Online ISSN : 2249-4596
Print ISSN : 0975-5861
DOI : 10.17406/GJRE

Global Journal of Researches in Engineering: H

Robotics & Nano-Tech

Obstacle Avoiding Robot

Robot Manipulator Control

Highlights

Efficient Plasmonic Solar

Statics Including Cable Sag

Discovering Thoughts, Inventing Future

VOLUME 17 ISSUE 1 VERSION 1.0

Global Journal of Researches in Engineering: H
Robotics & Nano-Tech

Global Journal of Researches in Engineering: H

Robotics & Nano-Tech

Volume 17 Issue 1 (Ver. 1.0)

Open Association of Research Society

Incorporation No.: 0423089
License No.: 42125/022010/1186
Registration No.: 430374
Import-Export Code: 1109007027
Employer Identification Number (EIN):
USA Tax ID: 98-0673427

Global Journals Inc.

*(A Delaware USA Incorporation with "Good Standing"; **Reg. Number: 0423089**)*

Sponsors: Open Association of Research Society
Open Scientific Standards

Publisher's Headquarters office

Global Journals® Headquarters
945th Concord Streets,
Framingham Massachusetts Pin: 01701,
United States of America
USA Toll Free: +001-888-839-7392
USA Toll Free Fax: +001-888-839-7392

Offset Typesetting

Global Journals Incorporated
2nd, Lansdowne, Lansdowne Rd., Croydon-Surrey,
Pin: CR9 2ER, United Kingdom

Packaging & Continental Dispatching

Global Journals Pvt. Ltd.
E-3130 Sudama Nagar, Near Gopur Square,
Indore, M.P., Pin:452009, India

Find a correspondence nodal officer near you

To find nodal officer of your country, please email us at *local@globaljournals.org*

eContacts

Press Inquiries: *press@globaljournals.org*
Investor Inquiries: *investors@globaljournals.org*
Technical Support: *technology@globaljournals.org*
Media & Releases: *media@globaljournals.org*

Pricing (Including by Air Parcel Charges):

For Authors:
22 USD (B/W) & 50 USD (Color)
Yearly Subscription (Personal & Institutional):
200 USD (B/W) & 250 USD (Color)

Editorial Board

Global Journal of Research in Engineering

Contents of the Issue

Global Journal of Researches in Engineering: H
Robotics & Nano-Tech
Volume 17 Issue 1 Version 1.0 Year 2017
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN:2249-4596 Print ISSN:0975-5861

Kinematics and Statics Including Cable Sag for Large CableSuspended Robots

By Dheerendra Sridhar & Robert L. Williams II

Ohio University

Abstract- Cable sag can have significant effects on the cable length computation in a cable suspended robot and this is more pronounced in largescale outdoor systems. This requires modeling the cable as a catenary instead of an approximated straigh-tline model. Furthermore, when there is actuation redundancy involved, the modeling and simulation of the system becomes much more complex, requiring optimizing routines to solve the problem.

A cable-sag-compensated (catenary) model was implemented in simulation for an example large outdoor cable-suspended robot system to solve the coupled kinematics and statics problems. This involved optimization of cable tensions and finding the errors involved in the cable length. A comparative analysis between the straight-line and cable sag model is presented, the main contribution of this paper. Based on the qualitative and quantitative results obtained, recommendations were made on the choice of model and solution methodologies.

Keywords: cable-suspended robot, cable sag, non-negligible cable mass, catenary model, forward and inverse position kinematics, pseudostatics.

GJRE-H Classification: *FOR Code: 091007*

KINEMATICSANDSTATICSINCLUDINGCABLESAGFORLARGECABLESUSPENDEDROBOTS

Strictly as per the compliance and regulations of:

Kinematics and Statics Including Cable Sag for Large Cable-Suspended Robots

Dheerendra Sridhar [α] & Robert L. Williams II [σ]

Abstract- Cable sag can have significant effects on the cable length computation in a cable suspended robot and this is more pronounced in large-scale outdoor systems. This requires modeling the cable as a catenary instead of an approximated straight-line model. Furthermore, when there is actuation redundancy involved, the modeling and simulation of the system becomes much more complex, requiring optimizing routines to solve the problem.

A cable-sag-compensated (catenary) model was implemented in simulation for an example large outdoor cable-suspended robot system to solve the coupled kinematics and statics problems. This involved optimization of cable tensions and finding the errors involved in the cable length. A comparative analysis between the straight-line and cable sag model is presented, the main contribution of this paper. Based on the qualitative and quantitative results obtained, recommendations were made on the choice of model and solution methodologies.

Keywords: cable-suspended robot, cable sag, non-negligible cable mass, catenary model, forward and inverse position kinematics, pseudostatics.

I. Introduction

A distinct attribute of cable-suspended robots is the possibility of achieving very large workspaces which is difficult or impossible to achieve using rigid link manipulators. In the past two decades major progress has been made in the design and implementation of large scale robots throughout the world. The Five hundred meter Aperture Spherical radio Telescope (FAST) is large scale cable-suspended robot under development in China for astronomical study [1]. Another example is the Skycam [2], which is an aerial camera system that is widely used in sporting arenas. Other examples include CoGiRo (Control of Giant Robots) used for industrial purposes [3] and the Large Cable Mechanism (LCM) used for Radio Telescope Application [4].

Kozak et al. [5] addressed the issue of cable sag by studying the effects of considering mass in the statics and stiffness analysis of the FAST robot. This research used the “elastic catenary” discussed by Irvine [6], to model the cable lengths and subsequently address the inverse pose kinematics problem. Kozak et al. [5] also provided experimental validation and showed that the equations of the elastic catenary are in good agreement with experimental results. Additionally, Russell and Lardner [7] provided experimental validation of the elastic catenary model and quantified the difference between theoretical and experimental cable tensions.

An accuracy and error compensation study of the 6-dof FAST robot was presented by Yao et al. [8] and force distribution in the cables by Li et al. [9]. These results showed that cable sag has a considerable effect on the overall accuracy and control of the robot.

Research on the effects of sag on the workspace and cable characteristics was performed by Riehl et al. [10]. The findings, based on simulations for a 3-cable, 3-dof robot, showed that the workspace and the cable tension distribution for straight-line and elastic catenary (cable sag) models differ. Cable tension under cable sag, unlike the cable tension for the straight-line model, is not constant throughout the cable.

Irvine [6] presented a simplified model for cable sag based on perturbation analysis. This was used by Gouttefarde et al. [11] to model and simulate a 6-cable, 6-dof robot. Although this model is still nonlinear and does not give an analytical solution, it is simpler compared to the elastic catenary. Also, the relationship between the components of the cable tension is linear in this model. This model was further researched by Nguyen et al. [12] to find the limitation of the simplified model, which is that the straight-line model is not necessarily applicable throughout the workspace of the robot, unlike the catenary model. This model also lacks sufficient experimental validation, whereas the catenary model has been experimentally verified.

Another noteworthy work was by Dallej et al. [13], which was vision-based control of a cable-suspended robot. This method used cameras in 3D space to instantaneously compute inverse kinematics, thereby attempting to compensate for cable sag. But this approach is expensive and requires further research to make it viable for field operations and also to mitigate the iterative steps involved.

The mathematical modeling of kinematics and pseudostatics for small scale cable suspended robots generally works well with the assumption of ideal massless cables (straight-line model). However, for large-scale cable-suspended robots, significant errors may arise when assuming the straight-line model for all cables. The main purpose of this paper is to investigate the differences in cable length errors and computation,

Author α σ: Ph.D, Mechanical Engineering, Ohio University 251 Stocker Center Athens OH 45701-2979. e-mails: ds843012@ohio.edu, williar4@ohio.edu

comparing the straight-line cables assumption vs. a cable-sag model. dit Sandretto et al. [14] test the hypothesis that ignoring cable mass and cable sag is sufficient, with regard to their CoGiRo project. This hypothesis was confirmed for their current prototype hardware, but it was rejected for a planned larger robot. Riehl et al. [10] simply conclude that the cable caternaries must be accounted for, in large workspace cable robots, "in order to achieve good positioning and accuracy." Yaun et al. [15] develop static and dynamic stiffness models for large cable-suspended robots; they conclude that the cable catenary is "important" for stiffness studies.

This paper first presents the methods, followed by results and discussion.

II. Methods

The methods used by Kozak et al. [5] and subsequently used in [10-12] will be followed in this research.

a) *Cable Sag Catenary*

The equations of the cable catenary have been known for more than 80 years and they have been applied in various contexts of engineering. and their derivations are not presented (see [5, 6]). Consider a cable suspended between two points A and B as in Figure 1.

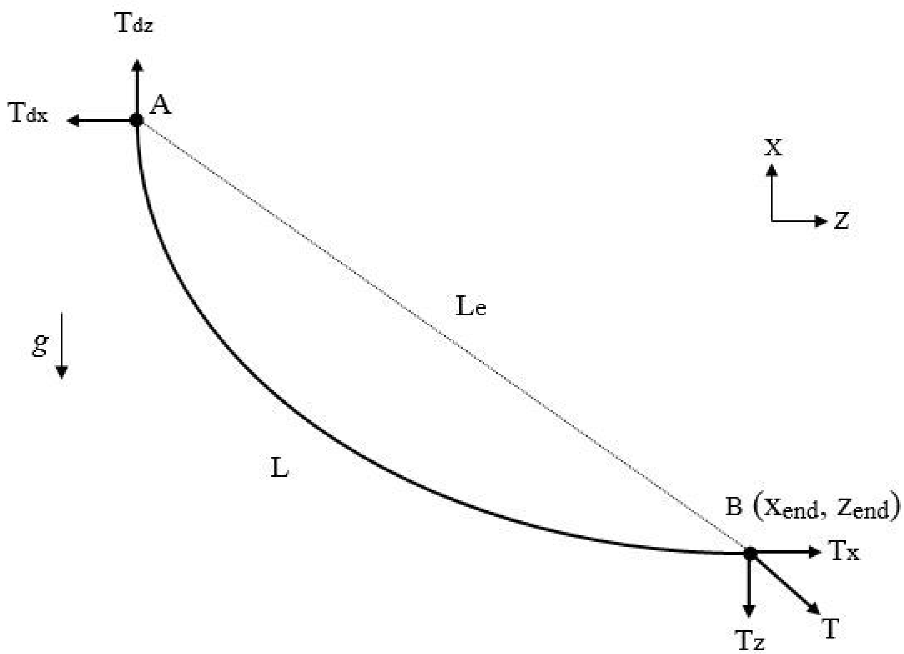


Figure 1: Cable suspended between two points

Where A is the cable drawing point, B is the end-effector attachment point, L_e is the straight-line (Euclidean norm) distance between A and B, L is the catenary (actual) length between A and B, g is the acceleration due to gravity, T is the cable tension with X and Z components T_x and T_z at the end effector side, T_{dx} and T_{dz} are the X and Z components of the cable tension at the cable drawing point, and (x_{end}, z_{end}) are the coordinates of the cable at the end-effect or attachment point. For this cable, the static catenary displacement equations for the inextensible case after simplification are (we ignore the axial elasticity since the cable mass dominates the sag):

$$x_{end} = \frac{|T_x|}{\rho_L g}\left[\sinh^{-1}\left(\frac{T_z}{T_x}\right) - \sinh^{-1}\left(\frac{T_z - \rho_L g L}{T_x}\right)\right] \quad (1)$$

Where ρ_L is the linear density of the cable material.

$$z_{end} = \frac{1}{\rho_L g}\left[\sqrt{T_x^2 + T_z^2} - \sqrt{T_x^2 + (T_z - \rho_L g L)^2}\right] \quad (2)$$

b) *Cable-suspended Robot Model*

The kinematic diagram of the cable-suspended robot considered is shown in Figure 2. The base frame {A} is fixed to the center of the robot footprint. The end-effector control point is point P, with hi being the height of the towers. Points B_i and Pi are the base and top points of the towers / poles respectively and points Ai are the points where winches / motors are located on the ground. L_i (or L_{ei} according to the notation in Figure 1 and used later in this paper) are the Euclidean norm (straight-line) cable lengths. In all cases i = 1,2,3,4. The length and width of the cable-suspended robot footprint are *L* and *W*, respectively.

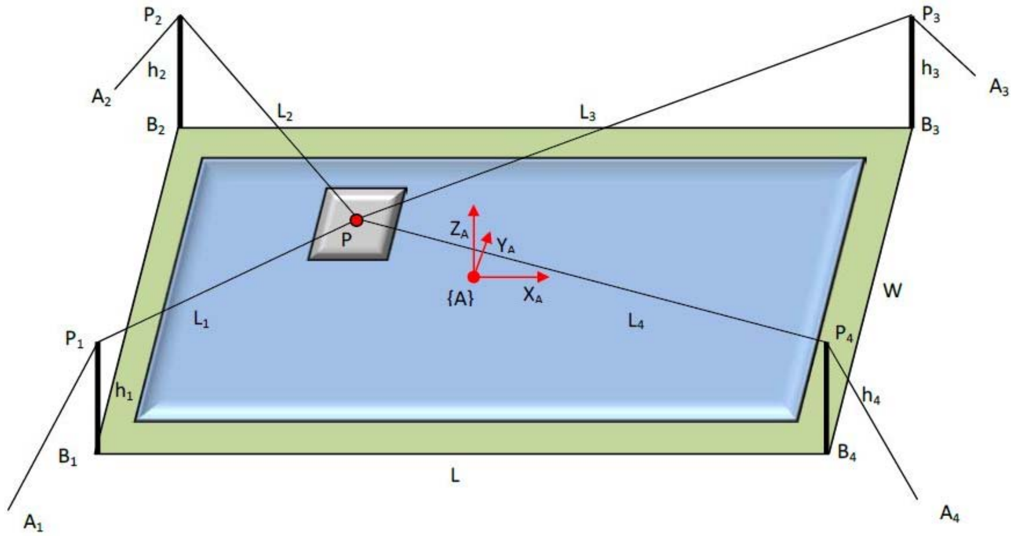


Figure 2: Kinematic diagram of the cable-suspended robot (1 acre footprint, 4047 m2) 1 acre is about the size of an American Football Field

c) Inverse Position Kinematics (IPK) and Statics

The IPK problem consists of finding the active cable lengths for a given position. When considering the effects of cable sag (i.e., the mass of the cables) in modeling, cable tension is involved in finding the cable length, unlike the traditional straight-line IPK problem. Hence, the kinematics and pseudostatics problems are coupled and have to be solved simultaneously, as evident from equations (1) and (2). This is a system of nonlinear implicit equations, hence there are no analytical solutions, thus forcing the use of numerical methods.

As shown in [5] and [10], for a minimally or perfectly constrained case, the catenary equations (1) and (2) are solved along with the static equilibrium equations (3).

$$\sum F_x = 0$$
$$\sum F_y = 0 \qquad (3)$$
$$\sum F_z = 0$$

For a redundant or overconstrained case, an additional impediment is that the static problem does not have a unique solution. Since the number of variables outnumbers the equations available, there are infinite valid solutions. Consider a 4-cable 3-dof (*XYZ* translation) cable-suspended robot as shown in Figures 2 and 3.

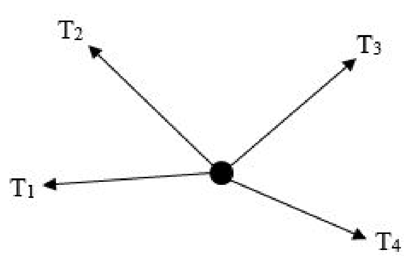


Figure 3: Free-Body Diagram of a four-cable robot

Solving only the static equations, for a given valid position, can have infinite solutions i.e. infinite valid combinations for $T = [T_1 \quad T_2 \quad T_3 \quad T_4]^T$. The physical interpretation of this scenario is that at a given position there are multiple valid ways of tensing the cables to maintain static equilibrium. To get one desired solution out of the many feasible solutions, techniques of mathematical optimization are used.

There are various methods available for mathematical optimization based on the nature of the problem. One popular approach used in field of robotics is that of the Moore–Penrose pseudoinverse of the statics Jacobian matrix, which minimizes the Euclidean norm of the cable tensions. Another useful technique is Linear Programming, which helps to find a solution to the above problem, provided the objective function and constraints are linear.

As pointed out in [5], when using the catenary equations for finding the cable lengths of a redundant cable-suspended robot, one feasible approach is to solve it as constrained optimization problem or specify the (m-n) number of forces prior to solving.

The methodology adapted here to address the Inverse Position Kinematics and Statics problem is as described in [5,8,9,12]. The details of the method adapted and coded in MATLAB are shown in Figure 4 and described below.

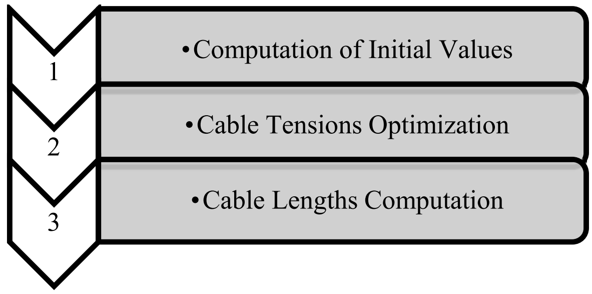


Figure 4: Steps involved in the solution of the inverse position problem

Step 1 - Computation of Initial Values

In this step, all the required inputs are entered for solving the IPK problem, along with necessary parameters such dimensional details of the robot footprint, robot variables, and properties of the cable. Then necessary coordinate transformations are made, which includes transforming global coordinates to local cable coordinates and vice versa. Subsequently, the Euclidean norm lengths of the cable and statics Jacobian matrix are calculated. Table 1 shows the input variables required.

Table 1: Input variables

Input Variable	Symbol	Unit
Length	L	m
Width	W	m
Pole Height	h	m
End-effector mass	m	kg
Cable Diameter	d	mm
Density of the Cable	ρ	kg/m^3
End-effector location	(x,y,z)	m

The Euclidean norm length of the straight-line cable is calculated using:

$$L_{ei} = \sqrt{(P_{xi}-x)^2+(P_{yi}-y)^2+(P_{zi}-z)^2} \qquad (4)$$

The straight-line static Jacobian matrix expressed in {A} coordinates is given by:

$$\left[{}^{A}A\right] = \begin{bmatrix} \frac{P_{x1}-x}{L_{e1}} & \frac{P_{x2}-x}{L_{e2}} & \frac{P_{x3}-x}{L_{e3}} & \frac{P_{x4}-x}{L_{e4}} \\ \frac{P_{y1}-y}{L_{e1}} & \frac{P_{y2}-y}{L_{e2}} & \frac{P_{y3}-y}{L_{e3}} & \frac{P_{y4}-y}{L_{e4}} \\ \frac{P_{z1}-z}{L_{e1}} & \frac{P_{z2}-z}{L_{e2}} & \frac{P_{z3}-z}{L_{e3}} & \frac{P_{z4}-z}{L_{e4}} \end{bmatrix} \qquad (5)$$

Step 2 – Cable Tensions Optimization

In this step, the cable tensions for a given position are calculated. As mentioned previously, this is a case with multiple valid solutions. To find a unique solution, this problem is solved as a constrained minimization problem. So, the statics problem is treated as a linear programming problem with an aim of minimizing the cable tensions. The problem is formulated as shown below:

Objective function: Minimize $(T_1+T_2+T_3+T_4)$

Subject to Constraints: $\left[{}^{A}A\right]\{T\}+\left\{{}^{A}F\right\}+m\,{}^{A}g=\{0\}$

$$T_{\min} \le T_i \le T_{\max}$$

Where the cable tensions are $T=\begin{bmatrix}T_1 & T_2 & T_3 & T_4\end{bmatrix}^T$, $\left\{{}^{A}F\right\}$ is the external force, $m^{A}g$ is the end-effector weight (both expressed in {*A*} coordinates), and $T_{\min}$ and $T_{\max}$ are the minimum and maximum allowable cable tensions.

This problem is a standard linear programming problem in four variables, with the static equilibrium equations used as constraints and bounds on the cable tensions based on necessary conditions ($Ti > 0$). Bounds not only help in obtaining non-negative solutions (a negative solution for cable tension means a cable must push, which is unacceptable), but also restrict the solution to be within practical limitations, avoiding extremely high cable tensions, which might break the cable or which cannot be supported by the winch / motor. This problem is solved using the linear programming solver **linprog( )** in MATLAB. Additionally, the pseudoinverse method was also implemented using the **pinv( )** command in MATLAB for comparison purposes.

Step 3 – Cable Lengths Computation

In this final step, cable lengths are computed using the catenary equations, by numerically solving a system of equations. This system of equations is shown below:

$$x_{iend} = \frac{|T_{xi}|}{\rho_L g}\left[\sinh^{-1}\left(\frac{T_{zi}}{T_{xi}}\right) - \sinh^{-1}\left(\frac{T_{zi} - \rho_L g L_i}{T_{xi}}\right)\right] \tag{6}$$

$$z_{iend} = \frac{1}{\rho_L g}\left[\sqrt{T_{xi}^2 + T_{zi}^2} - \sqrt{T_{xi}^2 + (T_{zi} - \rho_L g L_i)^2}\right] \tag{7}$$

$$T_i = \sqrt{T_{xi}^2 + T_{zi}^2} \tag{8}$$

where i = 1,2,3,4. For each cable this a system of three equations with three variables (T_{xi}, T_{zi}, and L_i). To solve this system of equations the **fsolve()** command in MATLAB is used, which is an iterative solver used to solve a system of nonlinear equations with real variables. Also, the number of iterations is recorded. Finally, this solver returns the components of the cable tensions along with the cable lengths.

To summarize, the methodology consists of finding the initial variables and subsequent coordinate transformation. An optimization routine is then performed to get a valid set of cable tensions $\{T\}$, such that the sum of cable tensions $(\sum T_i)$ is minimized. Finally, these cable tensions are used in the catenary equations to obtain the cable lengths. The code combines all the three steps to solve the Inverse Position Kinematics and Statics Problem comprehensively, such that when the user enters a valid position, the program returns the cable tensions and lengths.

d) Forward Position Kinematics (FPK) And Statics

The FPK problem consists of finding the position of the robot when the cable lengths are given. There are analytical methods to solve this problem such as the 3-sphere intersection algorithm presented in [14], which is valid only for the straight-line model. When cable sag is considered, FPK suffers the same hindrances that the IPK problem faces, i.e. the kinematics and statics problems are coupled, highly nonlinear, and have to be solved iteratively. The methodology here involves finding components of cable tensions using cable lengths and tensions and subsequently finding the position of the robot.

