mobile Robot to deviate from or move towards the planned path. The following figures illustrate the universe of discourse of the inputs **Distance**, **CD**, **S** and **CS** respectively.

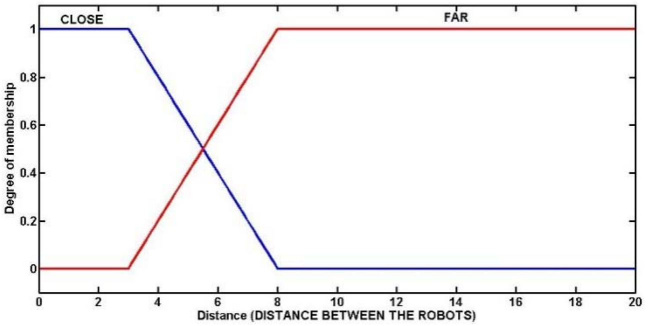


Fig.6 : Universe of discourse for the input **Distance** (Distance between the Robots).

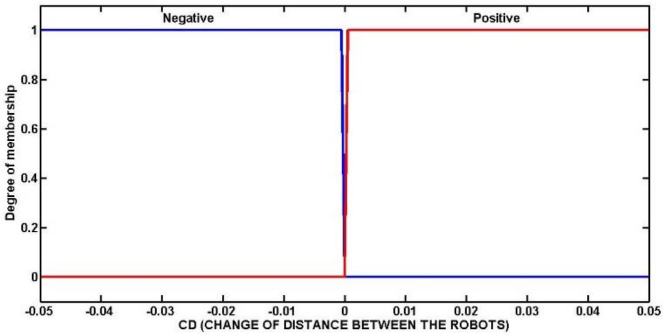


Fig.7 : Universe of discourse for the Input **CD** (Change of distance).

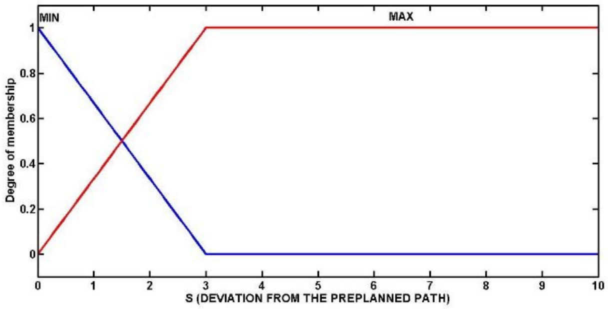


Fig.8 : Universe of discourse for the input **S** (Deviation from the planned path).

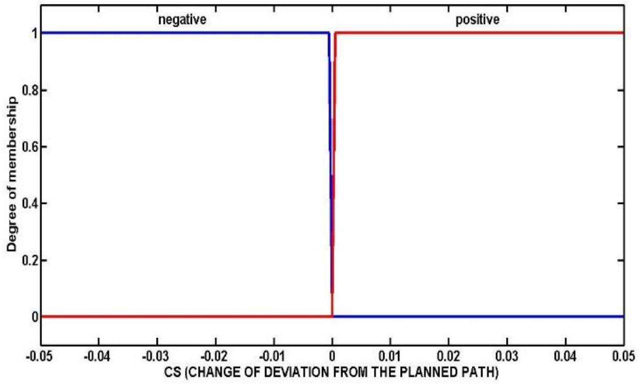


Fig.9 : Universe of discourse for the input **CS** (Change in deviation).

The input space of the FIS is connected through a number of rules to the output space. The rules are very simple IF, THEN statements which connects different input membership functions to the output membership functions. Example of a few rules are given below.

1. IF (Distance is Far) and (CD is Negative) and (S is min) and (CS is Negative) THEN (Offset is Null).
2. IF (Distance is Far) and (CD is Negative) and (S is MAX) and (CS is Negative) THEN (Offset is Null).
3. IF (Distance is Far) and (CD is Negative) and (S is min) and (CS is Positive) THEN (Offset is Null).
4. IF (Distance is Close) and (CD is Negative) and (S is min) and (CS is Negative) THEN (Offset is MAX).

The perception of Human being is basically the interpretation of a situation and each rule above define a particular situation and a judgment or output for it and in the process help to implement the concept of perception. There are altogether fifteen rules, which relates the input membership functions to the output membership functions, depicting different situations and their corresponding output. The figure 10 below illustrates the universe of discourse for the output Offset.

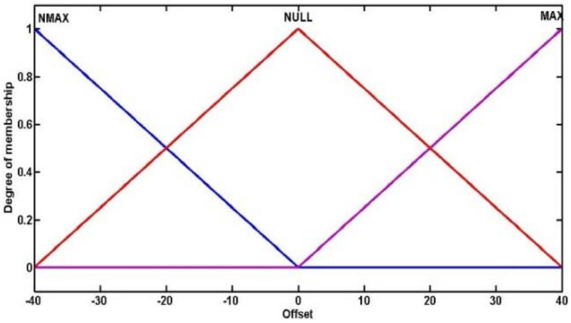
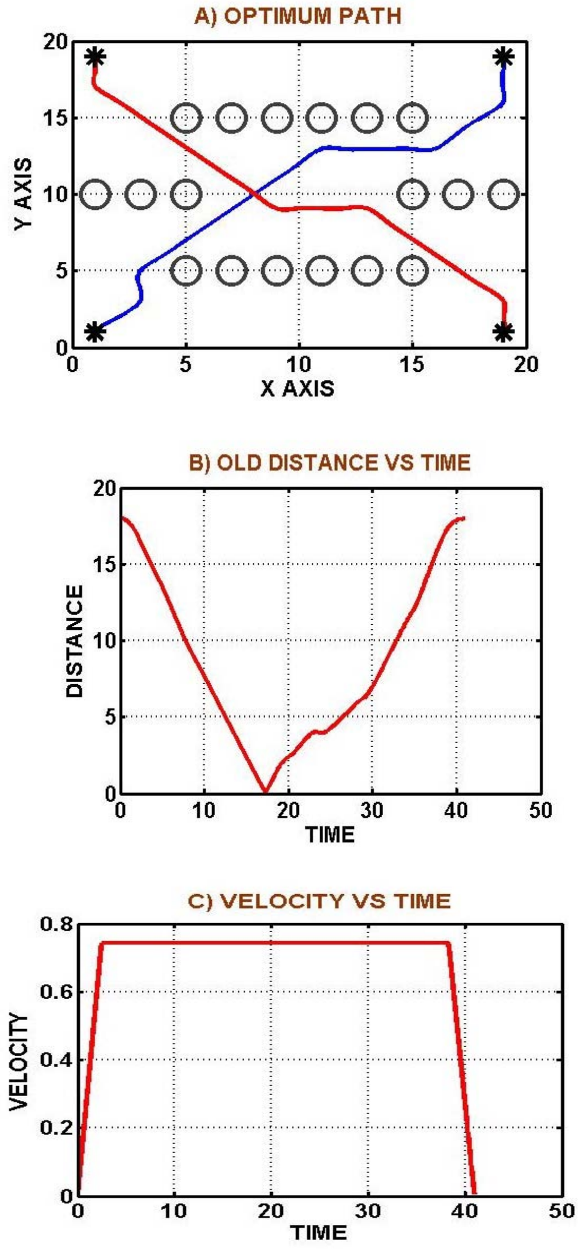


Fig.10 : Universe of discourse for the output **Offset**.

The proceeding section, gives the detailed results based on the simulation of the two situations discussed above and thus will verify the credibility of the proposed design.

V. Simulation Results

To carry out the validation of the entire design a simulation based on MATLAB in a 2D environment was carried out. The environment consisted of known static obstacles which represents a known industrial environment and two Mobile Robots which are to travel from their initial locations to their final locations. To verify the flexibility of the entire design, similar simulations were carried out in different maps. However, the results provided in this particular paper are from one of the maps on which the design was simulated. Figure 11 and Figure 12 below show, A) Optimum Path, B) Old Distance between the Mobile Robots vs Time, C) Velocity profile of the Controlled Mobile Robot vs Time, and D) Calculated Angle vs Time for Situation 1 and Situation 2 respectively.



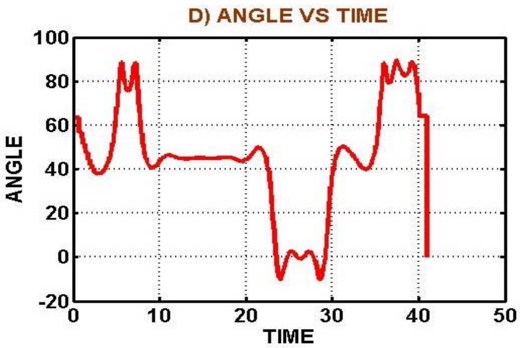
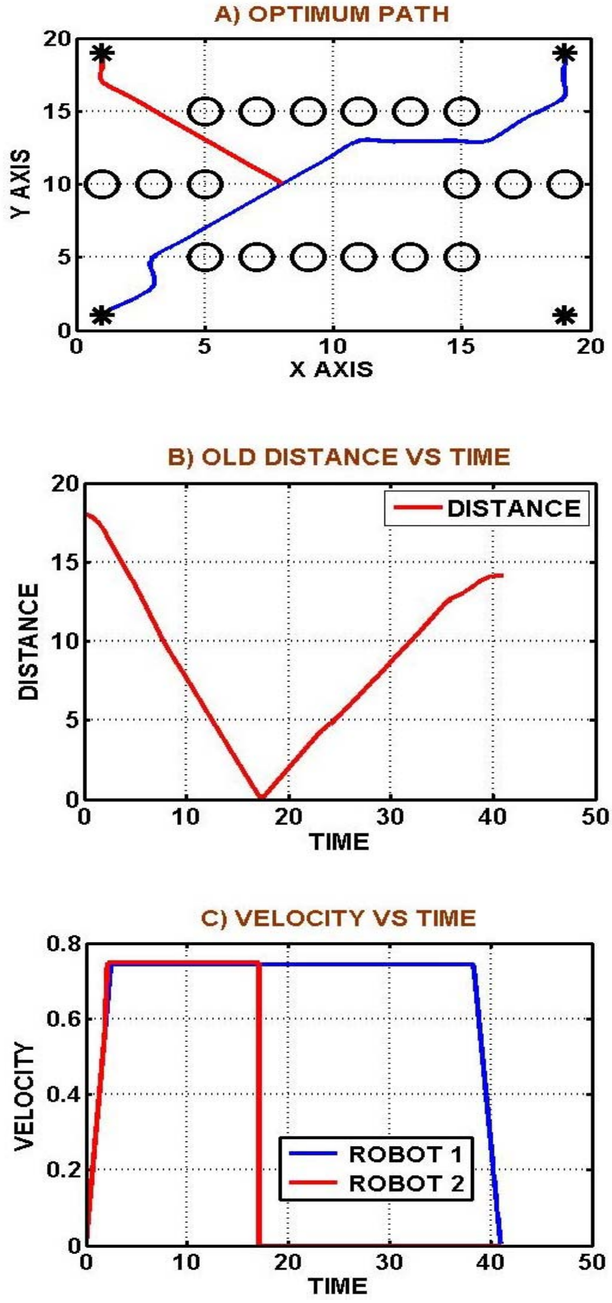


Fig.11 : A) Optimum Path, B) Distance vs Time, C) Velocity vs Time, and D) Angle vs Time(SITUATION 1).



