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An Approach To Mechatronics System Design

Vaibhav V. Khond, Prashant K. Kavale, Neha S. Dixit
Assistant Professor
K. K. Wagh Institute of Engineering Education & Research, Nashik, Maharashtra, India

Abstract - Concepts of mechatronics are applicable in the design of complex and multi-domain dynamic systems. The current mechatronics systems acquire very advanced capabilities as well as characteristics based on the evolution of the mechatronics enabling technologies and the mechatronics design methodology. This paper presents a broad approach based on the mechatronic design for development of various system and products.

Keywords - Mechatronics, Sensor, Controller, Actuators

1. INTRODUCTION

Mechatronics in a general sense is a synergistic combination of various branches of engineering such as mechanical, electrical, electronics & computer etc. in order to design and manufacture various products, equipments, process, devices & systems which are simpler, more economical, reliable and versatile. Basically any mechatronics system consist of three components 1- Sensors – part which perceives with environment/surrounding, 2- controller – part which takes the decision and 3- actuators - part which takes the action .

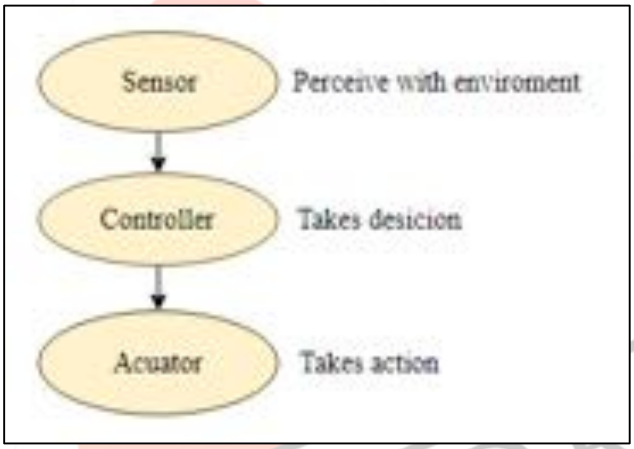

Fig: 1 Theme of mechatronics system

2. MECHATRONIC DESIGN PROCESS:

The mechatronic design process consists of three phases: modeling and simulation, prototyping, and deployment. All modeling, whether based on first principles (basic equations) or the more detailed physics, should be modular in structure. A first principle model is a simple model which captures some of the fundamental behavior of a subsystem. A detailed model is an extension of the first principle model providing more function and accuracy than the first level model. Connecting the modules (or blocks) together may create complex models. Each block represents a subsystem, which corresponds to some physically or functionally realizable operations, and can be encapsulated into a block with input/output limited to input signals, parameters, and output signals. Of course, this limitation may not always be possible or desirable; however, its use will produce modular subsystem blocks which easily can be maintained, exercised independently, substituted for one another (first principle blocks substituted for detailed blocks and vice versa), and reused in other applications.