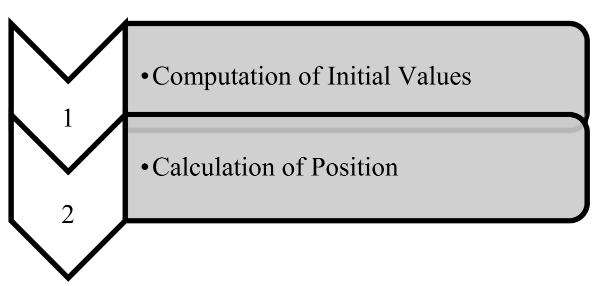


Figure 5: Steps involved in the solution of the forward position problem

Step 1 – Computation of Initial Values

Similar to the IPK problem, in this step all the necessary input values and coordinate transformations are entered. The active cable lengths and their respective tensions, dimensional details of the robot footprint, and the geometrical and material properties of the cables are entered.

Step 2 – Calculation of Position

In this step, the static displacement equations of the catenary (6-8) along with the static equilibrium equations (3) are solved numerically along with necessary transformations of coordinate system. This system of equations is also solved using the **fsolve()** command in MATLAB and its solution yields the *XYZ* position of the robot. In summary, the method consists of finding the initial values and necessary transformations. This is followed by solving a system of nonlinear equations whose solution gives the position. A major difference in this FPK problem, when compared to the inverse position problem, is the absence of optimization step, thus making it considerably faster to solve. However, both problems must be solved numerically (i.e. iteratively), when the effect of cable sag has to be considered.

III. Results and Discussion

Based on the methods described in the previous section, simulations were performed. This included simulating snapshot examples, a trajectory, and parameter variations. The results obtained and their interpretations are discussed in this section. The simulation results presented here use the values in Table 2.

Table 2: Values of the variables used for simulation

Variable	Value	Notes
Length (L)	50 m	1 acre footprint
Width (W)	80.9 m	
Pole Height (h)	7.6 m	All poles are same height
End-effector mass (*m*)	258.6 kg	-
Cable Diameter (d)	20 mm	-
Density of the Cable (ρ)	7860 kg/m^3	Density of a steel cable
External Force (^AF)	{0}	0 *xyz* vector
Tension Lower Limit (T_{min})	2537 N	-
Tension Higher Limit (T_{max})	+ ∞	To find the maximum force

a) *Snapshot Example*

Both the Inverse and Forward Position Problems were solved for four random positions and a nominal position $\{0 \quad 0 \quad 0\}^T$. The five positions are graphically shown in Figure 6 and stated numerically in Table 3.

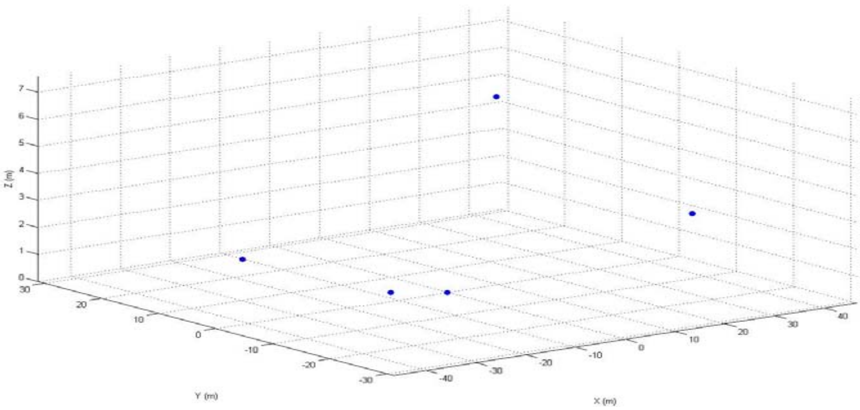


Figure 6: Snapshot points

When the code for the inverse problem is executed with these snapshot points as inputs, the program calculates the cable lengths and tensions.

Table 3: Cartesian coordinates of snapshot points

Point No.	End-effector position (m)		
	X	***Y***	***Z***
1	0	0	0
2	-29.4	10.2	1.5
3	-33.0	-18.8	2.0
4	28.5	-18.0	3.1
5	35.0	22.0	5.0

First, the circular check is performed to verify and partly validate the results obtained. To serve this purpose, both the inverse and forward problems were solved for all the five snapshot points. The results are summarized in Table 4 and the circular check is verified (the highlighted columns have equal corresponding values).

Table 4: Circular check for snapshot points

No.	Inverse Position Solution					Forward Position Solution				
	Input	Output				Input				Output
	Point	L_1	L_2	L_3	L_4	L_1	L_2	L_3	L_4	Point
1	0, 0, 0	56.70	56.70	56.70	56.70	56.70	56.70	56.70	56.70	0, 0, 0
2	-29.4, 10.2, 1.5	45.25	27.72	81.38	87.87	45.25	27.72	81.38	87.87	-29.4, 10.2, 1.5
3	-33, -18.8, 2	19.14	52.46	96.41	83.22	19.14	52.46	96.41	83.22	-33, -18.8, 2
4	28.5, -18, 3.1	77.75	90.26	53.11	22.75	77.75	90.26	53.11	22.75	28.5, -18, 3.1
5	35, 22, 5	97.64	84.7	14.93	54.92	97.64	84.7	14.93	54.92	35, 22, 5

The cable length difference between the cable sag and straight model is calculated, followed by cable length error computation:

$$D_i = L_i - L_{ei} \tag{9}$$

$$ER_i = \frac{L_i - L_{ei}}{L_i} \times 100\% \tag{10}$$

The results of difference in cable lengths and their percentage error are plotted in Figure 7 and 8.

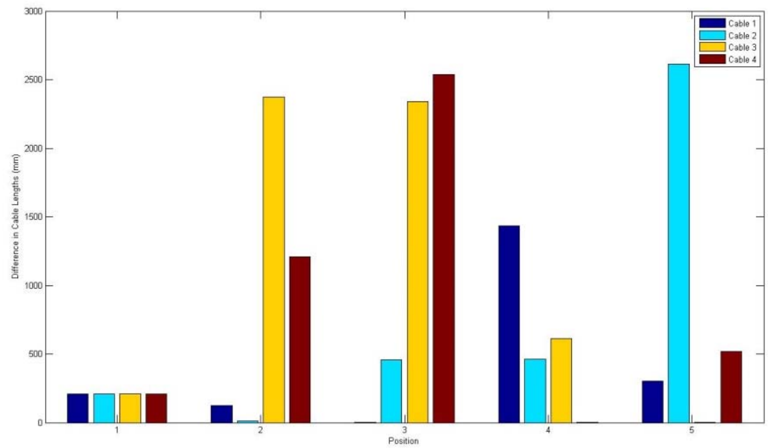


Figure 7: Difference in cable lengths vs. position

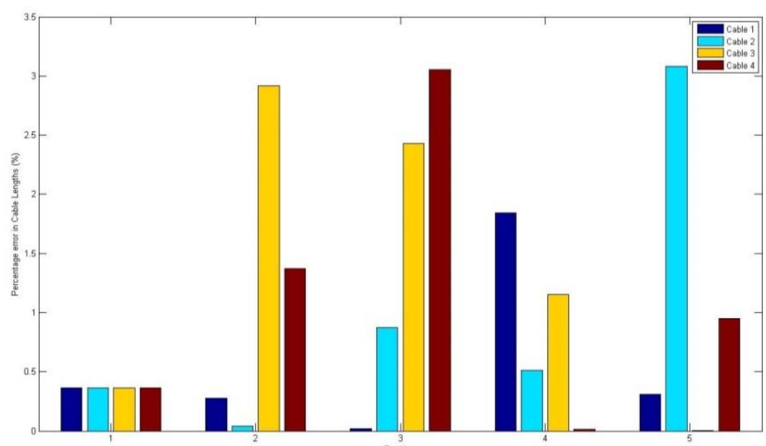


Figure 8: Percentage error in cable lengths vs. position

Along with computation of cable lengths, the cable tensions were also calculated using two methods; Linear Programming (LP) and Pseudoinverse Method (PI). These two methods give different values for cable tensions as the objective functions in both cases are different. The resulting graph is shown in Figure 9.

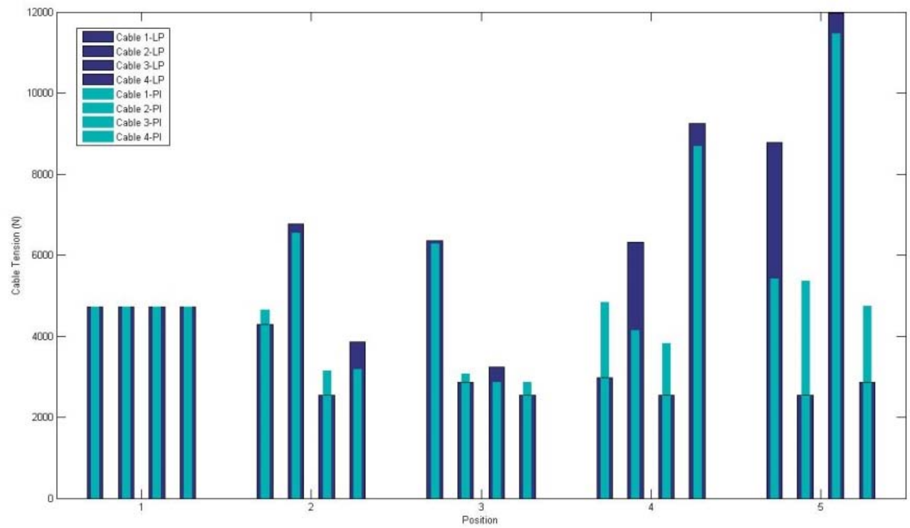


Figure 9: LP and PI Cable tensions vs. position

From the graphs, it can be observed that the difference in cable lengths obtained from the straight-line model and cable sag model ranges from 0 – 2600 mm, which appears to be significantly high. However, when the relative error is computed, the range is 0-3 %. The current cable-suspended Robot System, unlike the FAST [1] or LCM [4], is not meant for accurate positioning of the end-effector, hence from the snapshot examples the effects of cable sag appears to be tolerable. But the five examples are a small sample size of random points; this necessitates running the program to simulate a trajectory.

b) Trajectory Example

A pick-and-place robot trajectory was simulated with a step size of 0.5 m as shown in Figure 10. The ideal Cartesian coordinates and straight-line cable lengths for this trajectory are shown in Figures 11 and 12.

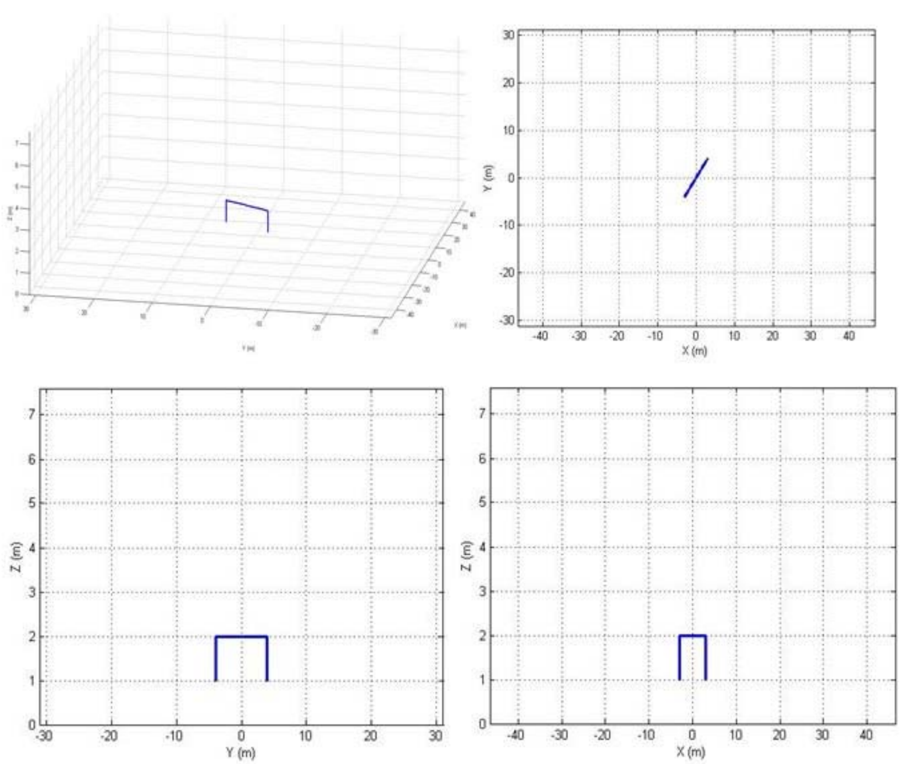


Figure 10: Pick-and-Place Trajectory Example

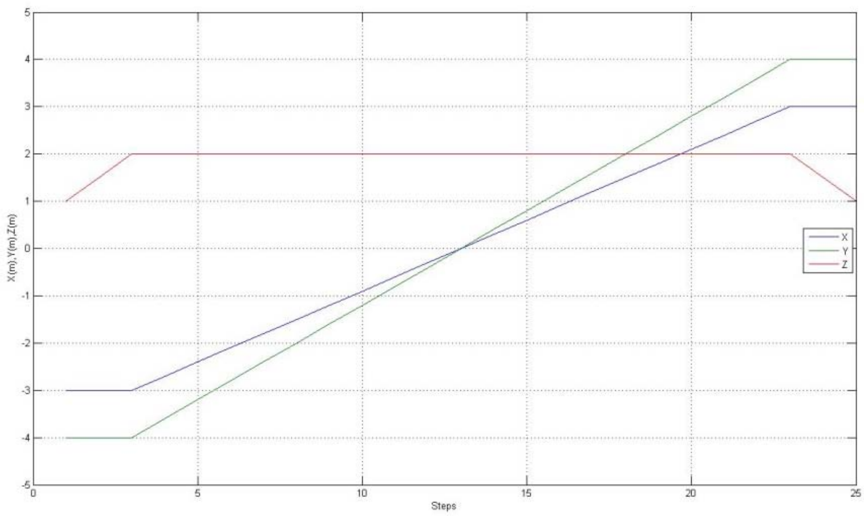


Figure 11: Cartesian coordinates vs. steps

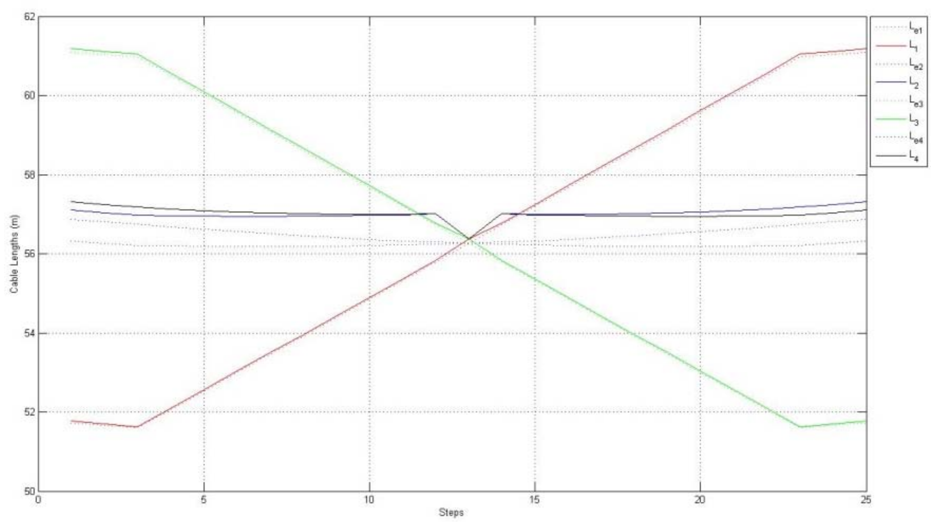


Figure 12: Straight-line cable lengths vs. steps

Similar to the snapshot example, the cable length differences between the cable sag and straight-line models are calculated, followed by cable length error computatio. This is shown in Figure 13 and 14. As observed from the graphs, the difference in cable lengths obtained from the straight-line model and cable sag model ranges from 0-800 mm and the relative error ranges from 0-1.4%. These values further indicate that, although cable sag contributes to erroneous cable length computation, the error is low enough for purposes where high accuracy is not a prime requirement.

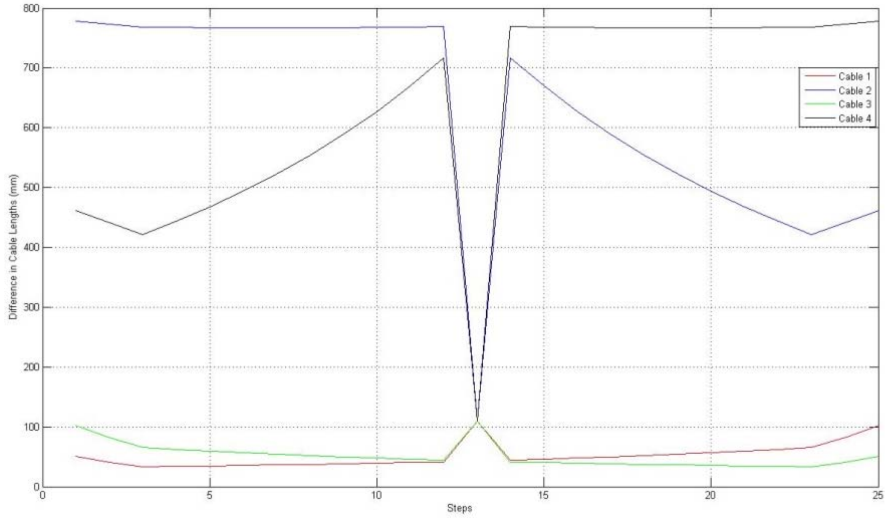


Figure 13: Difference in cable lengths vs. steps

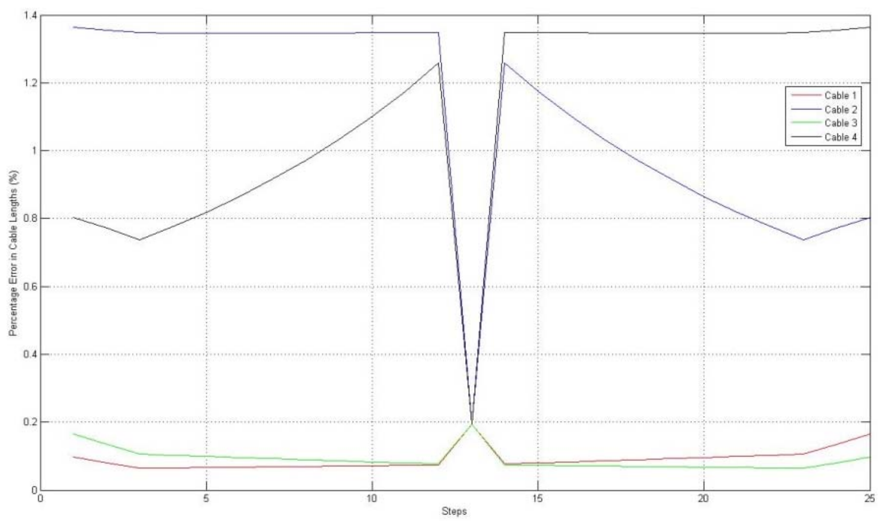


Figure 14: Percentage error in cable lengths vs. steps

The cable tensions were calculated for all the steps in the trajectory by both methods. This was followed by finding the difference between the summation of cable tensions obtained from linear programming (LP) and pseudoinverse (PI) methods $\sum T_{LPi} - \sum T_{PIi}$. The results are presented in Figures 15 and 16.

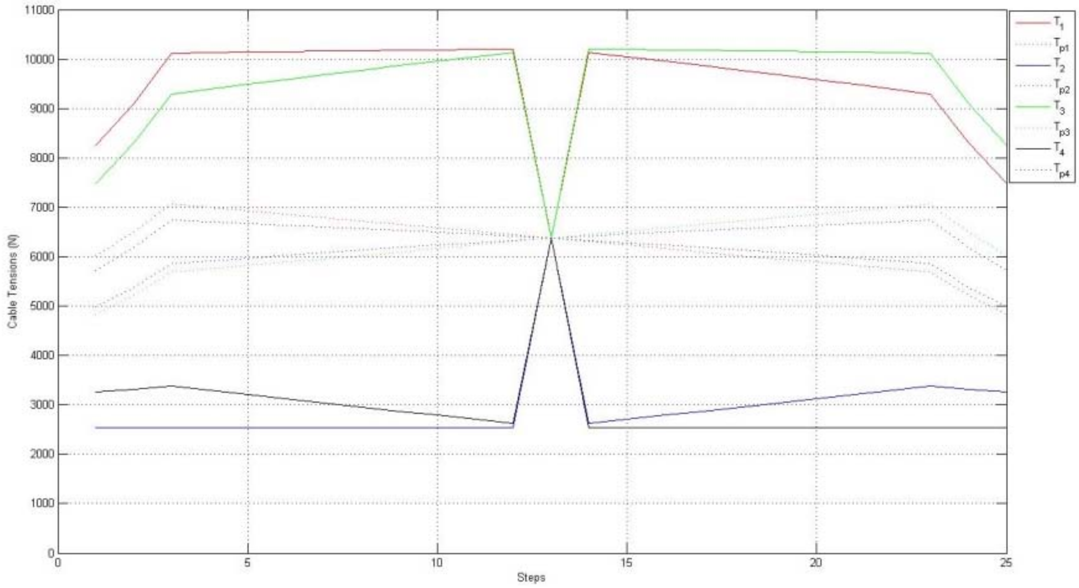


Figure 15: LP and PI Cable tensions vs. steps

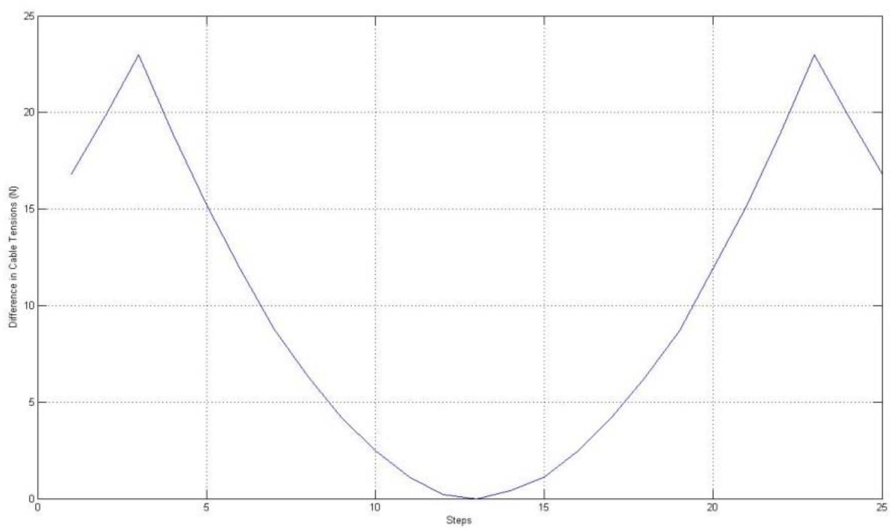


Figure 16: Difference in cable tensions between LP and PI vs. steps

From Figures 9, 15, and 16, a straightforward observation is that the two methods (LP and PI) give different solutions for cable tensions except when the cable lengths are equal. Except for this case, the linear programming method gives a solution such that the overall cable tensions are less, when compared to the corresponding pseudoinverse solution.