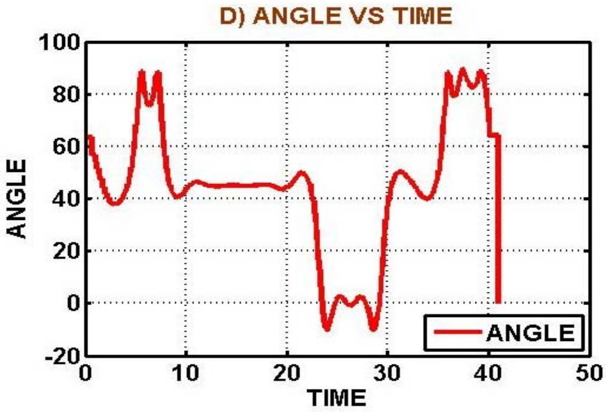
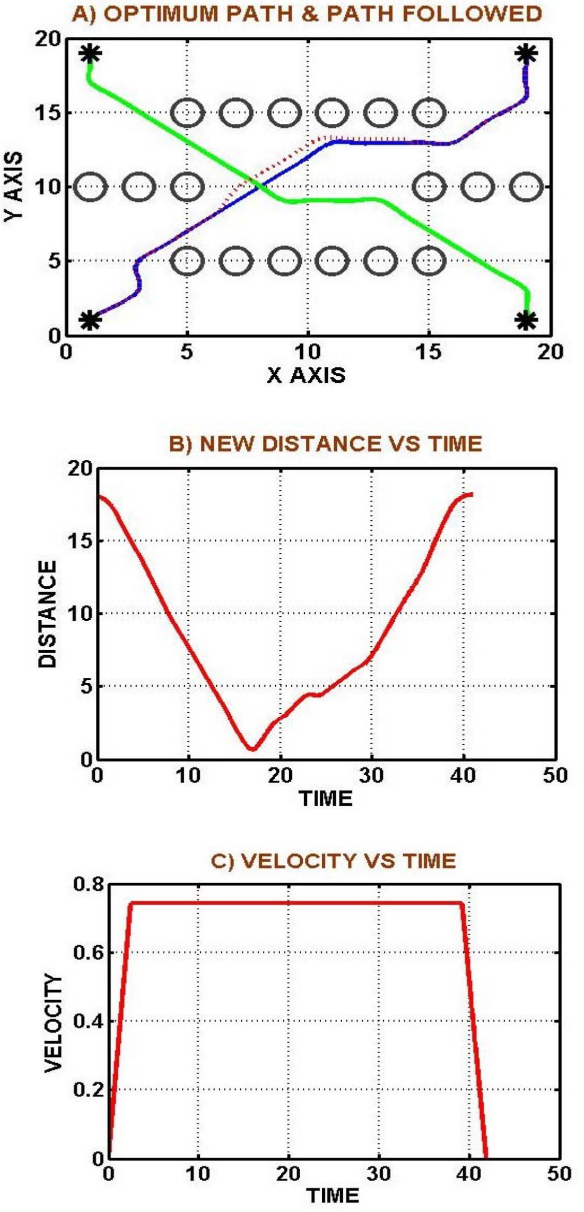


Fig.12 : A) Optimum Path, B) Distance vs Time, C) Velocity vs Time, and D) Angle vs Time(SITUATION 2).



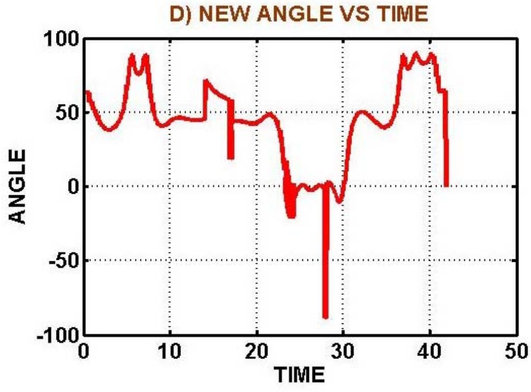
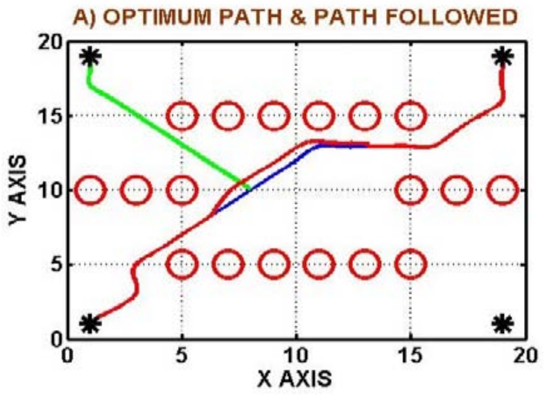
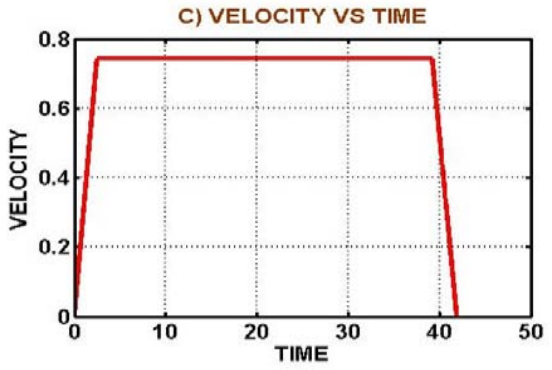
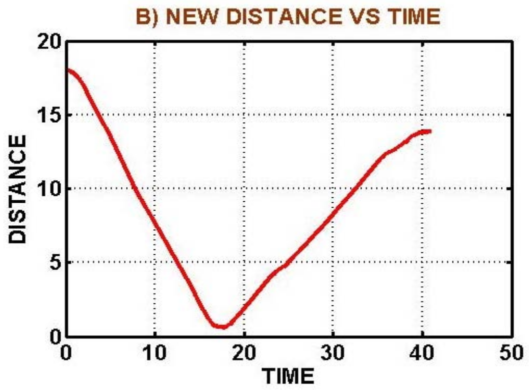


Fig.13 : **A)** Optimum Path and Path Followed **B)** New Distance vs Time, **C)** Velocity vs Time and **D)** New Angle vs Time**(SITUIATION 1)**.







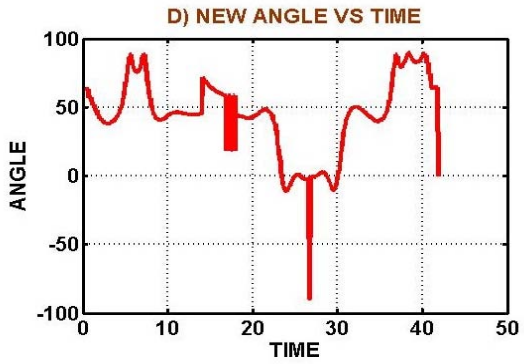
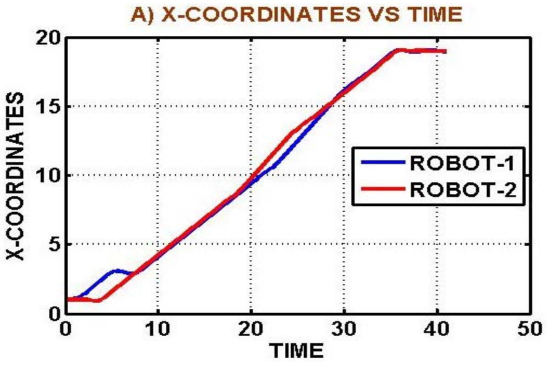
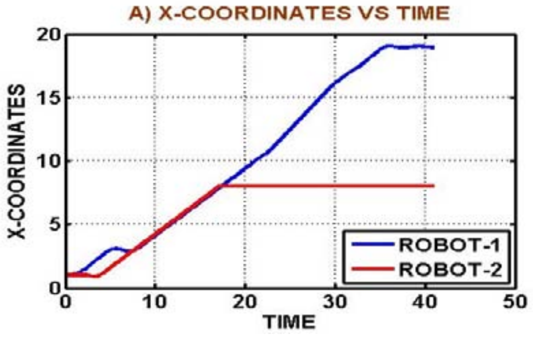


Fig.14 : **A)** Optimum Path and Path Followed **B)** New Distance vs Time, **C)** Velocity vs Time and **D)** New Angle vs Time. **(SITUIATION 2)**

Figure 13 and Figure 14 depict the change in trajectory followed between the initial planning and the actual path followed by the Mobile Robot. The changes are due to the instantaneous perceptual judgement made by the Mobile Robot due to the presence of another Mobile Robot in its proximity. Figure 13 and Figure 14 A) particularly show the path taken by Mobile Robot 1, in red dots, to avoid collision with Mobile Robot 2. Figure 13 and Figure 14 B) show that the distance between the two robots do not become zero, which in turn assure that the robots have maintained a safe distance between them to avoid collisions. Figure 13 and Figure 14 C) show the speed profile, which show an increase in time for the completion of task. This is particularly due to the increase in distance travelled compared to the travelling distance of the planned path. And finally, Figure 13 and Figure 14 D) illustrate the change in Angles made by the offset compared to the Angles needed to follow the initially planned path.





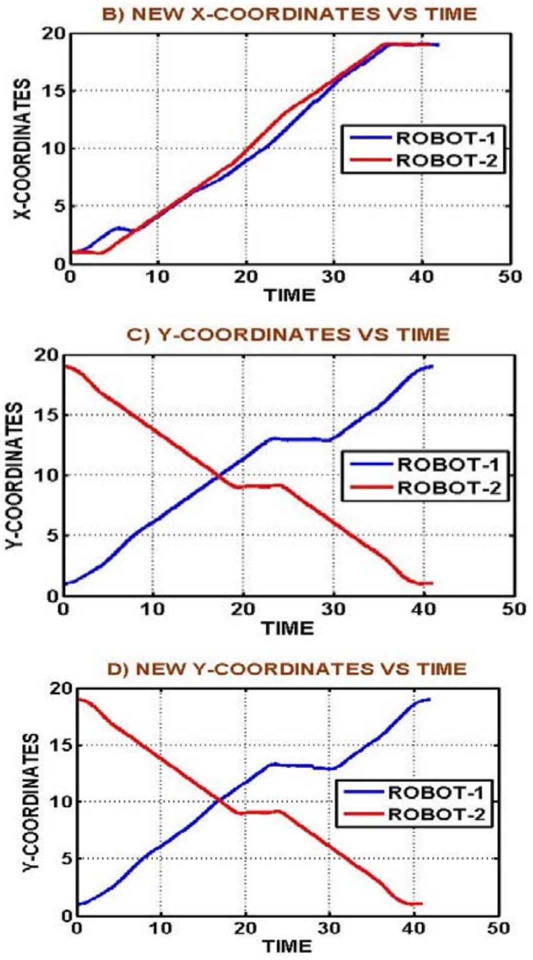
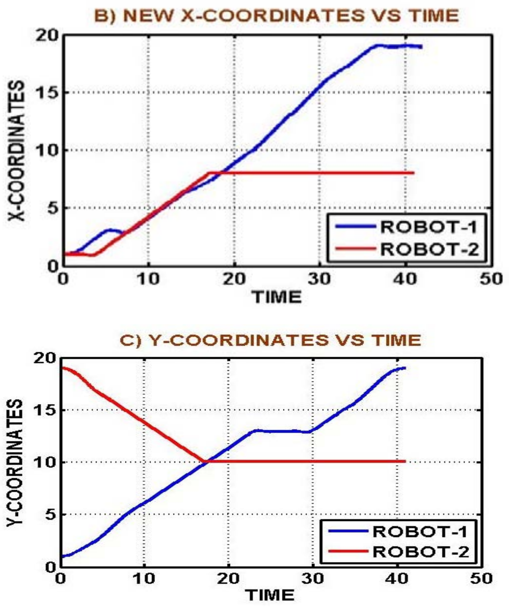


Fig.15 : **A)**Planned X-coordinates of Robot 1 and Robot 2 with respect to time, **B)** Instantaneous X-coordinates of Robot 1 and Robot 2 with respect to time after control action, **C)** Planned Y-coordinates of Robot 1 and Robot 2 with respect to time and **D)** Instantaneous Y-coordinates of Robot 1 and Robot 2 with respect to time after control action. **(SITUATION 1)**



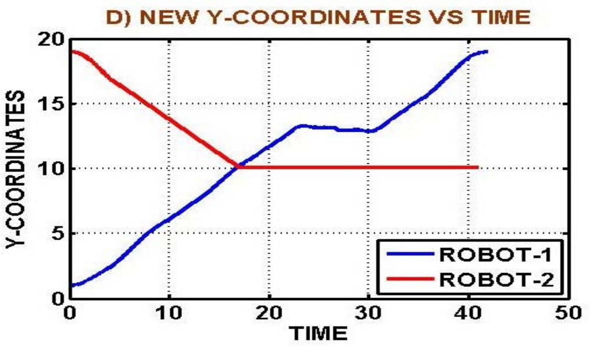


Fig.16 : **A)**Planned X-coordinates of Robot 1 and Robot 2 with respect to time, **B)** Instantaneous X-coordinates of Robot 1 and Robot 2 with respect to time after control action, **C)** Planned Y-coordinates of Robot 1 and Robot 2 with respect to time and **D)** Instantaneous Y-coordinates of Robot 1 and Robot 2 with respect to time after control action.**(SITUATION 2)**

Figure 15 and Figure 16 show the X and Y coordinates of both the Mobile Robots for Situation 1 and Situation 2 respectively. In Figure 15 and Figure 16, A) and B) are X and Y coordinates of the Mobile Robots corresponding to the initially planned trajectories. If carefully observed, the X and Y coordinates of both the Mobile Robot 1 coincides with X and Y coordinates of Mobile Robot 2 at the same time instant, which signifies they collide. However, in Figure 15 and Figure 16, B) and D), it can be observed that the X and Y coordinates of Mobile Robot 1 do not coincide with the X and Y coordinates at the same time instant. That is X coordinates become equal at different time to when the Y coordinates become equal. Therefore from the above observation, it can be further deduced that the position of the Mobile Robots do not intersect with each other and hence do not collide. And so from the above results it can be concluded the design approach successfully meets its desired requirements.

