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DISCOVERING THOUGHTS AND INVENTING FUTURE

Highlights

- Vehicles Integration Tower
- Environment Control System
- Characterization of Gasoline
- Structural Damage Mitigation

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Environmental Control System for Military & Civil Aircraft

By Prof. D.V.Mahindru, Ms Priyanka Mahendru
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Abstract - With a view to provide cooling, heating, ventilation, humidity/contaminant control and pressurization within aircraft occupied compartments, cargo compartments and electronic equipment bays Environmental Control system is a part of all Military and civil aircrafts . It also caters to other pneumatic demands like windshield demisting, aerofoil anti-icing, door-sealing, fuel-tank pressurization and engine bay ventilation.

The technology used for air conditioning of all types of Military/Civil aircrafts is predominantly Air Cycle air Conditioning. Based upon Joule or Reversed Brayton Cycle, the system utilizes the high temperature, high pressure bleed air extracted from compressor of main engine/APU. It not only enjoys the advantage of simplicity and inherent compactness of pneumatic equipment but also meets the integrated cooling and pressurization requirements of an aircraft.

Both air-cycle based refrigeration system which lowers the enthalpy level of air by transforming heat energy into work and conventional vapor compression cooling system that extracts heat by evaporating a suitable liquid refrigerant have their own limitations.

Keywords : *Air Management System, ventilation, humidity/ contaminant control windshield demisting, aerofoil anti-icing, door-sealing, fuel-tank pressurization engine bay ventilation and pressurization within aircraft.*

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ENVIRONMENTAL CONTROL SYSTEM FOR MILITARY CIVIL AIRCRAFT

Strictly as per the compliance and regulations of:

Environmental Control System for Military & Civil Aircraft

Prof. D.V.Mahindru[α], Ms Priyanka Mahendru[Ω]

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Therefore, off late, efforts are underway to integrate both the cooling systems to provide the most cost effective solution to the problem of dissipation of heat - generated both within (personnel, flight control systems, avionics, etc.) as well as outside (aerodynamic heating & solar radiation) the aircraft The technological challenges that the industry is currently facing in this sector are – reduction of power consumption, better overall reliability with free of scheduled maintenance and improved passenger comfort. While improved control through the use of digital controller, re-circulation and increase in individual efficiency factor would minimize power input, better constancy of temperature, faster air-conditioning of cabin/cockpit and lower noise level might cater to a more comfortable air conditioning system. A better overall reliability may be achieved by incorporating cutting-edge technologies like air-foil bearing in ACM. Air-foil bearing increases the reliability of high speed. A pack concept is also employed nowadays for major ECS components to ease the installation and maintenance in the aircraft and also to reduce overall weight.

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I. Introduction

Environmental Control System or Air Management System, as it is popularly called nowadays, is a generic term used in aircraft industry for system and equipment associated with cooling, heating, ventilation, humidity / contaminant control and Pressurization within aircraft occupied compartments, cargo compartments and electronic equipment bays. It also caters to other pneumatic demands like windshield demisting, aerofoil anti-icing, door-sealing, fuel-tank pressurization and engine bay ventilation. The real challenge for an ECS is to operate and supply adequate cooling over a wide range of ground and flight conditions in a most reliable and efficient manner. Both air-cycle based refrigeration system which lowers the enthalpy level of air by transforming heat energy into work and conventional vapor compression cooling system that extracts heat by evaporating a suitable liquid refrigerant have their own limitations. Therefore, off late, efforts are underway to integrate both the cooling systems to provide the most cost effective solution to the problem of dissipation of heat - generated both within (personnel, flight control systems, avionics, etc.) as well as outside (aerodynamic heating & solar radiation) the aircraft. The areas of concern in ECS which are also drawing much attention nowadays are reduction in power consumption, packaging, schedule free maintenance, easy diagnosis & trouble shooting of malfunction, passenger/pilot comfort and environmental compatibility.

II. Design Technology

a) Air Cycle Air Conditioning

The air cycle refrigeration is the predominant means of air conditioning for commercial and military aircraft of all types. It not only enjoys the advantage of simplicity and inherent compactness of pneumatic equipment but also meets the integrated cooling and pressurization requirements of an aircraft.

Based on Joule or Reversed Brayton air cycle, this system utilizes high pressure, high temperature bleed air, extracted from the compressor of either main engine or APU. It is first routed through a primary heat exchanger where temperature is brought close to the ram-air temperature. After having the pressure of the air boosted by the compressor of the Air Cycle Machine (ACM) it is again led through a secondary heat exchanger for further removal of heat. It is finally expanded in the turbine to obtain sufficiently cold air. This air is then delivered into the cabin/cockpit for cooling, ventilation, and air pressurization requirements. A water separator, normally placed at the exit of the ACM, helps in removing the moisture condensed during expansion process.

Heating is achieved by mixing controlled amount of hot bleed-air, after by-passing the ACM, with the cold air that comes out of it. ECS generally consists of three major sub-systems;

i. *Engine Bleed Air System (EBAS)*

This pneumatic system includes equipment and ducting that supply bleed air from the power source to the air conditioning system. Here the air, tapped from the compressor of the engine/APU, flows through bleed air shut-off-valve (BASOV), Non-Return Valve (NRV) and Pressure Regulating and Shut-Off Valve (PRSOV) before entering the air conditioning system. The solenoid operated BASOV opens when air-conditioning is selected. The NRV is normally fitted to prevent cross flow between engines in the event of single engine operation. The PRSOV limits the bleed air pressure to suit the system requirement.

The technology growth has enabled EBAS, nowadays, to handle bleed air at high temperature. The proprietary Ni-alloy (HAYNES 25 BS HR 40, DEVA Grade 7218/20, etc.) Sealing Rings & Bushes and Carbon Gaskets & Bearings, made out of St. Steel reinforced graphite laminated foils and Carbon Le Carbon JP 600 .Most often, there are two air-conditioning packs for safety (3 packs on B747 and DC10), nominally supplying 50% of air needs, but able to operate at their 180% nominal flow rate in case of one failures. On twin-engine aircraft, each engine bleeding is designed to supply half the total air flow (although the two bleedings are connected). On three-engine aircraft, the third engine bleed is on stand-by for redundancy. On 4-engine aircraft each bleeding only supplies ¼ of the total design flow.

Control valves in all the bleed system below protect against flow reversal, and maximum bleeding (e.g. in case of a break)

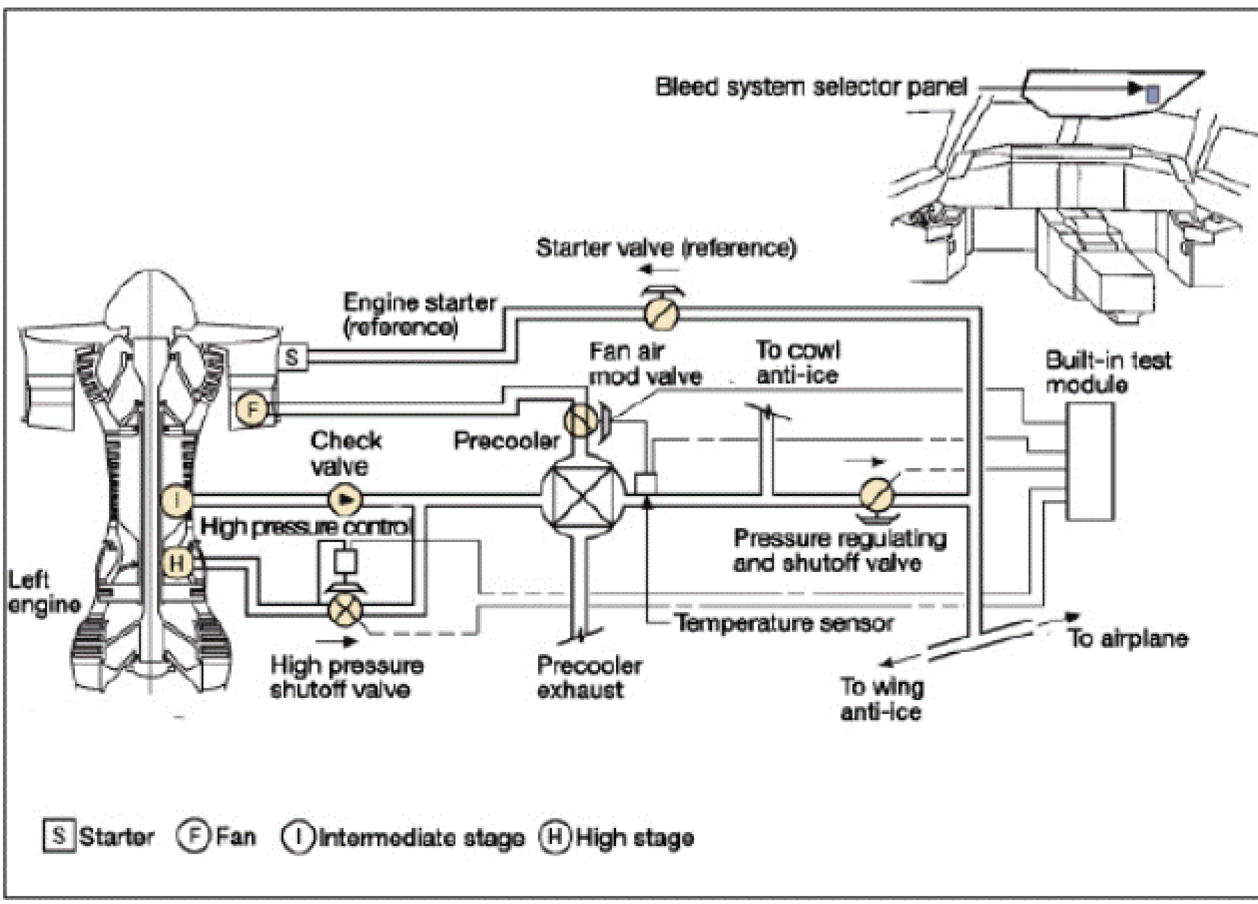

Fig : showing Some of the control valves in the bleed system (from Boeing)

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Flow rate multiplier. If only hot air is needed, a small amount of bled air at 250 kPa and 180 °C may be used to pump the necessary total flow rate (5 L/(s•pax)) from outside air (at 25 kPa, 250 K) with:

- A jet pump.
- A compressor, driven by a turbine in the bled stream.

Respectively are fitted to the high temperature valves and their control units. This enables the system to tap air at a temperature of 550°C to 650°C from high-pressure stages of compressor thus providing higher operational pressure for ECS.

The system has also gained capability of providing altitude compensated pressure regulation of bleed air where the pressure of the bleed-air flowing out of it is regulated with the aircraft altitude thus optimizing the tapping of bleed air in accordance with the cooling load of the aircraft. As for example, the pressure regulation characteristic of PRSOV used in LCA is a smooth curve that limits the pressure to 6.5, 5.0 and 4.3 bar at a height of 0, 7 and 15 km from the sea-level respectively. As a system protection device, when PRSOV fails open, EBAS incorporates an overpressure switch. The function of this switch is to sense the rising pressure downstream of the PRSOV and send signal to close all SOVs. The overpressure switch used in LCA EBAS has an over pressure setting of 7.35 $\pm$ 0.35 bars to restrict the max. transient downstream pressure of the PRSOV to this value.

ii. *Air conditioning System*

The design of air conditioning system always centers around its air cycle machine. Modern day's system has evolved from simple low flow turbo-cooler based refrigeration with low pressure water separator, manual temperature control and water-air/air-air radiator to intelligent digital controller based air conditioning & temperature Control System configured with 2-wheel, 3-wheel or 4-wheel boot strap air cycle machine, high pressure water extraction, regenerative heating and light weight air-to-air heat-exchangers.

a. *Digital Controller*

The digital controller based ECS not only maintain cabin/cockpit temperature with a high degree of precision but also offers numerous options such as digital temperature displays and inputs, digital bus connectivity (to on-board computer) Laptop based diagnostics s/w and re-programmable control equation inputs. Sensor at the inlet of the cabin/cockpit allows it to precisely control the temperature of air entering the cabin as control algorithms constantly calculate the inflow temperature required to meet the changing temperature requirements. The system is also capable of maintaining the correct air temperature entering the ACM through a sensor located at the d/s of the primary heat exchanger and then controlling the amount of by-pass bleed air for the Primary Heat Exchanger. This results in an optimum inlet condition for the ACM and guarantees an efficient operation of the unit.

The digitally controlled inflow control system also have the unique ability to set multiple inflow rates for multiple flight conditions as against single or dual flow setting system typically found in pressure regulator or flow limiting orifice based bleed flow control system. All these facilities reduce the pilot load tremendously.

b. *High Pressure Water Removal*

High pressure water extraction loop comprise of condenser, high pressure water separator and re-heater. This moisture removal technology eliminates icing at ACM outlet, enables turbine exit temperature to attain sub zero state and avoids the usage of complex condensing type heat exchanger. It also obviates regular maintenance involved in conventional type low-pressure water separator and complexity of ducting.

c. *Air Cycle Machine*

The design of ECS normally centers around a high efficiency air cycle machines. These are generally 2-wheel units comprising of either centrifugal compressor and radial turbine or radial/axial fan and a radial/axial turbine mounted on the same shaft. However, technology improvement has introduced 3 wheel ACM consisting of a turbine, compressor and fan and 4 wheel ACM consisting of two turbines, a compressor and a fan to achieve a high level of cooling capacity for ECS. These ACMs are in operation particularly in commercial aircraft/Helicopters. A pair of patented Hamilton-Sundstrand four wheel ACMs form the heart of the air management system on the world's largest twinjet the Boeing 777. The centrifugal/axial fans, used in the above units, are either to load the turbines or to induce air flow through heat exchangers or to discharge air over board.

The space and weight constraints in airborne application render the rotating elements in the ACM to extremely small sizes of O/D 75 to 100 mm. Therefore to handle huge air mass flow rate required by the system and also to effect a large enthalpy drop, these turbomachines have a very high rotational speed of 60,000 to 90,000 RPM. Hence criticality of design of these units involves handling of seal leakage, bearing lubrication, balancing of rotating assemblies and counter balancing the end thrusts for all flight conditions

The manufacturing of various detail parts of an air cycle machine maintaining close dimensional and geometrical tolerances is a major challenge to the industry. Generally, 4 or 5-axis CNC machines are used to fabricate Aluminium/Stainless Steel turbine wheels or titanium compressor impellers/blowers. The closeness of the tolerances can be gauged from the fact that the bore dia. of the wheels are maintained within 8-9 microns with ovality restricted to within 3 – 4 microns. The inducers and the exducers of the turbine wheel/compressor matched sets are fabricated using precise investment casting technology.