Another major advantage of using linear programming is that we can restrict the solution space by using the bounds (*Tmin* and *Tmax*). For example, in this simulation *Tmin* was set to be equal to the weight of end-effector, which can be increased if the cable tensions are found to be insufficient to keep it taut and decreased if feasible. A similar argument can be made for *Tmax*. In this simulation, *Tmax* was set to be $+\infty$ to get an idea of the maximum tension that a particular configuration reaches.

The pseudoinverse method on the other hand does not give this flexibility. But a major merit of the pseudoinverse approach is that it has a closed-form analytical solution, unlike the iterative linear programming method.

There are a few issues associated with the use of the LP method that require attention. The LP approach at times gives an abrupt increase or decrease in the tension solutions, thus not resulting in smooth curves for trajectories (see Figure 15). Another issue is that the LP solution at times tends to give a solution that is the lower bounds or upper bounds (T_{min} or T_{max}) for one of the cables. Regardless, a valid solution can be obtained by this method and research is being done in this field to get smoother results with less iterations. Borgstrom et al. [15] show that linear programming can be suitably modified and, with the assistance of suitable control systems, make it more efficient and computationally less expensive. Considering all of these factors, use of linear programming for cable tension calculation is advisable. A summary of this discussion is provided in the form of a comparison chart in Table 5.

Table 5: Comparison between linear programming and pseudoinverse methods

Linear Programming (LP)	**Moore Penrose Pseudoinverse (PI)**
Minimize the sum of the cable tensions; Min $(T_1 + T_2 + T_3 + T_4)$	Minimizes the second norm of the cable tensions; Min ($\sqrt{T_1^2 + T_2^2 + T_3^2 + T_4^2}$)
Can be applied for other objective functions.	Only one objective function possible
Iterative method	Closed form analytical solution possible
The overall cable tensions are relatively small	Cable tensions at the least can be equal to the LP solution
More flexible method	Less flexible method
Multiple solutions possible	Single solution results
MATLAB command – **linprog( )**	MATLAB command – **pinv( )**

c) *Variation of Parameters*

Effects of Cable Parameters and End-Effector Mass

The input parameters of the cable are diameter (geometric property) and density (material property). For a nominal position $\{0 \quad 0 \quad 0\}^T$ and an arbitrary position $\{8 \quad -5 \quad 2\}^T$, these parameters were varied independently and the results are graphically presented in Figures 17 and 18; all results compare the straight-line to the sag cable models.

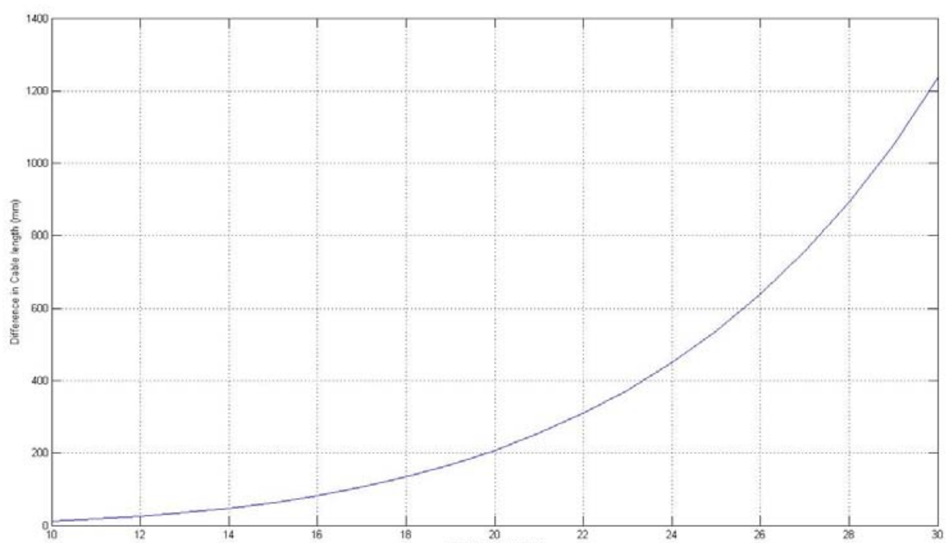


Figure 17: Difference in cable length vs. cable diameter for nominal position

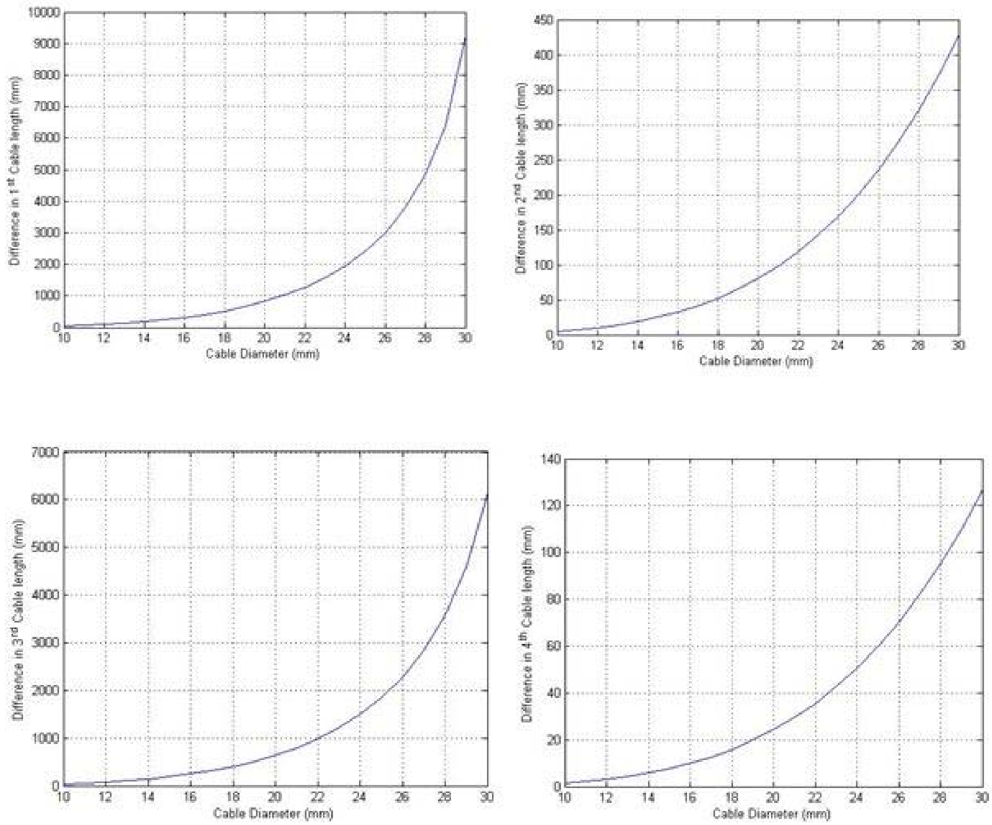


Figure 18: Difference in cable length vs. cable diameter for arbitrary position

From the effects of cable sag, it is evident that if the cable weight increases, then cable sag increases, which in turn increases the error or cable length difference between the cable sag and straight-line models. Increasing cable diameter and / or cable material density increases cable weight. Based on the nature of the catenary equations, we expect a nonlinear increase in the difference in cable lengths when cable diameter and density is increased, as verified by the simulations of Figures 17 and 18. The trends for increasing cable density are very similar to increasing cable diameter and hence are not shown [16].

Another important parameter is the end-effector mass. This is of special importance since it may vary during the operation of a cable-suspended robot. The variation of difference in cable length between the cable sag and straight-line models with an increase in end-effector mass is shown in Figures 19 and 20.

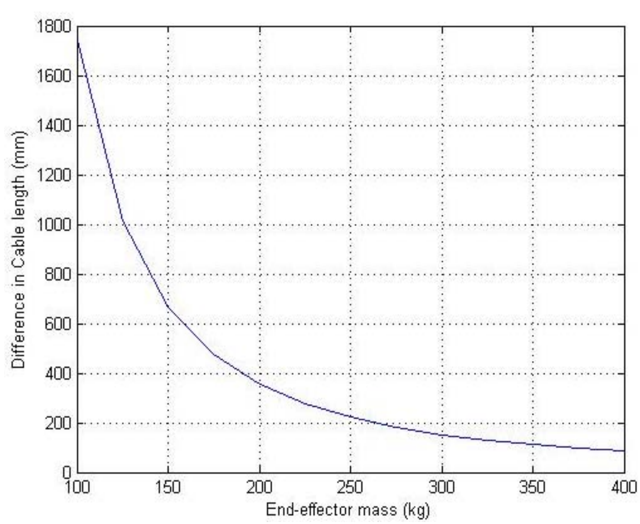


Figure 19: Difference in cable length vs. end-effector mass for nominal position

For this case there is an inverse relationship, i.e. the cable lengths differences decrease as the end-effector mass increases. This makes sense since, for a given cable size, larger end-effector mass will dominate more and more relative to the cable mass, meaning the straight-line model becomes more and more accurate.

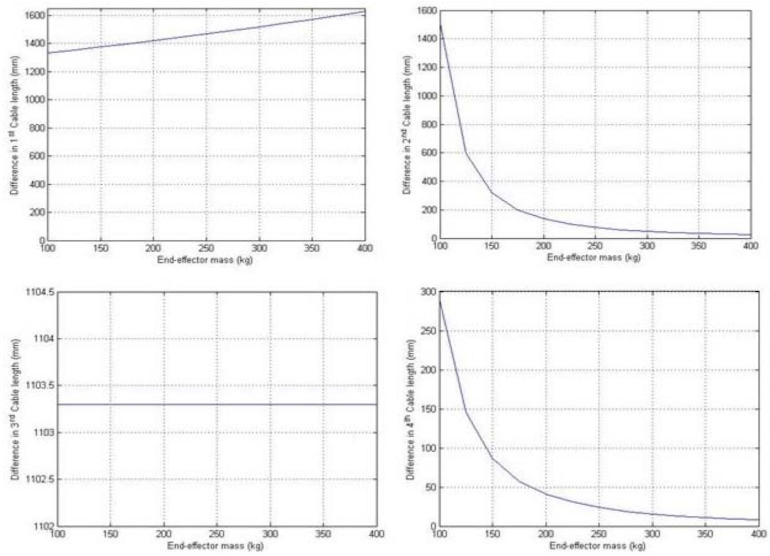


Figure 20: Difference in cable length vs. end-effector mass for arbitrary position

An increase in end-effector mass has different effects on different cables for the arbitrary position. The reason for this is one of the limitations of the LP method: solutions tend to fall on the tension bounds. In case of the arbitrary position (Figure 20), the third cable solution falls on the lower bound, hence the variation in cable length 3 is constant. Cables 2 and 4 follow the same inverse trend of Figure 19, and the cable 1 length difference actually increases with increasing end-effector mass.

d) Effects of Footprint Dimensions

As the size of the robot footprint increases, the cable length and its overall weight increases, thus increasing the cable sag and increasing the difference in cable length. Keeping the ratio of footprint length to width constant (L/W = constant), the area was increased in steps from 1 to 6 acres and the difference in cable lengths was computed. As expected, the cable length difference increases with an increase in area as shown in Figure 21.

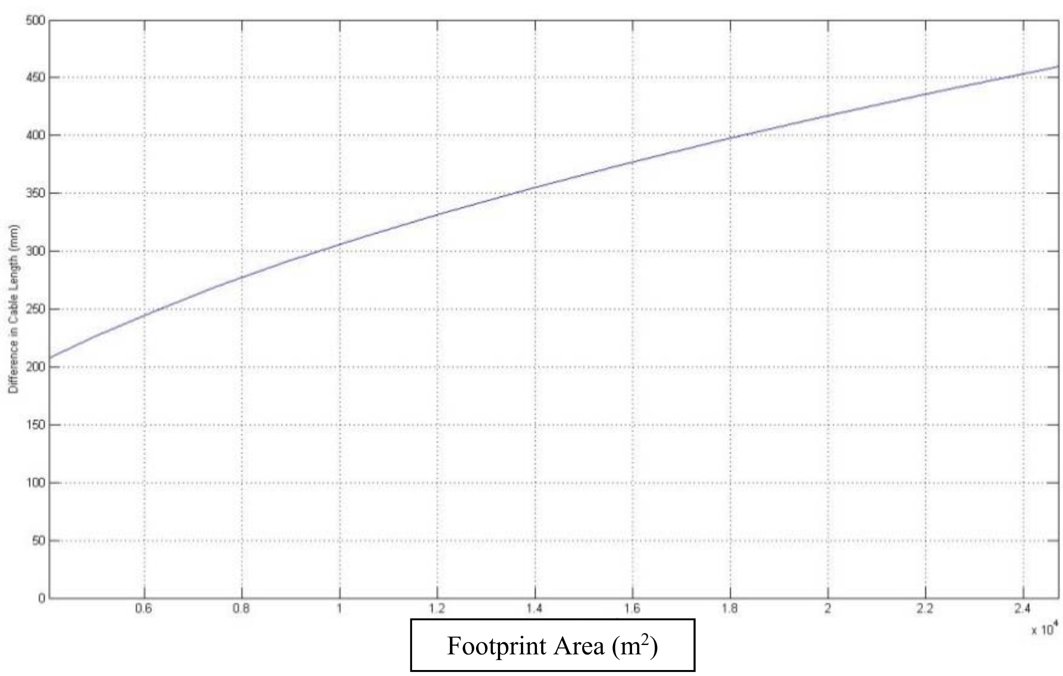


Figure 21: Difference in cable length vs. footprint area

Complimentary to the previous case, we next study the effects of variation of length to width (L/W) ratio, keeping the area constant. For the nominal position, at a constant tower height, the variation of the Euclidean norm length depends on the footprint length L and width W. By the Pythagorean Theorem, this is dependent on the term $\sqrt{L^2+W^2}$. Also, the point where the length and width interchange their values, we expect the difference in cable lengths to remain the same. All these facts are verified by simulation results as shown in Figure 22.

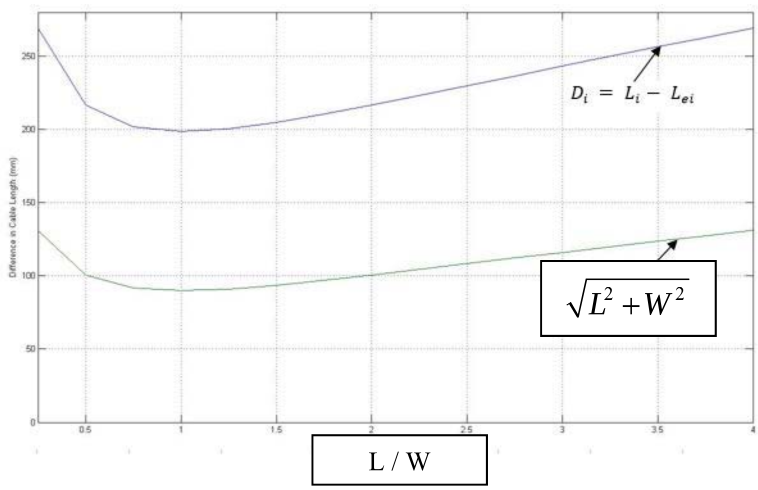


Figure 22: Difference in length (mm) vs. L/W (unitless)

e) Computational Considerations

The straight-line model has been used in most cable-suspended robot systems when compared to the cable sag model. One of the main reasons for this is its simplicity and an analytical model which is easy to use, manipulate, and implement in control systems.

The cable sag model which uses the catenary equations describes the profile of the cable more accurately when compared to the straight-line model. However, the methods required to handle this are highly complicated. Ultimately, any model has to be implemented in a real-time control system to manipulate the cable-suspended robot system. Hence, understanding the computational complexities involved is important.

The catenary equations by themselves are highly nonlinear and are implicit. These equations have to be solved simultaneously with other equations by numerical methods iteratively, which is not only time consuming, but may also involve iteration errors. This is a major drawback to the cable sag model.

Another major impediment in using iterative methods is the truncation errors involved. These are especially dominant when exponential and hyperbolic terms are approximated using truncated infinite series, thus reducing the accuracy of the solution. To improve the accuracy of the solution, such approximations have to be made with more terms in a series expansion, hence requiring more data storage and ultimately increasing the computational cost.

To investigate this issue, during the computation of cable lengths the number of iterations for both snapshot points and trajectory was recorded for the cable sag model. This information is presented in Figures 23 and 24. For comparison, the straight-line model requires no iteration, so the number of iterations for that case is always 1.

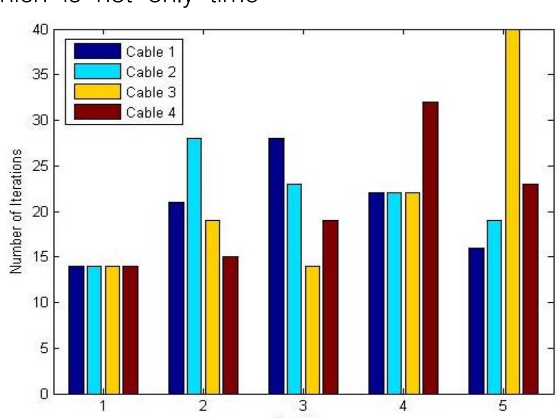


Figure 23: Number of iterations vs. position, snapshots

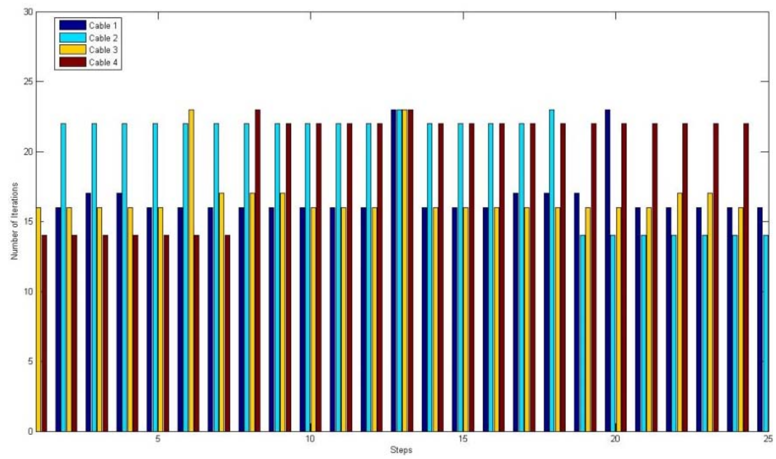


Figure 24: Number of iterations vs. steps, trajectory

There is no definitive prediction that can be made on the number of iterations for a different trajectory or snapshot example, but the examples shown above are representative. They show that even for the simplest trajectories or snapshot points, each cable length computation requires a considerable number of iterations, ranging from 10- 40. Thus, the cable sag model, despite being an accurate model, suffers from increased computational requirement. A relative comparison between the straight-line model and cable sag model is shown in Table 6.

Table 6: Comparison between straight-line and cable sag model.

Criteria	**Straight-line model**	**Cable sag model**
Governing equations	Euclidean norm between two points	Catenary equations
Type of model	Approximate model	Accurate model
Kinematics and Statics	Analytical solution for both; problems solved independently.	Both problems are coupled and there is no analytical solution.
Nature of solutions	Analytical	Numerical
Mass of the cable	Neglected	Included
Areas of application	Small scale robots and where accuracy is not a prime concern.	Any cable-suspended robot system, especially large outdoor systems.
Errors involved	Cable length computation errors	Iterative errors, truncation errors
Control system application	Straight-forward	Difficult

Solving the cable tension and length problems independently in separate steps (i.e. using the straight-line model) offers significant practical benefits. Firstly, it offers easy control system implementation, since ensuring positive cable tension is a necessary condition and cable sag computation can be circumvented if the corresponding error is within limits. Secondly, solving the steps separately greatly reduces the computational time. Additionally, if the steps are combined (i.e. using the cable- sag model) the problem becomes a constrained non-linear optimization problem (instead of a robust linear programming problem) which needs more sophisticated optimization routines and is not practical to implement in simple, cost-effective, real-time control system architectures.

IV. Conclusion and Recommendations

The current research was conducted primarily with an intention of studying and understanding the qualitative and quantitative effects of cable sag on the calculation of cable lengths in cable-suspended robots. The research also involved studying the effects of cable density, cable diameter, robot footprint size, and computational requirements.

Based on the results of the snapshot and trajectory examples (for a 1-acre footprint robot), the relative error in cable lengths does not exceed 3%. The cable sag model suffers from computational complexities. On the other hand, the straight-line model is simple to manipulate, control, and implement practically. Considering all these factors and quantitative comparison results presented earlier, the straight-line model is preferred over the cable sag model at this particular scale (1-acre footprint, 4047 m2). In cases where the cable sag and errors are greater, the use of a Cartesian servo controller based on GPS sensing of the end-effector location is recommended.

Cable tension distribution is an important aspect of cable-suspended robots and, based on the results of this research, linear programming serves as an efficient tool for computing and ensuring appropriate cable tensions in cables (the pseudoinverse-based method is much more common). An additional benefit of the LP method is to help in finding if a given cable tension range is acceptable for motion control of a cable-suspended robot system and is within the torque limitations of a winch / motor. Conversely, the simulation results could be used for appropriate choices in winch / motor design.