VI. Conclusion and Suggestion for Future Work

Collision Avoidance being one of the fundamental problems for Mobile Robots, this paper tries to address this problem and also provide a novel solution of tackling this problems. A collision avoidance mechanism, designed with Fuzzy Inference System and based on the idea of mimicking human perception is being presented in this paper. The scope of this work is particularly intended for Mobile Robots working within structured, known environments with known static or dynamic obstacles. In order to verify the credibility of the design, simulations were carried out in a 2D environment in two different situations. The results from situation one, clearly depicts that both the Mobile Robots were able to successfully avoid collision in both the situations and complete their respective tasks. Whereas, the results from the second situation depicts, that, despite one of the Mobile Robot-2 was stranded in the path of the other Mobile Robot-1, Mobile Robot-1 could still avoid collision and complete its tasks. And so, it can be concluded, that the design perfectly overcomes the problem of collision situations defined in this paper.

As future work, this work can be extended:

1) To develop the FIS design to give better responses in terms of getting back to its path once the collision is avoided.
2) To change, add or alter the input parameters of the FIS to improve the results of perceptual judgment.
3) To solve the problem of collision avoidance of Mobile Robots with unknown dynamic or static obstacles with in the environment.

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Effects of Yarn Count on Crimp% and Take-Up% of 2/1(S) Twill Woven Fabric

By Ayesha Siddika, Nur Nahar Akter, Kowshik Saha, Md. Mazharul Islam & Muhammad Mufidul Islam

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Keywords: crimp, uncrimp, take-up, count, Ne, twill weave, R.H., interlacing field, contact point.

GJRE-J Classification: FOR Code: 860499p

Effects of Yarn Count on Crimp% and Take-Up% of 2/1(S) Twill Woven Fabric

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Abstract- In this experiment, we have attempted to investigate the effects of yarn count on crimp% and take-up% of $\frac{2}{1}$(S) twill weave design. Experimental studies were conducted by woven fabrics with five different yarn count. For this purpose five woven fabric samples, each of $\frac{2}{1}$(S) twill designs with different count, were made on same rapier weaving machine by keeping all parameters constant with same atmospheric condition. Crimp% and take-up% was calculated by dividing the difference between umcrimped length and crimped length of yarn by crimped length of yarn and uncrimped length of yarn respectively. It was observed that when the count of yarn changes the crimp% and take-up% of yarns are affected. Finally found that, as expected, with increase of yarn count the crimp% and take-up% of warp yarn decreases while crimp% and take-up% of weft yarn increases.

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I. INTRODUCTION

The warp and weft crimp is an important aspect of the design and production planning of woven fabrics. In order to predict the quantity of warp and weft yarns required to obtain a certain fabric dimension, the relationship between the yarn dimensions and the fabric parameters should be known (Yukhin & Yukhina, 1996). The parameters determining warp and weft crimps of the grey fabric are the yarn linear densities, fabric thread densities, reed count, and the weave design. Other factors which may affect the warp and weft crimp include weaving conditions such as the loom type, warp and weft tension etc. (Yukhin & Yukhina, 1996). [1]

The waviness or distortion of a yarn owing to interlacing in the fabric is called crimp. In woven fabric, the crimp is measured by the relation between the length of the fabric test specimen and the corresponding length of yarn when it is removed from there and straightened under suitable tension. The crimp may then be expressed numerically as a percentage or as a ratio, i.e. the ratio of yarn length to fabric length. In both methods, fabric length is the basis. [2]

According to Random House Kernerman Webster's College Dictionary, crimp is the waviness of a fiber, either natural, as in sheep wool or produced by weaving, plaiting, or other processes. [3]

Crimp Percentage is defined as the mean difference between the straightened thread length and the distance between the ends of the thread while in cloth, expressed as a percentage. [4]

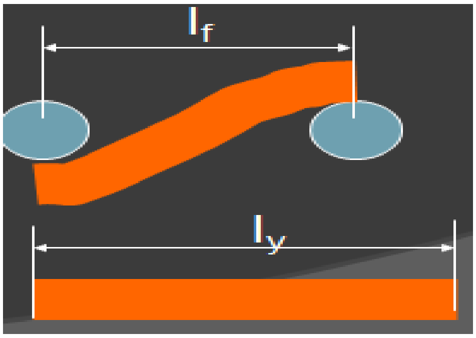
$$\text{Crimp\%, } C = \frac{L-P}{P} \times 100$$

$$= \frac{\text{Straighten length} - \text{Crimped length}}{\text{Crimped length}} \times 100$$

Besides, the crimp is defined as one less than the ratio of the yarn's actual length to the length of fabric it traverses. Crimp levels influence fiber volume fraction, thickness of fabric, and mechanical performance of fabric.

Crimp is defined as the ratio of excess length of yarn in a fabric to the length of the fabric

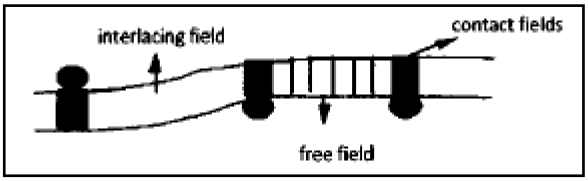
$$C = l_Y / l_f - 1$$



$l_{Y=}$ Uncrimped length, $l_{f=}$ Crimped length[5]

Crimp is determined by the texture of the weave, the yarn size, interlacing field, contact points etc. The contact points are the points where warp and weft crossing each other at right angle

Interlacing fields are the points where a yarn of one system of threads changes its position inrelation to the other system.[6]



Various models of crimp exist, the most rigorous developed by Pierce in the 1930s.

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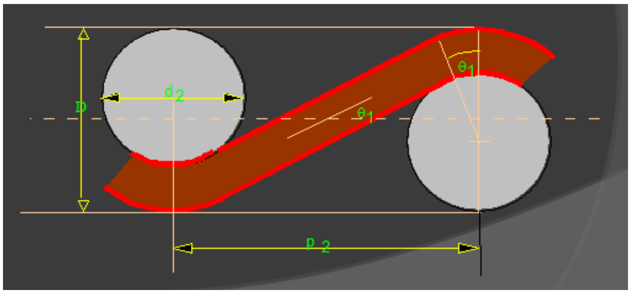
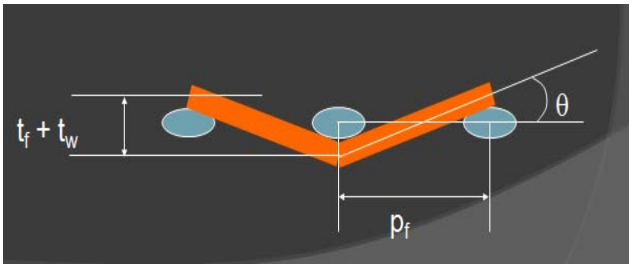


- $p_i = (l_j – D\ q_j) \cos q_j + D \sin q_j$
- $h_i = (l_i – D\ q_i)\sin q_i + D(1 - \cos q_i)$
- $c_i = (l_i/p_j) - 1$
- $h_1 + h_2 = d_1 + d_2 = D$

✓ Where p_i= Thread spacing; l_i= Modular length; c_i= Yarn crimp; d_i= Yarn diameter; h_i = Modular height; q_i= Weave angle D= Scale factor; sum of warp and weft diameters

✓ i,j= warp and weft directions.
Simplified crimp calculations: assume triangle wave shape

- $\tan\ q = (t_f + t_w)\ p_f$
- $C = 1/\cos q – 1$[5]



A crimp will normally give values ranging from 0.01 to 0.14 i.e. (1% to 14%). Crimp is related to many aspects of the fabric. It affects the cover, thickness, softness and hand of the fabric. When it is not balanced it also affects the wear behavior and balance of the fabric, because the exposed portions tend to wear at a more rapid rate than the fabric. The crimp balance is affected by the tensions in the fabric during and after weaving. If the weft is kept at low tension while the tension in warp directions is high, then there will be considerable crimp in the weft and very little in the warp. [7]

Take up percentage

Take up percentage or crimp rigidity is a measure of the ability of textured yarn to receive from stretch and is related to the bulking properties of the yarn before weaving and the length of yarn in the fabric after weaving, expressed as a percentage of the length of yarn before weaving.

Take up percentage, T = $\frac{L2-L1}{L2} \times 100$

Where,
T = Take up percentage
L = Length of yarn before weaving
p = Length of yarn in fabric after weaving [8]

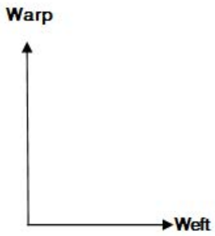
There is a relationship between Crimp% and Take-up% of the woven fabric as follow:

Take-up%, T= $\frac{100C}{100+C}$ Where, C= Crimp% [9]

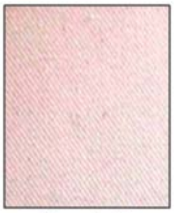
II. MATERIALS AND METHOD

a) Materials

The samples used in this experiment are of 100% cotton fabric having same EPI (110), PPI (70), warp and weft tension, weave type $\frac{2}{1}$(S) twill but different counts(20Ne, 30Ne, 40Ne, 50Ne, 60Ne). These samples are produced from same yarn type. Rapier loom (Dobby shedding) was used for this purpose.




Sample-1


Sample-2


Sample-3


Sample-4


Sample-5

b) Sample Preparation

Rectangular strips are carefully marked on the cloth and each strip is cut in the form of a flap. From each 10 threads are been removed having length 250mm in the cloth. The central part of the first thread is separated from the flap by means of a needle, but the two extreme ends are left secured. One end is then removed and placed in the clamp of the tester and the other end is removed and placed in the second clamp. By this method, there is no loss in the twist of the yarn and also due to minimum handling; there is no stretch in the yarn.

c) Method

Crimp of the samples is tested by MAG AccuCrimp tester and Take-up% is measured by using the formula $\frac{L2-L1}{L2}\times100$. The experiment is carried out at 65% relative humidity (R.H.) and 20℃ temperatures.

The MAG AccuCrimp tester provides means to measure yarn length accurately under known tension. The instrument is of 3 feet model. The tension range used is by means of a dual scale having 0-35 and 0-175 gram.

The tension arm oscillates on a 'V' grooved pivot fixed on the body of the instrument. A rider moves on the arm to be set according to the tension to be applied. The rider should be kept at the tension value marked on the tension scale. The tension to be applied is calculated using the formula,

$$\boxed{\text{Tension} = \text{Tex} \div 2}$$

The tension arm is fitted with A1. Moveable rider and corresponding balancing weight is mounted on the other side of the arm. This weight is the scale range of 0-35 gram. Additional two brass weights are given separately for the range of 0-175gram scale. When the higher range scale is used fix these two additional weights to the rider and other weight should be added to the balancing weight.

d) Testing Procedure

Hold the tension arm vertically. Slowly slide the knife-edge under the plate just above the 'v' grooved pivot. Place the knife-edge over the 'v' groove. The arm should oscillate freely over the pivot groove.

Place the instrument on a horizontal surface. See, through the mirror provided at the left hand side, whether the reference lines coincide. If not, adjust the leveling screw at the right extreme end till the reference marks coincide.

1. Mark a known length L1 on the fabric, the crimp of which is to be tested. The marking should be done in such a way that the mark is visible on the yarn removed from the fabric.
2. Set the rider against the calculated tension.
3. Fix the one end of the yarn, at the mark, on jaw of the tension arm.
4. Fix the other of the jaw provided on the sliding unit.
5. Move the sliding unit over the scale, seeing the reference marks through the mirror. Stop moving the rider when the reference marks coincide. Note the scale reading under RED mark of the Sliding unit. This is the extended length L2.