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The Scroll Sheet Metal Sub-Assy. is made out of 1 mm thick stainless steel sheet using argon gas welding to get the correct volute area distribution. The diffuser ring, which provides a divergent passage for the air at the Scroll Assy. inlet is manufactured through either investment casting or CNC milling and integrated with the cover plate using Electron Beam Welding technology.

The Drilled-hole Nozzle, made out of stainless steel, after fabrication is coated with tungsten-carbide to eliminate the erosion problem associated with high temperature air flow. The holes in this component are drilled in two rows to reduce vibrational effects and increase the endurance life of the expander. Due to space constraint, the two rows are staggered.

The Torus Assembly which houses torus inlet to receive and direct air it to nozzle inlet, torus-outlet for discharging cold air and bypass inlet is manufactured using investment casting.

The assembly of ACM is also equally challenging. The fits and clearances of the mating parts are to be precisely maintained to contain the internal vibration of the unit and prevent rubbing between two parts which leads to undesirable temperature rise within the unit. The rotating elements are also separately balanced in a balancing machine for a min. unbalance of 14 mgm-in. This prevents rotational vibration and ensures a service life of the unit that match with the other rotables fitted in the aircraft. The clearances between the stator and the rotor of the turbomachines e.g. the compressor wheel and the scroll assy. or the turbine wheel and nozzle are maintained to around 0.25 –0.3 mm since the efficiency of the turbo machines is very sensitive to this parameter.

The critical aspect of testing of Air Cycle Machines is accurate measurements of performance parameters at controlled/design inlet conditions. The temperatures are measured by using K type thermocouple or 4 wire RTD. The pressure values are sensed using the static pressure tapping and ceramic sensing elements based pressure transducers. Orifice plates and electronic multivariable flow transmitter are used to measure the mass flow. The vibration level & RPM of the unit is measured and dispayed through accelerometer & magnetic pick up respectively. While the Bourden tube pressure gauges, single/multiple channel digital temperature indicators display the reading on the panels, the output of the RTD, pressure transducer, variable flow transmitter, accelerometer and magnetic pick up are also simultaneously sent to data acquisition system for on line data logging /display and future data analysis and presentation.

iii. *Pressurization system*

The pressurization system comprises of pressurization control, outflow valve, positive pressure relief valve, vaccum/inward relief valve and pressurizing indicating and warning. The system controls absolute pressure of the cabin/cockpit by modulating the outflow of air from it through one or more outflow valve and the rate of pressure change. While the positive pressure relief valve prevents over-pressurizing the aircraft occupied space the vaccum/inward relief valve prevents the pressure inside the cockpit/cabin from becoming less than that desired. Pressure indicators are provided to allow monitoring of cabin altitude, differential pressure and rate of pressure change. Normally the control of cabin altitude in a civil aircraft is isobaric type and maintained around 8000 feet. The warning system sounds alarm if the cabin altitude exceeds approximately 10000 feet. For military aircraft this can be less stringent. Above a certain height the constant differential pressure control overrides the isobaric control and a constant difference between cockpit and ambient pressure of around 5 psi is maintained till the ceiling altitude.

Normally these pressure controllers are electrically operated. However, with the advent of digital controller the pressure controller can be electronically controlled. Algorithms for cabin pressure control can be programmed into the controller to enable maintenance of accurate and comfortable pressure levels inside the cabin/cockpit.

a. *Vapor Cycle System*

The Air cycle refrigeration system, operating on bleed air drawn from the engine, imposes a major fuel penalty on the aircraft. The associated large ram-air drag and icing at the exit of the turboexpander due to moisture content also restricts its application to a certain degree. The vapor cycle systems are free from these deficiencies. It has a high and fairly constant COP compared to air-cycle system whose COP falls with the aircraft Mach No.

The main components of this system are evaporator, compressor, condenser, refrigeration receiver, expansion valve, refrigerant filter drier, high-pressure cut-out switch & blow-out plug. The cooling of occupied and equipment compartment is accomplished by re-circulation of compartment air through the evaporator. Make-up air is generally ducted to the compartment to maintain pressurization and ventilation requirement. Heating is accomplished in the same manner as it is done in the air cycle system.

The filter-drier absorbs moisture and removes foreign matters, acid, sludge etc. As a safety device, the high-pressure cut-off switch shuts down the compressor in the event of excessive refrigerant vapor pressure and protects the system against operational overloads. Provisions are also made to prevent frosting of the evaporator during low cooling load condition and facilitate collecting and draining overboard the moisture.

The main advantage of vapor compressor cycle system is its packaged configuration that facilitates its installation, removal and maintenance in the aircraft. Also, reliability and life span of high performance flight control systems and avionics warrants supply of air at low and constant operating temperature with reduced humidity that is easily obtained using vapor cycle system.

Today, Hamilton-Sundstrand VCS, using high efficiency Nonazeotropic Refrigerant Mixture (NARM) are found in NH NATO helicopter, Sikorsky S-92 Civil Helicopter and USAF F-16. Hybrid systems are also becoming quite popular. Still a proprietory concept of companies like Honeywell, this new technology combines both Vapor Cycle and Air Cycle system to provide air conditioning in the cabin. The system switches from bleed-air to closed loop refrigerant in flight.

The reliability and life span of high performance flight control systems and avionic increase with low & constant operating temperature and reduced humidity and pollution. Only dedicated liquid cooling system can meet this environmental specifications needed for modern avionics. USAF is thus contemplating on integrating electrically driven on-board vapor cycle heat pump into the F-16's current cooling system so that the aircraft may be retrofitted with advanced, reliable avionics and electronics modules at low cost.

III. Conclusions

The technological challenges that the industry is currently facing in this sector are – reduction of power consumption, better overall reliability with free of scheduled maintenance and improved passenger comfort. While improved control through the use of digital controller, re-circulation and increase in individual efficiency factor would minimize power input, better constancy of temperature, faster air-conditioning of cabin/cockpit and lower noise level. All these cater to a more comfortable air conditioning system. A better overall reliability may be achieved by incorporating cutting-edge technologies like air-foil bearing in ACM. Air-foil bearing increases the reliability of high speed turbomachines more than tenfold. It enables the turbomachines to rotate at a higher speed. Since no lubrication is required, these bearings can withstand severe environmental conditions. It also eliminates routine maintenance and oil filling of rotating element bearings. A pack concept is also employed nowadays for major ECS components to ease the installation and maintenance in the aircraft and also to reduce overall weight. It is worth noting that the quality of the volume ofair is maintained from the time it enters the aircraft's engineto the time it is expelled overboard is very high. All of the processesinvolved maintain or reestablish the purity of the air volume.The results of many cabin air quality tests reinforce thisconclusion. As this brief paper illustrates, the ECS of today's jetliners is carefully engineered to provide superior cabin air.

IV. Abbreviations

ACM : Air Cycle Machine
APU : Auxiliary Power Unit
EBAS : Engine Bleed Air System
ECS : Environmental Control System
NATO : North Atlantic Treaty Organization
PSOV: Priming Shut off Valve
RTD : Resistance temperature detectors or resistive thermal devices (RTDs)
USAF : United States Airforce
VCS : Vapor Cycle System

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Petri Nets Applied to the Analysis of Algorithm For Space Vehicles Integration Tower Self Test

By Francisco C. P. Bizarria, Jose W. P. Bizarria, Joao M. Rosario

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Abstract - The satellite launch vehicle currently developed in Brazil, need that their modules are integrated into an unit called by Integration Movable Tower. In the tower structure is installed: moving bridge, elevator, work platforms, doors, movement trucks and other equipment that aids the accomplishment of integration tasks, tests and vehicle launching. In order to perform the foreseen procedures in the aforementioned tasks, the equipment are submitted to several operational tests prior to utilization of integration tower control system. On that context, this work presents a proposal of model developed by means of Petri Nets to represent the algorithm steps that tests the sensors and actuators included into the main equipment installed in the mentioned integration tower. That is carried out computational simulations with the target of identifying the Petri Nets properties that are related to the confusion conflicts and dead lock. The results obtained in the simulations indicates that the proposed model is able of representing the sensors and actuator operation embedded inside a standard equipment during the self test and based upon that is evaluated the algorithm performance.

Keywords : *Self Test, Integration Tower, Space Vehicles, Petri Nets.*

GJRE-D Classification : *FOR Code: 090199*

PETRI NETS APPLIED TO THE ANALYSIS OF ALGORITHM FOR SPACE VEHICLES INTEGRATION TOWER SELF TEST

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Francisco C. P. Bizarria[α], Jose W. P. Bizarria[Ω], Joao M. Rosario[β]

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Keywords : Self Test, Integration Tower, Space Vehicles, Petri Nets.

I. Introduction

The Satellite Launch Vehicle (SLV), illustrated in the figure 1, is currently being developed in Brazil by Institute of Aeronautics and Space. To be launched that vehicle requires that their modules are integrated vertically in the rockets launch center inside a specific site called by Integration Movable Tower (IMT), indicated in the figure 2 [1]. That tower is supported by means of a metallic structure, shaped as a rectangular cubic, with the main side settled on the vertical position.

Such tower is equipped with: movable bridge, elevator, work platforms (movable and fixed), doors, trucks for movement and other equipment that are dedicated to aid a group of task accomplishment specialists that are related to the integration, tests and also to the launch of the vehicle [2]. In order to comply with all procedures foreseen on these tasks is necessary to expose the people, dedicated to perform such tasks, to the risks inherent to the space segment. That scenario of risks defines a situation where is strategic, in

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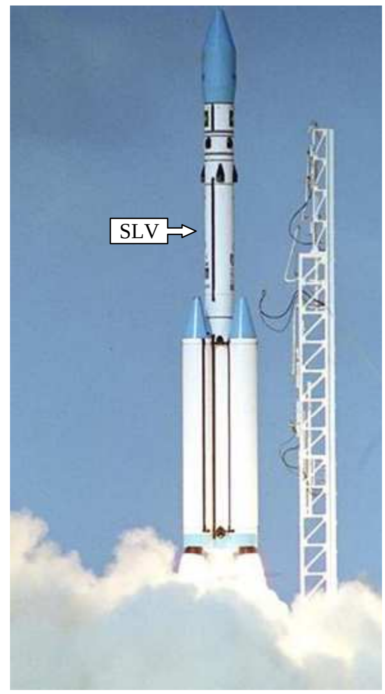

Fig.1 : Satellites Launcher Vehicle Take-off.

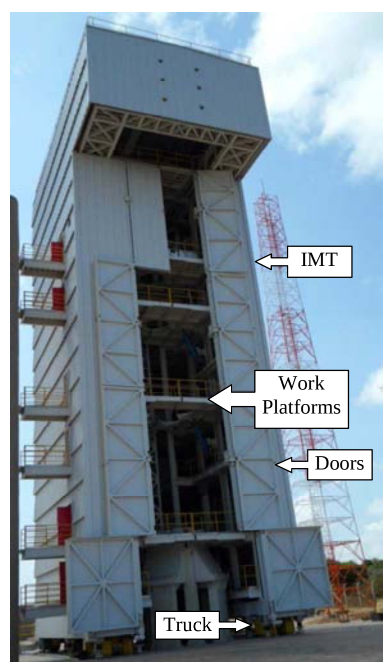

Fig.2 : Integration Movable Tower.

order to increase the safety, that each one of the mentioned equipment is submitted to a several operational tests prior to being used by the tower control system.

The actuation of equipment installed in the Integration Movable Tower (IMT) is carried out by remote mode and managed by an automated system that has basically, in its physical architecture, the elements presented in the figure 3.

The block called Control, represented in the figure 3, has as main function to perform the management of activities developed by the physical architecture of the Integration Movable Tower (IMT) in order to support the procedures established to the accomplishment of integration tasks, tests and vehicle launch.The more relevant parts present on that block are:

Network Interface for Deterministic Protocol (NIDP), Central Processing Unit (CPU) and Network Interface for Probabilistic Protocol (NIPP). The Network Interface for Deterministic Protocol (NIDP), is responsible for generating and receiving signals, related to the deterministic protocol, to allow the communication between the control module and the Input and Output Remote Units (IORU) and/or Smart Actuators (SA).

The main function of the Central Processing Unit (CPU) is to generate the necessary signals to run the system management program [3].Network Interface for Probabilistic Protocol (NIPP) generates and receives signals, related to the probabilistic protocol, to allow the communication between the control module and the Host Computer (HC) of the Server (SER).

The Deterministic Communication Line (DCL) is the physical link that transfers the signals between the Network Interface for Deterministic Protocol (NIDP) and the Input and Output Remote Units (IORU) and/or Smart Actuators (SA) of bidirectional mode.