References Références Referencias

1. Nan, R., Li, D., Jin, C., Wang, Q., Zhu, L., Zhu, W., Zhang, H., Yue, Y., and Qian, L., 2011, "The five-hundred-meter aperture spherical radio telescope (FAST) project," Int. J. Mod. Phys. D, 20(06), pp. 989–1024.
2. L.L. Cone, 1985, "Skycam: An aerial robotic system", BYTE, October.
3. Michelin, M., Baradat, C., Nguyen, D. Q., and Gouttefarde, M., 2015, "Simulation and Control with XDE and Matlab/Simulink of a Cable-Driven Parallel Robot (CoGiRo)," Cable-Driven Parallel Robots, A. Pott, and T. Bruckmann, eds., Springer International Publishing, Cham, pp. 71–83.
4. Meunier, G., Boulet, B., and Nahon, M., 2009, "Control of an Over actuated Cable- Driven Parallel Mechanism for a Radio Telescope Application," IEEE Trans. Control Syst. Technol., 17(5), pp. 1043–1054.
5. Kozak, K., Qian, Z., and Jinsong, W., 2006, "Static analysis of cable-driven manipulators with non-negligible cable mass," IEEE Trans. Robot., 22(3), pp. 425–433.
6. Irvine, H. M., 1981, Cable structures, MIT Press, Cambridge, Mass.
7. Russell, J. C., and Lardner, T. J., 1997, "Statics experiments on an elastic catenary," J. Eng. Mech., 123(12), pp. 1322–1324.
8. Yao, R., Li, H., and Zhang, X., 2013, "A Modeling Method of the Cable Driven Parallel Manipulator for FAST," Cable-Driven Parallel Robots, T. Bruckmann, and A Pott, eds., Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 423–436.
9. Li, H., Zhang, X., Yao, R., Sun, J., Pan, G., and Zhu, W., 2013, "Optimal Force Distribution Based on Slack Rope Model in the Incompletely Constrained Cable- Driven Parallel Mechanism of FAST Telescope," Cable-Driven Parallel Robots, T. Bruckmann, and A. Pott, eds., Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 87–102.
10. Riehl, N., Gouttefarde, M., Krut, S., Baradat, C., and Pierrot, F., 2009, "Effects of non-negligible cable mass on the static behavior of large workspace cable-driven parallel mechanisms," Robotics and Automation, 2009. ICRA'09. IEEE International Conference on, IEEE, pp. 2193–2198.
11. Gouttefarde, M., Collard, J.-F., Riehl, N., and Baradat, C., 2012, "Simplified static analysis of large-dimension parallel cable-driven robots," Robotics and Automation (ICRA), 2012 IEEE International Conference on, IEEE, pp. 2299–2305.
12. Nguyen, D. Q., Gouttefarde, M., Company, O., and Pierrot, F., 2013, "On the simplifications of cable model in static analysis of large-dimension cable-driven parallel robots," Intelligent Robots and Systems (IROS), 2013 IEEE/RSJ International Conference on, IEEE, pp. 928–934.
13. Dallej, T., Gouttefarde, M., Andreff, N., Dahmouche, R., and Martinet, P., 2012, "Vision-based modeling and control of large-dimension cable-driven parallel robots," 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 1581 1586.
14. dit Sandretto, J.A., Trombettoni, G. and Daney, D., "Confirmation of hypothesis on cable properties for cable-driven robots", In Mechanisms and Machine Science, Vol. 7, pp. 85{93, Kluwer Academic Publishers, Santander, Spain, ISSN 22110984, 2013.
15. Yuan, H., Courteille, E., and Deblaise, D., 2015, "Static and dynamic stiffness analyses of cable-driven parallel robots with non-negligible cable mass and elasticity", Mechanism and Machine Theory, 85: 64–81.
16. Williams II, R. L., Albus, J. S., and Bostelman, R. V., 2004, "3D Cable-Based Cartesian Metrology System," J. Robot. Syst., 21(5), pp. 237–257.
17. Borgstrom, P. H., Jordan, B. L., Sukhatme, G. S., Batalin, M. A., and Kaiser, W. J., 2009, "Rapid Computation of Optimally Safe Tension Distributions for Parallel Cable-Driven Robots," IEEE Trans. Robot., 25(6), pp. 1271–1281.
18. D. Sridhar, 2015, "Mathematical Modeling of Cable Sag, Kinematics, Statics, and Optimization of a Cable Robot", April 29, advisor R.L. Williams II.

Global Journal of Researches in Engineering: H
Robotics & Nano-Tech
Volume 17 Issue 1 Version 1.0 Year 2017
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN:2249-4596 Print ISSN:0975-5861

Obstacle Avoiding Robot

By Faiza Tabassum, Susmita Lopa, Muhammad Masud Tarek & Dr. Bilkis Jamal Ferdosi
East West University

Abstract- Obstacle detection and avoidance can be considered as the central issue in designing mobile robots. This technology provides the robots with senses which it can use to traverse in unfamiliar environments without damaging itself. In this paper an Obstacle Avoiding Robot is designed which can detect obstacles in its path and maneuver around them without making any collision. It is a robot vehicle that works on Arduino Microcontroller and employs three ultrasonic distance sensors to detect obstacles. The Arduino board was selected as the microcontroller platform and its software counterpart, Arduino Software, was used to carry out the programming. The integration of three ultrasonic distance sensors provides higher accuracy in detecting surrounding obstacles. Being a fully autonomous robot, it successfully maneuvered in unknown environments without any collision. The hardware used in this project is widely available and inexpensive which makes the robot easily replicable.

Keywords: obstacle avoidance, ultrasonic sensor, arduino microcontroller, autonomous robot, arduino software.

GJRE-H Classification: FOR Code: 090602

OBSTACLEAVOIDINGROBOT

Strictly as per the compliance and regulations of:

Obstacle Avoiding Robot

Faiza Tabassum[α], Susmita Lopa[σ], Muhammad Masud Tarek[ρ] & Dr. Bilkis Jamal Ferdosi[Ѡ]

Abstract- Obstacle detection and avoidance can be considered as the central issue in designing mobile robots. This technology provides the robots with senses which it can use to traverse in unfamiliar environments without damaging itself. In this paper an Obstacle Avoiding Robot is designed which can detect obstacles in its path and maneuver around them without making any collision. It is a robot vehicle that works on Arduino Microcontroller and employs three ultrasonic distance sensors to detect obstacles. The Arduino board was selected as the microcontroller platform and its software counterpart, Arduino Software, was used to carry out the programming. The integration of three ultrasonic distance sensors provides higher accuracy in detecting surrounding obstacles. Being a fully autonomous robot, it successfully maneuvered in unknown environments without any collision. The hardware used in this project is widely available and inexpensive which makes the robot easily replicable.

Keywords: obstacle avoidance, ultrasonic sensor, arduino microcontroller, autonomous robot, arduino software.

I. Introduction

From its initiation in the 1950s, modern robots have come a long way and rooted itself as an immutable aid in the advancement of humankind. In the course of time, robots took many forms, based on its application, and its size varied from a giant 51 feet to microscopic level. In the course of technological developments of robots, one aspect remained instrumental to their function, and that is mobility. The term "obstacle avoidance" is now used in modern robotics to denote the capability of robot to navigate over an unknown environment without having any collision with surrounding objects (Duino-Robotics, 2013). Obstacle avoidance in robots can bring more flexibility in maneuvering in varying environments and would be much more efficient as continuous human monitoring is not required.

Author α: MS Student in Telecommunications Engineering Program, East West University, Dhaka, Bangladesh.
e-mail: mfaiza22214@gmail.com
Author σ: MS Student in Computer Science and Engineering Program, Jahangir Nagar University, Dhaka, Bangladesh.
e-mail: susmita.lopa006@gmail.com
Author ρ: Assistant Professor, Department of Computer Science and Engineering, State University of Bangladesh, Dhaka, Bangladesh.
e-mail: tarek@sub.edu.bd
Author Ѡ: Associate Professor, Department of Computer Science and Engineering, University of Asia Pacific, Dhaka, Bangladesh.
e-mail: bilkisjamal@gmail.com

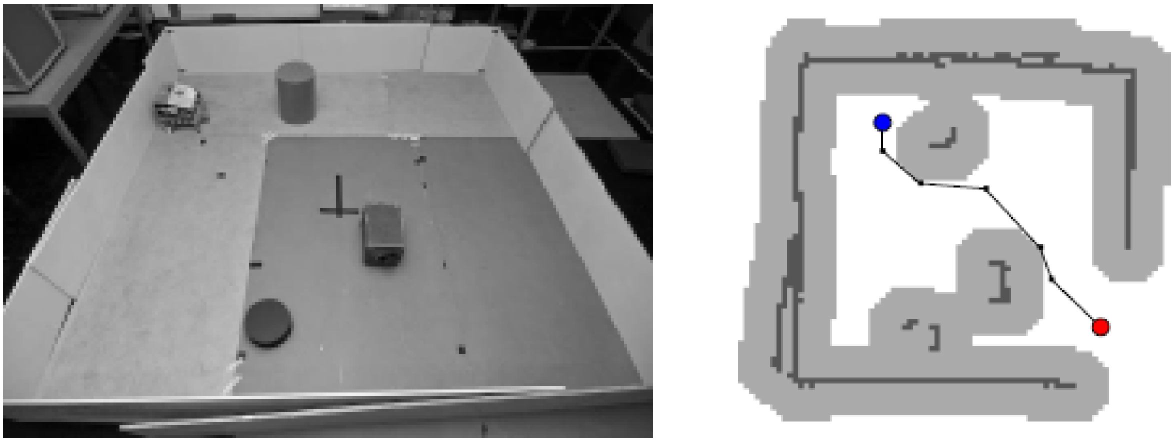
This project developed an obstacle avoiding robot which can move without any collision by sensing obstacles on its course with the help of three ultrasonic distance sensors. Robots guided with this technology can be put into diversified uses, e.g., surveying landscapes, driverless vehicles, autonomous cleaning, automated lawn mower and supervising robot in industries. The robot developed in this project is expected to fulfill the following objectives:

- The robot would have the capacity to detect obstacles in its path based on a predetermined threshold distance.
- After obstacle detection, the robot would change its course to a relatively open path by making autonomous decision.
- It would require no external control during its operation.
- It can measure the distance between itself and the surrounding objects in real-time.
- It would be able to operate effectively in unknown environment.

II. Relevant Works in Obstacle Detection and Avoidance

To date, there have been a number of successful attempts in designing obstacle avoiding robots. These works differ by selection of sensors, path mapping process and the algorithms applied to set the operational parameters. There have been numerous projects in this arena using laser scanner, infrared sensor, GPS and multiple sensors to accomplish obstacle detection and avoidance (Ryther & Madsen, 2009; Ahasan, Hossain, Siddiquee, & Rahman, 2012; Shahdib, Ullah, Hasan, & Mahmud, 2013; Gray, 2000)

Researchers are persistently trying to find more precise ways to develop autonomous robot or vehicle movement technology. In obstacle detection, the selection of sensor is vital for the required application of the robot, otherwise it might fail to operate even though all hardware and software are working properly. For example, a robot with optical sensors in a room with glass walls might create more collisions than avoidance. Hence sensors should be selected in accordance with the characteristics of the obstacles. Ryther and Madsen (2009) used 240° laser scanner as a sensor to build a robot based on Small Mobile Robot (SMR) platform. The robot generates a collision free path from a grid map using wavefront algorithm (*Fig.*1).



Source: Ryther & Madsen (2009)

Fig.1: Obstacle Avoidance Setup and the Resultant Grid Map with the Collision Free Path

The robot developed in this project uses ultrasonic sensors to detect obstacles in real time and requires no path planning. Its processing unit is based on the Arduino platform.

The Autonomous Surface Vehicle (ASV) developed by Heidarsson and Sukhatme (2011) employed a single-beam mechanically-scanning profiling sonar to detect obstacles under water. The profiling sonar has the ability to produce cone-shaped beam which is ideal for detecting near surface obstacles. One of the objectives of their work was to investigate the suitability of using sonar near the water-air boundary for which the study found promising results. Although similar detection technology is used, our robot is designed to work on the ground and detect obstacles above the surface. It is uses the Arduino software which enables to upload a code written in C programming language.

There were other works using multiple sensors to make the robot more accustomed to its surroundings by employing both range and appearance based obstacle detection (Shahdib, Ullah, Hasan, & Mahmud, 2013; Gray, 2000). Their obstacle detection also includes a combination of global and local avoidance. In one of these projects, Shahdib, Ullah, Hasan and Mahmud (2013) fused the strengths of an image and an ultrasonic sensor to detect objects and measure its size. Detection of object was carried out by the ultrasonic sensor and its measurement required the help of a camera. The code was designed to receive the distance to object, its height and width.

Our project employs multiple sensors, but unlike the last example, we used the same sensors for enhancing the horizontal range of searching obstacles. These ultrasonic distance sensors work in combination to measure distance to the surrounding objects and detect the presence of obstacles if they are within the threshold distance. The inclusion of three sensors of the same kind provides more accuracy in obstacle detection as it widens the field of searching.

III. Working Principle

The robot in this project detects obstacles with the help of three ultrasonic distance sensors to measures the distance to surrounding objects. Although the project is started with a single ultrasonic sensor, two more sensors is added since the robot had blind spots in its right and left direction for which it was having collision while maneuvering. Unlike the projects discussed above, our project concentrates on coordinating multiple ultrasonic sensors for maneuvering without collision and also maintaining a minimum travel distance. *Fig.*2 describes this algorithm in a flow chart.

The robot was designed to detect the presence of any object within the specified threshold distance. If any object is found within this distance, it is designated as an obstacle and the robot will turn away from it. The three ultrasonic sensors are placed in the frontal section of the robot at the right, middle and left position. The three sensors emit an ultrasonic pulse every 300 ms which echoes from the neighboring objects. Using time difference between the input and echo, the Arduino calculates the distance to the obstacle from which the echo is coming by using the constant speed of sound 340 m/s. When one of the sensors detects obstacle within the threshold distance, the robot changes its direction. Along with these basic movements, the robot is designed to handle a more complex situation when all three sensors have obstacles within the specified range. In this case, the robot will move backward for 10 ms and again check the distance to objects with the help of right and left sensors. The robot will then compare the two distances and move in the direction where the distance is larger.

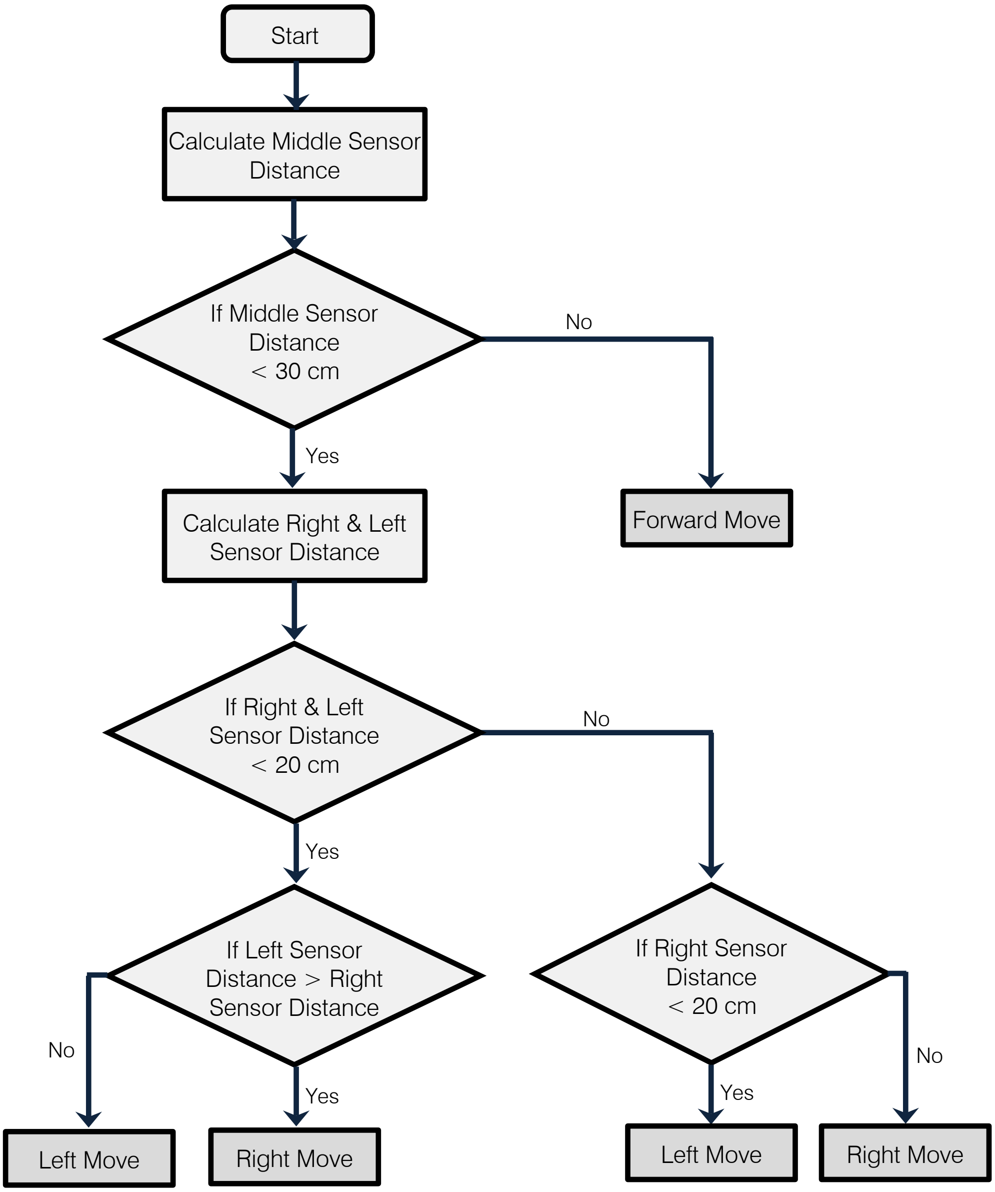


Fig. 2: Algorithm for Obstacle Avoiding Robot

IV. Robot Architecture and Programming

a) *The Arduino Platform*

There are numerous hardware platforms in use based on which obstacle avoiding robots or in general mobile robots are built. We have selected the Arduino board as the microcontroller platform and its software counterpart to carry out the programming. Arduino is an open-source platform which is an integration of hardware (microcontroller) and software components. The microcontroller can read input in the form of light or sound through a sensor and convert it into an output (e.g., driving a motor) according to the instruction given by the Arduino programming (Arduino, 2015).

The Arduino microcontroller can only be functional with the help of a code. To write this code, Arduino Integrated Development Environment or Arduino Software (IDE) is used which is also open-source like the Arduino Uno board (Arduino, 2015). It is much popular software used by many for its simplicity and the ability to communicate with all Arduino boards. Arduino Software version 1.6.5 is used to write the code in C programming language which is then uploaded to the Arduino microcontroller through an USB cable. The software saves the code in a file with .ino extension. While there are many other microcontroller platforms available, Arduino gained much popularity which attributed to its distinctive features such as:

- Economical
- It can run in various platforms like Windows, Linux and Macintosh
- Programming environment is easy to comprehend
- Both software and hardware are open source and can be customized to meet specific needs.

Global Journal of Researches in Engineering (H) Volume XVII Issue I Version I Year 2017

In this project, the Arduino board will take input from ultrasonic sensor, calculate the distance to the obstacle and control rotation of the servo motor as an output response.

b) Hardware Components and Assembly

The following flowchart in *Fig.*3 shows the hardware used to build the robot and explains relationship (input and output) among them.

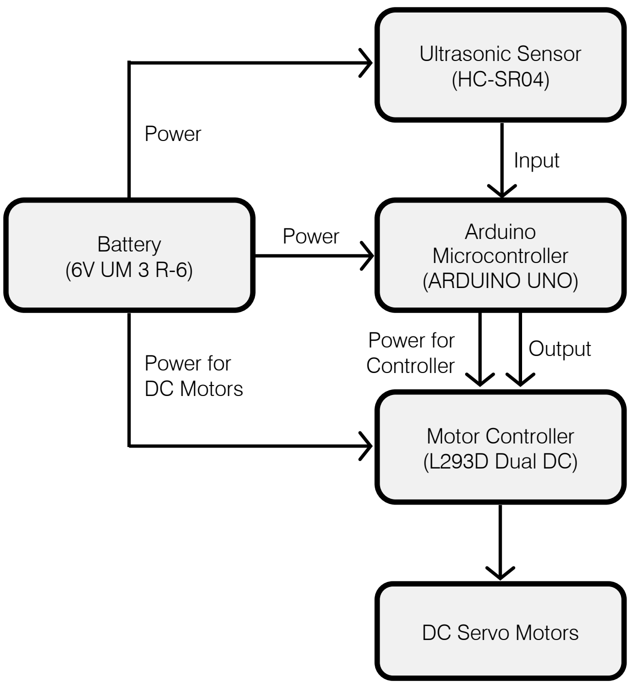


Fig.3: Algorithm for Obstacle Avoiding Robot

The hardware were assembled to form the obstacle avoiding robot in *Fig.*4 with the help of a chassis, wheels and connecting cables.

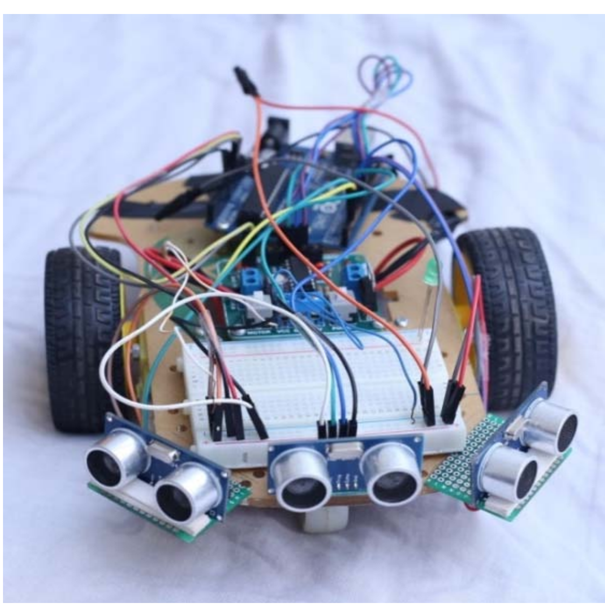


Fig. 4: Front View of the Robot

V. Conclusion

This project developed an obstacle avoiding robot to detect and avoid obstacles in its path. The robot is built on the Arduino platform for data processing and its software counterpart helped to communicate with the robot to send parameters for guiding movement. For obstacle detection, three ultrasonic distance sensors were used that provided a wider field of detection. The robot is fully autonomous and after the initial loading of the code, it requires no user intervention during its operation. When placed in unknown environment with obstacles, it moved while avoiding all obstacles with considerable accuracy.

The work done in this project can act as a base for further improvements to increase accuracy and adaptability of obstacle detection in diverse environments. In future, the authors of this project intend to test the feasibility of integrating different types of sensors to complement each other's disadvantages. For instance, imaging sensor can be beneficial when ultrasonic sensor may not correctly identify obstacles in environment subjected to ambient noise and varying temperature or air pressure. The accuracy of determining the distance to the obstacles can be increased by the inclusion of an electronic barometer for automatic adjustment of the speed of sound in air. Also the addition of a Bluetooth device can offer the flexibility of remotely changing control parameters in the code.