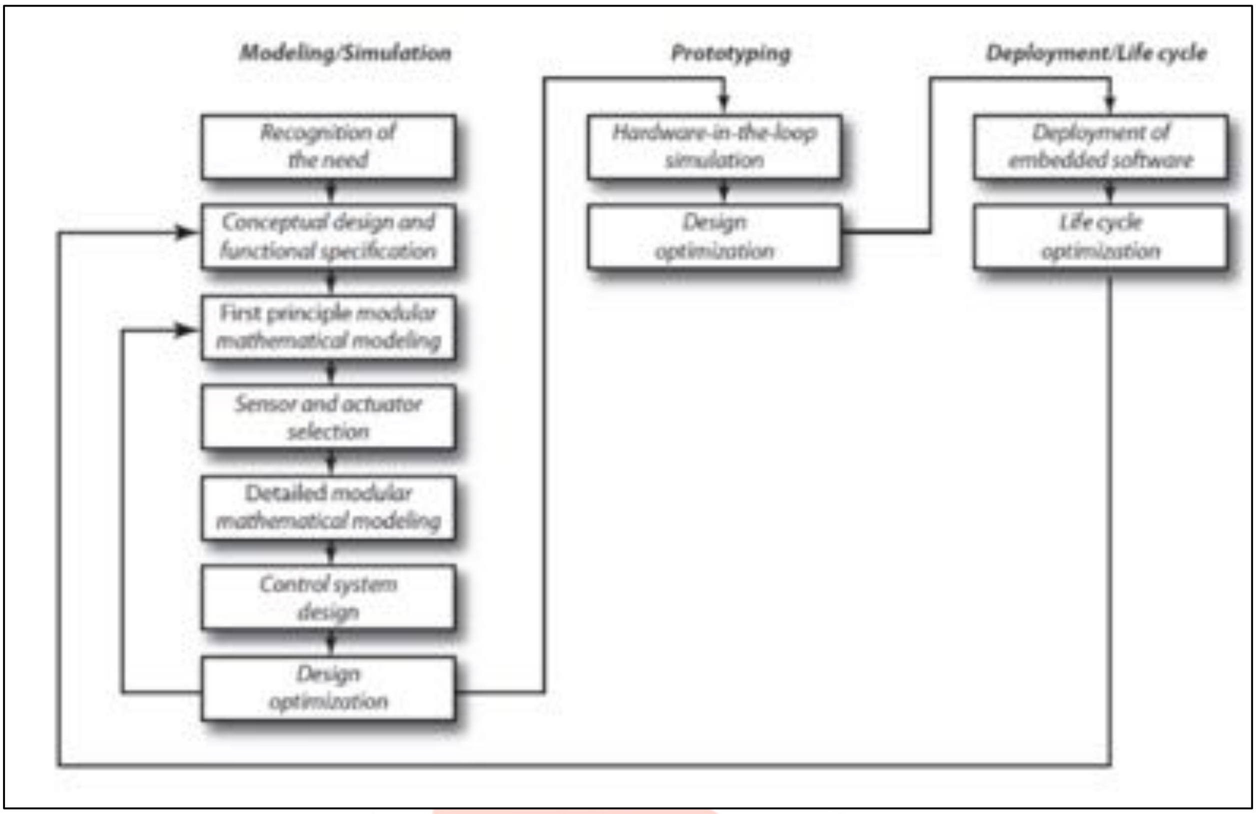

Fig 2 Mechatronic design process [10]

Because of their modularity, mechatronics systems are well suited for applications that require reconfiguration. Such products can be reconfigured either during the design stage by substituting various subsystem modules or during the life span of the product.

3. LITERATURE SURVEY:

Miatliuk et.al, 2010 [5] suggests a mechanism for using new information technology in mechatronic systems design. Traditional mathematical models do not allow mechatronic systems to be described at all levels on common formal basis. They do not describe the structure of systems (the set of dynamic subsystems with their interactions), the system as a dynamic unit in its environment, and the environment itself.

Shetty et.al, 2012 [4] shows the simulation based mechatronic model of a complex system with a better understanding of the dynamic behavior and interactions of the components. This offers improved possibilities of evaluating and optimizing the dynamic motion performance of the entire automated system in the early stages of the design process. Another effect is the growing influence of interactions between machine components on achievable machine dynamics and precision and quality of components.

P. Hehenberger 2014 [8] gives an overview of hierarchical modeling techniques which helps to describe product models and data from different viewpoints that, representing the different disciplines involved in the design process of mechatronic systems.

Chen Zheng et.al, 2014 [3] presents the different product data models, proposes specific criteria to evaluate them during the mechatronic system design process. They concluded that the product data model is an effective support to the mechatronic system design process, for product data model can support all the product information throughout the entire product lifecycle.

Barbieri et.al,2015 [1] refined a model based design methodology defining a workflow for integrating modeling and simulation, and identifying which simulations may be performed for an integrated design

Habchi & Barthod 2016 [5] proposed an overall ten-step methodology dedicated to the analysis and quantification of reliability during the design phase of a mechatronic system, considered as a complex system. The ten steps of the methodology are detailed according to the downward side of the V-development cycle usually used for the design of complex systems.