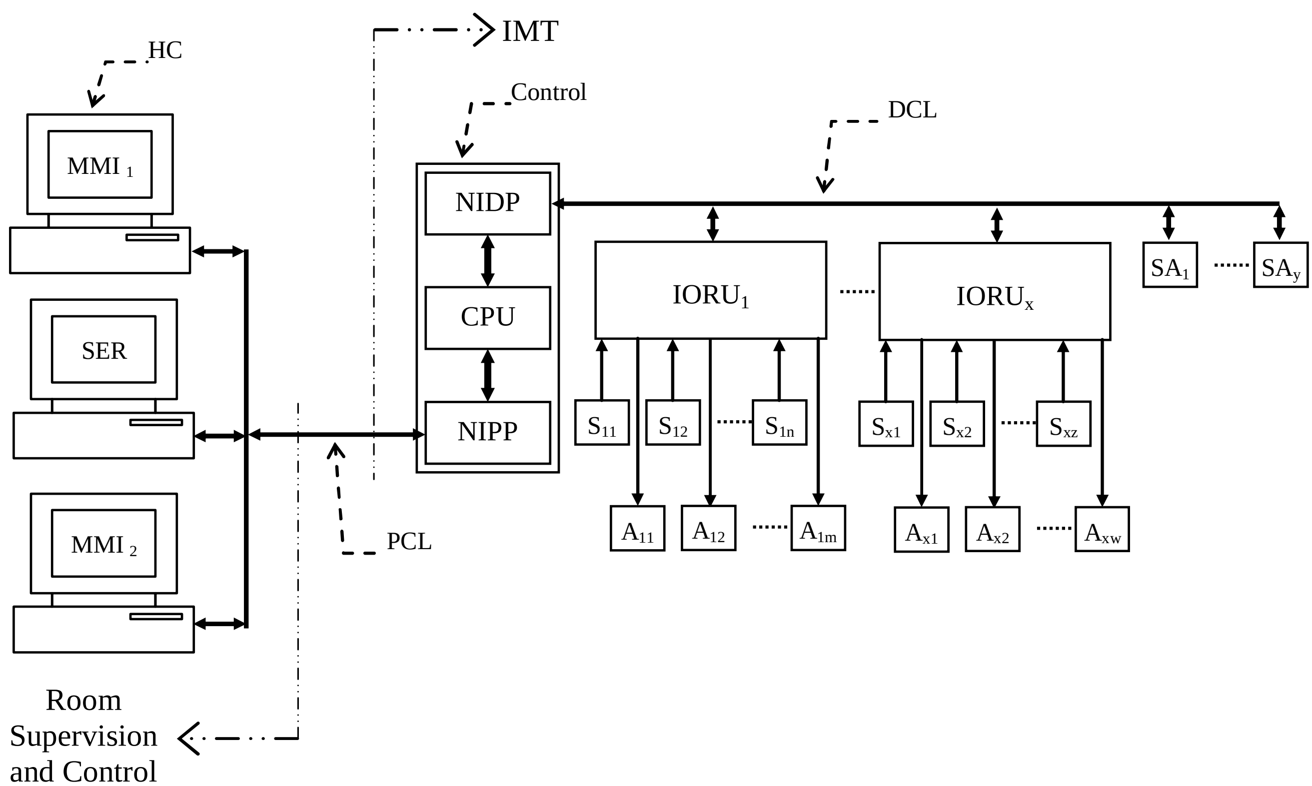

Fig.3 : Elements from physical architecture adopted for automation of the Integration Movable Tower.

The Input and Output Remote Units (IORU) are responsible for generating and receiving signals, related to the deterministic protocol, to allow the communication between the Network Interface for Deterministic Protocol (NIDP) and the sensors and/or actuators, which have no self test system, present in the equipment installed in the Integration Movable Tower (IMT). Those units are able of operating with digital and/or analog inputs and outputs, which support a large range of amplitudes and frequencies of signals [4].

The sensors and actuators present in the equipment(for instance: work platforms, doors etc) installed in the Integration Movable Tower (IMT), which have no self test system are represented respectively by: S11, S12, ... S1n, Sx1, Sx2, ... Sxz and A11, A12, ... A1m, Ax1, Ax2, ... Axw.

The equipment (for instance: movable bridges,elevator, movement trucks etc) present in the Integration Movable Tower (IMT) which have smart actuators equipped with self test are represented by : SA1, ... SAy.

The Probabilistic Communication Line (PCL) is the physical link that transfers the bidirectional signals between: i) the Network Interface for Probabilistic Protocol (NIPP) and the Host Computer (HC) of the Server (SER), ii) the Host Computer (HC) of the Server (SER) and the Host Computer (HC) of the Man Machine Interface 1 (MMI1) and iii) the Host Computer (HC) of the Server (SER) and the Host Computer (HC) of the Man Machine Interface 2 (MMI2) [5].

The main functions of the Server (SER) Host Computer (HC) are focused on: i) managing the system supervision layer, ii) storing and becoming available information related to the database and iii) supporting the requests from Man Machine Interface 1 (MMI1) and Man Machine Interface 2 (MMI 2). Those interfaces are the means that operator uses to supervise and command the actuation of the equipment installed in the Integration Movable Tower. On that context, this work presents a proposal of model created to evaluate the steps of the algorithm that was developed to perform self test of the actuators and sensors that are present in the main equipment installed in the space vehicle integration tower, by means of Petri Nets [6]. Computational simulations are performed on that model, with the goal of identifying the Petri Nets properties that are related mainly with the confusion conflicts and dead lock.

II. Targets of Thework

The main target of this work is to present a proposal of model, created by means of Petri Nets, to evaluate the algorithm that performs the self test in actuators and sensors which are present in the main equipment installed in the Integration Movable Tower (IMT). To present the most relevant results that were obtained in the simulations performed with that model within the context of the confusion conflicts and dead lock.

III. Model Proposed

In the model proposed in the figure 4 are represented the main status that are determined by the algorithm that performs the evaluation of actuators and sensors which are present in the equipment installed in the Integration Movable Tower (IMT), that have no self test incorporated, by means of Petri Nets.

During the development of those nets was used the gathering procedure [7] and considered the components foreseen in the architecture presented in the figure 3.

That model indicates separately the Petri Nets that were developed to represent:

i) Control (CONTROLLER), ii) the actuator and sensors which are present in the equipment (EQUIPMENT) and have no self test, iii) the Man Machine Interface (SELF TEST INTERFACE) and iv) the system to generate faults in the actuator and/or sensors of equipment (FAULTS GENERATOR).

That way of modeling has as main target to allow observing the operational behavior of each part involved in the process during the program simulation that includes the steps foreseen in the self test algorithm. The distribution of positions, transitions, arcs and the quantity of tokens, showed in the figure 4, aims to establish the initial condition of operation of an equipment, that have no self test, present in the physical architecture adopted for the automation of the Integration Movable Tower (IMT).

In the model developed for the CONTROLLER are foreseen specified positions to represent the inputs (I1, I2, I3, I4, I5, I6 and I7) and outputs (O1, O2, O3, O4, O5, O6, O7, O8 and O9) which perform the connections with the models of EQUIPMENT and SELF TEST INTEFACE.

The model operation presented in the figure 4 must comply with the steps foreseen in the analytic flowchart that represents a typical sequence of actions that are performed by the program that runs the actuator and sensors self test, present in a typical equipment (one actuator with two sensors) installed in the Integration Movable Tower (IMT), which is presented in the figure 5.

In the flowchart presented in the figure 5 is foreseen the necessary steps to: i) generate the command of activation and deactivation of the actuators present in the equipment that have no self test and ii) check the faults during operation of actuators and/or sensors [8].

The main status determined by the actuators and sensors present in the equipment installed in the Integration Movable Tower (IMT) are: i) Actuator Off, ii) Actuator On, iii) Sensor Off and iv) Sensor On. Based on that it is important to highlight that the actuator is able of attributing status to the sensors, nonetheless the reciprocal is not true.

The FAULTS GENERATOR was developed to interact directly with the EQUIPMENT model in order to establish the following status possibilities: i) Actuator Off with Sensor Indicating Off, ii) Actuator Off with sensor Indicating On, iii) Actuator Off with one Sensor Indicating Off and other Sensor Indicating On, iv) Actuator Off, v) Actuator On with Sensor Indicating On, vi) Actuator On with Sensor Indicating Off, vii) Actuator On with one Sensor Indicating Off and other Sensor Indicating On and viii) Actuator On. The aforementioned status shall be identified and indicated by the self test algorithm during the equipment test.

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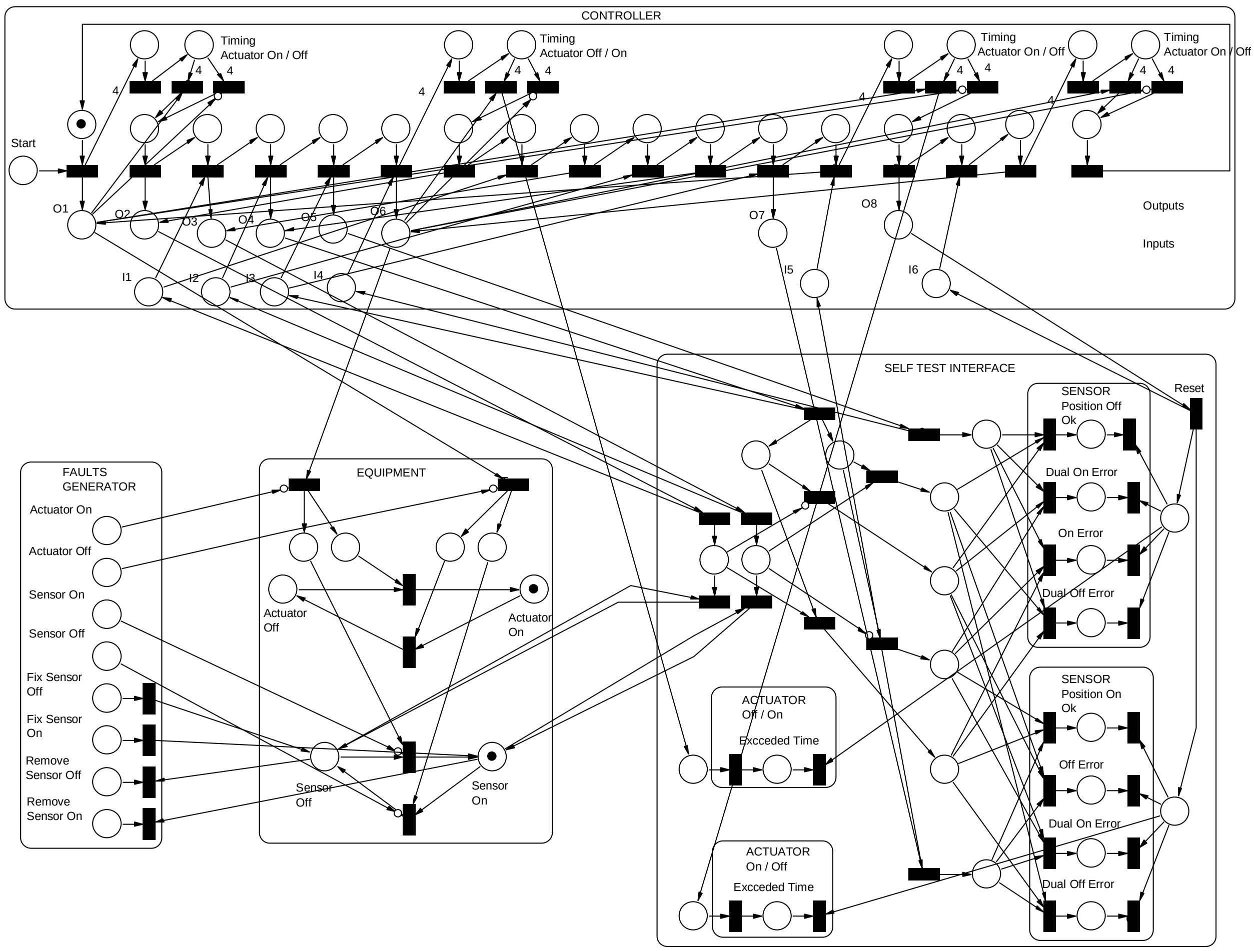

Fig.4 : Models by Petri Nets of physical architecture adopted in the automation of the Integration Movable Tower.

The results obtained in the self test performed by the actuators and sensors present in the equipment are presented in the SELF TEST INTERFACE. That interface is able of indicating the following status: i) Sensor Ok, ii) Sensors with indication of On and Off status (Dual Error On), iii) Sensor failed to On (Error to On), iv) Sensors without status indication (Dual Error Off), v) Actuator with timeout to On (Timeout to On) and vi) Actuator with timeout to Off (Timeout to Off).

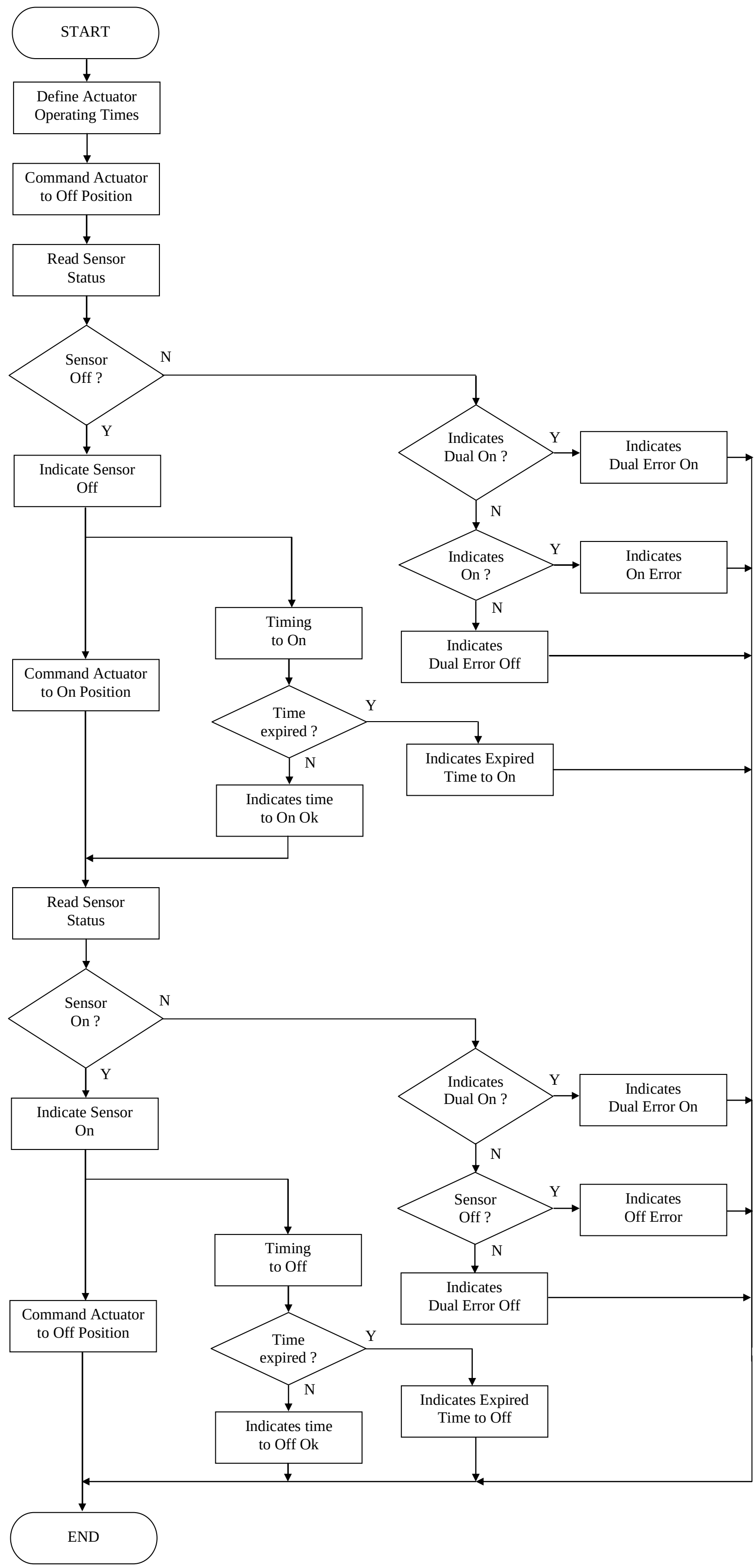

Fig.5 : Analytic flowchart for equipment self test.