References Références Referencias

1. Ahasan, M. A., Hossain, S. A., Siddiquee, A. U., & Rahman, M. M. (2012). *Obstacles Invariant Navigation of An Autonomous Robot based on GPS.* Khulna University.
2. Arduino. (2015). *Arduino Software (IDE)*. (Arduino) Retrieved December 27, 2015, from https://www.arduino.cc/en/Guide/Environment
3. Arduino. (2015). *Introduction*. (Arduino) Retrieved December 12, 2015, from https://www.arduino.cc/en/Guide/Introduction
4. Duino-Robotics. (2013). *Obstacle Avoidance Tutorial*. (Duino-Robotics) Retrieved November 23, 2015, from http://www.duino-robotics.com/obstacle-avoidance.html
5. Gray, K. W. (2000). *Obstacle Detection and Avoidance for an Autonomous Farm Tractor.* Utah State University.
6. Heidarsson, H. K., & Sukhatme, G. S. (2011). Obstacle Detection and Avoidance for an Autonomous Surface Vehicle using a Profiling Sonar. *2011 IEEE International Conference on Robotics and Automation.* Shanghai.
7. Ryther, C. A., & Madsen, O. B. (2009). *Obstacle Detection and Avoidance for Mobile Robots.* Technical University of Denmark.
8. Shahdib, F., Ullah, M. W., Hasan, M. K., & Mahmud, H. (2013). Obstacle Detection and Object Size

Measurement for Autonomous Mobile Robot using Sensor. *International Journal of Computer Applications, 66*(9), 28-33.

This page is intentionally left blank

Global Journal of Researches in Engineering: H
Robotics & Nano-Tech
Volume 17 Issue 1 Version 1.0 Year 2017
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN:2249-4596 Print ISSN:0975-5861

PLC based Robot Manipulator Control using Position based and Image based Algorithm

By Harshavardhan Reddy Kunchala & Jack Toporovsky
University of Bridgeport

Abstract- Programmable Logic Controller (PLC) is making big role in the field of automation and robotics. This paper described the design and implementation of Programmable Logic Controller (PLC) based robot manipulator control using two different artificial intelligence algorithms - Position Based and Imaged Based algorithm. The controlled robot is 5 degrees of freedom (DOF) manipulator with a closed kinematic chain, designed for high-performance pick and place applications. The control software is fully developed on a commercial PLC system, using its standard programming tools and the multi-tasking features of its operating system.

Keywords: artificial intelligence, vision system, programmable logic controller, robot manipulator, industrial automation, design, hardware.

GJRE-H Classification: FOR Code: 090602

PLCBASEDROBOTMANIPULATORCONTROLUSINGPOSITIONBASEDANDIMAGEBASEDALGORITHM

Strictly as per the compliance and regulations of:

PLC based Robot Manipulator Control using Position based and Image based Algorithm

Harshavardhan Reddy Kunchala[α] & Jack Toporovsky[σ]

Abstract- Programmable Logic Controller (PLC) is making big role in the field of automation and robotics. This paper described the design and implementation of Programmable Logic Controller (PLC) based robot manipulator control using two different artificial intelligence algorithms - Position Based and Imaged Based algorithm. The controlled robot is 5 degrees of freedom (DOF) manipulator with a closed kinematic chain, designed for high-performance pick and place applications. The control software is fully developed on a commercial PLC system, using its standard programming tools and the multi-tasking features of its operating system. In particular, this paper analyze in detail the drawbacks and the advantages related to the choice of standard PLCs in this kind of applications, compared to the much common choice of specialized hardware or industrial personal computers, with particular emphasis on the computational performances obtained with the proposed control architecture.

Keywords: artificial intelligence, vision system, programmable logic controller, robot manipulator, industrial automation, design, hardware.

I. Introduction

Robot manipulators are largely used in packaging industry, especially for pick and place operations and box filling. In particular, packaging of small food products, like cookies or candies, requires high performance robots with short cycle times and precise motion control, even if their workspace is relatively small [1]. Such performances can be obtained by means of lightweight parallel-driven or delta-like kinematics, whose advantages in terms of reduced moving masses and inertias are well-known. These robots include a vision system to identify and localize large and unordered products on the conveyors. Typically robot controller is proprietary and limits its access for customers to extend its usage without support from the manufacturer. Since the integration of a robotic system with additional application-specific tools and features often requires the development of software or hardware that closely matches with the basic robot motion control system. In general, customers search for openness of robot controllers for addition or modification of its functionalities. In literature, several open architectures for robot controls has been developed by academic research that limits its application to a smaller scale [2], [3], [4]. In most cases, these architectures take advantage of hardware platforms based on Personal Computers (PC). On one hand, the use of PCs for robot control reduces software development costs that use high level languages and well-designed Integrated Development Environments (IDE). On the other hand, standard PCs doesn't meet the reliability required by complex industrial environments. In summary, the use of more protective enclosures and usage of robust electronic components increase the cost of PC based robot controllers.

Programmable Logic Controllers (PLCs) is a typically a control device playing a dominant role in industrial automation. PLCs provides higher degree of robustness, cheaper than alternative options and ease of use[1]. Electronic components in PLCs are benchmarked for their reliability and robustness ultimately guaranteeing high performance. For this reasons, PLCs are commonly considered as low-level systems, whose main purpose is to control using simple Boolean signals (i.e. discrete control and sequencing) and to supervise the safety and integrity of plants and operators. However, modern PLCs have sufficient computational power to perform complex mathematical calculations using various programming languages (i.e. IEC 61131-3 [5]). This allows developers to implement various algorithms for robot control on PLCs.

Typically, most PLCs support only their proprietary IDE. The respective IDE provides an option for users to custom build/modify their applications which is a limiting factor in PC-based approaches [3]. Therefore, PLC programs can be updated and extended by end-users even without the original source code, which makes PLCs as "open" systems. Despite of these features, PLC-based control systems for robot manipulators are quite rare and, in general, limited to simple Cartesian or gantry-like structures[7].

A robot arm is the combination of links and joints in the form of a chain with one end isfixed while the other end can be moved with certain degree of freedom in native axis of the arm and is termed as end effector. The joints are either prismatic or revolute, driven by actuators. In order to move the end effector along a certain path, the respective joints should be moved appropriately [8]. In this process, it is necessary to perform inverse kinematics equation. In case of redundant manipulator, inverse kinematics is more challenging when compared to a non-redundant manipulator whose kinematics is not so complicated[7].

Author α σ: Department of Electrical and Computer Engineering University of Bridgeport, Bridgeport, CT, 06604.
e-mails: hkunchal@my.bridgeport.edu, ytoporov@bridgeport.edu

Global Journal of Researches in Engineering (H) Volume XVII Issue I Version I Year 2017

There are traditional methods such as algebraic solutions, geometric solutions and iterative solutions in order to solve the inverse kinematics problem [5]. However, these methods are computationally complex and exhibits higher execution times. Recently, the particle swarm optimization (PSO) has been successfully applied to various optimization problems. This new optimization algorithm combines social psychology principles in socio-cognition human agents and evolutionary computations[9].

In this paper, authors discusses about the capabilities of a commercial PLCs and its multi-tasking operating system to implement a robot control system including inverse kinematics for on-line trajectory planning. Our design is an integration of vision systems with Robot manipulator and PLC used for implementing Imaged Based Intelligence algorithm. This system design provides location information of object using Position Based algorithm. The particle swarm optimization is used for Position based algorithm as it is characterized as a simple concept. This methodology is easy to implement and computationally efficient [9, 10]. The robotic platform described in the paper is designed and developed in Programmable Logic Controller laboratory at University of Bridgeport, CT, USA[1]. The rest of the paper is organized as follows: Sec. II describes the problem definition; Sec. III provides details about the solution, add Sec. IV describes the hardware setup. Sec. V describes about the result and Sec VI describes the conclusion and the future works.

II. Problem Definition

Increase in automation needs with revolutionary advancement in technology motivates the researchers to develop next generation automation applications [11]. Typically industrial processes uses manipulator arms for picking and placing the objects in close proximity. This involves robot arms to repeatedly perform movements with high accuracy and with precise joint angles[12]. The common industrial manipulator is often referred as robot arm with joints and angles as shown in Figure 1. The robot arm used in our application is an articulated arm consists of all revolute joints. The articulated robot arm has maximum flexibility and can reach over and under the objects. As all joints are revolute these robots can cover large workspace and are easy to seal. The robot manipulators are assigned to accomplish the specific task in unstructured environment with minimal joint movements and with best shortest path.

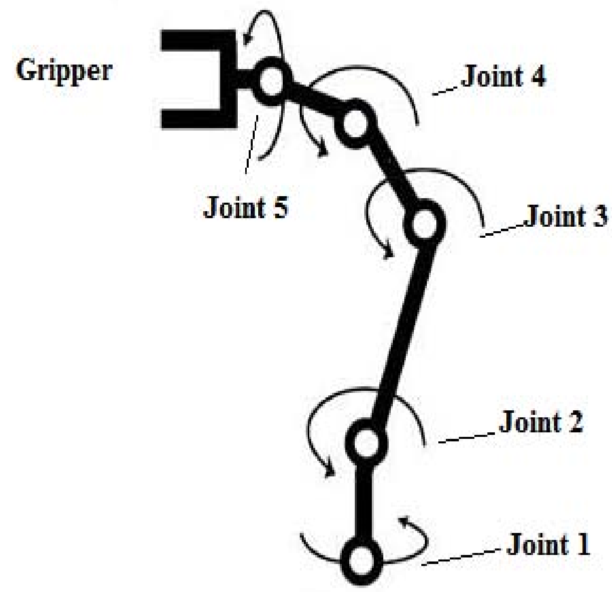


Figure 1: Robot Arm with Joint Angle

The robot motion path planning has been studied more than two decades [13]. Deriving the best possible inverse kinematic solution for end effector is challenging and difficult. Some of the challenging aspects in designing reverse kinematic solution are:

a) *State Space*

As the manipulator is designed for pick and place application, the manipulator picks up the object and places it in relative positions such and are termed as good position or bad position or rejection area according to the sensory data. So finding the states for the robot manipulator is finite. The arm has its work space and can reach to those positions by various paths.

b) *Initial State*

The initial state for the robot manipulator could be any state depends on the signal send by the sensors to the arm. But at the start of the operations the manipulator always go to the home or nesting position.

c) *Action*

The manipulator action depend on the perceived signal from the sensors (camera, part detect sensor, etc.). The manipulator takes action based on the sensor data to the controller and controller performs the movement of arm. So manipulator moves toward the destination area by avoiding the obstacles in the path in a given time limit with respective speed. To reach the object, the manipulator has to find out the best possible path with minimal joint angle movement within its work space. The end effector will try to reach the object as soon as position coordinates are calculated. There are also other actions performed such as for open and close the gripper, take snap shot of parts, start/stop the conveyor, start/stop the motor etc.

Global Journal of Researches in Engineering (H) Volume XVII Issue I Version I Year 2017

d) Transition Model

The transition model for the manipulator depends on the action taken. In the start, the manipulator returns to the homing position. So we consider the initial state as the homing position, but not all the time. The camera mounted on the end effector will continuously feed the current position coordinates of the robot manipulator to the controller and the algorithm controls the motion of robot arm.

The complete transition model is shown in Figure 2.

e) Goal test

The goal test of this model is to pick and place the objects/parts with respective area for further processing by detecting metal and nonmetallic parts and avoiding the obstacle or collision of the robot arm with any other part of the system.

f) Path Cost

The path cost of this application varies according to the product cost, i.e. parts used for the system assembling, and other factors.

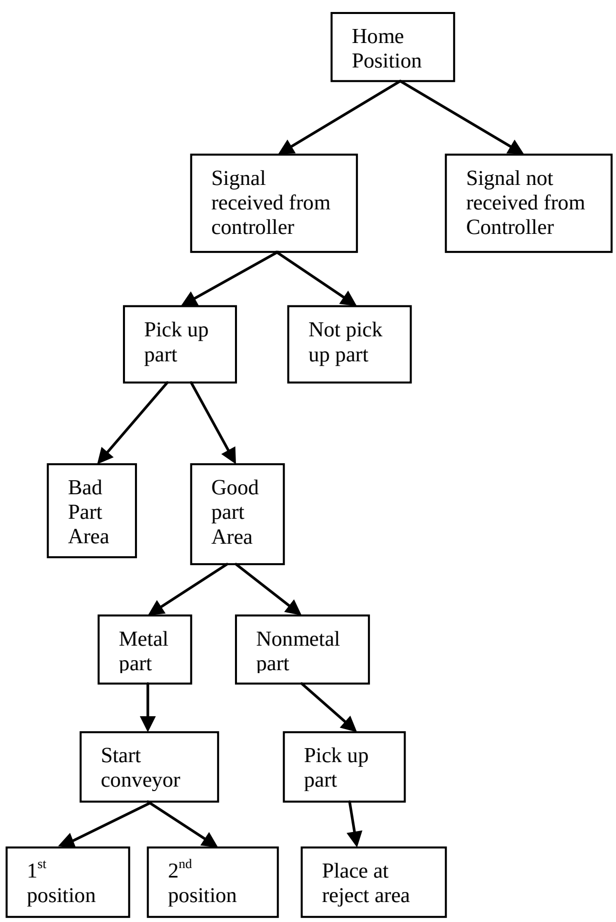


Figure 2: Transition Model of the system

The complete flow chart of the application designed and implemented as given in Figure 3.

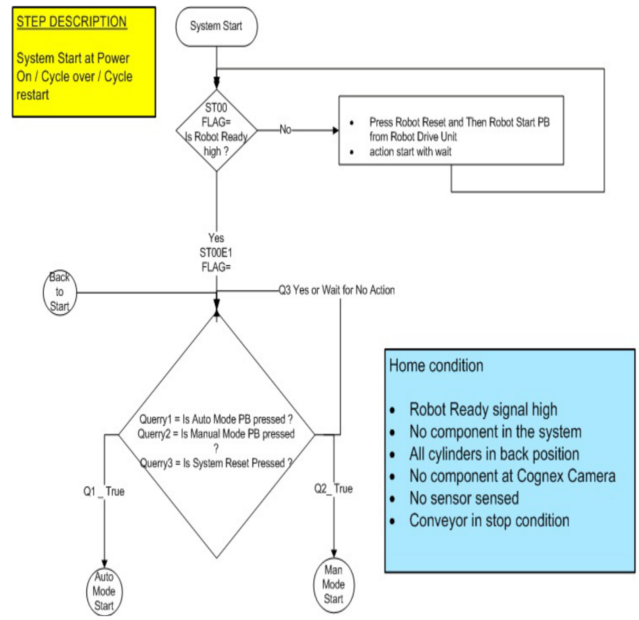


Figure 3: Flow Chart of the complete process

To achieve the goal in this study, the position trajectory calculation of the robot manipulator is the most challenging task, as it has to avoid the obstacle and reach the product for picking[14]. As stated in above problem transition state for the robot manipulator has various possible paths to reach object. Among those paths, the best path will have the minimal joint movements and shortest distance within its workspace. Many techniques have been developed for finding the inverse kinematics of the manipulator. The complexity of finding the kinematics solution increases with number of joints or Degree Of Freedom (DOF). The robot manipulator position, path planning and motion control in 3 dimensional workspace become a key factor for control system design engineers and robot manufacturers. To achieve this functionality, the robot arm should be self-proficient, flexible, low power consumptions, fully efficient. One of the challenging task for robot arm in industry is to move its end effector from initial position to desired position in working environment with least residual vibration, minimal torque, obstacle avoidance and collision free kinematics, shortest time interval and/or distance in a desired path[15].

III. Solution Methodology

Dealing with complex, higher level control system with continuous interactive subsystem in dynamic environment is difficult and requires sophisticated and intellectual controllers with continuous process optimization. In this study, we proposed the solution for path planning as stated in the previous section. The proposed solution has been applied and tested on robot manipulator with 5 DOF. The experimental set up is explained in Section IV. In this experiment we are using position based algorithm in combination with Image based algorithm to finding the best possible solution for path planning. In this study, we are implementing Artificial Intelligence in the robot arm control system using PLC as shown in Figure 4. The system is completely knowledge based as it uses information from the sensors and performs the action using robot arm and actuators. The position based search algorithm uses the visual data provided by the imaged based algorithm and calculates the joint velocity and angles to form the inverse kinematic solution in 3 dimensional workspace[16]. By adding vision or imaged based algorithm, the robotic control system is more flexible, adaptable and increases the accuracy in the joints movement.

The principal advantage of using position-based control is the chance of defining tasks in a standard Cartesian frame. On the contrary, the image-based control is less sensitive to calibration errors; however, it requires online calculation of the image Jacobean that is a quantity depending on the distance between the target and the camera which is difficult to evaluate. A control of a manipulator in the image plane when mapped with the joint space is strongly nonlinear and may cause problems when crossing those points which are singular for the kinematics of the manipulator.

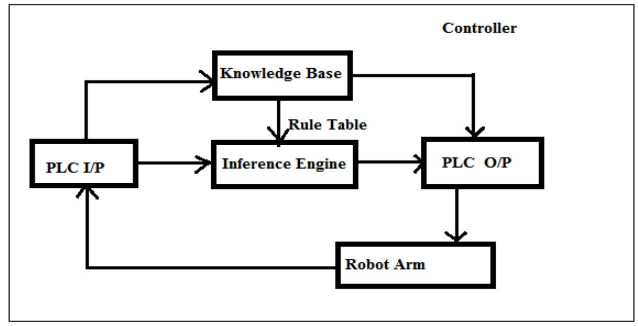


Figure 4: Block diagram of PLC based robot arm control system

The pseudo code for the position based algorithm is as given below,

```
For each position
{
   Initialize position
 }
   Do until maximum iterations or minimum error criteria
     {
      For_each position
      {
        Calculate joint angle kinematics
         If_ Joint1 better than Joint2
          {
            Set pBest = current Joint angle
          }
           If pBest is better than gBest
          {
            Set gBest = pBest
          }
       }
     }
   For each position
   {
      Calculate joint Velocity
      Use gBest and Velocity to update position Data
   }
```

The main purpose or goal of this study is to use the visual feedback from images captured by the camera and the Cartesian space co-ordinates of the target object which ultimately controls the motion of the robot to perform a task. The starting position and coordinate frame boundary is taught to the robot arm. From the calculated co-ordinates of the target object, the surface model in 3 dimensional co-ordinate systems will be constructed for robot manipulator. The sensor data will be used for knowledge base and will be used to avoid collision as well as can be used to find optimal

Global Journal of Researches in Engineering (H) Volume XVII Issue I Version I Year 2017

shortest possible path or trajectory by checking each point in its workspace. The sensors can give a signal when contact is made with obstacles, detect metal or nonmetal objects, or measure a force being applied. Due to this knowledge provided by sensory units to the system, robot path can be planned before its execution to the target position.

Firstly, a camera is mounted on a manipulator end effector and it catches a 2-D image, a true potential can be exactly calculated. We assign the two dimensional coordinate system with the x-axis and y-axis forming a basis for the image plane and the z-axis perpendicular to the image plane. The origin located at distance ʎ behind the image plane as shown in Figure 5.

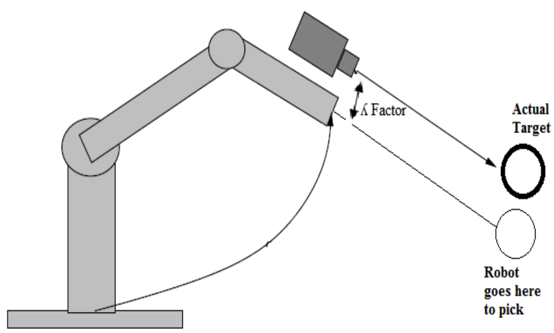


Figure 5: Camera Mount Position

In order to determine the position of the target object in the image plane, camera will capture the images and through which only the central point (only a single pixel) have to be identified, without knowing this point's co-ordinates in the attached Cartesian reference system. This coordinates will be feed to the Position Based Algorithm for calculating the joints angle and trajectory. The position finding algorithm outputs the x-coordinate and y-coordinate in the image frame along with a scaling factor (ʎ). The scaling factor is related to the dimensions of the gripper and is used to get an idea of the elevation of the gripper. This helps in making the gripper co-planar with the target object.

IV. Hardware Setup

We implemented our proposed algorithms and optimal path planning schemes on a PLC based Robot arm control system for sorting, pick and place application as shown in Figure 6.

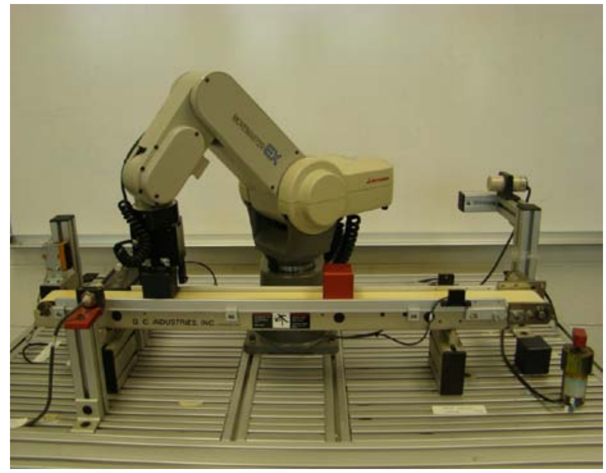


Figure 6: PLC System Setup

Following are the main components of the project,

1. Mitsubishi Fx3G Programmable Logic Controller.
2. Mitsubishi RV-M1 Mitsubishi Robot along with Movemaster Drive Unit.
3. Mitsubishi touch screen E-1061 HMI (Human Machine Interface).
4. VGA Camera.
5. Cognex Vision Camera unit.
6. A servomotor for controlling belt conveyor and another servomotor for displacing a component as a kicker
7. Sensor system comprising of laser sensors, capacitive sensor, track sensor and proximity.
8. Two pneumatic cylinders which act as component pusher.

The Mitsubishi RV-M1 robot is driven with robot drive unit Movemaster EX from which it interfaces with Mitsubishi PLC with help of 50 pin connector and to an another interface for robot teach pendant. This drive unit stores the code in the robot. The nomenclature of the robot arm is shown in Figure 7.