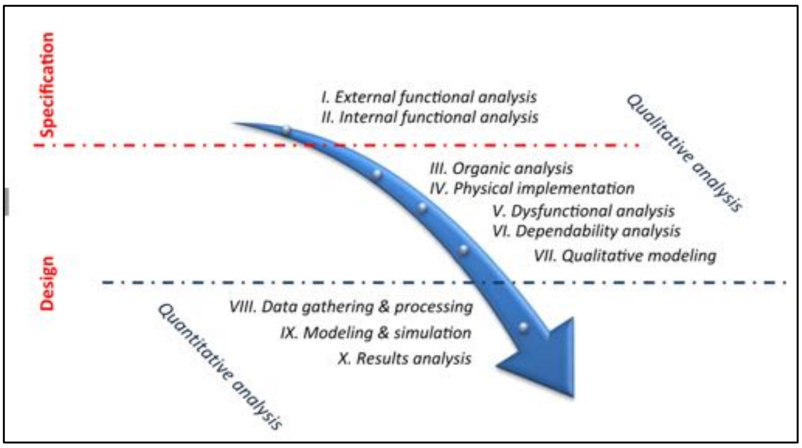

Fig: 3 Proposed overall methodology evaluating the predictive reliability of mechatronic systems [5]

Zheng et.al, 2016 [2] presents a multidisciplinary interface model for design of mechatronic systems in order to enable the multidisciplinary integration among design team members from different disciplines. On the one hand, the proposed model ensures the consistency of interface defined by the designers. On the other hand, it helps the designers to guarantee the different components integrate correctly. The interface model including three concepts: classification, data model and compatibility rules.

V.C. Moulianitis, et.al, 2018 [9] proposed a new mechatronics index for the evaluation of the alternatives in the conceptual design phase. The criteria aggregated to the index are acquired mostly by the collective knowledge presented in the Multi Annual Roadmap for robotics in Europe and adapted by considering the recent advancements in mechatronics.

4. PROPOSED METHODOLOGY FOR DESIGN OF MECHATRONICS SYSTEM

We proposed methodology for design of mechatronics system shown in flow chart.

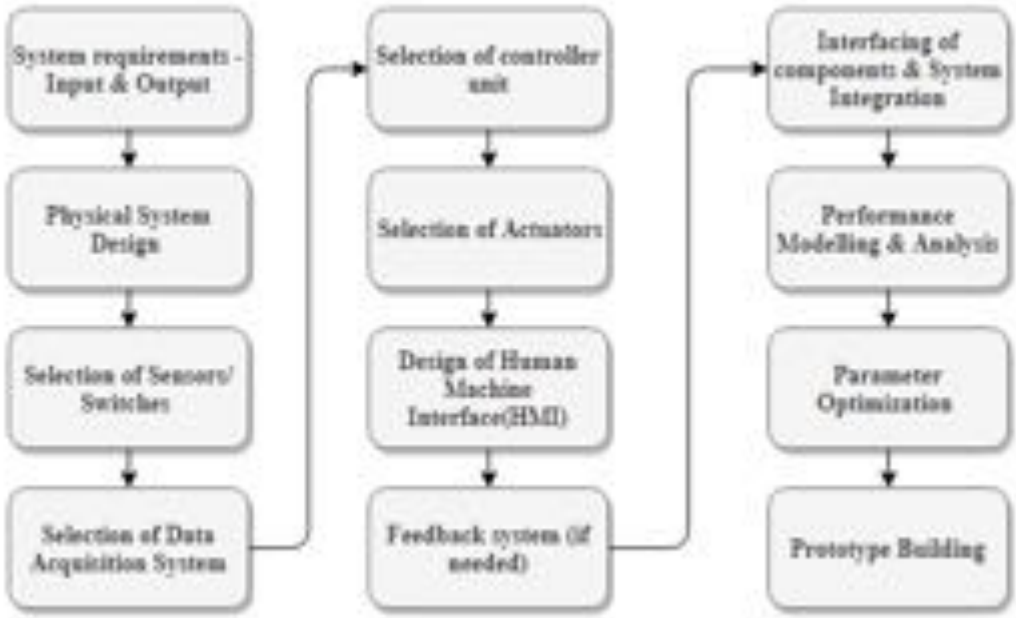

Fig: Proposed methodology for design of mechatronics system

4.1 System requirements - Input & Output: Keeping track of requirements through the complex system is a challenge. By mapping the requirements to lower level of system, it is more clear what is expected from each components and chance that the final product will meet the design requirements increases.

4.2 Physical System Design: is the process of defining the architecture, modules, interfaces, and data for a system to satisfy specified requirements.

4.3 Selection of Sensors/ Switches –

The working principle of sensors is based on any property change such as resistance, inductance, capacitance, optical property. The various criteria for selection of sensors are Variables measured and application, Dynamic range, Required resolution and sensitivity, Required accuracy and precision, Environmental conditions, Power available for sensing, Availability, Cost, Size and available space, Ease of use, Ease of maintenance, Required signal processing.