IV. Simulation Andanalysis of Properties

The computational simulation of the model proposed in this work aims to represent the algorithm that performs evaluation of the actuators and sensors present in the equipment installed in the Integrated Movable Tower (IMT), that have no self test, by means of Petri Nets. Such simulation was performed exploring all status foreseen in the networks, specially those included in the analytic flowchart presented in the figure 5, employing software Visual Object Net [9].

The confusion conflicts were observed in simulations performed in this work and they were solved inserting restrictions in the transitions involved with the same conflict. The dead lock was not observed in the simulations of the self test algorithm. In the simulation of the proposed model all positions and transitions were respectively achieved and trigged. The quantities of tokens varied during the Petri Nets simulations, nevertheless that situation did not create neither an overflow nor lack of tokens in positions that could degrade the accomplishment of the self test algorithm.

V. Conclusion

The method adopted to model the system, employing Petri Nets, was able of showing details of CONTROLLER operation, EQUIPMENT, SELF TEST INTEFACE and the phases foreseen in the self test algorithm. These elements are included in the physical and logical architecture of the Integration Movable Tower (IMT). That method allowed the individual operational analysis of each part foreseen in the system architecture and that fact facilitates the evaluation of the algorithm performance, which was developed to perform the self test of actuators and sensors that are present in the equipment installed in the mentioned tower.

Regarding to the properties evaluated in this work, only confusion conflict was identified in the system simulation with characteristics for causing undesired consequences. The solution for that situation was obtained inserting restrictions in the transitions involved with the mentioned conflict. Furthermore, that is quite important to emphasize that the installation of sensors in strategic points of the architecture is one possibility of physical solution to limit the effects of the confusion conflict.

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Adaptive Control for Structural Damage Mitigation

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Abstract - Substantial progress has been made in analyzing the integrity of composite structures when macro or nano sensors and actuators are embedded into it. The resulting structure in a dynamic environment is said to be "intelligent" if it performs a certain functional requirements related to vibrations, health, shape, etc. In health, after the damage has been detected, the subject of damage mitigation becomes important, so that in prognosis context (Farrar and Lieven, 2007), the remaining life of the structure is extended. The damage is said to be mitigated if the sensor data of the damaged structure matches with the sensor data of the healthy structure. This is done by applying an actuator loading. In this paper, Model Reference Adaptive Control (Slotine and Li, 1991) is applied for structural damage mitigation. A known finite element model resulting from the structural health monitoring and assessment techniques is adopted to determine the control parameters that mitigate the damage. An example is illustrated using a spring-mass-damper model that depicts a structural model with modal coordinates.

Keywords : Self Test, Integration Tower, Space Vehicles, Petri Nets.

GJRE-D Classification : FOR Code: 090204

ADAPTIVE CONTROL FOR STRUCTURAL DAMAGE MITIGATION

Strictly as per the compliance and regulations of:

Adaptive Control for Structural Damage Mitigation

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Abstract - Substantial progress has been made in analyzing the integrity of composite structures when macro or nano sensors and actuators are embedded into it. The resulting structure in a dynamic environment is said to be "intelligent" if it performs a certain functional requirements related to vibrations, health, shape, etc. In health, after the damage has been detected, the subject of damage mitigation becomes important, so that in prognosis context (Farrar and Lieven, 2007), the remaining life of the structure is extended. The damage is said to be mitigated if the sensor data of the damaged structure matches with the sensor data of the healthy structure. This is done by applying an actuator loading. In this paper, Model Reference Adaptive Control (Slotine and Li, 1991) is applied for structural damage mitigation. A known finite element model resulting from the structural health monitoring and assessment techniques is adopted to determine the control parameters that mitigate the damage. An example is illustrated using a spring-mass-damper model that depicts a structural model with modal coordinates.

I. Introduction

In the last several years, many developments have taken place in the areas of structural health monitoring (SHM). Majority of them not only determine the presence of damage in a structure but also attempt to find the status of the structure through an accurate dynamic model that is uncertain when structural damage identification is divided into high- and low-frequency based excitation methods. Stiffness, damping and mode shape parameter changes are modeled for a relatively broad inspection zone (Yan, Yam, Cheng, and Yu, 2006., Ma and Lui, 2005., Tee, Koh, and Quek, 2005., Meng, Lin, Dong and Wei, 2006) but it applies to a specific frequency range. The bandwidth of the sensor technologies such as fiber-optic sensor (Shivakumar and Bhargava, 2005) and piezoelectric sensors (Ghasemi-Nejhad, 2005) usually limits this frequency-range, model size as well as the damage size. When size and location of the damage through SHM and assessment are known, damage prognosis (Papazian, et al., 2009) and structural health management (Xiaomo, 2010) studies assume a given sensor technology and attempt to determine the remaining life of the material. In this effort, the dynamic loading is assumed to be external and the actuator loading is completely ignored. Through the actuator loads, Model Reference Adaptive Control (MRAC) can be used such that the sensor data from the damaged structure can mimic the healthy structure. Although, damage prognosis study using similar sensor data for healthy and damaged structures is difficult to distinguish, the damage with such actuator loads is then said to be mitigated (Maryam and Luciana, 2010). In this paper, MRAC in state feedback format is investigated for structural damage mitigation (SDM). Some of the attributes of the MRAC are illustrated using the second order spring-mass-damper model that represents a finite element model of structural material in modal coordinate form.

MRAC has been recently investigated for Civil engineering structures (Tu, Jiang, and Stoten, 2010., Chu, Lo, and Chang, 2010), where the response of the structure in real-time is minimized under an earthquake excitations. To extend similar applications of MRAC for other aeronautical and mechanical structures, the SDM problem proposed in this paper assumes integrity of the composite material when macro (Case and Carman, 1994., Mall, 2002., Trease and Kota, 2009) or nano (Chunyu, Thostenson and Tsu-Wei, 2008) sensors and actuators are embedded into it.

The paper is organized with the problem formulation in Section II. In Section III, adaptation law is explained. In Section IV, a procedure to acquire damage and compute control parameters is briefed. In Section V, an example with spring mass-damper system is illustrated. In Section VI, conclusions are presented.

II. Problem Formulation

Consider a single input healthy material in control canonical form as follows:

$$y_m^{(n)} + \bar{\alpha}_{n-1} y_m^{(n-1)} + \cdots + \bar{\alpha}_0 y_m = u(t) + r(t) \qquad (1)$$

Where $r(t)$ is an exogenous input. The n^{th} order differentiation with respect to time variable t is denoted by $y_m^{(n)}$. Let,

$$u(t) = -k_{n-1} y_m^{(n-1)} - \cdots - k_0 y_m \qquad (2)$$

Substituting (2) in (1),

$$y_m^{(n)} + \alpha_{n-1} y_m^{(n-1)} + \cdots + \alpha_0 y_m = r(t) \qquad (3)$$

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Where $\alpha_{n-i} = \overline{\alpha}_{n-i} + k_{n-i}$, $i = 1,2\cdots n$ Without loss of generality, the open loop structure with an excitation load $r(t)$ can be studied by assuming $k_{n-i} = 0$, $i = 1,2\cdots n$. Let the finite element model of a material with damage be,

$$y^{(n)} + a_{n-1}y^{(n-1)} + \cdots + a_0 y = \hat{u}(t) \qquad (4)$$

The parameters a_{n-1}, $a_{n-2}, \cdots, a_0$ are to be acquired using a structural damage assessment technique [18]. The state variables $y, \dot{y}, \cdots y^{(n-1)}$ are measurable. The SDM problem is posed as follows: Find a control law $u\hat{}(t)$ in Eq. (4) such that the sensor data $\{y, \dot{y}, \cdots, y^{(n-1)}\}$ mimics the sensor data of the healthy material $\{y_m, \dot{y}_m, \cdots, y_m^{(n-1)}\}$. In the process, acquire the parameters $\boldsymbol{a} = \{1, a_{n-1}, a_{n-2}, \cdots, a_0\}$ when applying $u\hat{}(t)$ to the damaged material. MRAC is particularly attractive to address this problem. However, to separate control parameters defining the control law $\hat{u}(t)$ from that of the system parameters $\boldsymbol{a}$, a state and parameter estimation technique such as an extended Kalman filter (EKF) (Bauer and Andrisani, 1990., Speyer and Crues, 1987) is required. Currently, all the state variables are assumed to be available as the sensor data. Within this framework, the SDM problem is addressed using two design steps. First, adaptation parameters in MRAC are selected such that the damaged response to an excitation load tracks the healthy response of the material. Next, the adaptation parameters are fixed and this damaged response is utilized as sensor data to find a procedure that acquires damage and determines control parameters. Finally, the control parameters are verified to check if the damaged response is indeed tracking the healthy response.

III. Adaptation Law

Let the Laplace variable be s. Given a Hurwitz polynomial $s^n + \beta_{n-1}s^{n-1} + \cdots + \beta_0$, the control law $\hat{u}(t)$ is given by (Slotine and Li, 1991),

$$\hat{u}(t) = \hat{a}_n z + \hat{a}_{n-1}y^{(n-1)} + \cdots + \hat{a}_0 y = \boldsymbol{v}^T(t)\hat{\boldsymbol{a}}(t), \qquad (5)$$

Where, v^T refers the transpose of v and

$$z(t) = y_m^{(n)} - \beta_{n-1}e^{(n-1)} - \cdots - \beta_0 e,$$

$$e(t) = y(t) - y_m(t),$$

$$\hat{\boldsymbol{a}} = [\hat{a}_n, \hat{a}_{n-1}, \cdots, \hat{a}_1, \hat{a}_0],$$

$$\boldsymbol{v} = [z(t), y^{(n-1)}, \cdots, \dot{y}, y]^T.$$

Let $\tilde{\boldsymbol{a}} = \hat{\boldsymbol{a}} - \boldsymbol{a}$. Then the adaptation law is given by,

$$\dot{\boldsymbol{x}} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{b}\boldsymbol{v}^T\tilde{\boldsymbol{a}}, \quad e = \boldsymbol{c}\,\boldsymbol{x}, \qquad (6a)$$

$$\dot{\tilde{\boldsymbol{a}}} = -\boldsymbol{\Gamma}\boldsymbol{v}\boldsymbol{b}^T\boldsymbol{P}\boldsymbol{x} \qquad (6b)$$

Where,

$$\boldsymbol{x}^T(t) = [y - y_m, \dot{y} - \dot{y}_m, \cdots y^{(n-1)} - y_m^{(n-1)}],$$

$$\boldsymbol{A} = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & . \\ . & . & . & \cdots & . \\ . & . & . & \cdots & . \\ 0 & 0 & 0 & 0 & 1 \\ -\beta_0 & -\beta_1 & -\beta_2 & \cdots & -\beta_{n-1} \end{bmatrix}; \quad \boldsymbol{b} = \begin{bmatrix} 0 \\ 0 \\ . \\ . \\ 0 \\ 1 \end{bmatrix}$$

$$\boldsymbol{c} = [1 \quad 0 \quad . \quad . \quad 0 \quad 0].$$

P, the symmetric positive definite constant matrix, is the solution matrix to the Lyapunov equation given by,

$$\boldsymbol{P}\boldsymbol{A} + \boldsymbol{A}^T\boldsymbol{P} = -\boldsymbol{Q}$$

Q is any positive definite matrix. $\boldsymbol{\Gamma}$ is a positive definite diagonal matrix whose entries refer to an adaptation mechanism with slow or fast parameter convergence depending upon the diagonal values one would like to choose. From Eq. (6), it is further observed that, upon an appropriate numerical integration scheme, the sensor data $\{y, \dot{y}, \cdots, y^{(n-1)}\}$ and the vector $\tilde{\boldsymbol{a}}$ are obtained. Clearly, the adaptation parameters in $\boldsymbol{\Gamma}$ are adjusted in such a way that,

$$y(t) \to y_m(t), \ \dot{y}(t) \to \dot{y}_m(t), \cdots, y^{(n-1)} \to y_m^{(n-1)}.$$

The response $\tilde{\boldsymbol{a}}$ is coupled with the control parameters $\hat{\boldsymbol{a}}$ and system parameters $\boldsymbol{a}$. In fact, when $\boldsymbol{a}$ is time invariant, Eq. (6b) modifies to,

$$\dot{\hat{\boldsymbol{a}}} = -\boldsymbol{\Gamma}\boldsymbol{v}\boldsymbol{b}^T\boldsymbol{P}\boldsymbol{x}.$$

In this paper, an EKF algorithm is applied to separate the control parameters $\hat{\boldsymbol{a}}$ from the system parameters $\boldsymbol{a}$ appearing in $\tilde{\boldsymbol{a}}$, where $\tilde{\boldsymbol{a}}$ can be recalled as given by $\tilde{\boldsymbol{a}} = \hat{\boldsymbol{a}} - \boldsymbol{a}$. It is interesting to observe that the MRAC is sensitive to initial conditions $\tilde{\boldsymbol{a}}(0)$, $\hat{\boldsymbol{a}}(0)$ and $\boldsymbol{a}(0)$. Accordingly, the time histories of $\hat{\boldsymbol{a}}(t)$ and $\boldsymbol{a}(t)$ vary with time. However, $\hat{u}(t)$ in Eq. (5) is guaranteed to track .

$$y(t) \to y_m(t), \ \dot{y}(t) \to \dot{y}_m(t), \cdots, y^{(n-1)} \to y_m^{(n-1)}$$

This attribute of MRAC is utilized to acquire damage, where an appropriate initial condition for $\boldsymbol{a}(t)$ is selected such that $\lim_{t\to\infty} \boldsymbol{a}(t)$ converges to a damaged model which is assumed to be known through a damage assessment techniques. This process is refereed as the *damage acquisition* for SDM. Given $\{y, \dot{y}, \cdots, y^{(n-1)}\}$ a formulation to compute by acquiring $\boldsymbol{a}$ is presented in the next section.