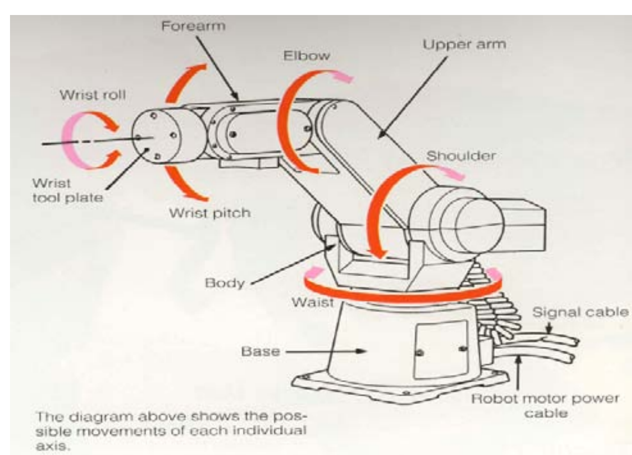


Figure 7: Nomenclature of Robot Arm

The specification of Movemaster robot arm is as given in Figure 8.

MOVEMASTER RV-M1		
Construction		Vertical, articulated
Degrees of freedom		5 (not including hand)
Electrical drive system		DC servo motors
Reach		250 + 160 mm
Operation range	Waist rotation	300° (max. 120°/s)
	Shoulder rotation	130° (max. 72°/s)
	Elbow rotation	110° (max. 109°/s)
	Wrist pitch	± 90° (max. 100°/s)
	Wrist roll	± 180° (max. 163°/s)
Maximum path velocity		1,000 mm/s (PTP at wrist tool plate)
Lifting capacity		1.2 kg incl. hand
Position repeatability		± 0.3 mm at wrist tool plate
Position direction		Limit switches and encoders
Installation position		Horizontal
Ambient temperature		5° C - 40° C
Weight		19 kg

Figure 8: Specification of Robot Arm

The Programmable Logic Controller used in this experimental set up is Mitsubishi Fx3G and its basic specification are given below,

Power Supply: 100-240 V AC/ 12-24 V DC, 50/60 Hz
No. of Outputs: 16.
No. of Inputs: 24.
Input form: sink / source with photocoupler isolation
Input / Output response: Approx 10 ms
Digital Output: Relay Transistor.
Program Cycle Period: 0.55-1 us
Memory: 32K steps EEPROM.
Software: GX Developer.
USB Port, Profibus or Ethernet Connection

V. Results

The application we used for testing these two algorithm with PLC is Pick and Place application with Quality Inspection. As an initial step we localize the object using a traditional Haar classifier. We trained multiple models for recognition various objects in the scene. At time of training process each Haar object detection model will be fed with respective positive samples or in class samples and out of class samples. We then evaluate the performance of the trained model using test data. The processing is performed on a windows machine using Matlab Software. We chose this method (Haar classifier) as it is one of the successful and simple object detection method used widely in machine vision technologies. Some of the sample training images are shown in below Figure 9, Figure 10, Figure 11, and Figure 12.

The pseudo code for Experimental Setup is as given bellow.

1. Initialize:

Start node Stack = empty

End node Stack = empty

All other variables initialized.

Load the mode into Start node Stack equivalent to sNODE out degree each time incrementing the start index. Start index to point to sNODE the Root, on top of stack. Now pop the top of stack and assign to the Depth First Search (DFS) proceed to 2

2. **begin** (At start node Get the unvisited adjacent)

while (there are bNODEs proceed with PBA and IBA algorithm and generate Step code for the branch till you reach a tNODE or xNODE)

if (xNODE proceed to 3)

else if (tNODE go to 7)

else go to 10

3. At xNODE check node status;

if (we are meeting this xNODE for the first time) go to 4

else (top of end index points to this xNODE pop End node Stack and go to 5)

4. Make this xNODE as an end node, if bad part is detected on Cognex vision system Stack equivalent to its in degree each time incrementing the end index. Then go to 5

5. Process this xNODE and increment the in degree processing count for this node.

If (the in degree processing count equal to the xNODE in degree) go to 6

else if (Start node Stack not empty) get the start node ID from stack by popping Start node Stack assign ID to DFS then go to 2

else go to10.

6. Make this node a start node, put its ID on Start node Stack equivalent to its out degree

if (Start node Stack not empty,) pop the Start node Stack assign ID to DFS and then go to 2

else go to 10.

7. Process this tNODE then

if (Start node Stack is empty) proceed to 8

else pop the Start node Stack assign to DFS and then go to 2

8. **if** (End node Stack empty and statistic check correct) proceed to 9

else go to 10

9. good metal product successfully processed to packaging/loading area

exit (Normal)

10. bad non metal product. Encountered an error, **send to rejection area.**

Exit

Following are the test images that were used as a target image to evaluate proposed methodology. We assigned 4 different jobs. Each job has different

Global Journal of Researches in Engineering (H) Volume XVII Issue I Version I Year 2017

products with unique features to distinguish whether it is good or bad product.

JOB 1

We used relay for job 1, it will check whether screw in the socket is present or not. If cognex checker detects screw on the right position then it will consider it as good part and send it to accept position else it will send it to reject position.

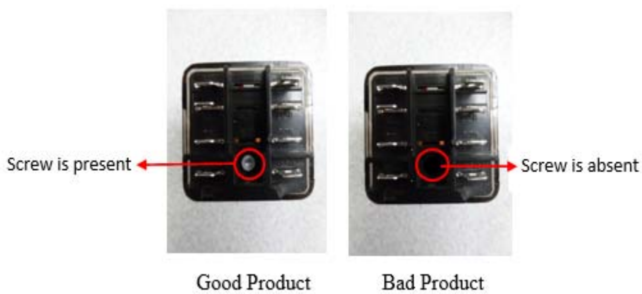


Figure 9: Job 1 Test Product Images

JOB 2

We used holder for job 2, checker will check whether holding pins are assembled in holder during manufacturing process or not. If all holding pins are present in holder then checker will consider it as good product else it will consider it as bad product and send the good product to accept position and bad product to reject position.

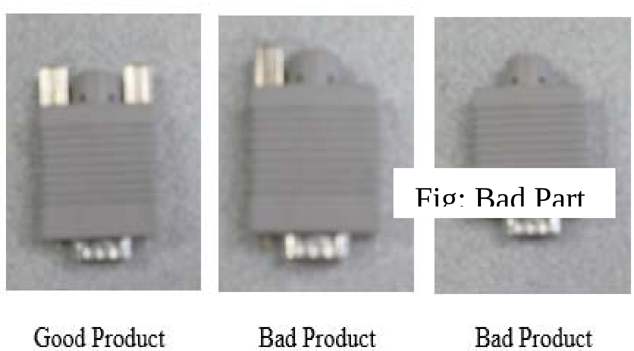


Figure 10: Job 2 Test Product Images

JOB 3

Purell hand sanitizer is used in job 3. In this job we check the label of Purell brand name in the hand sanitizer container. Container with Purell brand name is considered as a good product and without Purell brand name is considered as a bad product.

Figure 11: Job 3 Test Product Images

JOB 4

We used nut for job 4. Nut with two marks is considered as good product and nut without marks will be considered as a bad part.

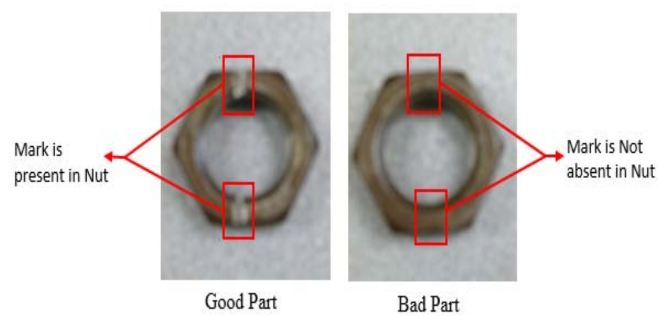


Figure 12: Job 4 Test Product Images

VI. Conclusion

In this paper we proposed an algorithms and implementation method for calculating the inverse kinematic solution and trajectory planning for industrial robot manipulator using the Position based algorithm in combination with Image based algorithm. The implementation is carried out on Movemaster Robot Arm with PLC for sorting metal and nonmetal objects, pick and place application. The proposed combination algorithm reduces the computation time and positioning error for finding the target in real time.

References Références Referencias

1. M. Patil and J. Toporovsky, "Integration of Vision System, Intelligent ROBO Actuator, HMI and PLC to Design a Universal Quality Inspection or Control Machine," *i-manager's Journal on Mechanical Engineering,* vol. 2, no. 3, pp. 5-14, 2012.
2. M. Patil, T. Abukhalil, S. Patel and T. Sobh, "UB Swarm: Hardware Implementation of Heterogeneous swarm robot with fault detection

and power management," *International Journal of Computing,* vol. 15, no. 3, pp. 162-176, September 2016.

3. I. Kao and C. Gong, "Robot-based computer-integrated manufacturing as applied in manufacturing automation," *Robotics and Computer-Integrated Manufacturing,* vol. 13, no. 2, pp. 157-167, 1997.
4. T. Abukhalil, M. Patil, S. Patel and T. Sobh, "Coordinating a heterogeneous robot swarm using Robot Utility-based Task Assignment (RUTA)," in *2016 IEEE 14th International Workshop on Advanced Motion Control (AMC)*, Auckland, New Zealand, 2016.
5. M. Bonfe, M. Vignali and M. Fiorini, "PLC-based control of a robot manipulator with closed kinematic chain," in *IEEE International Conference in Robotics and Automation*, 2009.
6. M. Patil, T. Abukhalil, S. Patel and T. Sobh, "UB robot swarm — Design, implementation, and power management," in *12th IEEE International Conference on Control and Automation (ICCA)*, Kathmandu, 2016.
7. F. Arvin, S. Khairulmizam and R. Abdul Rahman, "A short-range infrared communication for swarm mobile robots," in *2009 International Conference on Signal Processing Systems*, 2009.
8. A. L. Christensen, R. OGrady and M. Dorigo, "From fireflies to fault-tolerant swarms of robots," *IEEE Transactions on Evolutionary Computation,* vol. 13, no. 4, pp. 754-766, 2009.
9. T. Abukhalil, M. Patil and T. Sobh, "A Comprehensive Survey on Decentralized Modular Swarm Robotic systems and Deployment Environments," *International Journal of Engineering (IJE),* vol. 7, pp. 44-60, 2013.
10. M. Patil, T. Abukhalil and T. Sobh, "Hardware Architecture Review of Swarm Robotics System: Self-Reconfigurability, Self-Reassembly, and Self-Replication," *ISRN Robotics,* vol. 2013, p. 11, 2013.
11. K. Hashimoto, T. Kimoto, T. Ebine and H. Kimura, "Manipulator control with image-based visual servo," in *IEEE International Conference on Robotics and Automation*, Sacramento, CA, USA, 1991.
12. A. Macchelli and C. Melchiorri, "A real-time control system for industrial robots and control applications based on real-time Linux," in *15th IFAC World Congress*, Barcelona, Spain, July 2002.
13. H. Asada and K. Youcef-Toumi, "Analysis and design of semidirect drive robot arms," in *in Proc. American Control Conference*, San Francisco, CA, June 1983.
14. D. Whitney and A. Lozinski, "Industrial robot forward calibration method and results," *ASME Journal of Dynamic Systems, Measurement and Control,* vol. 108, pp. 1-8, 1986.
15. G. Palmieri, M. Palpacelli, M. Battistelli and M. Callegari, "A Comparison between Position-Based and Image-Based Dynamic Visual Servoings in the Control of a Translating Parallel Manipulator," *Journal of Robotics,* vol. 2012, p. 11, 2012.
16. J. Borenstein, H. Everett, L. Feng and D. Wehe, "Mobile Robot Positioning - Sensors and Techniques," *Journal of Robotic Systems, Special Issue on Mobile Robots,* vol. 14, no. 4, pp. 231-249, 1996.

This page is intentionally left blank

Global Journal of Researches in Engineering: H
Robotics & Nano-Tech
Volume 17 Issue 1 Version 1.0 Year 2017
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN:2249-4596 Print ISSN:0975-5861

Progressing Highlights Towards Efficient Plasmonic Solar Cells

By Gurjit Singh & SS Verma

Abstract- Solar cells as a light-electricity conversion device, light absorption plays crucial role towards their high performance conversion. Incorporation of plasmonic nanostructures with semiconductor materials offer great potential to improve the conversion efficiency of solar cells with much reduced material usage. So, developing low-cost and large-scale plasmonic nanostructures integratable with solar cells promises new solutions for high efficiency and low cost solar energy. Metal nanoparticles can improve the performance of solar cells by plasmonic scattering enhancement and plasmonic near field enhancement. Further, the localized absorption of metal nanoparticles via surface plasmon resonance has attracted great attention because of large electromagnetic field enhancement, the wavelength selective photon absorption and the adjustable resonance wavelength with the changing material, size, period and dielectric environment of metallic nanoparticles. This work highlight the progress made towards efficient plasmionic solar cells.

Keywords: *plasmonic solar cells, absorption, conversion efficiency enhancement.*

GJRE-H Classification: *FOR Code: 090608*

PROGRESSINGHIGHLIGHTSTOWARDSEFFICIENTPLASMONICSOLARCELLS

Strictly as per the compliance and regulations of:

Progressing Highlights Towards Efficient Plasmonic Solar Cells

Gurjit Singh[α] & SS Verma[σ]

Abstract- Solar cells as a light-electricity conversion device, light absorption plays crucial role towards their high performance conversion. Incorporation of plasmonic nanostructures with semiconductor materials offer great potential to improve the conversion efficiency of solar cells with much reduced material usage. So, developing low-cost and large-scale plasmonic nanostructures integratable with solar cells promises new solutions for high efficiency and low cost solar energy. Metal nanoparticles can improve the performance of solar cells by plasmonic scattering enhancement and plasmonic near field enhancement. Further, the localized absorption of metal nanoparticles via surface plasmon resonance has attracted great attention because of large electromagnetic field enhancement, the wavelength selective photon absorption and the adjustable resonance wavelength with the changing material, size, period and dielectric environment of metallic nanoparticles. This work highlight the progress made towards efficient plasmionic solar cells.

Keywords: plasmonic solar cells, absorption, conversion efficiency enhancement.

I. Introduction

Global climate change and rising prices of fossil fuels have derived us to use clean and environment friendly solar energy. Solar cell is most important renewable energy source which can convert incoming sunlight directly into usable electrical energy (Green, 1998). But cost always remains an important factor in the success of solar cells. So, the key aim of photovoltaics in the manufacturing of solar cells is to reduce production costs in order to compete with other fossil fuel technologies. With solar cell thickness of several micron or less (Luque and Hegedus, 2011), we can significantly decrease the amount of semiconductor material used and thus, production costs are reduced (Green, 2003). Hence, thin film solar cells promise a viable solution to these challenges (Chu and Majumdar, 2012). But thin film solar cells have limitation of poor absorption of sunlight as compared to wafer based solar cells. So, efficient light absorption mechanisms should be adopted for better performance of thin film solar cells. The surface texturing mechanism used in wafer based solar cells for light trapping (Green, 1998; Mullar et.al., 2004) cannot apply to thin film cells because of the surface recombination losses. To date, various light absorption mechanisms have been examined but promising mechanism for the light absorption enhancement was developed by the metal nanoparticle plasmons ([a]Cathpole and Polman, 2008). The metal nanoparticle plasmons are the collective oscillations of the free electrons in response to the irradiated light (Maier, 2007). The basic mechanism behind the functioning of plasmonic solar cells is the scattering and absorption of solar light by depositing metal nanoparticles across the surface of solar cell. As thin sheet of substrate does not absorb much light coming from sun, for this reason, more light needs to be scattered across the surface in order to increase the absorption of solar cell and convert it into the useful electricity. It has been found that metal nanoparticles help to scatter the incoming light across the surface of the substrate at resonance wavelengths. The scattering and absorption cross-sections are given by ([a]Bohren et. al., 1983):

Auhtor σ: Department of Physics S.L.I.E.T., Longowal, Distt.-Sangrur (Punjab)-148106. e-mail: ssvermaus2001@yahoo.com

$$C_{scat} = \frac{1}{6\pi}\left(\frac{2\pi}{\lambda}\right)^4 |\alpha|^2 \quad ; \quad C_{abs} = \frac{2\pi}{\lambda} Im|\alpha| \qquad (1)$$

Where $$\alpha = 3V\frac{\omega_p^2}{\omega_p^2 - 3\omega^2 - \iota\omega\gamma} = 3V\left[\frac{\epsilon_p/\epsilon_m - 1}{\epsilon_p/\epsilon_m + 2}\right] \qquad (2)$$

Where α is the polarizability of the particle, V is the particle volume, ϵ_p is the dielectric function of the particle and ϵ_m is the dielectric function of the embedding medium. If $\epsilon_p = -2\epsilon_m$, the particle polarizability will become very large. This occurs when the frequency is close to the surface plasmon resonance ω_{sp}, allowing the light to interact over an area larger than the geometric cross section of the particle ([b]Bohren et. al., 1983). In the case of a spherical structure the surface plasmon resonance occurs at $\omega_{sp}=\sqrt{3}\,\omega_p$.

The metal nanoparticles can enhance the performance of solar cells by: (a) plasmonic scattering enhancement and (b) plasmonic near field enhancement. In plasmonic scattering enhancement, when sun light hits the solar cell a surface plasmon is excited on the metal nanoparticle, which then re-radiates most of its energy into the semiconductor material so that the light is trapped inside the cell. In the plasmonic near field enhancement, the electric field around the particles is enhanced due to strong interaction between sun light and metal nanoparticles. The particles concentrate the light into small regions more effectively. If these particles are placed across the semiconductor then more light will be absorbed by the semiconductor in that region.

As metal nanoparticles support localized surface plasmons in both visible and near-infrared regions, can be used to enhance the optical path length inside the solar cell (Sun et.al., 2012) which strongly increases the light absorption inside the thin film solar cell. The plasmonic resonance peak can be easily tuned by particle size, shape, material and dielectric environment (Sekhon and Verma, 2012; Muhammad et.al., 2015; Noguez, 2007; Akimov, et.al. 2010). Metal nanoparticles used at the front side as scatterers in solar cells can be used to qualitatively reduce the reflection and increase the short circuit current density (Schaadt et.al., 2005; Nakayama et.al., 2008; Sharma et.al., 2014, Pudasaini and Ayon, 2012).

II. Methodology

Numerical electromagnetic models for the scattering analysis of general structures have been developed using differential, integral, variational, and hybrid-based approaches. Differential-based approaches include the finite-difference frequency-domain (FD) and finite-difference time-domain (FDTD) methods. Integral-based approaches include both volume integral methods (VIMs) and boundary integral methods (BIMs). A variational-based approach is the finite element method (FEM). Hybrid-based approaches are models that incorporate combinations of the above methods. Because numerical techniques must be used in the application of these techniques they may be broadly referred to as computational electromagnetic methods (CEM). FDTD is most widely used among the available techniques. FDTD formulations find a number of applications in the area of electromagnetic radiation, scattering, and coupling as they provide for simulating the behavior of electromagnetic fields (John and Daniel, 1973). Further, FDTD method gives the direct solution to Maxwell's equations without converting the problem into another form. FDTD approach uses the formulation which was initially purposed by Kane S. Yee (Yee, 1966). Many researchers have contributed immensely to extend the method to many areas of science and engineering (Sadiku, 1992; Kunz and Lubbers, 1993; Taflove, 1998).
The Finite-Difference Time-Domain (FDTD) method (www.lumerical.com, Sullivan 2000; Taflove 2005; Stephen, 2011) is a state-of-the-art method for solving Maxwell's curl equations in non-magnetic materials:

$$\frac{\partial \vec{D}}{\partial t} = \vec{\nabla} \times \vec{H} \quad (3)$$

$$\vec{D}(\omega) = \varepsilon_0 \varepsilon_r(\omega) \vec{E}(\omega) \quad (4)$$

$$\frac{\partial \vec{H}}{\partial t} = -\frac{1}{\mu_0} \vec{\nabla} \times \vec{H} \quad (5)$$

where $\vec{H}$, $\vec{E}$ and $\vec{D}$ are the magnetic, electric and displacement fields respectively, while $\varepsilon_r(\omega)$ is the complex relative dielectric constant. In three dimensions, Maxwell equations have six electromagnetic field components. The components in TE (Transverse electric) are E_x, E_y, E_z and in TM (Transverse Magnetic) are H_x, H_y, H_z.
Further, Maxwell's equations reduce to (in TM mode):

$$\frac{\partial D_Z}{\partial t} = \frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} \quad (6)$$

$$\vec{D}_z(\omega) = \varepsilon_0 \varepsilon_r(\omega) \vec{E}_z(\omega) \quad (7)$$

$$\frac{\partial H_x}{\partial t} = -\frac{1}{\mu_0}\frac{\partial E_z}{\partial y} \quad (8)$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu_o}\frac{\partial E_z}{\partial x} \quad (9)$$

The solar surface was illuminated under a plane wave source of wavelength ranging from 400-1100nm weighted against the 1.5AM solar spectrum (http://rredc.nrel.gov/solar/spectra/am1.5/). To account for multiple scattering caused by nanoparticle-nanoparticle, nanoparticle – substrate and nanoparticle-substrate - nanoparticle interactions, perfect matched layers (PML) are put on the top and bottom boundaries of computation area and periodic boundary conditions (PBC) are set along the periodic direction. Thus, the performed simulations will take into account all major effects of metal nanoparticles decorated on the top of photoactive layer.

The absorption per unit volume can be calculated from the divergence of the Poynting vector

$$P_{abs} = -0.5\, Re(\vec{\nabla}.\vec{S}) = -0.5\omega|E(\omega)|^2 Im(\varepsilon(\omega)), \quad (10)$$

Where $|E(\omega)|^2$ is electric field intensity squared and ε(ω) the corresponding material dielectric function.
To see how the efficiency of solar cell with metallic nanoparticles is improved comparing with bare solar cell, we define the following quantities, absorption enhancement g(λ) and conversion efficiency enhancement (G),

$$g(\lambda) = \frac{QE_{particle}(\lambda)}{QE_{bare}(\lambda)} \quad (11)$$

and

$$G = \frac{IQE_{particle}}{IQE_{bare}} \quad (12)$$

where QE(λ) and IQE are quantum efficiency and integrated quantum efficiency respectively.