Now the crimp percentage,

$$C = \frac{(L2-L1)\times100}{L1} = \frac{\text{Difference in length}}{Originallengt\ h}\times 100$$

Where,

C = Crimp percentage
L1 = Original length in fabric from
L2 = Uncrimped yarn

Repeat the test as many times required.

III. Experimental Data

Measurement of Crimp% and Take-up% for Warp yarn:

Table 1: Data for Warp way crimp% and take-up% due to count variation.

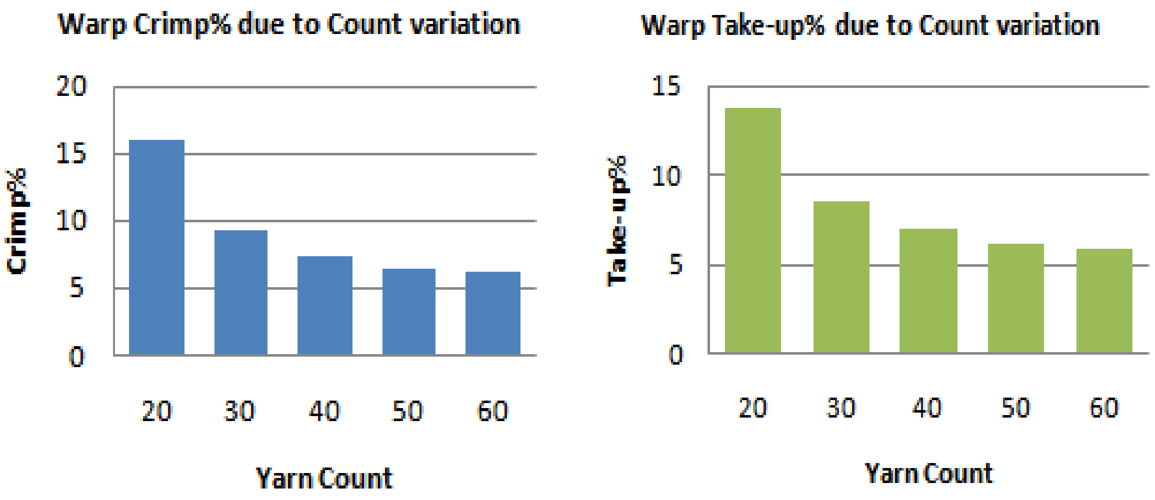
Sample No.	Warp and Weft count	Crimp%	Take-up%
1	20	16.00	13.79
2	30	9.32	8.33
3	40	7.40	6.89
4	50	6.40	6.02
5	60	6.20	5.84

Measurement of Crimp% and Take-up% for Weft yarn:

Table 2 : Data for Weft way crimp% and take-up% due to count variation.

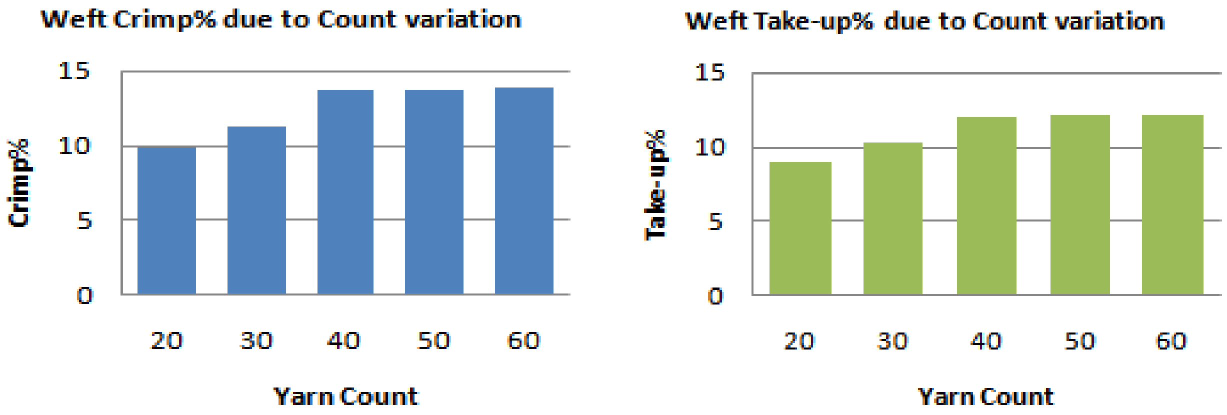
Sample No.	Warp and Weft count	Crimp%	Take-up%
1	20	9.74	8.88
2	30	11.32	10.17
3	40	13.64	12.00
4	50	13.75	12.09
5	60	13.86	12.17

IV. Discussion on Result



Graph-1 : Effects of yarn count on Warp yarn Crimp% and Take-up%

Table-1 shows that with the increase of yarn count, the crimp% and take-up% of the warp yarn is decreased. It may be because of less interlacing field and less contact points (as PPI=70) in finer yarn, the warp yarns make little waviness resulting lower crimp% as well as take-up%. It is notable that a significant change is found both for warp crimp% and take-up% while using lower yarn count. But with the higher count of yarn, changes are less evident.



Graph.2 : Effects of yarn count on Weft yarn Crimp% and Take-up%

Table-2 shows that with the increase of yarn count, the crimp% and take-up% of the weft yarn is increased. It probably because of less interlacing field but more contact points (as EPI=110) in finer yarn, the warp yarns make more waviness resulting higher crimp% as well as take-up%.

V. Conclusion

In this investigation, we have found an indicative relationship between the yarn count and the crimp% & take-up%. The study shows with the increase of yarn count, the crimp% & Take-up% of warp yarn is reduced whereas it is increased for weft yarn. Warp and weft crimp percentages are two factors which have influence on the fabric properties such as resistance to abrasion, shrinkage, fabric behavior during tensile strength, faults in fabric, fabric design, fabric costing etc. [10] It is hoped that the result of this study will play an important role in the woven fabric sector.

VI. Acknowledgements

We would like to thank Robin Hawlader for providing samples, and are grateful for the support of the Lab Demonstrator at Textile Engineering Department of Northern University Bangladesh.

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Experimental Study of the Visualization of Vortex Structures Ogives Revolution

By Dr. Abene Abderrahmane

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Abstract- A large number of studies of flow visualisations, developed on the upper surface of delta or gothic wings and on that of ogives of revolution, have been carried out in the wind tunnel of the Valenciennes University aerodynamics and hydrodynamics laboratory (LAH). These studies have provided a better understanding of the development and the positioning of vortex structures and have enabled, in particular, the preferential nature of inter vortex angles, thereby defined, to be determined on a wide range of Reynolds.

This paper concerns in particular the study by visualisations of the behavioural properties on the upper surface of an ogive of revolution having an apex angle of 68.6° at a low angle of attack and conducted at variable speeds. It has been noted that variations in speed have no influence at all on the behavioural properties of the development of vortex structures whereas, by contrast, changes to the angles of incidence do indeed strongly influence that development. The study of the ascent of the vortex breakdown at high angles of attack has revealed original behavioural properties which find expression notably in the discontinuous evolution, in terms of the apex angle, of those angles of attack which define the beginning and the end of the ascent of this vortex breakdown.

GJRE-J Classification: FOR Code: 090101

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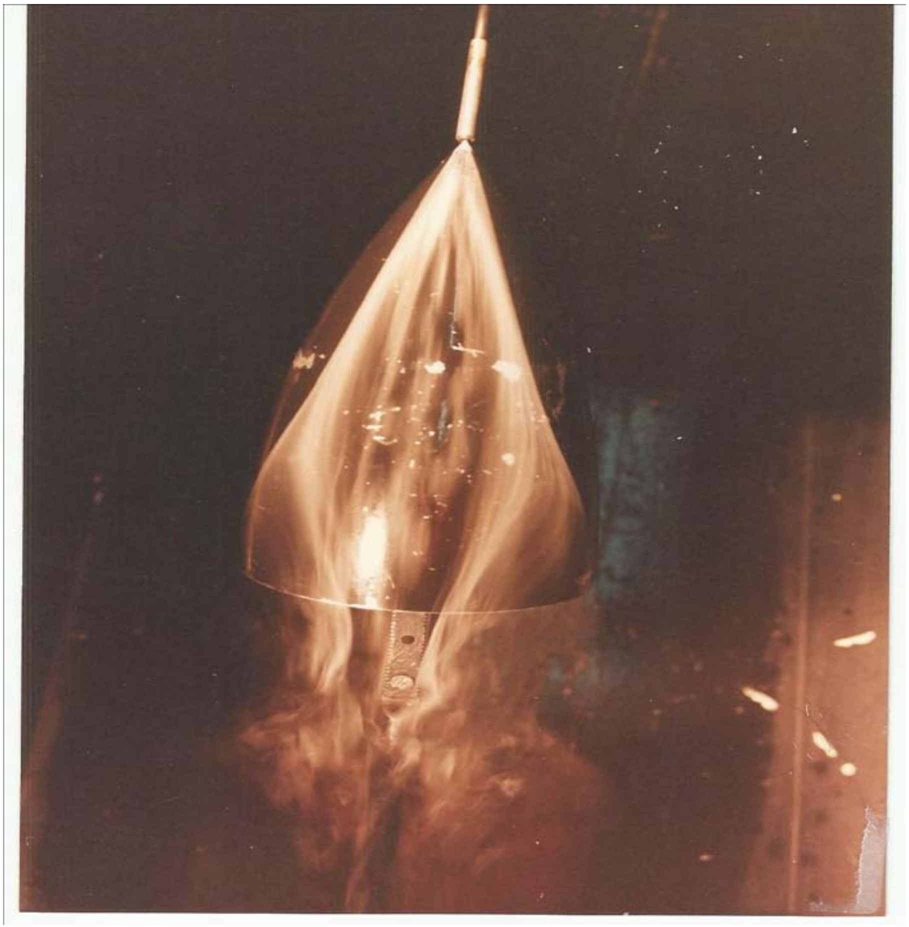

View n° 1
$\beta = 68.6°$ $i = 8°$
$19000 < Re < 80000$

View n° 1 : the study to evidence a low incidence of birth vortex structures that will become a stable average impact is concentrated and pass a web structure in the classical.[22,33and38]

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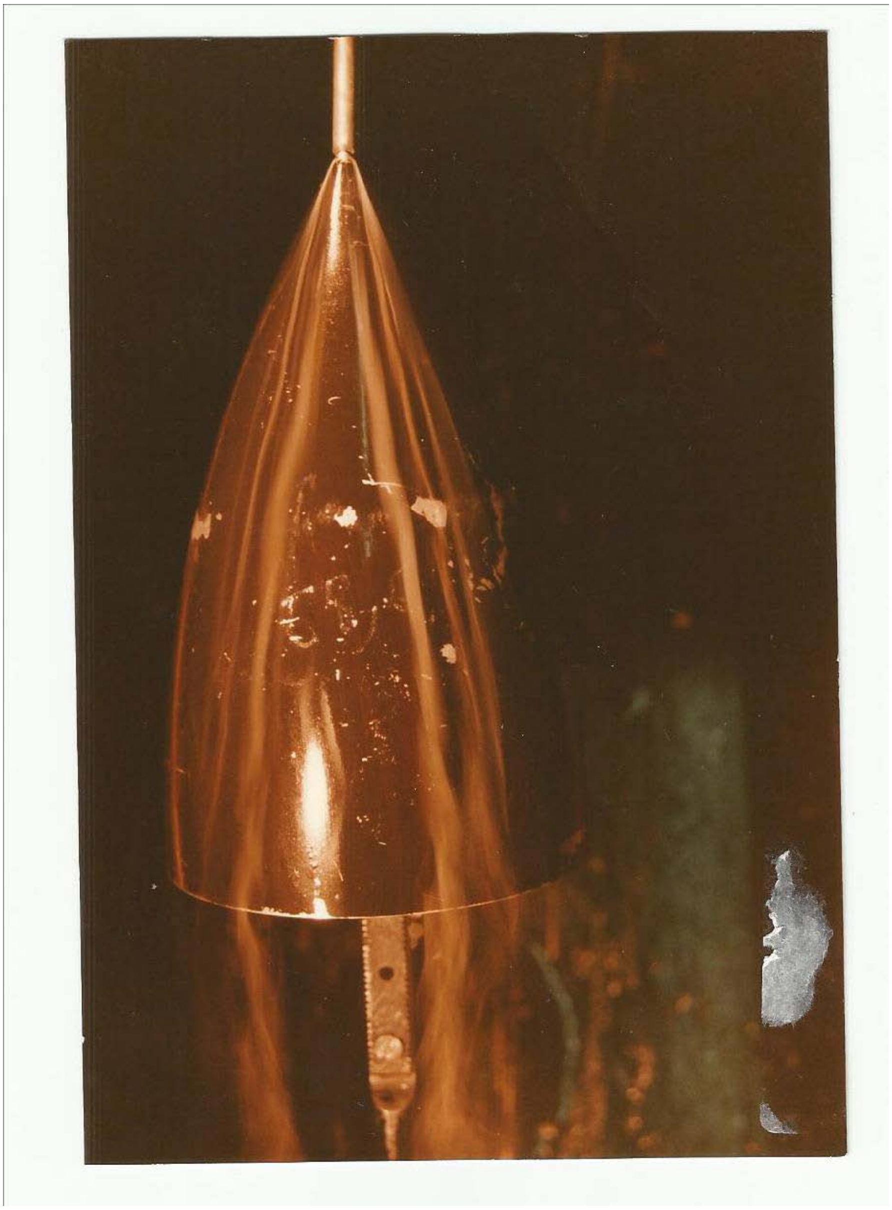

View n° 2

$\beta = 68.6°$ $i = 32°$ $\omega 1 = 12.9°$ $\omega 2 = 18.4°$

$19000 < Re < 80000$

View n° 2 : when the incidence is increased, the main vortices and the secondary vortex torque are now observed, the speed remaining constant. However, variation in the speed have no effect at all on the formation of vortex angle of 28°.[22,33,35]

View n° 5
$\beta = 68.6°$ $i = 70°$
$19000 < Re < 80000$

View n° 3 : At 70 ° incidence i, I notice the fusion vortex bursts which are unstable and back to the top of the cone of revolution. the application of this phenomenon of vortex breakdown in the solar collectors has baffles variables [22,33, 36, 37].