IV. Computation of Control Parameters Through Damage Acquisition

Given $\{y, \dot{y}, \cdots, y^{(n-1)}\}$ obtained by integrating Eq. (6) from the previous section, EKF is applied to separate $\hat{\boldsymbol{a}}$ and $\boldsymbol{a}$ appearing in $\tilde{\boldsymbol{a}}$. The state equations compatible to the EKF will be of the form,

$$\dot{\boldsymbol{\delta}} = \boldsymbol{F}(t, \boldsymbol{\delta}) \tag{7a}$$

$$\boldsymbol{z}_k = \begin{bmatrix} y_k \\ \dot{y}_k \\ \vdots \\ y_k^{(n-2)} \\ y_k^{(n-1)} \end{bmatrix}, \quad k = 1, 2\cdots \tag{7b}$$

Where $\delta^T = \begin{bmatrix} x^T & \hat{\boldsymbol{a}}^T & a_{n-1} & \cdots & a_0 \end{bmatrix}$ is a vector with $3n+1$ components, $\boldsymbol{z}_k$, $k = 1,2\cdots$ is the measurement vector available at discrete time instants t_k, $k = 1,2\cdots$ and $F(t,\boldsymbol{\delta})$ is a system dynamic vector presented below. Note that the sensor measurements for the EKF are the response of the damaged material computed in the previous section using the adaptation parameters specified in the matrix $\boldsymbol{\Gamma}$.

$$\boldsymbol{F}(t, \boldsymbol{\delta}) = \begin{bmatrix} \boldsymbol{Ax} + \boldsymbol{bv}^T\hat{\boldsymbol{a}} - \boldsymbol{bv}^T\boldsymbol{a} \\ -\boldsymbol{\Gamma vb}^T\boldsymbol{Px} \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

Eq. (7) completely specifies the required formulation to apply an EKF algorithm [19, 20]. When $k_{n-i} = 0$, $i = 1, 2 \cdots n$ Or when $y_m(0) = \dot{y}_m(0) = \cdots,\ y_m^{(n-1)}(0) = 0$ the initial condition for the control parameters can be selected as $\boldsymbol{a}$ ^(0) 0. However, for $\boldsymbol{a}$, one has to select the initial conditions $\boldsymbol{a}$ (0) to match the model of the damaged structure as stated in damage acquisition.

The computed system ($\boldsymbol{a}$) and control ($\hat{\boldsymbol{a}}$) parameters are used back again in Eq. (4) and the response of the system is simulated to check if it matches with the sensor data $\{y_m, \dot{y}_m, \cdots, y_m^{(n-1)}\}$ for a for a given exogenous input $r(t)$.If it matches, as adopted by Maryam and Luciana, 2010, the resulting structure with damage is said to be mitigated under an applied load from the actuator that is adaptive to the dynamic loads $r(t)$ appearing in the control input $\hat{u}(t)$. Further, it is inferred that the MRAC adopts a certain trajectory for the system parameters $\boldsymbol{a}$ to compute the control parameters $\hat{\boldsymbol{a}}$ such that the response of the damaged model in Eq. (4) tracks the reference model in Eq. (3). Yet, the problem of finding a finite element model with parameters $\boldsymbol{a}$, remains a fundamental problem in composite materials whenever damage is present (Reddy, 2004). It is observed that the finite element model by MRAC is given in transfer function framework. In the next section, an example is illustrated using a second order spring-mass-damper system.

V. Example

Consider a second order spring-mass-damper system representing a structure in modal coordinates. The undamaged model is taken with the parameters 1.4 $\alpha_1 = 1.4$ And $\alpha_0 = 1$. The exogenous input is $r(t) = \sin(t)$. Let the damaged model be $\ddot{y} + a_1\dot{y} + \cdots + a_0 y = \hat{u}(t)$. Assume steady state values as $a_1(\infty) = 1.2$ and $a_0(\infty) = 0.8$.

The objective in SDM is to find an initial condition for the $\boldsymbol{a}^T = [1\, a_1(0)\ a_0(0)]$ system parameters and determine the control parameters $\hat{\boldsymbol{a}}^T = [\hat{a}_2, \hat{a}_1, \hat{a}_0]$ such that the control law $\hat{u}(t)$ given by $\hat{u}(t) = \hat{a}_2 z - \hat{a}_1\dot{y} - \hat{a}_0 y$ mitigates damage by the tracking Performance $y(t) \to y_m(t)$ and $\dot{y}(t) \to \dot{y}_m(t)$, where $y_m(t)$ and $y_m(t)$ are the response of the undamaged material due to exogenous input $r(t)$. Further $\boldsymbol{a}(t)$ converges to $\boldsymbol{a}^T(\infty) = [1\ 1.2\ \ 0.8]$. Here $z(t)$ is selected such that $z(t) = \ddot{y}_m - 2\dot{e} - 2e$ with $\beta_1 = 2$ and $\beta_0 = 2$. Note that the control law is adaptive to the exogenous input $r(t)$ through the $\ddot{y}_m$ term.

In the first design step, the tracking performance is achieved through the adaptation parameters which were found out to be $\boldsymbol{\Gamma} = diag$ (10,1, 30) . Integrating Eq. (6), with an initial condition for $\tilde{\boldsymbol{a}}$ as $\tilde{\boldsymbol{a}}^T(0) = \begin{bmatrix} -1 - 0.3 - 0.2 \end{bmatrix}$ the responses of the damaged and undamaged material is shown in Fig. 1, which suggest that $y(t) \to y_m(t)$ and $\dot{y}(t) - \dot{y}_m(t)$. These responses of $y(t)$ and $\dot{y}(t)$ are used as measurements in EKF that is used to compute control

($\hat{a}$) and system parameters with damage acquisition in the responses of a . In Fig. 2, the error responses of position $y(t)-y_m(t)$ and speed $\dot{y}(t)-\dot{y}_m(t)$ contained in $x(t)$ are compared with the Kalman filter estimates $\hat{x}$ (t) . In Fig. 3, the parameters response $a_1(t)$ and $a_0(t)$ are provided. We observe that the steady state values of these parameters represent the damaged state of the material. In Fig. 4, the control parameters, namely, $\hat{a}_2(t)$, $\hat{a}_1(t)$ and $\hat{a}_0(t)$ are presented. In order to verify that these parameters indeed performs SDM, the control law with these parameters in Eq. (4) are used to get the responses $y_s(t)$ and $\dot{y}_s(t)$. The error responses $y_s(t)-y_m(t)$ and $\dot{y}_s(t)-\dot{y}_m(t)$ are shown in Fig. 5. Clearly SDM is performed; however, the error build up in certain time intervals are due to the choice of initial condition $\tilde{a}$ (0) that also governs the slow and fast adaptation rates.

VI. Conclusions

Presently, damage prognosis and structural health management schemes assume a given sensor technology and attempt to diagnose the data to predict the remaining life of the structure when an exogenous input load in a damaged structure is present. Structural damage mitigation proposed in this paper considers both sensor and actuator technologies embedded in a structure and modifies the actuator loading such that the sensor data from the damaged structure mimics the sensor data from the healthy structure. Model Reference Adaptive Control is recognized to fulfill this objective. A damaged finite element model for the material is assumed through a structural damage assessment techniques and a technique to mitigate the effects of damage in an uncertain environment is proposed. A second order spring-mass-damper model that represents a finiteelement structural model in modal coordinates is considered to illustrate the foundations of SDM using MRAC.

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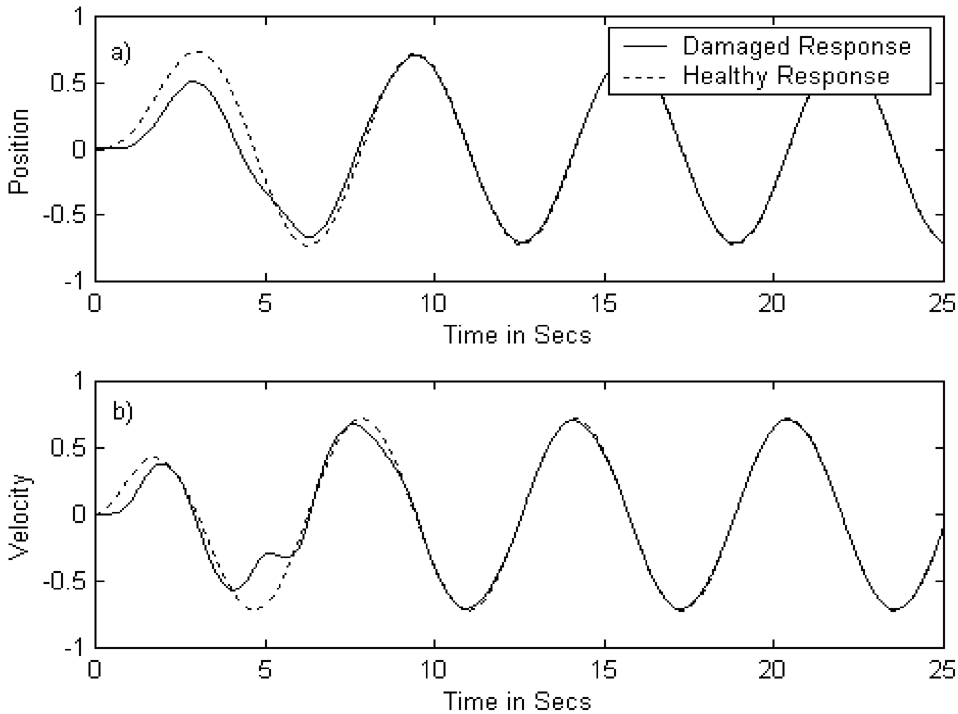

Figure 1 : An Adaptation Law for Structural Damage Mitigation with Healthy and Damaged Responses a) $y(t)$ and $y_m(t)$ and b) $\dot{y}(t)$ and $\dot{y}_m(t)$

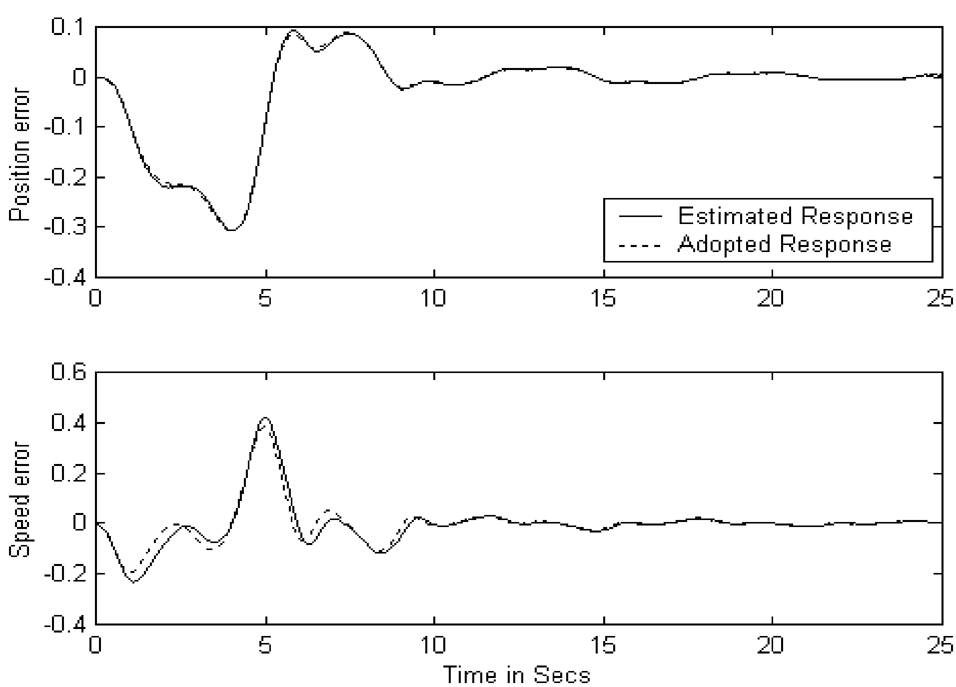

Figure 2 : $\mathbf{x}(t)$ and $\hat{\mathbf{x}}(t)$ by EKF.

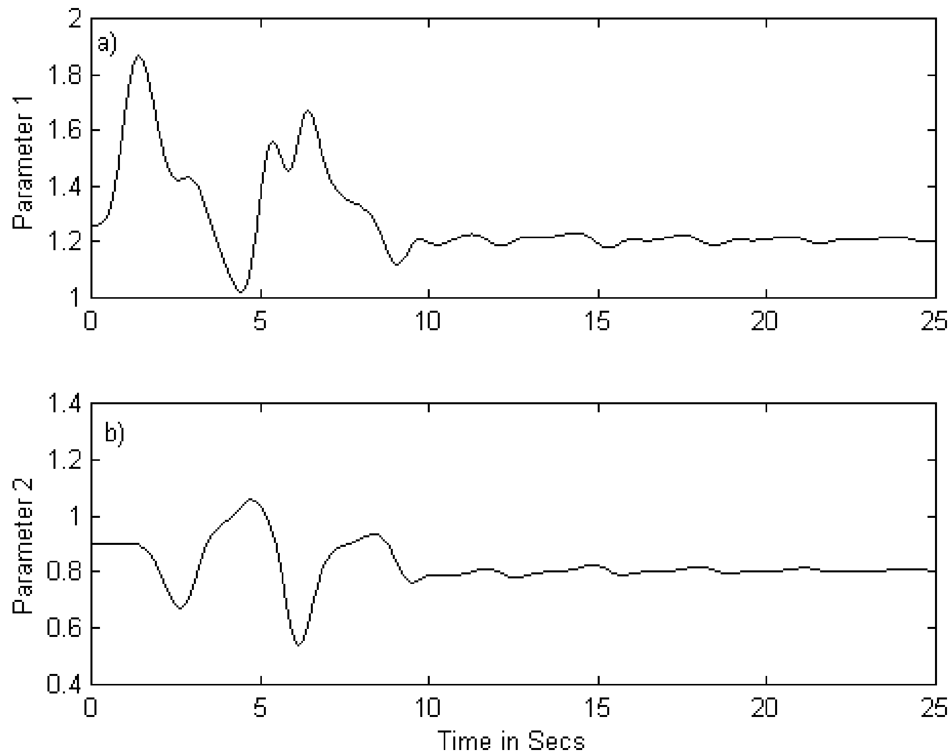

Figure 3 : System Parameters Computed by EKF a) $a_1(t)$ and b) $a_0(t)$.