P_{abs_t} basically evaluates what fraction of input optical power gets absorbed by the solar cell at each wavelength. Mathematically, it is given by

$$P_{abs\_t} = \frac{P_{abs}(\lambda)}{P_{in}(\lambda)} \quad (13)$$

Finally, in order to quantify the absorption enhancements of nanoparticle deposited thin film solar cell across the solar spectrum, the short circuit current density (J_{sc}) is calculated by

$$J_{sc} = e \int \frac{\lambda}{hc} QE(\lambda) I_{AM1.5}(\lambda) d\lambda \qquad (14)$$

where e is charge on electron, λ is wavelength, h is Planck's constant, c is speed of light in the free space and $I_{AM1.5}$ (λ) is spectral irradiance(power density) of the ASTM AM 1.5G solar spectrum.

The strengths of FDTD modeling can be summarized as:

- FDTD is a versatile modeling technique used to solve Maxwell's equations.
- FDTD is a time-domain technique, and when a broadband pulse (such as a Gaussian pulse) is used as the source, then the response of the system over a wide range of frequencies can be obtained with a single simulation. This is useful in applications where resonant frequencies are not exactly known, or anytime that a broadband result is desired.
- Since FDTD calculates the E and H fields everywhere in the computational domain as they evolve in time, it lends itself to providing animated displays of the electromagnetic field movement through the model. This type of display is useful in understanding what is going on in the model, and to help ensure that the model is working correctly.
- The FDTD technique allows the user to specify the material at all points within the computational domain. A wide variety of linear and nonlinear dielectric and magnetic materials can be naturally and easily modeled.
- FDTD uses the E and H fields directly. Since most EMI/EMC modeling applications are interested in the E and H fields, it is convenient that no conversions must be made after the simulation has run to get these values.

III. Progress Made so Far

Incorporation of plasmonic nanostructures into thin-film solar cells has been extensively discussed in recent years. Pillai *et.al* (2007) investigated that absorption of thin film c-Si solar cells can be enhanced by silver nanoparticles of small diameters less than 30 nm. They showed smaller silver metal nanoparticles can provide the maximum overall enhancement in visible and the near- infrared region and larger metal nanoparticles can be used for light emission from both thin and thick silicon light emitting diodes. The scattering of light from a single silver or gold nanoparticle with different material of nanoparticles, shape, size, and dielectric environment was theoretically studied ([b]Catchpole and polman, 2008) and showed that path length enhancements in cylindrical and hemispherical nanoparticles is higher than spherical nanoparticles. Further, path length enhancements for silver nanoparticles are much higher than gold nanoparticles. For absorption enhancement the distance of nanoparticles from the substrate is an important factor which is related to the excitation of gap modes ([a]Akimov et.al., 2009, Sreekanth et.al., 2011, Xu, R. et.al., 2012).

To study the effect of higher-order modes on plasmonic enhancement of thin film amorphous silicon solar cell, 3D modeling was used ([b]Akimov et. al., 2009). They used silver nanoparticles for both size and coverage optimization and given two optimal configurations of silver nanoparticles with diameters of 30 nm and 80 nm and showed that optimal coverage was 33% for 30nm and 11% for 80nm for silver nanoparticles respectively. Ferry et.al. (2010) report on the design, fabrication, and measurement of ultrathin film a-Si:H solar cell with nanostructured plasmonic back contacts, which demonstrate enhanced short circuit current densities compared to cells having flat or randomly textured back contacts. The primary photocurrent enhancement occurs in the spectral range from 550 nm to 800 nm. They use angle-resolved photocurrent spectroscopy to confirm that the enhanced absorption is due to coupling to guided modes supported by the cell.

Spinelli *et al.* (2011) used silver nanoparticle array geometries to study the coupling of light into a crystalline silicon substrate by scattering light. After simulation and optimization, the best impedance matching for a spectral distribution was observed with spheroidal silver nanoparticles 200 nm wide and 125 nm high in a square array with 450 nm pitch on top of a 50-nm-thick Si3N4 layer corresponding to the A. M. 1.5 solar spectrum. Byun *et al.* (2014) used silver nanoparticles of parabolic antenna-type and showed that the field intensity of the absorbing layer in a visible wavelength range(over 650 nm) is enhanced due to its simplified shape. Marco Notarianni et.al. (2014) showed that power conversion efficiency of a bulk heterojunction solar cell can be increased up to 10% by embedded gold nanoparticles by depositing and annealing a gold film on transparent electrode which can generate a plasmonic effect.

Mohammad Sabaeian et.al. (2015) investigated by putting the nano-strips of different cross sections (triangle, rectangular and trapezoidal) as a grating structure on the top of the solar cells. The waveguide, surface plasmon polariton (SPP), and localized surface plasmon (LSP) modes were evaluated in Transverse Electric (TE) and Transverse Magnetic (TM) polarizations by exciting them with the help of nano-strips. TM modes are more effective than TE modes in optical and electrical properties enhancement of solar cell. The optical absorption, generation rate and short-circuit

Global Journal of Researches in Engineering (H) Volume XVII Issue I Version I Year 2017

current density enhancement for trapezoidal nano-strips showed noticeable impact than triangle and rectangular ones. Keya Zhou et.al. (2015) used different kinds of solar cells, such as amorphous silicon (a-Si) thin film solar cells, crystalline silicon (c-Si), organic solar cells, single nanowire solar cells and nanowire array solar cells and reviewed various current approaches. An experimental work by Varlamov et.al (2012) and Park *et al.* (2013) used optimized plasmonic silver nanoparticles and polycrystalline silicon thin film solar cells showed increased photocurrent of ~45%. Without a back reflector their absolute efficiency was 5.32% and with the back reflector was 5.95%.

Besides metallic nanoparticles, two-dimensional metallic nanostructures have also been used. Ferry *et al.* (2008) used thin film Si and GaAs solar cells using a back interface coated with a corrugated metal film and reported their findings that sub-wavelength scatterers can couple sunlight into guided modes. Pala *et al.* (2009) optimized the Ag strip geometries and reported that they could simultaneously take advantage of both effective coupling to waveguide modes of the semiconductors and high near-field concentration close to their SPs resonance frequency. Munday *et al.* (2011) showed that optimized integrated structure can result in a 1.8-fold total integrated current improvement by combining plasmonic gratings with traditional antireflection coatings together under AM 1.5G solar illumination.

Muhammad et. al. (2015) studies the effects of the structure geometrical parameters on the absorption and showed that 35% absorption improvement is achieved over the conventional thin film solar cell without metallic nanoparticles. Zhang et.al. (2012) simulated aluminium (Al) nanoparticles and shows 28.7% photon absorption enhancement as compared to noble metals. Further, combining with SiN_x ARC , particles can produce 42.5% enhancement which is 4.3% more than Standard SiN_x ARC in both blue and near-infrared region. Hong et.al. (2012) and Hylton et.al. (2013) simulated Al nanoparticles over GaAs solar cell and showed enhanced photocurrent and integrated efficiency at optimal structural parameters. Li et.al. (2015) purposed a plasmon enhanced solar cell structure based on GaAs nanowire array decorated with metal nanoparticles. The results show a large absorption enhancement of 50% at 760nm and a high conversion efficiency of 14.5% can be obtained at D/P ratio of 0.3.

Tanabe (2016) developed a simple model for photocurrent enhancement by plasmonic metal nanoparticles atop solar cell which can be used as powerful tool for investigations of surface plasmon enhanced thin film solar cells to provide design principle for improvement of device performance. Liu et.al. (2011) performed a systematic study of SPR on GaAs thin film solar cell with different sizes of Ag nanoparticles on the surface and found that SPR wavelength does not undergo red shift with increasing metal thickness but depends upon shape of nanoparticles and period. Further, observed that the short circuit current density of solar cell with 6nm Ag film after annealing was increased by 14.2% over that of untreated solar cell. Singh et.al (2013) study the absorption enhancement using a periodic array of cylindrical silver nanowire placed on thin silicon substrate. Studies show an absorption enhancement of 1.32 for nanoparticles of diameter of 140nm and period of 360nm.

IV. Future Scope of Work

For large scale implementation of solar light conversion to electricity through solar cells, the cost of manufacturing of solar cells needs to be reduced. Thin film solar cells reduce the materials consumption but have poor light absorption as compared to conventional solar cells. The localized absorption of metal nanoparticles via surface plasmon resonance has attracted attention because of large electromagnetic field enhancement, the wavelength selective photon absorption and the adjustable resonance wavelength by changing material, size, period and dielectric environment of metallic nanoparticles (Catchpole et.al. 2008). Hence, plasmonic nanostructures can enhance light trapping in solar cells which can be used in various photo detectors (Stuart et.al. 1996), photodiodes (Sachaadt et.al. 2005) and solar cell applications (Mullar et.al. 2004, Byun et.al. 2011).

There is no systematic study had been reported on GaAs thin film solar cells using plasmon enhanced light absorption. Hence, a systematic study on the optimization of the various parameters (like material, size and period) of metal nanoparticles for various optical properties is critically required for efficiency enhancement of GaAs thin film solar cells. The objective is to enhance the efficiency of solar cells by using different plasmonic nanostructures by optimizing the different materials as well as size and period for their use towards solar cell efficiency enhancement.

Study of various optical properties given below for plasmonic nanostructures by using FDTD simulations over the solar spectrum would be useful for strengthening the existing data base towards making efficient plasmonic solar cells.

- To investigate the absorption of solar cell for different materials, size and period of nanoparticles
- To investigate absorption enhancement for different material and size
- To investigate total power absorbed for different material and size
- To investigate enhanced conversion efficiency

a) With period of nanoparticles at different sizes
b) With different sizes at fixed period

- To investigate current density for different sizes at fixed period
- To investigate integrated current density for various sizes at fixed period

References Références Referencias

1. [a]Akimov Y.A, Koh W.S, Ostrikov, K. 2009. Enhancement of optical absorption in thin-film solar cells through the excitation of higher-order nanoparticle plasmon modes. *Opt. Express.* 17: 10195–10205.
2. [b]Akimov Y.A, Ostrikov K, Li, E.P. 2009. Surface plasmon enhancement of optical absorption in thin-film silicon solar cells. *Plasmonics,* 4: 107–113.
3. Akimov, Yu. A. and et.al. 2010. Nanoparticle-enhanced thin film solar cells: Metallic or dielectric nanoparticles?. *Appl. Phys. Lett.* 96:073111.
4. [a]Bohren, C. F. and Huffman, D. R. 1983. Absorption and scattering of light by small particles, Wiley-Interscience,New York.
5. [b]Bohren, Craig, F. 1983. How can a particle absorb more than the light incident on it? *Am. J. Phys.* 51: 323–327.
6. Byun S, Lee H.Y, Yoo, J. 2011. Systematic approach of nanoparticle design to enhance the broadband plasmonic scattering effect. *J. Appl. Phys.* 115: doi:10.1063/1.4875660.
7. [b]Catchpole K.R, Polman, A. 2008. Design principles for particle plasmon enhanced solar cells. *Appl. Phys. Lett.* 93: 191113
8. [a]Cathpole, K.R. and Polman, A. 2008. Plasmonic solar cells. *Optics Express* 16:21793-21800.
9. Chu, S. and Majumdar, A. 2012. Opportunities and challenges for a sustainable energy future. *Nature.* 488: 294-303.
10. Ferry V.E, Marc A. Verschuuren, Hongbo B. T. Li, Ewold Verhagen, Robert J. Walters, Ruud E. I. S, Harry A. A, Albert, P. 2010. Light trapping in ultrathin plasmonic solar cells, *Opt. Express*. 18: 237-245
11. Ferry V.E, Sweatlock L.A, Pacifici D, Atwater, H.A. 2008. Plasmonic nanostructure design for efficient light coupling into solar cells. *Nano Lett.* 8: 4391–4397
12. Green, M.A. 1998. Solar cells: Operating Principles, Technology and system Applications. The University of New South Wales, Sydney.
13. Green, M.A. 2003. Third generation photovoltaics. Springer, Berlin.
14. Hong, L and et.al. 2012. Design principles for plasmonic thin film GaAs solar cells with high absorption enhancement. *J of Appl. Phys.* 112: 054326
15. Hylton, N.P and et.al. 2013. Loss mitigation in plasmonic solar cells: aluminium nanoparticles for broadband photocurrent enhancements in GaAs photodiodes. *Scientific Reports*. 3: 2874
16. John Kraus, Daniel, A. Fleisch. 1973. Electromagntics with Applications, McGraw-Hill – pp560-563.
17. Keya Zhou , Zhongyi Guo , Shutian Liu and Jung-Ho Lee. 2015. Current Approach in Surface Plasmons for Thin Film and Wire Array Solar Cell Applications, *Materials.* 8: 4565-4581; doi:10.3390/ma8074565
18. Kunz A.S. and Lubbers, R.J. 1993. The Finite-Difference Time –Domain method for Electromagnetics. CRC Press, Boca Raton(FL)
19. Li Y, Yan X, Wu Y, Zhnag X, Ren, X. 2015. Plasmon-enhanced light absorption in GaAs nanowire array solar cells. *Nanoscale Research Letters*. 10:436
20. Liu W, Wang X, Li Y, Geng Z, Yang F, Li, J. 2011. Surface plasmon enhanced GaAs thin film solar cells. *Solar energy materials & solar cells*. 95: 693-698
21. Luque, A. and Hegedus, S. 2011. Handbook of Photovoltaic Science and Engineering. Wiley.
22. Maier, S.A. 2007. Plasmonics : Fundamentals and Applications. Springer, Berlin, Germany.
23. Marco Notarianni , Kristy Vernon , Alison Chou , Muhsen Aljada , Jinzhang Liu , Nunzio Motta. 2014. Plasmonic effect of gold nanoparticles in organic solar cells. *Solar Energy.* 106: 23–37
24. Mohammad Sabaeian, Mehdi Heydari and Narges, A. 2015. Plasmonic excitation assisted optical and electric enhancement in ultra-thin solar cells: the influence of nano-strip cross section, *AIP Advances*. 5: 087126-(1-12)
25. Muhammad H. Muhammad, Mohamed Farhat O. Hameed, Obayya, S.S.A. 2015. Broadband absorption enhancement in Periodic structure plasmonic solar cell. *Opt Quant Electron*. 47: 1487-1494
26. Mullar J, Rech B, Springer J and Vanecek, M. 2004. TCO and light trapping in silicon thin film solar cells. *Sol. Energy* 77: 917-930.
27. Munday J.N, Atwater H.A. 2011. Large integrated absorption enhancement in plasmonic solar cells by combining metallic gratings and antireflection coatings. *Nano Lett.* 11: 2195–2201
28. Nakayama, K and et.al. 2008. Plasmonic nanoparticle enhanced light absorption in GaAs solar cells. *Appl. Phys. Lett.* 93:121904.
29. Noguez, C. 2007. Surface Plasmons on Metal Nanoparticles: The Influence of Shape and Physical Environment. *J Phys. Chem. C* 111: 3806-3819.
30. Pala R.A, White J, Barnard E, Liu J, Brongersma, M.L. 2009. Design of plasmonic thin-film solar cells with broadband absorption enhancements. *Adv. Mater.* 21: 3504–3509
31. Park J, Rao J, Kim T, Varlamov, S. 2013. Highest efficiency plasmonic polycrystalline silicon thin-film

Global Journal of Researches in Engineering (H) Volume XVII Issue I Version I Year 2017

solar cells by optimization of plasmonic nanoparticle fabrication. *Plasmonics.* 8: 1209–1219

32. Pillai S, Catchpole K.R, Trupke T, Green M.A. 2007. Surface plasmon enhanced silicon solar cells. *J. Appl. Phys.* 101, doi:10.1063/1.2734885.
33. Pudasaini, P.R. and Arturo, A. A. 2012. High Efficiency nanotextured silicon solar cells. *Optics Communications* 285:4211-4214.
34. Sadiku, M.N.O. 1992. Numerical Techniques in Electromagnetics. CRC Press, Boca Raton (FL)
35. Schaadt D.M, Feng, B and Yu, E.T. 2005. Enhanced semiconductor optical absorption via surface plasmon excitation in metal nanoparticles. *Appl. Phys. Lett.* 86: 063106.
36. Sekhon, J.S. and Verma, S.S. 2012. Rational selection of nanorod plasmons: material, size and shape dependence mechanism for optical sensors. *Plasmonics* 7: 453-459.
37. Sharma, M. and et.al. 2014. Plasmonic effects of Au/Ag bimetallic multispiked nanoparticles for photovoltaic applications. *ACS Appl. Mater. Interfaces* 6:15472-15479.
38. Singh Y.P, Kumar A, Jatin A, Kapoor, A. 2013. Enhancement in optical absorption of plasmonic solar cells. *The open Renewable Energy Journal.* 6: 1-6
39. Spinelli P, Hebbink M, De Waele R, Black L, Lenzmann F, Polman, A. 2011. Optical impedance matching using coupled plasmonic nanoparticle arrays. *Nano Lett.* 11: 1760–1765.
40. Sreekanth K.V, Sidharthan R, Murukeshan, V.M. 2011. Gap modes assisted enhanced broadband light absorption in plasmonic thin film solar cell. *J. Appl. Phys.* 110, doi:10.1063/1.3622149.
41. Stephen, D. Gedney. 2011. Introduction to the Finite-Difference Time-Domain (FDTD) Method for Electromagnetics.
42. Stuart H.R, Hall, D.G. 1996. Absorption enhancement in silicon-on-insulator wave-guides using metal island films. *Appl. Phys. Lett.* 69: 2327-2329
43. Sullivan, D. M. 2000. Electromagnetic simulation using the FDTD method, New York.
44. Sun Z, Zuo X. and Yang, Y. 2012. Role of surface metal nanoparticles on the absorption in solar cells. *Opt. Lett.* 37: 641-643.
45. Taflove, A. 1998. Advances in Computational Electromagnetics: The Finite-Difference Time-Domain Method. Artech House, Norwood, MA.
46. Taflove, A. 2005. Computational Electromagnetics: The Finite-Difference Time-Domain Method, Boston.
47. Tanabe, K. 2016. A simple optical model well explains plasmon-nanoparticle-enhanced spectral photocurrent in optically thin solar cells. *Nanoscale Research Letters*. 11:236
48. Varlamov S, Rao J, Soderstrom, T. 2012. Polycrystalline silicon thin-film solar cells with plasmonic-enhanced light-trapping. *J. Vis. Exp*, doi:10.3791/4092
49. Xu R, Wang X, Song L, Liu W, Ji A, Yang F, Li, J. 2012. Influence of the light trapping induced by surface plasmons and antireflection film in crystalline silicon solar cells. *Opt. Expres.* 20: 5061–5068.
50. Yee, K.S. 1966. Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media. *IEEE Trans. Antennas Propag.* 14: 302-07
51. Zhang, Y and et.al. 2012. Low cost and high performance Al nanoparticles for broadband light trapping in Si wafer solar cells. *Appl. Phys. Lett.* 100: 151101(1-4)

Global Journals Inc. (US) Guidelines Handbook 2017

www.GlobalJournals.org

Fellows

FELLOW OF ASSOCIATION OF RESEARCH SOCIETY IN ENGINEERING (FARSE)

Global Journals Incorporate (USA) is accredited by Open Association of Research Society (OARS), U.S.A and in turn, awards “FARSE ” title to individuals. The 'FARSE' title is accorded to a selected professional after the approval of the Editor-in-Chief /Editorial Board Members/Dean.

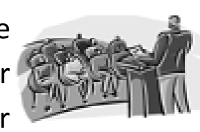
- The “FARSE” is a dignified title which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., FARSE or William Walldroff, M.S., FARSE.

FARSE accrediting is an honor. It authenticates your research activities. After recognition as FARSE, you can add 'FARSE' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, and Visiting Card etc.

The following benefits can be availed by you only for next three years from the date of certification:

FARSE designated members are entitled to avail a 40% discount while publishing their research papers (of a single author) with Global Journals Incorporation (USA), if the same is accepted by Editorial Board/Peer Reviewers. If you are a main author or co-author in case of multiple authors, you will be entitled to avail discount of 10%.

Once FARSE title is accorded, the Fellow is authorized to organize a symposium/seminar/conference on behalf of Global Journal Incorporation (USA).The Fellow can also participate in conference/seminar/symposium organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent.

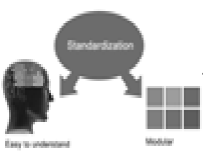


You may join as member of the Editorial Board of Global Journals Incorporation (USA) after successful completion of three years as Fellow and as Peer Reviewer. In addition, it is also desirable that you should organize seminar/symposium/conference at least once.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The FARSE can go through standards of OARS. You can also play vital role if you have any suggestions so that proper amendment can take place to improve the same for the benefit of entire research community.

As FARSE, you will be given a renowned, secure and free professional email address with 100 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.



The FARSE will be eligible for a free application of standardization of their researches. Standardization of research will be subject to acceptability within stipulated norms as the next step after publishing in a journal. We shall depute a team of specialized research professionals who will render their services for elevating your researches to next higher level, which is worldwide open standardization.

The FARSE member can apply for grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A. Once you are designated as FARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria. After certification of all your credentials by OARS, they will be published on your Fellow Profile link on website https://associationofresearch.org which will be helpful to upgrade the dignity.

The FARSE members can avail the benefits of free research podcasting in Global Research Radio with their research documents. After publishing the work, (including published elsewhere worldwide with proper authorization) you can upload your research paper with your recorded voice or you can utilize chargeable services of our professional RJs to record your paper in their voice on request.

The FARSE member also entitled to get the benefits of free research podcasting of their research documents through video clips. We can also streamline your conference videos and display your slides/ online slides and online research video clips at reasonable charges, on request.

The FARSE is eligible to earn from sales proceeds of his/her researches/reference/review Books or literature, while publishing with Global Journals. The FARSE can decide whether he/she would like to publish his/her research in a closed manner. In this case, whenever readers purchase that individual research paper for reading, maximum 60% of its profit earned as royalty by Global Journals, will be credited to his/her bank account. The entire entitled amount will be credited to his/her bank account exceeding limit of minimum fixed balance. There is no minimum time limit for collection. The FARSE member can decide its price and we can help in making the right decision.

The FARSE member is eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get remuneration of 15% of author fees, taken from the author of a respective paper. After reviewing 5 or more papers you can request to transfer the amount to your bank account.

MEMBER OF ASSOCIATION OF RESEARCH SOCIETY IN ENGINEERING (MARSE)

The ' MARSE ' title is accorded to a selected professional after the approval of the Editor-in-Chief / Editorial Board Members/Dean.

The “MARSE” is a dignified ornament which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., MARSE or William Walldroff, M.S., MARSE.

MARSE accrediting is an honor. It authenticates your research activities. After becoming MARSE, you can add 'MARSE' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, Visiting Card and Name Plate etc.

The following benefitscan be availed by you only for next three years from the date of certification.