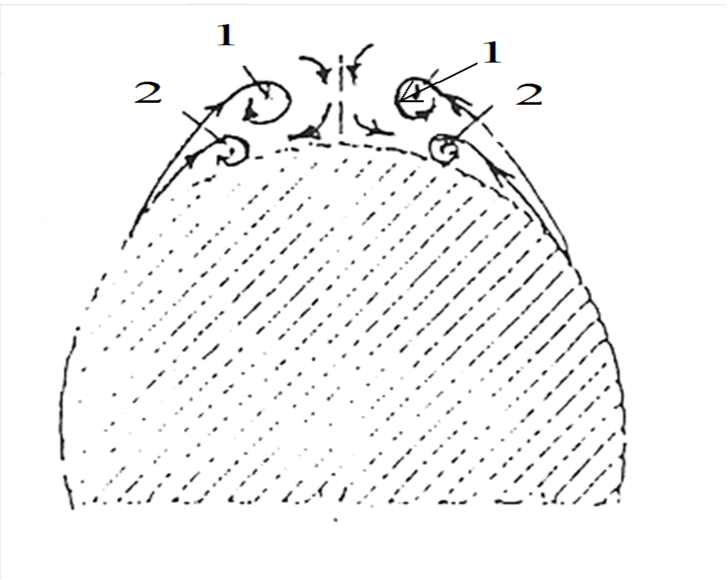

Diagram n° 1
1: interior vortex
2: exterior vortex
[8,22and 34]

I. Conclusion

While, on a wide range of Reynolds, the preferential nature of the intervortex angles present on the upper surface of delta and gothic wings and of ogives of revolution would seem to be fully catalogued, the very existence of **the law of filiation** relative to such slender bodies expresses a certain universality of behaviour and reveals the fundamental feature of our study.

At the present time, however, no complete theoretical approach would seem to be capable of providing a straightforward explanation of the simplicity of these results. The progressive evolution from elementary vortices of the sheer flow before take-off towards a particularly stable vortex system, wherein spatial positioning reveals an original organisation, still remains today an enigma. It is, of course, difficult to prejudge the lines along which one or more future studies may follow, studies which could lead to a theoretical explanation. However, perhaps we may be permitted to note that the phenomena, in which the sine squared of an angle also plays a part, are created by the simple structures of stationary and unsteady fluid mechanics.

It is in this way that the flow - emitted by an ogive of revolution having a demi-span of θ at its summit on a tridimensional dipole with the same axis as that of the cone, or with its summit at the centre of a vortex ring equivalent to the dipole - is proportional to $\mathrm{Sin}^2\theta$. This is how energy - emitted by an oscillating electromagnetic dipole (with properties analogous to those of the oscillating fluid dipole that plays a part in aerodynamics or in hydrodynamics) in a θ direction with regard to the axis of the dipole - is, energy too, proportional to $\mathrm{Sin}^2\theta$ or to $\cos^2\theta = 1 - \sin^2\theta$ in the case of the acoustic dipole. It is also a law in $\mathrm{Sin}^2\theta$ that gives the dependence, with regard to the angle of attenuation of the second sound thermal waves in liquid helium, by rectilinear vortices which form the θ angle with the direction of the propagation of this wave.

It is, moreover, by coupling this law with the concept of that preferential angle, formed by helicoidally vortices with their axes, that the authors of the papers referred to in [1] and [2] interpreted the discontinuous angular behaviour of these vortex systems in liquid helium [1, 2 and 19].

Finally, and this ultimate remark is probably not the least important one, the suction force, to which a profile - an infinitely thin and localised plane, let us remember - is subjected in the immediate vicinity of its leading edge, is, that force, too, proportional to the sine squared of an angle, in this case the angle of incidence.

As concerns the possible links, of the phenomena we have described, with the properties of an emission or of an absorption of a flow or of a wave - whose source may be dipolar or multipolar - it is perhaps interesting to note that the range of speeds of a tridimensional dipole {characterised by the angle between the radius vector of a point of the fluid and the speed of this fluid} is linked to the angular positioning of this point, with regard to the dipole {characterised by the polar angle between the axis of the dipole and the radius vector}, by a series of striking correspondences between the most simple preferential angles. Moreover, if we now consider the force of interaction between two dipoles of relatively simple orientation - the most simple is one with two parallel dipoles, but numerous other layouts give equally curious results - the range of interaction forces {characterised by the angle between the radius vector joining the two dipoles with this interaction force}, possesses, in its turn, together with the two other ranges of relative positioning and of speeds {characterised as described above}, two new entireties of quite striking correspondences **E. TRUCKENBRODT** [24].

Where the notable orientations of interaction forces between two parallel dipoles are concerned, and with regard to the common direction of the axes of these dipoles, we have extracted a few particular cases from the general calculations made by **W. KÖNIG** [25] and from his final result given in **J.W-C. RAYLEIGH**'s very famous book on acoustics [26].

These references contain expressions of : the components of the force exerted by one sphere on another in the presence of a uniform wind pattern to infinity; where the fluid flow is perfect; the line joining the centres of spheres forming the θ angle with the direction of the wind to infinity - this force is the same as that exerted by one sphere on another when those spheres are moving parallel to each other and at the same speed in an immobile fluid to infinity - but it is known that each of these spheres is equivalent to a tridimensional dipole.

The sole particular cases commented on by **W. KÖNIG** [25] and **J.W-C. RAYLEIGH** [26] are those where the centres of the spheres are aligned, {*i.e.* in the direction of the wind}, and where these spheres therefore exert on each other a repulsion force {*i.e.* perpendicularly to the wind} with, in this case, a gravitational interaction force which explains the formation of very fine powder ridges, perpendicular to the axis of a sound tube, within its antinodes (ventral segments) of vibration.

But a whole series of other consequences from the general formulae found in references [25] and [26] seem, they too, to be very significant. One of the most important of these particular cases seems to us to be that where the interaction force between two parallel dipoles is itself parallel to them. Formula n° 4 on page 47 of reference [26] immediately shows that this case corresponds to the θ angle, cancelling the Legendre polynomial $1\text{-}5\cos^2\theta$, *i.e.* at

$$\cos\theta = \frac{1}{\sqrt{5}} = \frac{2}{\sqrt{4(4+1)}} = \cos\theta_{42} \qquad (10)$$

according to the defining formula of preferential angles given at the beginning of this paper.

This angle θ_{42}=63.4° is, moreover, the angle between the diagonals of the famous "Golden Rectangle" discovered by architects and employed by them from time immemorial [21].

In this same train of thought, it is striking to note, in references [27 to 29] the role played systematically by the angle θ_{32}=54.7° (cancelling the Legendre polynomial $1\text{-}3\cos^2\theta$) in the sound emission of an axisymetric jet and of two interaction forcing vortex rings or of one forcing vortex ring in the presence of a sphere.

In short, many other well-known hydrodynamic and aerodynamic phenomena are rich in preferential angles, the theory of which has at some or other been fully elaborated. This is the case found in the very subtle and elegant theory described in particular in the works of **H. LAMB** [30] and of **J. LIGHTHILL** [31]. In the wake, the crests of waves, in a curvilinear triangle form, will in fact each disappear at two counter flow points, the alignment of which, along two right-hand sides, determines a total span of the wake at twice **19.4°** here and there of the axis of this wake, axis with which the counterblow tangents, associated with the crests, form an angle of **54.7°** while also forming with each corresponding edge of the wake an angle of **35.3°** {*i.e.* 54.7° - 19.4°}.

It is there where the following relation is to be found, never interpreted before now, in terms of preferential angles :

$$\theta_{32} = \theta_{22} + \theta_{88} \qquad (11)$$

$$54{,}7° = 35{,}3° + 19{,}4° \qquad (12)$$

The link between the wake of a ship, being the result of the combination of bidimensional surface waves shed in various directions, and the phenomena described above may appear at first sight to be very mysterious. We may, however, be permitted to reason that the paper by **E. LEVI** [32] under the title "*An oscillating approach to turbulence*", so suggestively illustrated by figure n° 1 on page 352 of his study {an illustration which represents the frontier of a wake or of a maximum layer as a swell induced by the emission of vortices} perhaps provides the starting point of a profitable line of further research which could lead to a better understanding of the omnipresence of preferential angles and of their filiations in tridimensional flows, and in particular in those developed around slender bodies.

The essential question to be pursued, and one which remains as yet to be entirely addressed, seems to us primarily to lie with structures and wave propagation. What is required is the explanation of the link between those preferential angles, which appear in structures exterior to the borderline layer, and structures, which would also probably need to be termed preferential angles, to be found in the forms and modes of wave propagation. The latter have recently been the subject in a close study of "*the coherent structures of turbulence*", structures that are, in particular, present in laminar-turbulent transition zones or in zones of anisotropic turbulence, especially where they relate to layers.

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Mathematic Model and Kinematic Analysis for Robotic Arm

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Abstract- In this paper the mathematic model and kinematics of robotic arm are mainly analyzed. The robotic arm uses the Denavit Hartenberg (D-H) method to determine the parameters with transformation matrices. The direct kinematic analysis was conducted to determine the parameter of robotic arm by using Denavit Hartenberg (D-H) method. The calculated parameters of robotic arm were implemented by direct kinematics and compared with the measured parameter by rotary encoder to determine the accuracy of each parameter.

Keywords: robotic arm, denavit hartenberg, direct kinematic, forward kinematic.

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I. Introduction

A robotic arm is a type of mechanical arm, which can usually be programmed with similar functions to a human arm. The links of such a manipulator are connected by joints allowing either rotational motion translational displacement. The links of the manipulator can be considered to form a kinematic chain. The terminus of the kinematic chain of the manipulator is called the end effector and it is analogous to the human hand. The end effector or robot hand can be designed to perform any desired depended on the application such that robotic arms in automotive assembly lines perform a variety of tasks such as welding and parts rotation and placement during assembly. Huang and et al. [1] introduces method for solving the inverse kinematics equations with the D-H notation. The geometric analysis is use to calculate the motion trajectory of a robotic arm. They used Matlab software to verify and compare the results of the inverse kinematics equations analysis with the experimental results. Jie-Tong Zou and Des-Hun Tu [2] purposed a six D.O.F robotic arm for an intelligent robot. The used kinematic equations to verify the robotic arm by using the Denavit-Hartenberg (D-H) coordinate transformation method. The Inverse Kinematics analysis is used to determine six axes data and computed the forward or inverse kinematics by the Simulink function of Matlab software. Yoshimi, T and et al. [3] introduced robotic arm to execute a beverage can opening task. They control position trajectories for single robotic arm and dual robotic arm to open beverage can.