The need for less expensive and precise sensors, as well as integration of the sensor and signal processing on a common carrier or on one chip, has become important.

4.4 Selection of Data Acquisition System

Carefully choose data acquisition system to ensure that it supports a measurement range that is consistent with your signal sources.

Signal conditioning –

• Examples of signal conditioning are signal scaling, amplification, linearization, cold-junction compensation, filtering, attenuation, excitation, common-mode rejection, and so on.

Analog to Digital conversion - Analog to digital (A/D) conversion changes analog voltage or current levels into digital information. The conversion is necessary to enable the computer to process or store the signals.

4.5 Selection of controller unit

Control system is a Major part of a Mechatronic system. Basically any control system can be of two types

- Open loop control – in which feedback is not taken
- Closed loop control – where the feedback of response is taken

The basic action of the control system start with connecting with the various inputs such as switches, sensors and receives the information. The information may be in analog or digital form. The controller is having Logic or algorithm installed through PC in the software. Depending upon the logic it will produce output or response to the actuators or actuation circuit which may be an indicator, lamp, motors, solenoid, timers or counter, coil.

Depending upon controlling action, different types of controllers are in use

- Microcontrollers – used for Discrete Processes
- PLC controllers – Used for Event based sequential process
- PID controllers – for continuous parameter control
- Advanced controllers – Fuzzy logic, Artificial intelligence etc.

Performance of controllers –

- The performance of various controllers can be analyzed with respect to time and frequency.
- Performance of the control system could be started by designing a physical system; also it requires input and output parameters. So the initial step is mathematical modeling of Physical system. The system may be Mechanical (translational or Rotational), Electrical, Thermal, Fluid (Hydraulic & Pneumatic), electromechanical etc.
- We generally use the term Transfer Function in the performance of linear time invariant system.
- Our job is to find out the roots of Numerator and Denominator. The roots of the Numerator are called as Zeros, while the roots of the denominator are called Poles. By the use of Poles and zeros we can judge the relative stability of the system. For absolute stability we must satisfy Routh Hurwitz criteria
- For the frequency response analysis, sinusoidal input is given at various frequencies and the response of the system is studied. The stability can be judged by plotting the Bode Plot which has both amplitude and Phase plot vs. frequency which is to be plotted on Logarithmic scale.

4.6 Selection of Actuators

Actuation involves a physical action on the process, such as the ejection of a work piece from a conveyor system initiated by a sensor.

•Actuators can be classified into three general groups.

- Electromagnetic actuators, (e.g., AC and DC electrical motors, stepper motors, electromagnets)
- Fluid power actuators, (e.g., hydraulics, pneumatics)
- Unconventional actuators (e.g., piezoelectric, magnetostrictive, memory metal)

•There are also special actuators for high-precision applications that require fast responses. They are often applied to controls that compensate for friction, nonlinearities, and limiting parameters.

Actuator validation: An ideal actuator is one which gives static response and has unity gain within an operational range. Outside the range it gives a steady limiting output. A real actuator may have hysteresis, dead zone, curved response, offset and delay etc. Generally, the conventional actuators are troubled by their inherent characteristics and fault conditions. This degrades the performance of the loop. As credible sensing has been a prerequisite for mechatronic systems, actuator validation is also essential. Currently, it is achieved at the device level by adjusting a loop PID regulator, by using auxiliary variables. Applications of soft computing tools and techniques tools play major role in actuator validation.

4.7 Design of Human Machine Interface (HMI)

It is process of fusing and synchronizing model, sensor, and actuator information is called real-time interfacing or hardware-in-the-loop simulation.

For mechatronics applications real-time interfacing includes analog to digital (A/D) and digital to analog (D/ A) conversion, analog signal conditioning circuits, and sampling theory.

The main purpose of the real-time interface system is to provide data acquisition and control function for the computer.

4.8 Feedback system (if needed)

A feedback loop is a common and powerful tool when designing a control system. Feedback loops take the system output into consideration, which enables the system to adjust its performance to meet a desired output response

4.9 Interfacing of components & System Integration: is understood as bringing together the individual parts to form a whole system. The types of integration are as follows:

Integration of distributed components: Components such as actors, sensors and power actuators are integrated into one new whole via signal and energy flows. Signal processing is carried out via communication systems (for example sensor-actor bus, fieldbus, etc.), energy flows via cabling and plug-in connectors.