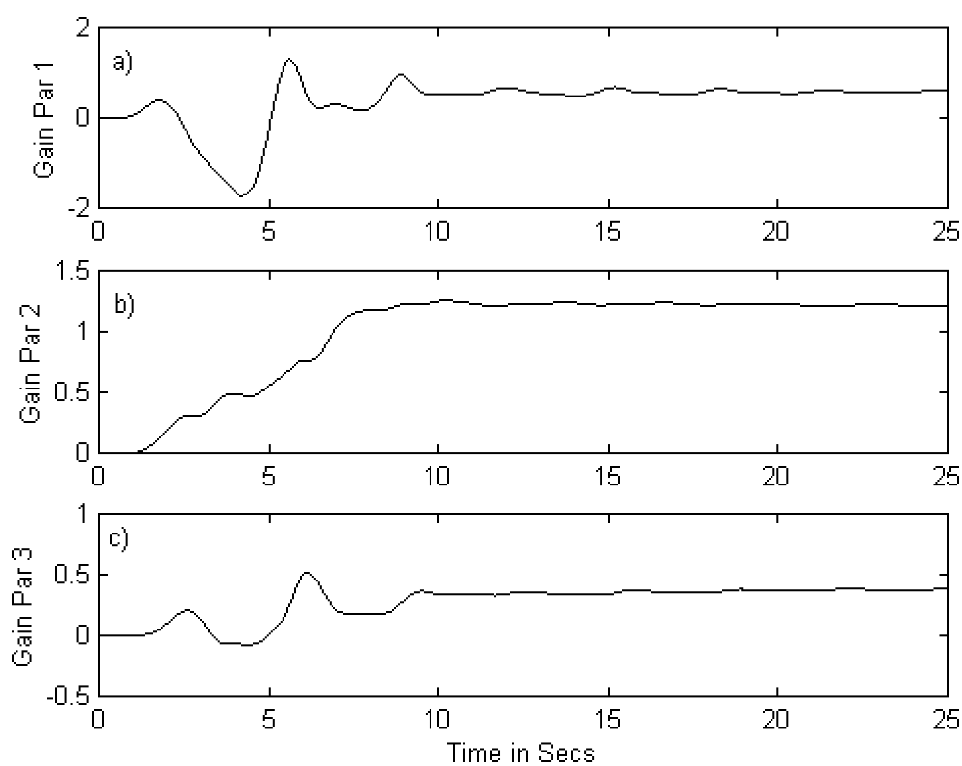

Figure 4 : Control Parameters Computed by EKF a) $\hat{a}_2(t)$, b) $\hat{a}_1(t)$ and c) $\hat{a}_0(t)$.

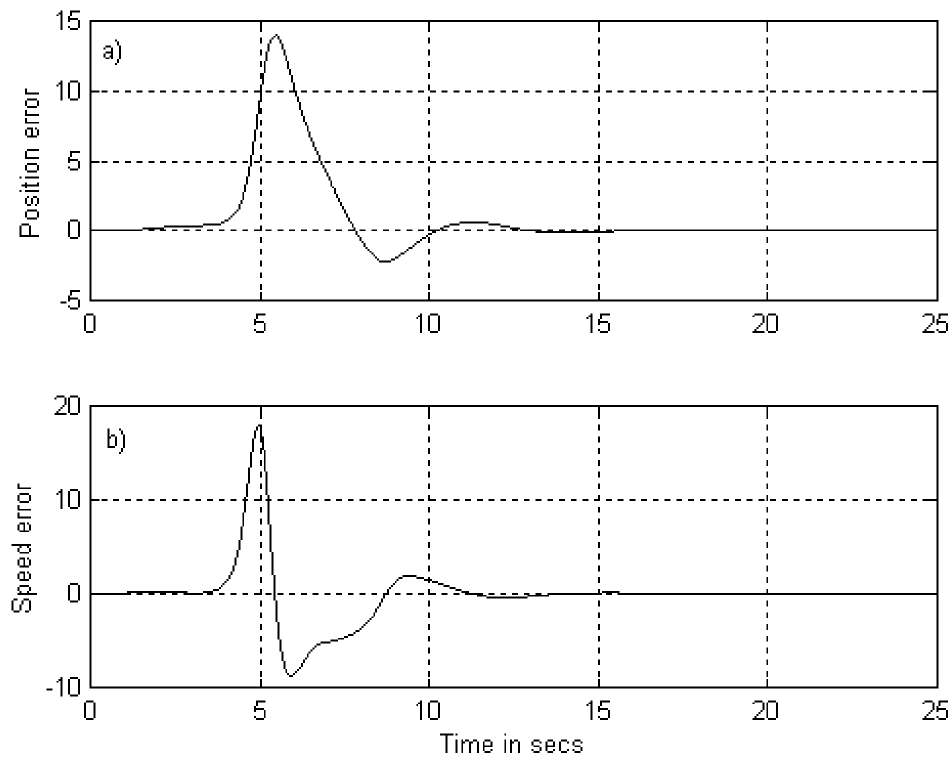

Figure 5 : Simulated Errors a) $y_s(t) - y_m(t)$ and b) $\dot{y}_s(t) - \dot{y}_m(t)$

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Characterization of Gasoline Engine Exhaust Fumes Using Electronic Nose Based Condition Monitoring

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Abstract - An electronic nose-based condition monitoring of three automobile engines was conducted to obtain smell prints that correspond to normal operating conditions and various induced abnormal operating conditions. Fuzzy C- means clustering was used to ascertain the extent to which the smell prints can characterize faulty engine conditions. Silhouette diagrams and silhouette width figures were used to validate the clusters. Results obtained indicate that the smell prints do in general characterize the faults as most clusters have silhouette width greater than 0.5. In particular the results showed that the following automobile engine faults; plug-not-firing faults and loss of compression faults are diagnosable from the automobile exhaust fumes.

Keywords : Electronic nose, Condition Monitoring, mobile,Fault, Diagnosis,Fuzzy C-means, silhouette diagram.

GJRE-D Classification : FOR Code: 090201

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Strictly as per the compliance and regulations of:

Characterization of Gasoline Engine Exhaust Fumes Using Electronic Nose Based Condition Monitoring

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Abstract - An electronic nose-based condition monitoring of three automobile engines was conducted to obtain smell prints that correspond to normal operating conditions and various induced abnormal operating conditions. Fuzzy C-means clustering was used to ascertain the extent to which the smell prints can characterize faulty engine conditions. Silhouette diagrams and silhouette width figures were used to validate the clusters. Results obtained indicate that the smell prints do in general characterize the faults as most clusters have silhouette width greater than 0.5. In particular the results showed that the following automobile engine faults; plug-not-firing faults and loss of compression faults are diagnosable from the automobile exhaust fumes.

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I. Introduction

Condition monitoring is a method by which small variations in the performance of equipment can be detected and used to indicate the need for maintenance and the prediction of failure [1].Condition monitoring and performance estimation are used to appraise the current state and estimate the future state of plant by using real time measurements and calculations. Such monitoring provides ongoing assurance of acceptable plant condition [2]. Some of the condition monitoring technologies that are widely used for detecting imminent equipment failures in various industries include vibration analysis, infra-red thermal imaging, oil analysis, motor current analysis and ultra-sonic flow detection [3]. Diesel engine cooling system model based on condition monitoring was developed by Twiddle [4]. The developed model was tested on a real life diesel engine powered electricity generator to simulate detection of fan fault, thermostat fault and pump fault using temperature measurements. Agoston et al. [5], used micro-acoustic viscosity sensors to conduct on - line condition monitoring of lubricating oils in order to monitor the thermal aging of automobile engine oils and predict appropriate timing of engine oil change.

Electronic noses are technology implementation of systems that are used for the automated detection and classification of odours, vapours and gases[6]. The main motivation for the implementation of electronic noses is the need for qualitative low cost, real-time and portable methods to perform re- liable, objective and reproducible sensing of volatile compounds and odours [7]. Guadarrama et al. [8] reported the use of electronic nose for the dis- crimination of odours from trim plastic materials used in automobiles. Huyberechts et al. [9] used electronic nose to quantify the amount of carbon monoxide and methane in humid air. A method for determining the volatile compounds present in new and used engine lubricant oils was reported by Sepcic, et al. [10]. The identification of the new and used oils was based on the abundance of volatile compounds in headspace above the oils that were detectable by electronic nose. The electronic nose sensor array was able to correlate and differentiate both the new and the used oils by their increased mileages. Hunter et al., [11] applied high temperature electronic nose sensors to exhaust gases from modified automotive engine for the purpose of emission control. The array included a tin-oxide-based sensor doped for nitrogen oxide (NOx) sensitivity, a SiC -based hydrocarbon (CxHy) sensor, and an oxygen sensor (O2) [11]. The results obtained showed that the electronic nose sensors were adequate to monitor different aspect of the engine's exhaust chemical components qualitatively

In the present study, a prototype of an electronic nose-based condition monitoring scheme using array of broadly tuned Taguchi metal oxide sensors (MOS) was used to acquire the exhaust fume of three gasoline-powered engines operating under induced fault conditions. Three gasoline engines were

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used so as to compare and establish the viability or otherwise of using exhaust smell prints to diagnose the fault conditions.

II. Materials And Methods

a) The Automobiles Engine

The automobile engine is a mechanical system based on the internal combustion process and its parts vary depending on the type of engine and the manufacturer. In a gasoline fuelled engine, a mixture of gasoline and air is sprayed into a cylinder where the mixture is compressed by a piston. The ignition systemproduces a high-voltage electrical charge that is transmitted to the spark plugs via ignition wires. The hot gases in the cylinder are at a higher pressure than the air-fuel mixture and thus drive the piston down. In a perfectly operating engine with ideal combustion conditions, the following chemical reactions would take place in the presence of the of air, fuel and electrical spark:

1. Hydrocarbons (HxCy) would react with oxygen to produce water vapour(H2O) and carbon dioxide (C O2), and
2. Nitrogen (N2) would pass through the engine without being affected by the combustion process

If there is any variation in the components of basic combustion or lossof compression due to worn piston rings or high operating temperature the composition of the exhaust gases will change. Specifically, the exhaust will contain H2O , CO2, N2, NOX , CO , HxCy and O2. Measurements of exhaust gases such as C O2 , C O , N Ox, and O2 can provide information about the chemical process inside the combustion chamber and the state of other parts of the engine unit. For example, CO2 is an excellent indicator of efficient combustion; high CO2 measurement is indicative of high efficiency of the engine. High HxCy indicates poor combustion that can be caused by ignition misfire (ignition system failures) or insufficient cylinder compression.

Experiments were conducted on three gasoline fuelled spark ignition automobile engines, namely, Toyota Carina II, Nissan Sunny and Mitsubishi Gallant engines. The main experimental rig is a test bed based on the Toyota Carina II engine (see Figure 1). The other two engines, Nissan Sunny engine and Mitsubishi Gallant engine, are fitted in two operational automobiles. Table 1 shows the specification of one of the three engines, the Toyota Carina II engine. Samples of the exhaust fumes from the three engines operating in normal and various induced faulty conditions were collected for analysis using an electronic nose system comprising an array of ten broadly tuned chemical sensors.

Table 1 : Toyota Carina II Engine Specification

S/N	Item	Value
1	Track (rear axle)	50.6 in
2	Kerb weight	900 Kg.
3	Engine capacity	1.61 L
4	Number of valves	8
5	Number of cylinder	4
6	Bore/Stroke ratio	1.21
7	Displacement	96.906 Cu in
8	Compression ratio	9.5:1
9	Maximum output	78.3 kW
10	Maximum rpm coolant Water	66.1 bhp/litre
11	Top gear ratio	0.86

b) Chemical Sensor

The chemical sensor is usually enclosed in an air tight chamber or con- tainer with inlet and outlet valves to allow volatile odour in and out of the chamber. The most popular sensors used to develop electronic noses are;semiconductor metal oxide chemoresistive sensors, quartz-resonator sensors and conducting polymers. Semiconductor metal oxide chemoresistive sen- sors types were used in this study because of their high sensitivity to com- bustible materials such as alcohols and poor efficiency at detecting sulphur-or nitrogen-based odours [12]. The overall sensitivity of these types of sen- sors is quite good. They are relatively resistant to humidity, ageing, and are made of particularly strong metals[13]. Taguchi metal oxide semiconductor (Figaro Sensor, Japan) TGS 813, TGS 822, TGS 816, TGS 2602, TGS 5042, TGS 2104 and TGS 2201 were used based on their broad selectivity to some exhaust gases such as C O2 , N2, N OX , C O , uncombusted HxCy , and some other gases such as H2 , methane, ethanol and benzene.

c) Induced Fault Conditions

In order to produce repeatable conditions, known faults were induced for investigation. The major fault classes under consideration in this study are plug-not-firing faults and worn piston ring (loss of compression).

Plug-not-firing faults: Any malfunctioning of the spark plugs results in a sub-optimal ignition of the air-fuel mixture; however the air-fuel mixture is still compressed by the piston thereby producing unburnt hydro-carbon with lean quantity of carbon dioxide and appreciable amount of carbon monoxide. Three different ignition faults are considered: one- plug, two-plug and the three-plug faults. The faults were induced in the engines by removing the cables connected to the spark plugs one after the other.