II. System Architecture of Robotic Arm

a) Mechanical Part

This research has main purpose to construct six degree of freedom robotic arm that it is firstly designed by graphic software and implemented by real hardware. The robotic arm is constructed onto a base that the drive and the part of first degree of freedom are mounted. In this work, the joints of the manipulator are driven through a worm drive gear arrangement. This provides great strength with relatively small motors, a zero backlash, the self locking properties of this arrangement, and zero power consumption while not moving. The disadvantage of this solution is the relatively low speed of the system. The robotic arm consists of six joints, which are two joints rotated about parallel axis with ground and four joints rotated about vertical axis with ground as shown in figure 1.

b) Electronic Components

In term of electronic control system, ET-BASE LPT is designed to be connected with motor drive board to perform desired robotic arm movements. Based on figure 1, ET-BASE LPT is connected with PC through parallel port. The interface circuit of control system is shown in figure 2.

Fig.1: Model of robotic arm.

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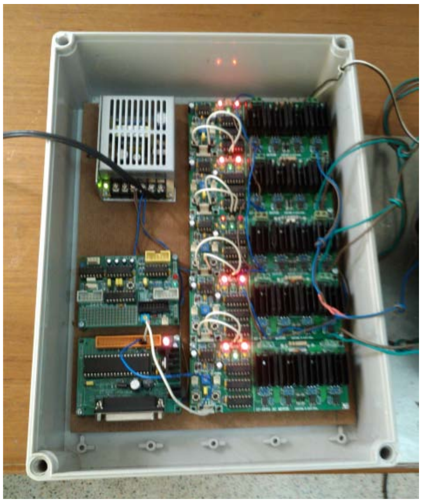

Fig.2 : Interface circuit of control system.

III. KINEMATICS OF ROBOTIC ARM

The relationships between the position, velocities and accelerations of a manipulator mainly are discussed in robotic arm research. Mathematical methods are developed to explain these relationships especially about position. The transformation between coordinate frames located in the base of the robot. The transformation specified position and orientation of manipulator in space respect to the base of the robot. To achieve kinematic analysis, the manipulator transformation must be defined in term of joint space related to the Cartesian coordinate. In Cartesian coordinate, the manipulator transform is a function of the position and orientation. The direct kinematic model describes Cartesian coordinates and orientation angles of the manipulator the joint variable. Conversely, the indirect kinematic model explains joints variable in term of Cartesian coordinates and orientation angles of the manipulator that it inverses of the direct kinematic model. The angles at the joints are the joint coordinates in a n dimensional joint space. The direct transform of a n link manipulator is equation 1.

$$ {}^{R}T_{H} = A_1 \times A_2 \times A_3 \times \ldots A_n \qquad (1) $$

The transformation from link $n-1$ to link n is completely defined by four link parameters below.

- A rotation about the z_{n-1} axis by the angle between the link (θ_n)
- A translation along the z_{n-1} axis by the distance between the links (d_n)
- A translation along the x_{n-1} axis by the distance between the links (l_n)
- A rotation about the x_{n-1} axis by the angle between the link (α_n)

The transformation matrix of the coordinate could be abbreviated as D-H transformation matrix [5].

$$ {}^{n-1}_{\;\;n}T = \begin{bmatrix} \cos\theta_n & -\sin\theta_n\cos\alpha_n & \sin\theta_n\sin\alpha_n & l_n\cos\theta_n \\ \sin\theta_n & \cos\theta_n\cos\alpha_n & -\cos\theta_n\sin\alpha_n & l_n\sin\theta_n \\ 0 & \sin\alpha_n & \cos\alpha_n & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2) $$

Reference coordinate must be located on every joint and links between the joints. In this work, the link relations between the links and the joints are shown in figure 3. A joint's reference coordinate will change along with the rotation of the links. We need to consider the transformation relations between joint from link $n-1$ to link n that are in the two adjacent coordinate systems, while defining the four important parameters by the D-H transformation matrix is shown in table 1. The D-H transformation matrix can be formulated from two joints as below. General manipulators can move in three dimensions, so the orientation angles are complex to calculate, because the matrix elements contain terms with multiple angles. The method of orientation decomposition into three distinct rotations is not easy. The general roll-pitch-yaw orientation transform to obtain the orientation angles to the elements of the general transform matrix.

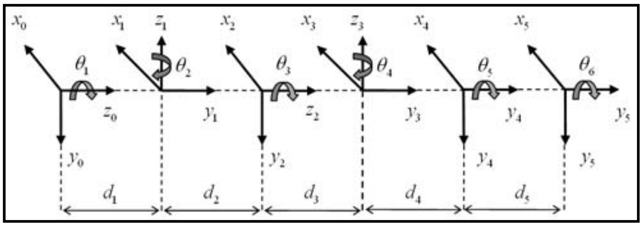

Fig.3 : Coordinate frames of robotic arm.

Table 1 : Parameter of robotic arm

Link	Variable	d_n	l_n	α_n
1	θ_1	d_1	0	90
2	θ_2	d_2	0	-90
3	θ_3	d_3	0	90
4	θ_4	d_4	0	-90
5	θ_5	d_5	0	90
6	θ_6	0	0	0

To obtain the Cartesian coordinates in term of joint coordinates and end effector, the elements of manipulator transformation matrix must be compared with general transformation matrix. The orientation elements of the general transform are dimensionless and translation elements have the dimension of length. The general transformation matrix can be given as

$$ {}^{R}T_{H} = \begin{bmatrix} X_x & Y_x & Z_x & P_x \\ X_y & Y_y & Z_y & P_y \\ X_z & Y_z & Z_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3) $$

$$ = Translation\left(P_x,\quad P_y,\quad P_z\right) \times Rotation\left(Roll(\phi),\quad Pitch(\theta),\quad Yaw(\psi)\right) $$

The compared manipulator transformation matrix with general transformation matrix is formulated as

$$ {}^{R}T_{H} = \begin{bmatrix} X_x & Y_x & Z_x & P_x \\ X_y & Y_y & Z_y & P_y \\ X_z & Y_z & Z_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4} $$

The element parameter can be determined by equating terms in these matrices as shown below.

$$ X_x = b_{11} = \begin{pmatrix} C_{123456} - C_{1456}S_{23} - C_{56}S_{14} - C_{126}S_{35} \\ - C_{36}S_{125} + C_1S_{2346} - C_{123}S_{46} - C_4S_{16} \end{pmatrix} $$

$$ X_y = b_{21} = \begin{pmatrix} C_{23456}S_1 - C_{456}S_{123} - C_{156}S_4 - C_{26}S_{135} \\ - C_{36}S_{235} - C_{23}S_{146} + S_{12346} + C_{14} \end{pmatrix} $$

$$ X_z = b_{31} = \left(C_{3456}S_2 - C_6S_{235} - S_{2346} \right) $$

$$ Y_x = b_{12} = \left(C_{35}S_{12} - C_{14}S_{235} + C_{1234}S_5 - S_{145} + C_{125}S_3 \right) $$

$$ Y_y = b_{22} = \begin{pmatrix} C_{35}S_{23} - C_4S_{1235} + C_{234}S_{15} - C_1S_{45} \\ + C_{25}S_{13} \end{pmatrix} $$

$$ Y_z = b_{32} = \left(C_{34}S_{25} + C_5S_{23} \right) $$

$$ Z_x = b_{13} = \begin{pmatrix} C_3S_{1256} - C_{12345}S_6 + C_{145}S_{236} + C_5S_{146} \\ + C_{12}S_{356} + C_{16}S_{234} - C_{1236}S_4 - C_{46}S_1 \end{pmatrix} $$

$$ Z_y = b_{23} = \begin{pmatrix} C_{45}S_{1236} - C_{2345}S_{16} + C_{15}S_{46} + C_2S_{1356} \\ + C_3S_{2356} - C_{236}S_{14} + C_6S_{1234} + C_{146} \end{pmatrix} $$

$$ Z_z = b_{33} = \left(S_{2356} - C_{345}S_{26} - C_6S_{234} \right) $$

$$ P_x = b_{31} = \left(C_{3456}S_2 - C_6S_{235} - S_{2346} \right) $$

$$ P_y = b_{24} = \begin{pmatrix} C_4S_{1235}d_6 - C_{234}S_{15}d_6 + C_1S_{45}d_6 \\ - C_{25}S_{13}d_6 - C_{35}S_{23}d_6 + C_{23}S_{14}d_5 \\ - S_{1234}d_5 - C_{14}d_5 - C_2S_{13}d_4 \\ - C_3S_{12}d_4 - 2C_1d_2 \end{pmatrix} $$

$$ P_z = b_{34} = \left(S_{234}d_5 - C_{34}S_{25}d_6 - C_5S_{23}d_6 + d_1 - S_{23}d_4 \right) $$

The orientations angles of the end effector can be determined by Roll-Pitch-Yaw orientation transform [5].

$$ \tan\phi = \frac{X_y}{X_x} = \frac{\begin{pmatrix} C_{23456}S_1 - C_{456}S_{123} - C_{156}S_4 \\ - C_{26}S_{135} - C_{36}S_{235} - C_{23}S_{146} \\ + S_{12346} + C_{14} \end{pmatrix}}{\begin{pmatrix} C_{123456} - C_{1456}S_{23} - C_{56}S_{14} \\ - C_{126}S_{35} - C_{36}S_{125} + C_1S_{2346} \\ - C_{123}S_{46} - C_4S_{16} \end{pmatrix}} \tag{5} $$

$$ \tan\theta = \frac{- X_z}{X_xC\phi + X_yS\phi} $$

$$ = \frac{- \left(C_{3456}S_2 - C_6S_{235} - S_{2346} \right)}{\begin{pmatrix} C\phi \begin{pmatrix} C_{123456} - C_{1456}S_{23} - C_{56}S_{14} \\ - C_{126}S_{35} - C_{36}S_{125} + C_1S_{2346} \\ - C_{123}S_{46} - C_4S_{16} \end{pmatrix} \\ + S\phi \begin{pmatrix} C_{23456}S_1 - C_{456}S_{123} - C_{156}S_4 \\ - C_{26}S_{135} - C_{36}S_{235} - C_{23}S_{146} \\ + S_{12346} + C_{14} \end{pmatrix} \end{pmatrix}} \tag{6} $$

$$ \tan\psi = \frac{Y_z}{Z_z} = \frac{\left(C_{34}S_{25} + C_5S_{23} \right)}{\left(S_{2356} - C_{345}S_{26} - C_6S_{234} \right)} \tag{7} $$

IV. Experiments and Results

The parameters of robotic arm were developed and tested by mathematic modeling and kinematic analysis. The robotic arm uses the Denavit Hartenberg (D-H) method to determine the parameters with transformation matrices. In experiment, we tested the accuracy of parameter from real hardware and the parameter is calculated from Denavit Hartenberg (D-H) method. The parameter of each joint is used in experiments to determine the rotation angle error of each joint. The angle error is difference angle between measured angle from rotary encoder compared with calculated angle. We selected the angle at 30 degree as desired angle and the results of angle error of each joint are shown in figure 4.

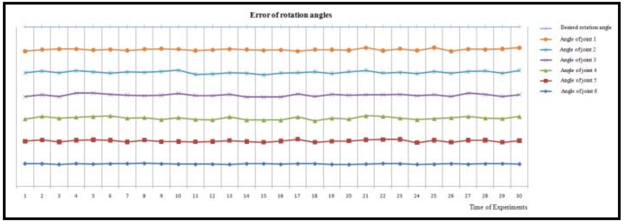

Fig.4 : Error angle of joint rotation.

V. Conclusion

A kinematic analysis of the real robotic arm was designed, analyzed and constructed. The direct kinematic analysis was conducted to determine the parameter of robotic arm by using Denavit-Hartenberg (D-H) method. The calculated parameters of robotic arm were implemented by direct kinematics and compared with the measured parameter by rotary encoder. The future work is to make the robotic arm that it can grab objects by using machine vision system.

VI. ACKNOWLEDGMENT

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Using Fuzzy Goal Programming Technique to Obtain the Optimum Production of Vehicle Spare Parts, A Case Study

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Abstract- This paper studies the vehicle spare parts production problem to obtain the optimum production rate under fuzzy capital budget. We applied the integer goal programming technique to determine the best compromise solution. There are two goals in our case study. These goals are minimization of the uncertain capital budget and maximization of the uncertain expected profits. The case study is a factory which produces different types of vehicle heat exchangers. The results indicate that the problem solution depends on the membership function and the **α**-cut. The optimum quantities of heat exchangers' production are found to be biased to the lower limit of production.