Modular integration: The system is made up of modules of defined functionality and standardized dimensions that are coupled via unified interfaces. These modules that are included in a modular system can be flexibly combined and make it possible to obtain a great functional variety. Modularly integrated systems have generally a larger component volume and a higher material expenditure and component complexity in comparison with spatially integrated systems.

Spatial integration: All components are spatially integrated and form a complex functional unit. Advantages include a smaller installation space; greater reliability brought about by reduction of the interfaces, faster data transmission/higher power and lower assembly effort. However, the spatial proximity of the components also allows undesired interactions to arise, such as heating, stray magnetic fields, vibrations, noises and voltage peaks, which are to be taken into consideration as early as possible. Spatial integration therefore requires a systematic procedure in designing and a support by modeling and IT tools

4.10 Performance Modelling & Analysis: The quality of model is decisive for the quality of analysis results. Only if the model truly describes the system, the subsequent model analysis can produce results transferable to reality.

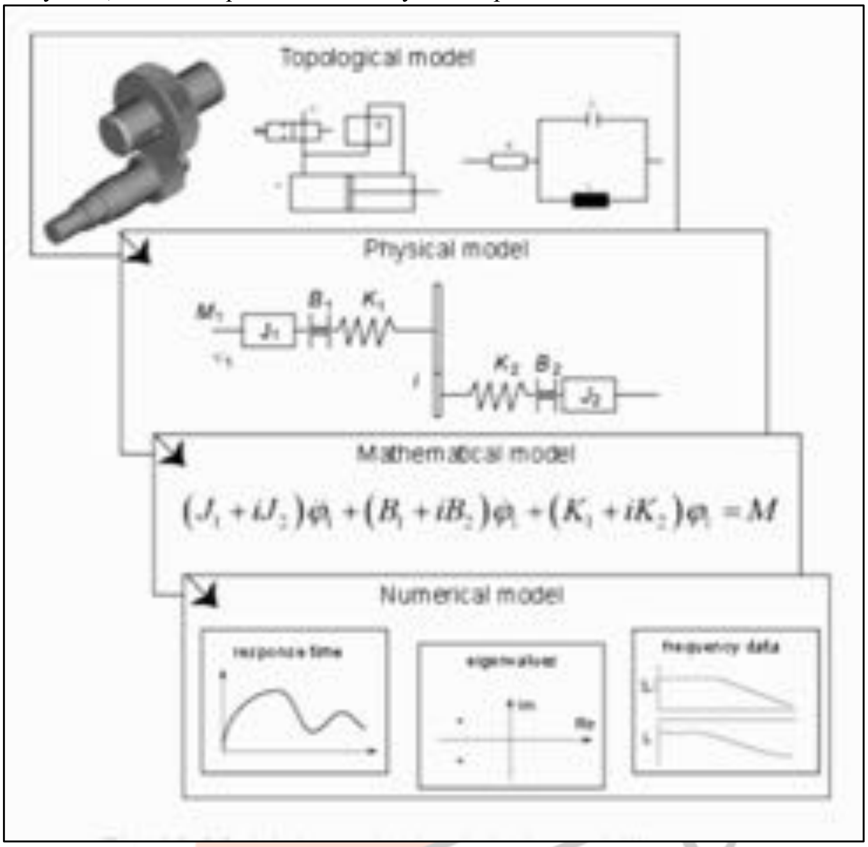

Fig: Model abstraction levels in the modeling process [10]

The model analysis generally serves for determination of properties for a prescribed system, also for establishing the actual state and analysis of possible behavior.

- Modeling is the process of representing the behavior of a real system by a collection of mathematical equations and logic.

- Simulation is the process of solving the model and it is performed on a computer. The process of simulation can be divided into three sections: initialization, iteration, and termination

Selection of software – depends on Environments, tools, computation algorithms to perform control, sensing, execution, emulation, information flow, data acquisition, simulation, visualization, virtual prototyping, and evaluation

4.11 Parameter Optimization - Optimization solves the problem of distributing limited resources throughout a system such that pre specified aspects of its behavior are satisfied.

It is applied to:

- Establish the optimal system configuration
- Identification of optimal trajectories
- Control system design
- Identification of model parameters

4.12 Prototype Building

The Prototyping Model is a systems development method (SDM) in which a prototype (an early approximation of a final system or product) is built, tested, and then reworked as necessary until an acceptable prototype is finally achieved from which the complete system or product can now be developed.