Worn piston ring faults: The piston ring prevents engine oil in the sump from seeping and mixing with the gasoline-air mixture in the engine combustion chamber and thus maintaining the engine compression at optimum level. When this ring is worn, the engine oil

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seeps and mixes with the gasoline-air mixture thereby increases the amount of unburnt hydrocarbon produced in the combustion chamber and escaping via the exhaust valve. The worn piston ring fault was induced by mixing the gasoline and engine oil in various proportional ratios as 90 : 10, 80 : 20, 70 : 30, 60 : 40, 50 : 50 and 40 : 60. The following calibration was used for the loss of compression faults: a 90 : 10 fuel mixture corresponds to a 1st degree worn ring and 80 : 20, 70 : 30, 60 : 40, 50 : 50 and 40 : 60 correspond to 2nd, 3rd, 4th, 5th and 6th degree worn ring respectively.

A high percentage of engine oil in the mixture corresponds to a high degree of wear in the piston ring and this adversely affects the efficiency of the engine.

d) Data acquisition

The required exhaust fumes of the gasoline fuelled engine operating under various induced fault conditions were obtained from the engine exhaust tail pipe in the absence of a catalytic converter. The exhaust gas specimens were collected into 1000ml Intravenous Injection Bags (IIB). Drip set was used to connect each of the IIB containing the exhaust gases to a confined chamber that contained the array of the selected Taguchi MOS sensors. Static headspace analysis odour handling and sampling method was used to expose the exhaust fume samples to the plastic chamber because the exhaust fume tends to diffuse upwards in clean air due to its lighter weight. Thus there was no need for elaborate odour handling and sampling method. Readings were taken from the sensors 60 seconds after the introduction of each ex- haust fume sample into the air tight plastic chamber so as to achieve odour saturation of the headspace. The digitized data were collected continuously for 10 minutes using Pico ADC 11/10 data acquisition system (connected to a personal computer) and stored further analysis. 1400 × 10 data samples (1 dataset) for each of the ten (10) fault classes making a total of 14000 ×10 data samples (10 data sets) were collected from the test bed engine. The sensors were purged after every measurement so they can return to their respective default states (also referred to as baseline) with the use of compressed air. These measurement procedures were repeated for the engine fitted into the two operational vehicles. The 6th degree worn ring fault measurement could not be carried out because it was difficult to start the engine. All data collection were done with the engine speed maintained at 1000 revolutions per second except for 5th degree worn ring, 6th degree worn ring and 3 plugs bad fault conditions that were collected at engine speed of 2000 revolutions per second.

e) Data analysis

Our hypothesis is that various induced fault conditions can be inferred from the odour prints of the exhaust gas. A clustering analysis of the data was conducted and the validity of the cluster generated was demonstrated. The data collected from the array of sensors represent features characteristic of each type of induced fault and form patterns in a 10-dimensional space. Data cluster analysis is an unsupervised learning technique that can be used to discover the underlying groupings in a data set, usually represented a vector of measurements, based on some measure of similarity [14]. Given a number of clusters, C, the idea is partition the data into the clusters based on some measure of similarity. Fuzzy clustering, also called fuzzy C-means (FCM), assigns each data point into clusters with some probability of belonging. This is in contrast to the popular k-means clustering where data points are assigned to exactly one cluster. Let u*ik* denote the strength of membership of the *i*-th data sample in the k-th cluster. The membership strength for each data sample behaves like probabilities with u*ik* > 0 for all *i* and *k* = 1. . . C, and $\sum_{k=1}^{c} uik$[15]. Usually, the pair wise distances of the data samples, {dij} is computed and the membership strengths are obtained iteratively by minimizing the objective function [15],

$$J = \sum_{k=1}^{k} \frac{\sum_i \sum_j u_{ik}^2 u_{jk}^2 d_{ij}}{2\sum_i u_{ik}^2} \quad (1)$$

subject to the non-negativity and unit sum constraints.

The quality of the clustering can be ascertained using several cluster validity techniques. In this paper, the quality of the clusters formed were validated using silhouette index proposed by Rousseeuw [16]. It has been shown to be a robust approach to predict optimal clustering partitions [17]. For a given cluster, Xk (k = 1, . . . , C), this method assigns to each sample of Xk a quality measure, s(i)(i = 1, . . . , m), (m is the number of samples in cluster Xk) known as the silhouette width.The silhouette width is a confidence indicator on the membership of the i-th sample in cluster Xk and is defined as

$$s(i) = \frac{b(i)-a(i)}{\max\{a(i),b(i)\}} \quad (2)$$

where a(i) is the average distance between the i-th sample and all of thesamples included in Xk ; and b(i) is the minimum average distance between the i-th sample and all of the samples clustered in Xj (j = 1, . . . , C; j = k). From Equation 2 it follows that the −1 ≤ s(i) ≤ 1.

When s(i) is close to 1, one may infer that the I -th sample has been “well clustered”, i.e. it was assigned to an appropriate cluster. When a s(i) is close to zero, it suggests that the i-th sample could also be assigned to the nearest neighbouring cluster. If s(i) is close to -1, one may argue that such a sample has been “misclassified” [16]. Thus, for a given cluster, Xk (k = 1. . . C),it is possible to calculate the average silhouette width or cluster silhouette value Sk , which characterizes the heterogeneity and isolation properties of the cluster,

$$S_j = \frac{1}{m}\sum_{i=1}^{m} s(i) \quad (3)$$

where m is number of samples in Sk

III. Result and Discussion

The results of data clustering analysis on the three engine data sets are shown in Figures 2 to 7. Figure 2 shows the results of FCM clustering algorithms on the Toyota Carina II engine data sets. Figures 4 and 6 show the results of clustering datasets from the Mitsubishi Gallant engine and Nissan sunny engine respectively. The results of FCM clustering shows that most of the data fall into distinct grouping and there are clear boundaries. Silhouette diagrams for the cluster validity are shown in Figures 3, 5 and 7 with the silhouette values for each cluster. None of the silhouette values in the silhouette graph of Figure 3 is negative. Considering the case of overlap in Figure 2 (40% worn ring and 10% worn ring faults); the silhouette values for clusters 2 and 5 are 0.70 and 0.75 respectively, this indicates that the clusters are well formed with high positive values. All other FCM clusters and silhouette diagrams in Figures 4 to 7 show results similar to that of Figures 2 and 3 except the silhouette diagrams in Figures 5 and 7 with two clusters having small negative silhouette values that suggest that the clusters involved overlap adjacent clusters. The silhouette graph in Figure 5 shows that clusters 6and 9 have silhouette values close to -0.2 with cluster 9 having more data points overlapping other clusters. Similar arguments hold for Figure 7 where clusters 1 and 5 are having small negative silhouette values.

The result of clustering all the data from the three engines is shown in Figure 8 and the silhouette diagram for same is shown in figure 9. These results show that irrespective of the automobile engine, the faults can be characterized accurately from the exhaust gases by electronic nose.

IV. Conclusion

Exhaust gas samples from three gasoline fuelled engines were collected and analyzed via electronic nose system comprising ten broadly tuned MOS sensors. The results of cluster analysis on the acquired smell prints samples from the three automobile engines using fuzzy C-means clustering algorithm showed close similarities among data items in same dataset and distant similarity among data items in different data sets with distinct fault class boundaries. The results of cluster validity showed that all the data samples were well clustered except for data sets of two induced faults in respect of Nissan Sunny engine and Mitsubishi Gallant engine that have some data points overlapping adjacent data sets. These results showed that the data samples acquired with the electronic nose based condition monitoring scheme were true representations of the normal and induced faults conditions investigated. The collected data samples could be well classified as normal and faulty states smell characteristic data for the faults investigated in this study.

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Figure 1 : Experimental rig: Toyota Carina II engine