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Abstract- This paper studies the vehicle spare parts production problem to obtain the optimum production rate under fuzzy capital budget. We applied the integer goal programming technique to determine the best compromise solution. There are two goals in our case study. These goals are minimization of the uncertain capital budget and maximization of the uncertain expected profits. The case study is a factory which produces different types of vehicle heat exchangers. The results indicate that the problem solution depends on the membership function and the α-cut. The optimum quantities of heat exchangers' production are found to be biased to the lower limit of production.

I. INTRODUCTION

Due to huge changes in vehicle prices, fuels, oils, and spare parts' prices, it is important for transportation companies to study their fleet of vehicles from the opinion of vehicle operations economics. The vehicle operations economics field studies the maximization of profit and/or minimization of costs. One of the topics that is needed to be studied and applied to the real world applications is finding the optimum production rate of vehicle spare parts.

The capital budgeting in automobile firms is introduced by AbouelNour [1]. The optimal distribution of a certain amount of capital budgeting in production of vehicle spare parts had been obtained using integer programming technique in formulation and solution. Mohan A. et al [2] developed a decision support system for budget allocation of an R&D organization.

Multiple criteria decision making (MCDM) refers to making decisions in the presence of multiple, usually, conflicting objectives. These problems can be solved either directly [10] or using different secularization forms (SOP) [11]. Most investigators in the general area of multiobjective mathematical programming agree that goal programming technique represents the work horse of multiobjective mathematical programming. Lee S.M. et al [3] introduced capital budgeting for multiple objectives. Zamfirescu, L. et al [4] prepared a goal programming as a decision model for performance-based budgeting.

Goal programming is found to be useful in real life situations, for many problems it may not be possible to satisfy certain specified goals within given constraints. Then problem then becomes one of maximizing the degree of attainment of these goals. Using goal programming for marketing decisions with a case study is illustrated by Lee, S. et al [5]. Lee, S. [6] introduced goal programming for decision analysis. Dauer, J.P. et al [7] introduce a finite iteration algorithm for solving general goal programming problems. The approach enables one to solve linear, no linear, integer and other goal programming problems using the corresponding optimization technique in an iterative manner.

In the real life systems, the uncertainties and vagueness accomplishing the determination of cost of production, the expected selling price and upper and lower pounds of the production of the spare parts make the problem fuzzy or stochastic rather than deterministic one.

Hu, C.F. et al [8] introduced a fuzzy goal programming approach to multi-objective optimization problem with priorities. Khalili, K. et al [9] presented a paper about solving multi-period project selection problems with fuzzy goal programming beased on TOPSIS and fuzzy preference relation. Eid, M.H. [12] gives methods of solving integer multi criteria decision making problems with fuzzy parameters.

This paper introduces the analysis of the optimum vehicle spare parts production, where the problem of distribution of fuzzy capital budget is applied.

The technique is introduced in Sakawa [13] for transforming fuzzy problems to non-fuzzy form is combined with the interactive approach to goal programming [12] to develop the method of solution of such problem, where the method is through two goals is used. The first goal is the fuzzy capital budgeting minimization, while the second one is fuzzy profit maximization.

Our study is applied on a company which produces different types of vehicles' heat exchangers. The aim of this study is to obtain the optimum number of

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heat exchangers which maximizes profits and minimizes the production cost under fuzzy budget.

II. CONCEPT OF GOAL PROGRAMMING

a) General

Goal programming is a modification and extension of linear programming technique. The goal programming approach allows a simultaneous solution of a system of complex objectives rather than a single objective. In other words, goal programming is a technique that is capable of handling decision problems that deal with a single goal and multiple sub-goals, as well as problems with multiple goals and multiple sub-goals. In addition, the objective function of a goal programming model may be composed of non-homogeneous units of measure, such as pounds and dollars, rather than one type of units. Often, multiple goals of management are in conflict or are achievable only at the expense of other goals. Furthermore, these goals are incommensurable. Thus, the solution of the problem requires an establishment of a hierarchy of importance among these incompatible goals so that the low-order goals are considered only after the higher-order goals are satisfied or have reached the point beyond which no further improvements are desired. In goal programming, instead of trying to maximize or minimize the objective criterion directly as in linear programming, deviations between goals and what can be achieved within the given set of constraints are to be minimized [6].

b) Formulation of the Goal Programming Proble

$$min.\, p_1\big(\varphi_1(w_1, d_1^+, d_1^-)\big) + p_2\big(\varphi_2(w_2, d_2^+, d_2^-)\big) + \cdots + p_n\big(\varphi_n(w_n, d_n^+, d_n^-)\big)$$

Subject to:

$F_i(x) + d_i^- - d_i^+ = b_i, \qquad i = 1, 2, \ldots, n\,,$

$x \in M\,,$

$x, d_i^+, d_i^- \geq 0, \qquad i = 1, 2, \ldots, n$

Where:

$P_1 >>> p_2 >> \ldots.. >>> p_n$: are the priority structure;

$\varphi_i(w_i, d_i^+, d_i^-)$: are linear functions of the concerned variables;

$w_i > 0$: are different weights;

d_i^+: are under achievement deviational variables;

d_i^-: are over achievement deviational variables;

M: is the set representing the system constraints.

c) Methods of Solving Goal Programming Problems

There are more than one method for solving goal programming problems. From these methods, the most common are:

1. The graphical method of goal programming.
2. The simplex method of goal programming.
3. The interactive approach of goal programming.

These methods are illustrated in [6, 7].

In this work the interactive approach of goal programming was used.

III. VEHICLE SPARE PARTS PRODUCTION FORMULATION

The mathematical model of vehicle spare parts production in fuzzy environment which minimizes the total fuzzy capital budgeting and maximizes the total expected fuzzy profit is formulated as an integer goal programming problem with fuzzy parameters. There are two goals here, fuzzy capital budgeting goal and fuzzy profit goal. Also, there are a set of constraints represent upper and lower bounds of the quantities which should be produced from the different types of spare parts.

Let:

x_i: is the quantity of production from spare parts i, i= 1, 2, …, n.

c_i: is the production cost of the spare part I, i= 1, 2, …, n.

$a + \lambda_1^{\sim}\bar{a}$: is the fuzzy budget which allocated to the production of spare parts.

b_i: is the profit associated with the spare part i, i= 1, 2, …, n.

$b + \lambda_2^{\sim}\bar{b}$: is the total fuzzy profit.

$L_i + \mu_i^{\sim}\bar{L}_i$: is fuzzy lower bound of the production of spare parts i, i= 1, 2, …, n.

$U_i + v_i^{\sim}\overline{U}_{i}$: is fuzzy upper bound of the production of spare parts i, i= 1, 2, …, n.

$p_1 >>> p_2$: is the priority structure.

d_1^-, d_2^-: are the under achievements of the deviational variables.

d_1^+, d_2^+: are the upper achievements of the deviational variables.

Then the problem takes the following form:

$$min.\ z = p_1 d_1^+ + p_2 d_2^-$$

Subject to:

$$\sum_{i=1}^{n} c_i x_i + d_1^- - d_1^+ = a + \tilde{\lambda}_1 \bar{a}$$

$$\sum_{i=1}^{n} b_i x_i + d_2^- - d_2^+ = b + \tilde{\lambda}_2 \bar{b}$$

$L_i + \tilde{\mu}_i \overline{L}_i \leq x_i \ \leq \ U_i + \tilde{v}_i \overline{U}_i$, i= 1. 2, …, n

$x_i\ , d_1^-, d_1^+, d_2^-, d_2^+ \ \geq 0, x_i\ integers$, i= 1. 2, …, n

IV. DETERMINISTIC (CRISP) FORM OF THE PROBLEM

The mathematical formulation of spare parts production in fuzzy environment problem can be transformed to the following non-fuzzy form (α − fuzzy integer goal programming problem):

$$min.\ z = p_1 d_1^+ + p_2 d_2^-$$

Subject to:

$$\sum_{i=1}^{n} c_i x_i + d_1^- - d_1^+ = a + \lambda_1 \bar{a}$$

$$\sum_{i=1}^{n} b_i x_i + d_2^- - d_2^+ = b + \lambda_2 \bar{b}$$

$S_1 \leq \lambda_1 \leq T_1$

$S_2 \leq \lambda_2 \leq T_2$

$L_i + \mu_i \overline{L}_i \leq x_i \ \leq \ U_i + v_i \overline{U}_i$, i= 1. 2, …, n

$Q_i \leq \mu_i \leq R_i$, i= 1. 2, …, n

$M_i \leq v_i \leq N_i$, i= 1. 2, …, n

$x_i\ , d_1^-, d_1^+, d_2^-, d_2^+, \lambda_1, \lambda_2, \mu_i, v_i \geq 0, x_i\ integers$, i= 1. 2, …, n

V. VEHICLE SPARE PARTS PRODUCTION APPLICATION

a) *Data Collection*

The application was carried out in a vehicle heat exchangers production factory which produce different types of vehicle heat exchangers, for a group of ten different types of heat exchangers used for different types of vehicles which operates with diesel engines.

Table (1) illustrates the variable name, company part number, minimum limit, maximum limit of production, production cost and selling price.

Table (1) : Collected Data

Variable Name	Company Part Number	Minimum Limit of Production	Maximum Limit of Production	Production Cost (in $)	Selling Price (in $)
x_1	450 501 22 01	30	100	277	366
x_2	450 501 70 01	500	12000	175	255
x_3	450 501 24 01	4600	15000	144	203.2
x_4	450 501 19 01	600	1500	168	240
x_5	620 50591 04	700	1500	100	160
x_6	620 50594 04	50	1200	41.4	90

x_7	630 501 01 01	600	2750	80.3	130
x_8	655 501 86 01	1000	5500	71.7	150
x_9	350 501 19 01	600	2100	359	400
x_{10}	560 501 22 01	40	450	149.5	200

Where:

x_1 : is the number of heat exchangers for 3.5t transporter.

x_2: is the number of heat exchangers for 2.8t transporter.

x_3: is the number of heat exchangers for 2t transporter.

x_4: is the number of heat exchangers for 2.5t transporter.

x_5: is the number of heat exchangers for 5 cylinder microbus.

x_6: is the number of heat exchangers for 4 cylinder microbus.

x_7: is the number of heat exchangers for 5 cylinder microbus.

x_8: is the number of heat exchangers for 5 cylinder microbus.

x_9: is the number of heat exchangers for 6t transporter.

x_{10}: is the number of heat exchangers for 2.5t transporter.

The fuzzy budget allocated to the production $(a + \tilde{\lambda}_1 \bar{a})$ = LE 4000000 + 100000 $\tilde{\lambda}_1$

The fuzzy expected profit (b + $\tilde{\lambda}_2 \bar{b}$) = LE 200000 + 500000 $\tilde{\lambda}_2$

b) Mathematical Formulation of Applied Proble

The applied problem takes the following form:

$$min.\ z = p_1 d_1^- + p_2 d_2^-$$

Subject to:

$$277\, x_1 + 175\, x_2 + 144\, x_3 + 168\, x_4 + 100\, x_5 + 41.4\, x_6 + 80.3\, x_7 + 71.7\, x_8 + 359\, x_9 + 149.5\, x_{10} + d_1^- - d_1^+ \le 4000000 + 100000\, \tilde{\lambda}_1$$

$$89\, x_1 + 80\, x_2 + 59.2\, x_3 + 72\, x_4 + 60\, x_5 + 48.6\, x_6 + 49.7\, x_7 + 78.3\, x_8 + 41\, x_9 + 50.5\, x_{10} + d_2^- - d_2^+ \ge 200000 + 50000\, \tilde{\lambda}_2$$

$$30 + 4\, \tilde{\mu}_1 \le x_1 \le 60 + 10\, \tilde{v}_1$$

$$500 + 200\, \tilde{\mu}_2 \le x_2 \le 800 + 500\, \tilde{v}_2$$

$$4600 + 150\, \tilde{\mu}_3 \le x_3 \le 9000 + 750\, \tilde{v}_3$$

$$600 + 100\, \tilde{\mu}_4 \le x_4 \le 700 + 100\, \tilde{v}_4$$

$$700 + 70\, \tilde{\mu}_5 \le x_5 \le 800 + 140\, \tilde{v}_5$$

$$50 + 10\, \tilde{\mu}_6 \le x_6 \le 600 + 100\, \tilde{v}_6$$

$$600 + 100\, \tilde{\mu}_7 \le x_7 \le 1250 + 200\, \tilde{v}_7$$

$$1000 + 200\, \tilde{\mu}_8 \le x_8 \le 2500 + 500\, \tilde{v}_8$$

$$600 + 100\, \tilde{\mu}_9 \le x_9 \le 1100 + 200\, \tilde{v}_9$$

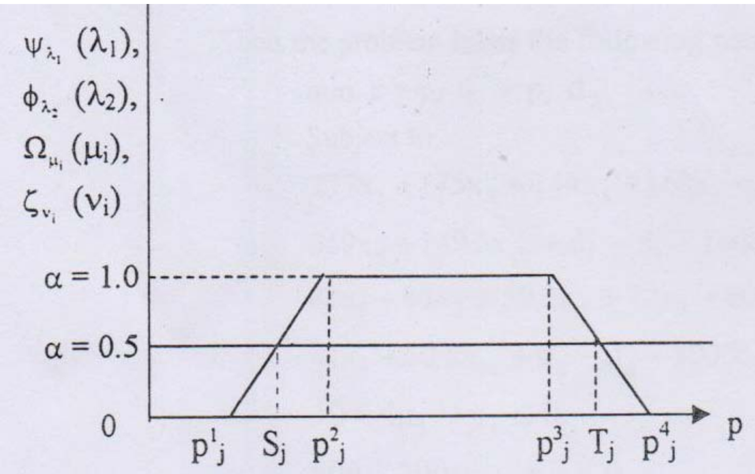
$$40 + 10\, \tilde{\mu}_{10} \le x_{10} \le 250 + 50\, \tilde{v}_{10}$$

$x_i, d_1^-, d_1^+, d_2^-, d_2^+, \tilde{\lambda}_1, \tilde{\lambda}_2, \tilde{\mu}_i, \tilde{v}_i \ge 0, x_i\ integers$, i= 1. 2, …, n

Where:

$\tilde{\lambda}_1, \tilde{\lambda}_2, \tilde{\mu}_i, \tilde{v}_i$, i= 1. 2, …, n are fuzzy parameters.