5. SAMPLE CASE STUDIES

Concept 1: Smart street lighting

In this case study as per mechatronics theme, the sensor is LDR (Light Dependent Resistor) also known as photocell, Controller is Arduino Uno board and actuators is LED. Software used for programming Arduino IDE 1.6.9.

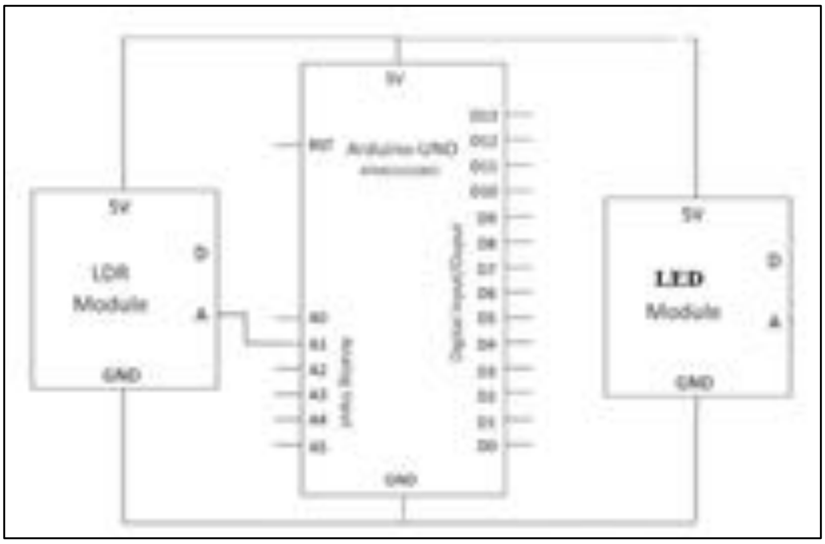

Fig: A line diagram for Smart street lighting system

Connect the components as per the circuits shown in fig and observe the output data of intensity on serial monitor as per the program and store the data. With the help of controller, we have flexibility of changing the value of intensity at which LED should be ON/OFF without changing hardware.

Concept 2: Fire Alarm System

In this case study as per mechatronics theme, the sensor is DHT11 Temperature & Humidity, Controller is Arduino Uno board and actuator is buzzer. Software used for programming Arduino IDE 1.6.9.

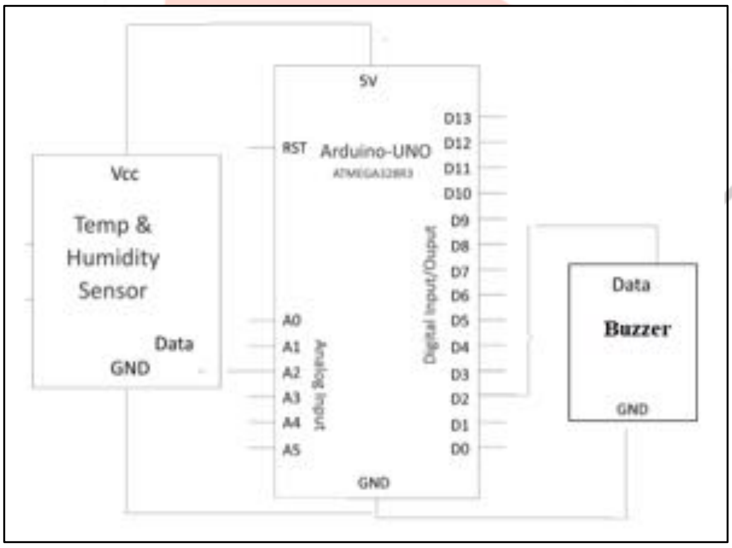

Fig: A line diagram for Fire Alarm System

Connect the components as per the circuits shown in fig and observe the output as temperature and humidity values on serial monitor as per the program. So we can keep critical value of temperature as per our design need for particular application.

6. CONCLUSION

In this paper a simple but effective methodology suggested for design of mechatronics system which help conceptual solutions for the design the mechatronics system. Thus, mechatronics product design is multidisciplinary and concurrent approach. As user interface become simple the background design complexity increases. So the final mechatronics product should be simpler, reliable, economical and versatile.

Future work include apply and investigate proposed methodology to existing mechatronics product and fine tune them.

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