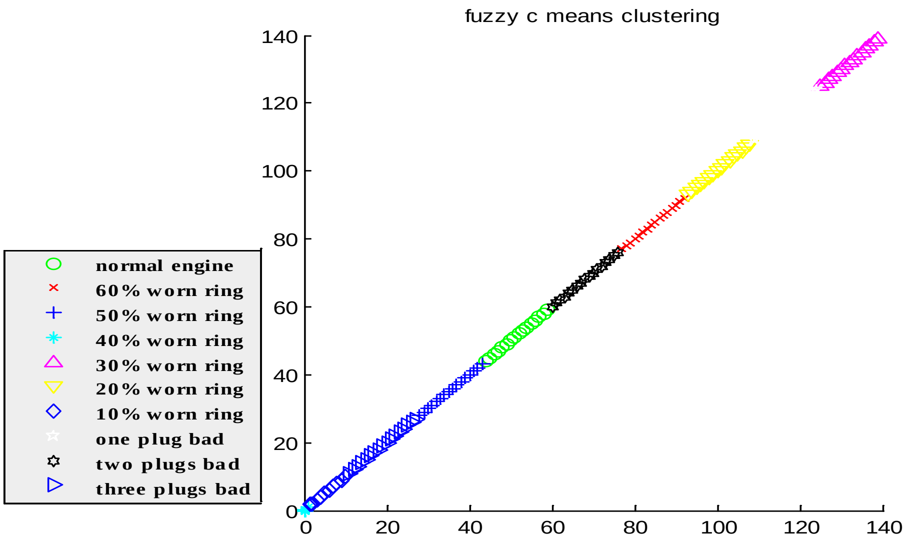

Figure 2 : FCM diagram for Toyota Carina II engine

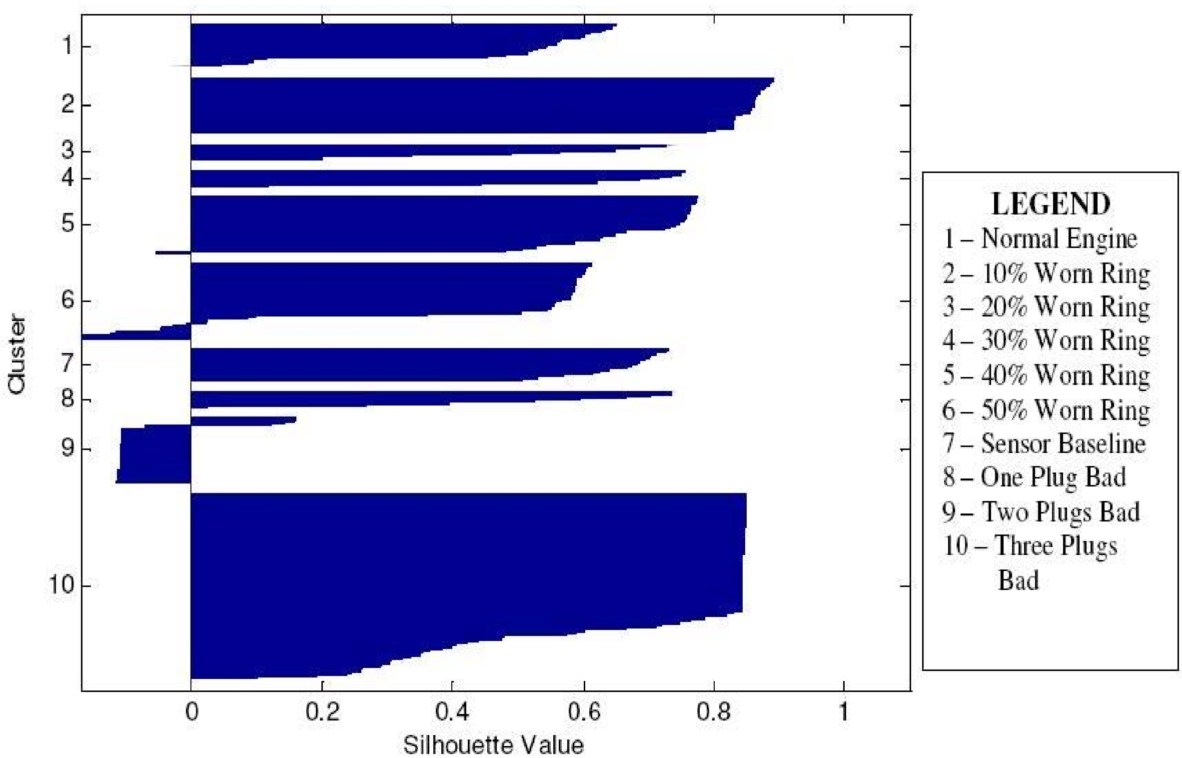

Figure 3 : FCM silhouette diagram for Toyota Carina II engine

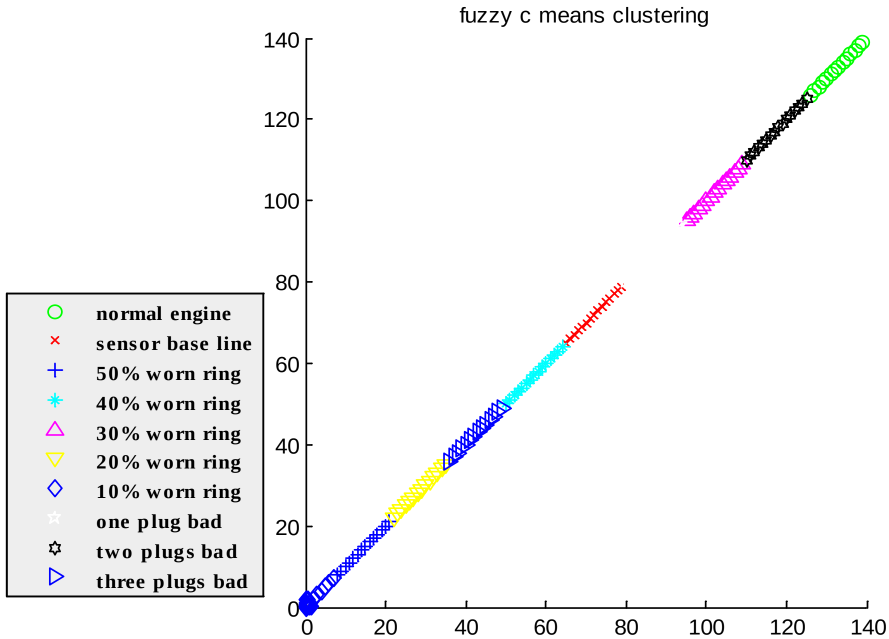

Figure 4 : FCM diagram for Mitsubishi Gallant II engine

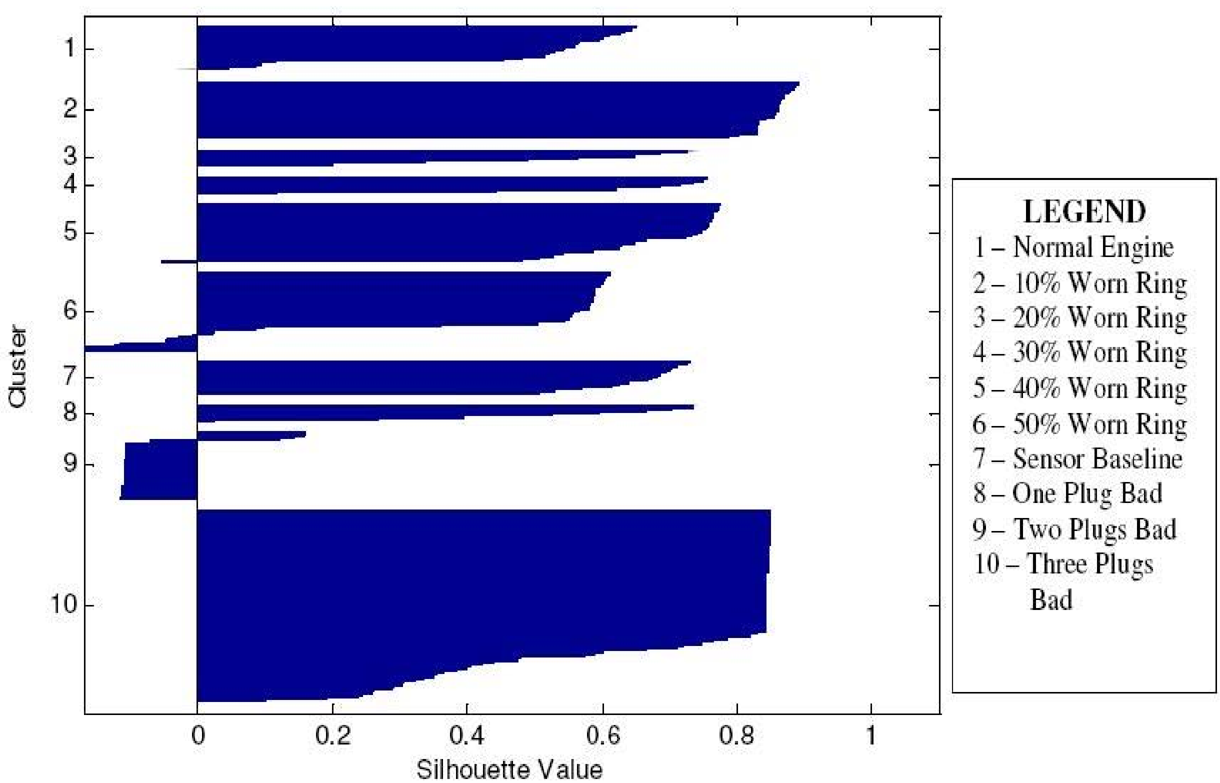

Figure 5 : FCM silhouette diagram for Mitsubishi Gallant engine

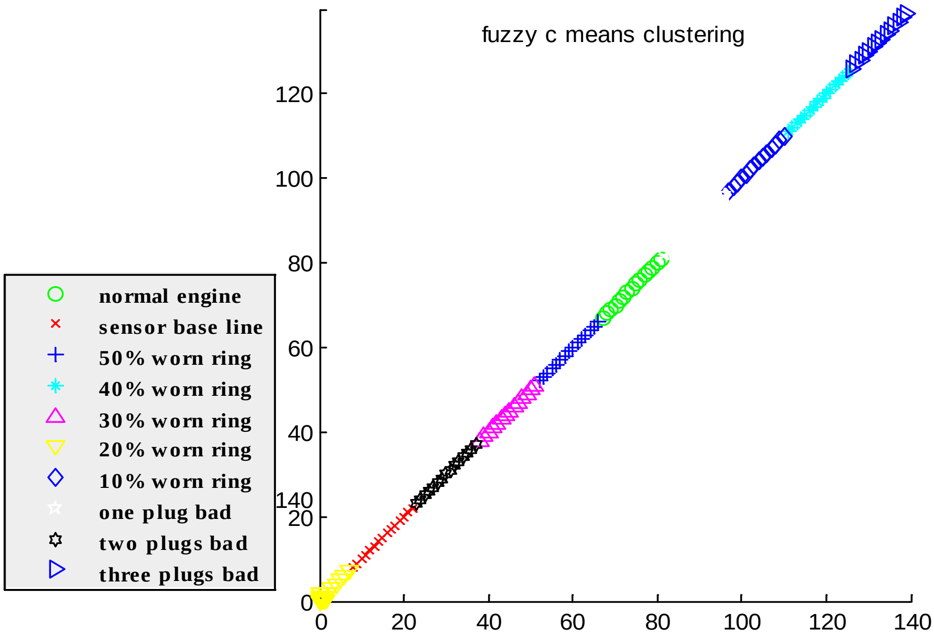

Figure 6 : FCM diagram for Nissan Sunny engine

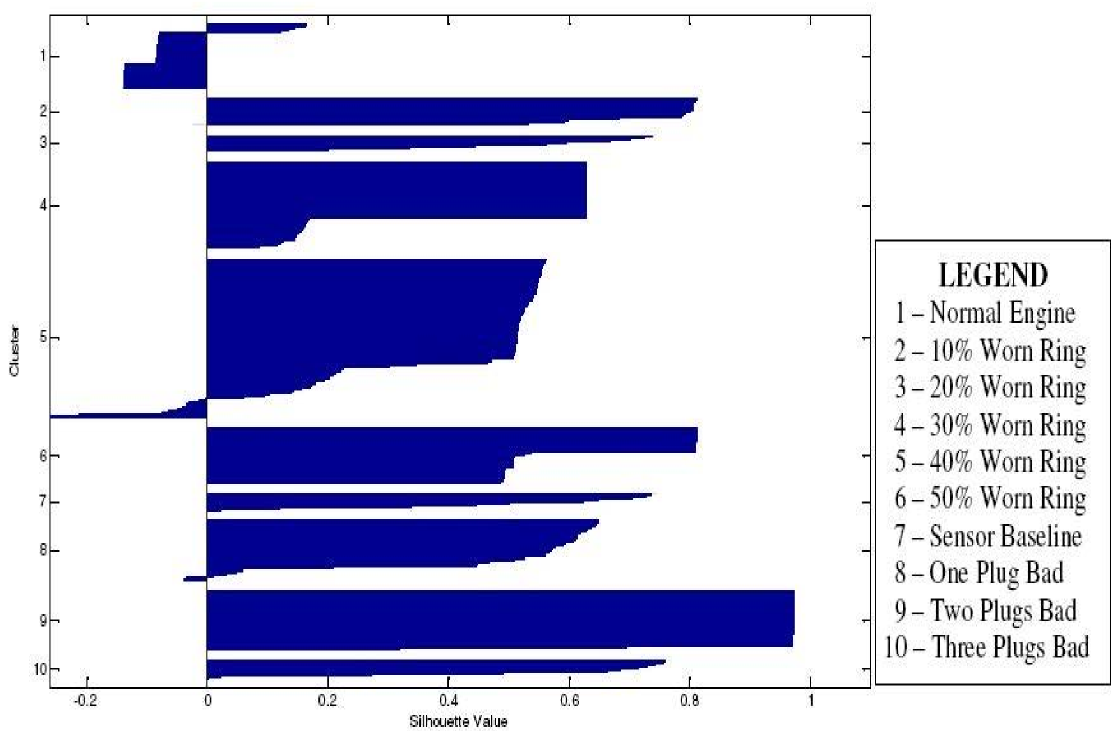

Figure 7 : FCM silhouette diagram for Nissan Sunny engine

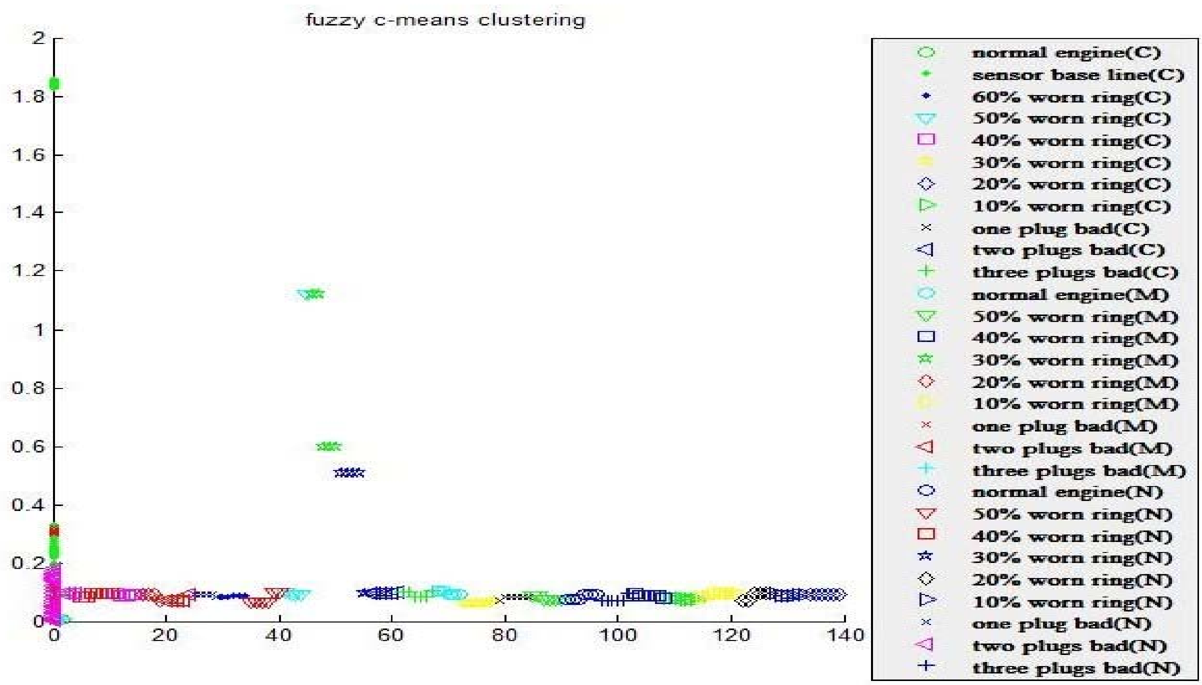

Figure 8 : FCM diagram for the three engines

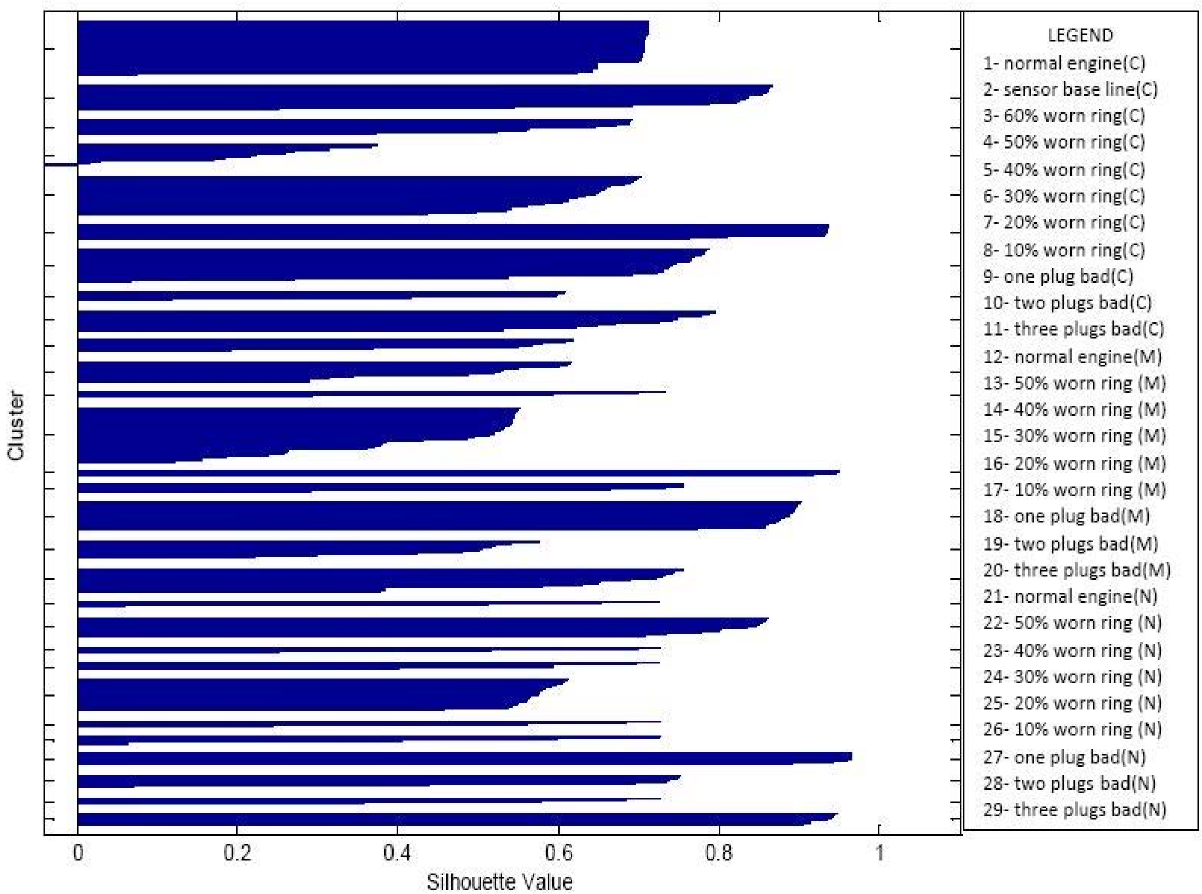

Figure 9 : FCM silhouette diagram for the three engines

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

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

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

Informal Guidelines of Research Paper Writing

Key points to remember:

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

Final Points:

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

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

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

General style:

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

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page

- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

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

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

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

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

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

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

Title Page:

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

Abstract:

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

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

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

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

Approach:

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

Introduction:

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

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

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.
- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

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

Materials:

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

Methods:

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

Approach:

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

What to keep away from

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

Results:

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

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

Content

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

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.

- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

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

Figures and tables

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

Discussion:

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

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

Approach:

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

Administration Rules Listed Before Submitting Your Research Paper to Global Journals Inc. (US)

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

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

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

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

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

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

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