The fuzzy parameters are represented by the following membership function.



Where:

$$\begin{array}{c} \psi_{\lambda 1}(\tilde{\lambda}_1), \\ \phi_{\lambda 2}(\tilde{\lambda}_2), = \\ \Omega_{\mu 1}(\tilde{\mu}_i), \\ \zeta_{v 1}(\tilde{v}_i) \end{array} \begin{cases} 0 & -\infty \le \lambda_i \le p_j^1 \\ \dfrac{\lambda_i - p_j^1}{p_j^2 - p_j^1} & p_j^1 \le \lambda_i \le p_j^2 \\ 1 & p_j^2 \le \lambda_i \le p_j^3 \\ \dfrac{\lambda_i - p_j^3}{p_j^4 - p_j^3} & p_j^3 \le \lambda_i \le p_j^4 \\ 0 & p_j^4 \le \lambda_i \le \infty \end{cases}$$

By taking the cut $\alpha = 0.5$, then table 2 illustrates values of S_j, T_j, Q_j, R_j, M_j, N_j.

Table (2) : Values of S_j, T_j, Q_j, R_j, M_j, N_j

	p_j^1	p_j^2	p_j^3	p_j^4	S_j	T_j	Q_j	R_j	M_j	N_j
λ_1	3	4	7	10	3.5	8.5				
λ_2	1	2	3	4	1.5	3.5				
μ_1	1	2	4	6			1.5	5		
μ_2	1	3	4	6			2	5		
μ_3	1	3	6	8			2	7		
μ_4	1	2	3	5			1.5	4		
μ_5	1	2	3	5			1.5	4		
μ_6	1	2	4	6			1.5	5		
μ_7	1	2	3	5			1.5	4		
μ_8	2	4	7	8			3	7.5		
μ_9	1	2	3	5			1.5	4		
μ_{10}	1	2	5	7			1.5	6		
v_1	1	2	3	5					1.5	4
v_2	3	5	7	9					4	8
v_3	2	4	7	9					3	8
v_4	3	5	7	9					4	8
v_5	2	4	4	6					3	5
v_6	2	4	5	7					3	6
v_7	1	3	7	8					2	7.5
v_8	3	4	5	7					3.5	6
v_9	2	4	4	6					3	5
v_{10}	1	2	3	5					1.5	4

Then the problem takes the following non-fuzzy (Crisp) form:

$min.\ z = p_1 d_1^+ + p_2 d_2^-$

Subject to:

$$277\,x_1 + 175\,x_2 + 144\,x_3 + 168\,x_4 + 100\,x_5 + 41.4\,x_6 + 80.3\,x_7 + 71.7\,x_8 + 359\,x_9 + 149.5\,x_{10} + d_1^- - d_1^+ - 100000\,\lambda_1 \le 4000000$$

$$89\,x_1 + 80\,x_2 + 59.2\,x_3 + 72\,x_4 + 60\,x_5 + 48.6\,x_6 + 49.7\,x_7 + 78.3\,x_8 + 41\,x_9 + 50.5\,x_{10} + d_2^- - d_2^+ - 50000\,\lambda_2 \ge 200000$$

$30 + 4\,\mu_1 - x_1 \le 0$

$x_1 - 10\,v_1 - 60 \le 0$

$500 + 200\,\mu_2 - x_2 \le 0$

$x_2 - 500\,v_2 - 8000 \le 0$

$4600 + 150\,\mu_3 - x_3 \le 0$

$x_3 - 750\,v_3 - 9000 \le 0$

$600 + 100\,\mu_4 - x_4 \le 0$

$x_4 - 100\,v_4 - 700 \le 0$

$700 + 70\,\mu_5 - x_5 \le 0$

$x_5 - 140\,v_5 - 800 \le 0$

$50 + 10\,\mu_6 - x_6 \le 0$

$x_6 - 100\,v_6 - 600 \le 0$

$600 + 100\,\mu_7 - x_7 \le 0$

$x_7 - 200\,v_7 - 1250 \le 0$

$1000 + 200\,\mu_8 - x_8 \le 0$

$x_8 - 500\,v_8 - 2500 \le 0$

$600 + 100\,\mu_9 - x_9 \le 0$

$x_9 - 200\,v_9 - 1100 \le 0$

$40 + 10\,\mu_{10} - x_{10} \le 0$

$x_{10} - 50\,v_{10} - 250 \le 0$

$3.5 - \lambda_1 \le 0 \lambda_1 - 8.5 \le 0$

$1.5 - \lambda_2 \le 0 \lambda_2 - 3.5 \le 0$

$1.5 - \mu_1 \le 0 \mu_1 - 5 \le 0$

$2 - \mu_2 \le 0 \mu_2 - 5 \le 0$

$2 - \mu_3 \le 0 \mu_3 - 7 \le 0$

$1.5 - \mu_4 \le 0 \mu_4 - 4 \le 0$

$1.5 - \mu_5 \le 0 \mu_5 - 4 \le 0$

$1.5 - \mu_6 \le 0 \mu_6 - 5 \le 0$

$1.5 - \mu_7 \le 0 \mu_7 - 4 \le 0$

$3 - \mu_8 \le 0 \mu_8 - 7.5 \le 0$

$1.5 - \mu_9 \le 0 \mu_9 - 4 \le 0$

$1.5 - \mu_{10} \le 0 \mu_{10} - 6 \le 0$

$1.5 - v_1 \le 0 v_1 - 4 \le 0$

$4 - v_2 \le 0 v_2 - 8 \le 0$

$3 - v_3 \le 0 v_3 - 8 \le 0$

$4 - v_4 \le 0 v_4 - 8 \le 0$

$3 - v_5 \le 0 v_5 - 5 \le 0$

$3 - v_6 \le 0 v_6 - 6 \le 0$

$2 - v_7 \le 0 v_7 - 7.5 \le 0$

$3.5 - v_8 \le 0 v_8 - 6 \le 0$

$3 - v_9 \le 0 v_9 - 5 \le 0$

$1.5 - v_{10} \le 0$

$v_{10} - 4 \le 0$

$x_i, d_1^-, d_1^+, d_2^-, d_2^+, \lambda_1, \lambda_2, \mu_i, v_i \ge 0, x_i\ integers$, i= 1. 2, …, n

c) *Application Results*

The problem is solved by a mixed integer linear programming package using the iterative approach of goal programming. The optimum solution which minimizes the allocated capital budget and maximizes the profit is given in Table (3).

Table (3) : 0.5 Application Optimum Quantity of Production

Variable Name	Company Part Number	0.5 Optimum Quantity
x_1	450 501 22 01	36
x_2	450 501 70 01	900
x_3	450 501 24 01	4900
x_4	450 501 19 01	750
x_5	620 50591 04	805
x_6	620 50594 04	65
x_7	630 501 01 01	750
x_8	655 501 86 01	1600
x_9	350 501 19 01	750
x_{10}	560 501 22 01	55

VI. CONCLUSION

1. A method of obtaining the optimum production of spare parts in fuzzy environment is presented. This method is based on the formulation of the problem in the form of integer goal programming problem with fuzzy parameters in the right hand side of its constraints. The problem is solved by a mixed integer linear programming (MILP) package using the interactive approach of goal programming. It should be mentioned that the solution depends on

the membership functions determination and the α–cut.

2. From the application of the vehicle heat exchangers production factory, it can be stated that:

- The minimum production cost is $1544680.5
- The maximum profit is $666825.5
- The optimum quantities of heat exchangers are biased to the lower limits of the production as a result of solution of the problem with the minimization of total capital budget goal with a higher priority than the maximization of the expected profit goal.

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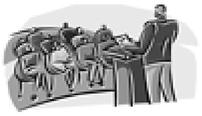

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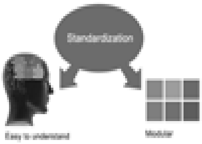

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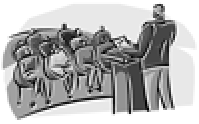
The IBOARS can initially review research papers of their institute and recommend them to publish with respective journal of Global Journals. It can also review the papers of other institutions after obtaining our consent. The second review will be done by peer reviewer of Global Journals Incorporation (USA) The Board is at liberty to appoint a peer reviewer with the approval of chairperson after consulting us.

The author fees of such paper may be waived off up to 40%.

The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.



The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of "Open Association of Research Society, U.S.A (OARS)" so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

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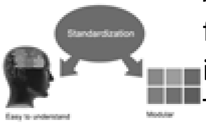

After nomination of your institution as “Institutional Fellow” and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.
The board can also take up the additional allied activities for betterment after our consultation.

The following entitlements are applicable to individual Fellows:

Open Association of Research Society, U.S.A (OARS) By-laws states that an individual Fellow may use the designations as applicable, or the corresponding initials. The Credentials of individual Fellow and Associate designations signify that the individual has gained knowledge of the fundamental concepts. One is magnanimous and proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice.

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- The Fellow can organize symposium/seminar/conference on behalf of Global Journals Incorporation (USA) and he/she can also attend the same organized by other institutes on behalf of Global Journals.
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Note :

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> - In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
> - In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
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>
> "

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2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript’s Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

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32. Never oversimplify everything: To add material in your research paper, never go for oversimplification. This will definitely irritate the evaluator. Be more or less specific. Also too, by no means, ever use rhythmic redundancies. Contractions aren't essential and shouldn't be there used. Comparisons are as terrible as clichés. Give up ampersands and abbreviations, and so on. Remove commas, that are, not necessary. Parenthetical words however should be together with this in commas. Understatement is all the time the complete best way to put onward earth-shaking thoughts. Give a detailed literary review.

33. Report concluded results: Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

34. After conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print to the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects in your research.

INFORMAL GUIDELINES OF RESEARCH PAPER WRITING

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

Title Page:

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

Abstract:

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

THE ADMINISTRATION RULES

Please carefully note down following rules and regulation before submitting your Research Paper to Global Journals Inc. (US):

Segment Draft and Final Research Paper: You have to strictly follow the template of research paper. If it is not done your paper may get rejected.

- The **major constraint** is that you must independently make all content, tables, graphs, and facts that are offered in the paper. You must write each part of the paper wholly on your own. The Peer-reviewers need to identify your own perceptive of the concepts in your own terms. NEVER extract straight from any foundation, and never rephrase someone else's analysis.

- Do not give permission to anyone else to "PROOFREAD" your manuscript.

- Methods to avoid Plagiarism is applied by us on every paper, if found guilty, you will be blacklisted by all of our collaborated research groups, your institution will be informed for this and strict legal actions will be taken immediately.)
- To guard yourself and others from possible illegal use please do not permit anyone right to use to your paper and files.

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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