MARSE designated members are entitled to avail a 25% discount while publishing their research papers (of a single author) in Global Journals Inc., if the same is accepted by our Editorial Board and Peer Reviewers. If you are a main author or co-author of a group of authors, you will get discount of 10%.

As MARSE, you will be given a renowned, secure and free professional email address with 30 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The MARSE member can apply for approval, grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A.

Once you are designated as MARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria.

It is mandatory to read all terms and conditions carefully.

Institutional Fellow of Open Association of Research Society (USA)-OARS (USA)

Global Journals Incorporation (USA) is accredited by Open Association of Research Society, U.S.A (OARS) and in turn, affiliates research institutions as "Institutional Fellow of Open Association of Research Society" (IFOARS).

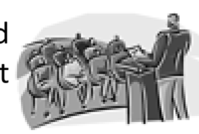
The "FARSC" is a dignified title which is accorded to a person's name viz. Dr. John E. Hall, Ph.D., FARSC or William Walldroff, M.S., FARSC.

The IFOARS institution is entitled to form a Board comprised of one Chairperson and three to five board members preferably from different streams. The Board will be recognized as "Institutional Board of Open Association of Research Society"-(IBOARS).

The Institute will be entitled to following benefits:

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%.



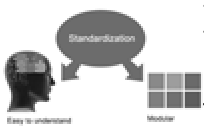
The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.

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.

The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.



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.

Open Association of Research Society (US)/ Global Journals Incorporation (USA), as described in Corporate Statements, are educational, research publishing and professional membership organizations. Achieving our individual Fellow or Associate status is based mainly on meeting stated educational research requirements.

Disbursement of 40% Royalty earned through Global Journals : Researcher = 50%, Peer Reviewer = 37.50%, Institution = 12.50% E.g. Out of 40%, the 20% benefit should be passed on to researcher, 15 % benefit towards remuneration should be given to a reviewer and remaining 5% is to be retained by the institution.

We shall provide print version of 12 issues of any three journals [as per your requirement] out of our 38 journals worth $ 2376 USD.

Other:

The individual Fellow and Associate designations accredited by Open Association of Research Society (US) credentials signify guarantees following achievements:

- The professional accredited with Fellow honor, is entitled to various benefits viz. name, fame, honor, regular flow of income, secured bright future, social status etc.

- In addition to above, if one is single author, then entitled to 40% discount on publishing research paper and can get 10%discount if one is co-author or main author among group of authors.
- 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.
- The Fellow can become member of Editorial Board Member after completing 3yrs.
- The Fellow can earn 60% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.
- Fellow can also join as paid peer reviewer and earn 15% remuneration of author charges and can also get an opportunity to join as member of the Editorial Board of Global Journals Incorporation (USA)
- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

Note :

"

- 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.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone. "

Process of submission of Research Paper

The Area or field of specialization may or may not be of any category as mentioned in 'Scope of Journal' menu of the GlobalJournals.org website. There are 37 Research Journal categorized with Six parental Journals GJCST, GJMR, GJRE, GJMBR, GJSFR, GJHSS. For Authors should prefer the mentioned categories. There are three widely used systems UDC, DDC and LCC. The details are available as 'Knowledge Abstract' at Home page. The major advantage of this coding is that, the research work will be exposed to and shared with all over the world as we are being abstracted and indexed worldwide.

The paper should be in proper format. The format can be downloaded from first page of 'Author Guideline' Menu. The Author is expected to follow the general rules as mentioned in this menu. The paper should be written in MS-Word Format (*.DOC,*.DOCX).

The Author can submit the paper either online or offline. The authors should prefer online submission.Online Submission: There are three ways to submit your paper:

(A) (I) First, register yourself using top right corner of Home page then Login. If you are already registered, then login using your username and password.

(II) Choose corresponding Journal.

(III) Click 'Submit Manuscript'. Fill required information and Upload the paper.

(B) If you are using Internet Explorer, then Direct Submission through Homepage is also available.

(C) If these two are not conveninet , and then email the paper directly to dean@globaljournals.org.

Offline Submission: Author can send the typed form of paper by Post. However, online submission should be preferred.

MANUSCRIPT STYLE INSTRUCTION **(Must be strictly followed)**

Page Size: 8.27" X 11'"

- Left Margin: 0.65
- Right Margin: 0.65
- Top Margin: 0.75
- Bottom Margin: 0.75
- Font type of all text should be Swis 721 Lt BT.
- Paper Title should be of Font Size 24 with one Column section.
- Author Name in Font Size of 11 with one column as of Title.
- Abstract Font size of 9 Bold, “Abstract” word in Italic Bold.
- Main Text: Font size 10 with justified two columns section
- Two Column with Equal Column with of 3.38 and Gaping of .2
- First Character must be three lines Drop capped.
- Paragraph before Spacing of 1 pt and After of 0 pt.
- Line Spacing of 1 pt
- Large Images must be in One Column
- Numbering of First Main Headings (Heading 1) must be in Roman Letters, Capital Letter, and Font Size of 10.
- Numbering of Second Main Headings (Heading 2) must be in Alphabets, Italic, and Font Size of 10.

You can use your own standard format also.
Author Guidelines:

1. General,

2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript’s Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

1. GENERAL

Before submitting your research paper, one is advised to go through the details as mentioned in following heads. It will be beneficial, while peer reviewer justify your paper for publication.

Scope

The Global Journals Inc. (US) welcome the submission of original paper, review paper, survey article relevant to the all the streams of Philosophy and knowledge. The Global Journals Inc. (US) is parental platform for Global Journal of Computer Science and Technology, Researches in Engineering, Medical Research, Science Frontier Research, Human Social Science, Management, and Business organization. The choice of specific field can be done otherwise as following in Abstracting and Indexing Page on this Website. As the all Global

Journals Inc. (US) are being abstracted and indexed (in process) by most of the reputed organizations. Topics of only narrow interest will not be accepted unless they have wider potential or consequences.

2. ETHICAL GUIDELINES

Authors should follow the ethical guidelines as mentioned below for publication of research paper and research activities.

Papers are accepted on strict understanding that the material in whole or in part has not been, nor is being, considered for publication elsewhere. If the paper once accepted by Global Journals Inc. (US) and Editorial Board, will become the copyright of the Global Journals Inc. (US).

Authorship: The authors and coauthors should have active contribution to conception design, analysis and interpretation of findings. They should critically review the contents and drafting of the paper. All should approve the final version of the paper before submission

The Global Journals Inc. (US) follows the definition of authorship set up by the Global Academy of Research and Development. According to the Global Academy of R&D authorship, criteria must be based on:

1) Substantial contributions to conception and acquisition of data, analysis and interpretation of the findings.

2) Drafting the paper and revising it critically regarding important academic content.

3) Final approval of the version of the paper to be published.

All authors should have been credited according to their appropriate contribution in research activity and preparing paper. Contributors who do not match the criteria as authors may be mentioned under Acknowledgement.

Acknowledgements: Contributors to the research other than authors credited should be mentioned under acknowledgement. The specifications of the source of funding for the research if appropriate can be included. Suppliers of resources may be mentioned along with address.

Appeal of Decision: The Editorial Board’s decision on publication of the paper is final and cannot be appealed elsewhere.

Permissions: It is the author's responsibility to have prior permission if all or parts of earlier published illustrations are used in this paper.

Please mention proper reference and appropriate acknowledgements wherever expected.

If all or parts of previously published illustrations are used, permission must be taken from the copyright holder concerned. It is the author's responsibility to take these in writing.

Approval for reproduction/modification of any information (including figures and tables) published elsewhere must be obtained by the authors/copyright holders before submission of the manuscript. Contributors (Authors) are responsible for any copyright fee involved.

3. SUBMISSION OF MANUSCRIPTS

Manuscripts should be uploaded via this online submission page. The online submission is most efficient method for submission of papers, as it enables rapid distribution of manuscripts and consequently speeds up the review procedure. It also enables authors to know the status of their own manuscripts by emailing us. Complete instructions for submitting a paper is available below.

Manuscript submission is a systematic procedure and little preparation is required beyond having all parts of your manuscript in a given format and a computer with an Internet connection and a Web browser. Full help and instructions are provided on-screen. As an author, you will be prompted for login and manuscript details as Field of Paper and then to upload your manuscript file(s) according to the instructions.

To avoid postal delays, all transaction is preferred by e-mail. A finished manuscript submission is confirmed by e-mail immediately and your paper enters the editorial process with no postal delays. When a conclusion is made about the publication of your paper by our Editorial Board, revisions can be submitted online with the same procedure, with an occasion to view and respond to all comments.

Complete support for both authors and co-author is provided.

4. MANUSCRIPT'S CATEGORY

Based on potential and nature, the manuscript can be categorized under the following heads:

Original research paper: Such papers are reports of high-level significant original research work.

Review papers: These are concise, significant but helpful and decisive topics for young researchers.

Research articles: These are handled with small investigation and applications

Research letters: The letters are small and concise comments on previously published matters.

5.STRUCTURE AND FORMAT OF MANUSCRIPT

The recommended size of original research paper is less than seven thousand words, review papers fewer than seven thousands words also.Preparation of research paper or how to write research paper, are major hurdle, while writing manuscript. The research articles and research letters should be fewer than three thousand words, the structure original research paper; sometime review paper should be as follows:

Papers: These are reports of significant research (typically less than 7000 words equivalent, including tables, figures, references), and comprise:

(a)Title should be relevant and commensurate with the theme of the paper.

(b) A brief Summary, "Abstract" (less than 150 words) containing the major results and conclusions.

(c) Up to ten keywords, that precisely identifies the paper's subject, purpose, and focus.

(d) An Introduction, giving necessary background excluding subheadings; objectives must be clearly declared.

(e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition; sources of information must be given and numerical methods must be specified by reference, unless non-standard.

(f) Results should be presented concisely, by well-designed tables and/or figures; the same data may not be used in both; suitable statistical data should be given. All data must be obtained with attention to numerical detail in the planning stage. As reproduced design has been recognized to be important to experiments for a considerable time, the Editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned un-refereed;

(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

(h) Brief Acknowledgements.

(i) References in the proper form.

Authors should very cautiously consider the preparation of papers to ensure that they communicate efficiently. Papers are much more likely to be accepted, if they are cautiously designed and laid out, contain few or no errors, are summarizing, and be conventional to the approach and instructions. They will in addition, be published with much less delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and to make suggestions to improve briefness.

It is vital, that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

Format

Language: The language of publication is UK English. Authors, for whom English is a second language, must have their manuscript efficiently edited by an English-speaking person before submission to make sure that, the English is of high excellence. It is preferable, that manuscripts should be professionally edited.

Standard Usage, Abbreviations, and Units: Spelling and hyphenation should be conventional to The Concise Oxford English Dictionary. Statistics and measurements should at all times be given in figures, e.g. 16 min, except for when the number begins a sentence. When the number does not refer to a unit of measurement it should be spelt in full unless, it is 160 or greater.

Abbreviations supposed to be used carefully. The abbreviated name or expression is supposed to be cited in full at first usage, followed by the conventional abbreviation in parentheses.

Metric SI units are supposed to generally be used excluding where they conflict with current practice or are confusing. For illustration, 1.4 l rather than 1.4 × 10-3 m3, or 4 mm somewhat than 4 × 10-3 m. Chemical formula and solutions must identify the form used, e.g. anhydrous or hydrated, and the concentration must be in clearly defined units. Common species names should be followed by underlines at the first mention. For following use the generic name should be constricted to a single letter, if it is clear.

Structure

All manuscripts submitted to Global Journals Inc. (US), ought to include:

Title: The title page must carry an instructive title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) wherever the work was carried out. The full postal address in addition with the e-mail address of related author must be given. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining and indexing.

Abstract, used in Original Papers and Reviews:

Optimizing Abstract for Search Engines

Many researchers searching for information online will use search engines such as Google, Yahoo or similar. By optimizing your paper for search engines, you will amplify the chance of someone finding it. This in turn will make it more likely to be viewed and/or cited in a further work. Global Journals Inc. (US) have compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Key Words

A major linchpin in research work for the writing research paper is the keyword search, which one will employ to find both library and Internet resources.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy and planning a list of possible keywords and phrases to try.

Search engines for most searches, use Boolean searching, which is somewhat different from Internet searches. The Boolean search uses "operators," words (and, or, not, and near) that enable you to expand or narrow your affords. Tips for research paper while preparing research paper are very helpful guideline of research paper.

Choice of key words is first tool of tips to write research paper. Research paper writing is an art.A few tips for deciding as strategically as possible about keyword search:

- One should start brainstorming lists of possible keywords before even begin searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in research paper?" Then consider synonyms for the important words.
- It may take the discovery of only one relevant paper to let steer in the right keyword direction because in most databases, the keywords under which a research paper is abstracted are listed with the paper.
- One should avoid outdated words.

Keywords are the key that opens a door to research work sources. Keyword searching is an art in which researcher's skills are bound to improve with experience and time.

Numerical Methods: Numerical methods used should be clear and, where appropriate, supported by references.

Acknowledgements: Please make these as concise as possible.

References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

References to information on the World Wide Web can be given, but only if the information is available without charge to readers on an official site. Wikipedia and Similar websites are not allowed where anyone can change the information. Authors will be asked to make available electronic copies of the cited information for inclusion on the Global Journals Inc. (US) homepage at the judgment of the Editorial Board.

The Editorial Board and Global Journals Inc. (US) recommend that, citation of online-published papers and other material should be done via a DOI (digital object identifier). If an author cites anything, which does not have a DOI, they run the risk of the cited material not being noticeable.

The Editorial Board and Global Journals Inc. (US) recommend the use of a tool such as Reference Manager for reference management and formatting.

Tables, Figures and Figure Legends

Tables: Tables should be few in number, cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g. Table 4, a self-explanatory caption and be on a separate sheet. Vertical lines should not be used.

Figures: Figures are supposed to be submitted as separate files. Always take in a citation in the text for each figure using Arabic numbers, e.g. Fig. 4. Artwork must be submitted online in electronic form by e-mailing them.

Preparation of Electronic Figures for Publication

Even though low quality images are sufficient for review purposes, print publication requires high quality images to prevent the final product being blurred or fuzzy. Submit (or e-mail) EPS (line art) or TIFF (halftone/photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Do not use pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings) in relation to the imitation size. Please give the data for figures in black and white or submit a Color Work Agreement Form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution (at final image size) ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs) : >350 dpi; figures containing both halftone and line images: >650 dpi.

Figure Legends: Self-explanatory legends of all figures should be incorporated separately under the heading 'Legends to Figures'. In the full-text online edition of the journal, figure legends may possibly be truncated in abbreviated links to the full screen version. Therefore, the first 100 characters of any legend should notify the reader, about the key aspects of the figure.

6. AFTER ACCEPTANCE

Upon approval of a paper for publication, the manuscript will be forwarded to the dean, who is responsible for the publication of the Global Journals Inc. (US).

6.1 Proof Corrections

The corresponding author will receive an e-mail alert containing a link to a website or will be attached. A working e-mail address must therefore be provided for the related author.

Acrobat Reader will be required in order to read this file. This software can be downloaded

(Free of charge) from the following website:

www.adobe.com/products/acrobat/readstep2.html. This will facilitate the file to be opened, read on screen, and printed out in order for any corrections to be added. Further instructions will be sent with the proof.

Proofs must be returned to the dean at dean@globaljournals.org within three days of receipt.

As changes to proofs are costly, we inquire that you only correct typesetting errors. All illustrations are retained by the publisher. Please note that the authors are responsible for all statements made in their work, including changes made by the copy editor.

6.2 Early View of Global Journals Inc. (US) (Publication Prior to Print)

The Global Journals Inc. (US) are enclosed by our publishing's Early View service. Early View articles are complete full-text articles sent in advance of their publication. Early View articles are absolute and final. They have been completely reviewed, revised and edited for publication, and the authors' final corrections have been incorporated. Because they are in final form, no changes can be made after sending them. The nature of Early View articles means that they do not yet have volume, issue or page numbers, so Early View articles cannot be cited in the conventional way.

6.3 Author Services

Online production tracking is available for your article through Author Services. Author Services enables authors to track their article - once it has been accepted - through the production process to publication online and in print. Authors can check the status of their articles online and choose to receive automated e-mails at key stages of production. The authors will receive an e-mail with a unique link that enables them to register and have their article automatically added to the system. Please ensure that a complete e-mail address is provided when submitting the manuscript.

6.4 Author Material Archive Policy

Please note that if not specifically requested, publisher will dispose off hardcopy & electronic information submitted, after the two months of publication. If you require the return of any information submitted, please inform the Editorial Board or dean as soon as possible.

6.5 Offprint and Extra Copies

A PDF offprint of the online-published article will be provided free of charge to the related author, and may be distributed according to the Publisher's terms and conditions. Additional paper offprint may be ordered by emailing us at: editor@globaljournals.org .

You must strictly follow above Author Guidelines before submitting your paper or else we will not at all be responsible for any corrections in future in any of the way.

Before start writing a good quality Computer Science Research Paper, let us first understand what is Computer Science Research Paper? So, Computer Science Research Paper is the paper which is written by professionals or scientists who are associated to Computer Science and Information Technology, or doing research study in these areas. If you are novel to this field then you can consult about this field from your supervisor or guide.

TECHNIQUES FOR WRITING A GOOD QUALITY RESEARCH PAPER:

1. Choosing the topic: In most cases, the topic is searched by the interest of author but it can be also suggested by the guides. You can have several topics and then you can judge that in which topic or subject you are finding yourself most comfortable. This can be done by asking several questions to yourself, like Will I be able to carry our search in this area? Will I find all necessary recourses to accomplish the search? Will I be able to find all information in this field area? If the answer of these types of questions will be "Yes" then you can choose that topic. In most of the cases, you may have to conduct the surveys and have to visit several places because this field is related to Computer Science and Information Technology. Also, you may have to do a lot of work to find all rise and falls regarding the various data of that subject. Sometimes, detailed information plays a vital role, instead of short information.

2. Evaluators are human: First thing to remember that evaluators are also human being. They are not only meant for rejecting a paper. They are here to evaluate your paper. So, present your Best.

3. Think Like Evaluators: If you are in a confusion or getting demotivated that your paper will be accepted by evaluators or not, then think and try to evaluate your paper like an Evaluator. Try to understand that what an evaluator wants in your research paper and automatically you will have your answer.

4. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

5. Ask your Guides: If you are having any difficulty in your research, then do not hesitate to share your difficulty to your guide (if you have any). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work then ask the supervisor to help you with the alternative. He might also provide you the list of essential readings.

6. Use of computer is recommended: As you are doing research in the field of Computer Science, then this point is quite obvious.

7. Use right software: Always use good quality software packages. If you are not capable to judge good software then you can lose quality of your paper unknowingly. There are various software programs available to help you, which you can get through Internet.

8. Use the Internet for help: An excellent start for your paper can be by using the Google. It is an excellent search engine, where you can have your doubts resolved. You may also read some answers for the frequent question how to write my research paper or find model research paper. From the internet library you can download books. If you have all required books make important reading selecting and analyzing the specified information. Then put together research paper sketch out.

9. Use and get big pictures: Always use encyclopedias, Wikipedia to get pictures so that you can go into the depth.

10. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right! It is a good habit, which helps to not to lose your continuity. You should always use bookmarks while searching on Internet also, which will make your search easier.

11. Revise what you wrote: When you write anything, always read it, summarize it and then finalize it.

12. Make all efforts: Make all efforts to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in introduction, that what is the need of a particular research paper. Polish your work by good skill of writing and always give an evaluator, what he wants.

13. Have backups: When you are going to do any important thing like making research paper, you should always have backup copies of it either in your computer or in paper. This will help you to not to lose any of your important.

14. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several and unnecessary diagrams will degrade the quality of your paper by creating "hotchpotch." So always, try to make and include those diagrams, which are made by your own to improve readability and understandability of your paper.

15. Use of direct quotes: When you do research relevant to literature, history or current affairs then use of quotes become essential but if study is relevant to science then use of quotes is not preferable.

16. Use proper verb tense: Use proper verb tenses in your paper. Use past tense, to present those events that happened. Use present tense to indicate events that are going on. Use future tense to indicate future happening events. Use of improper and wrong tenses will confuse the evaluator. Avoid the sentences that are incomplete.

17. Never use online paper: If you are getting any paper on Internet, then never use it as your research paper because it might be possible that evaluator has already seen it or maybe it is outdated version.

18. Pick a good study spot: To do your research studies always try to pick a spot, which is quiet. Every spot is not for studies. Spot that suits you choose it and proceed further.

19. Know what you know: Always try to know, what you know by making objectives. Else, you will be confused and cannot achieve your target.

20. Use good quality grammar: Always use a good quality grammar and use words that will throw positive impact on evaluator. Use of good quality grammar does not mean to use tough words, that for each word the evaluator has to go through dictionary. Do not start sentence with a conjunction. Do not fragment sentences. Eliminate one-word sentences. Ignore passive voice. Do not ever use a big word when a diminutive one would suffice. Verbs have to be in agreement with their subjects. Prepositions are not expressions to finish sentences with. It is incorrect to ever divide an infinitive. Avoid clichés like the disease. Also, always shun irritating alliteration. Use language that is simple and straight forward. put together a neat summary.

21. Arrangement of information: Each section of the main body should start with an opening sentence and there should be a changeover at the end of the section. Give only valid and powerful arguments to your topic. You may also maintain your arguments with records.

22. Never start in last minute: Always start at right time and give enough time to research work. Leaving everything to the last minute will degrade your paper and spoil your work.

23. Multitasking in research is not good: Doing several things at the same time proves bad habit in case of research activity. Research is an area, where everything has a particular time slot. Divide your research work in parts and do particular part in particular time slot.

24. Never copy others' work: Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

25. Take proper rest and food: No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

26. Go for seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

28. Make colleagues: Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

29. Think technically: Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

31. Adding unnecessary information: Do not add unnecessary information, like, I have used MS Excel to draw graph. Do not add irrelevant and inappropriate material. These all will create superfluous. Foreign terminology and phrases are not apropos. One should NEVER take a broad view. Analogy in script is like feathers on a snake. Not at all use a large word when a very small one would be sufficient. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Amplification is a billion times of inferior quality than sarcasm.

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.

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.

CRITERION FOR GRADING A RESEARCH PAPER (COMPILATION) BY GLOBAL JOURNALS INC. (US)

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals Inc. (US).

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

Index

save our planet

Global Journal of Researches in Engineering

Visit us on the Web at www.GlobalJournals.org | www.EngineeringResearch.org
or email us at helpdesk@globaljournals.org

9 70116 58698 2 61427 >

ISSN 9755861