MECHATRONIC DESIGN FOR STUDENTS: MODEL BASED ON INDUSTRIAL ENGINEERING TECHNIQUES

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ABSTRACT
The present paper proposes a methodology for mechatronic design projects based on industrial engineering techniques. Today, in industrial production the reduction of research and development time is one of the most important goals for engineers. This reduction will allow products to enter the market more efficiently, thus increasing profits for organizations. The analysis made on the Product Life Cycle (PLC) reveals the two areas where time is critical: R&D and project construction. The use of Design of Experiments (DOE), supported by Creativity Phase and Project Management techniques, are powerful tools to reduce time in the initial phase of the project. However, students, engineers, and scientists consistently avoid the use of industrial engineering and applied statistical techniques. Many textbooks and courses primarily focus on statistical analysis, thus forgetting planning, design, execution, analysis, and interpretation. The aim of this paper is to change today's teaching focus in engineering techniques towards new teaching models where scientific concepts and theories are applied to real world problems. To support this intention, students from ITESM Campus Queretaro worked on the development of a robotic project using a new model to design projects rapidly and efficiently. In line with the vision and mission of ITESM, this paper reflects the development of new models and techniques for learning projects oriented towards a methodology for the construction of high performance mechatronics design for students of mechatronic engineering.

Keywords: Mechatronics, concurrent engineering, creative phase, integration, design

1 INTRODUCTION

Nowadays, in regard to academic engineering programs, one common issue is the poor quality of finished projects. Experience has shown that even though students are given assignments four months in advance, they frequently postpone them until few days before the due date presenting unsatisfactory results. In most cases just the indispensable specifications are met, causing poor quality on the final product. In other cases, the projects are not delivered on time, or finished, due to lack of design.

Through Problems Based Learning techniques (PBL), ITESM has made an effort to implement methodologies that enable students to develop their academic projects in a disciplined way. However from the students' point of view, the methodologies are complex and bureaucratic, so they do not follow them. Based on this statement, there is a need to design a methodology capable to combine the best of each field of study to create a structured and robust project design to get excellent results.

On December 2012, a survey polling 50 professors from the ITESM's engineering division regarding the quality of projects, documents, and functional prototypes was made. The results are very interesting: 96% of the surveyed staff declared that they had received projects with the minimal functional specifications requested, and only 24% of them had received an innovative project that exceeded their expectations. Student efforts are isolated, lack a comprehensive approach and are delayed by concurrent engineering vision. Students tend to focus on the project elaboration, but not on the planning stage, which greatly impacts on the result of every activity they are performing.

During the Mechatronics Design course, one of the last courses that shape the program of the Mechatronics Engineering, the academy has designed a model that demands from students that in four

months, the length of the academic period, they have to deliver a robotic project, covering stages from design to manufacture. Outstanding quality, the use of creative phases and industrial engineering techniques are expected to be implemented in the project. The results are the reinforcement of their academic background and the development of skills in order to prepare students for professional life.
From August to December, 2012, a particular model was implemented as a new teaching strategy. High performance was reflected in the construction of final projects –a robotic helicopter that had to perform specific tasks powered with solar energy–. Students in this course improved skills such as problem solving and teamwork, in order to be prepared for their professional life. The most valuable deliverable was the documentation of the project, which showed the application of engineering techniques and the specialized knowhow that allowed students to deliver such high quality projects.

2 THE MECHATRONIC DESIGN MODEL

The model is based on three steps under the systematic and concurrent engineering vision [1] and the project management discipline. In general terms, the steps are described as follows:

- The first step has its basis in the training and assimilation of creative phase techniques [2]. This tool is essential in the design process since it allows the design team to generate innovative ideas in order to develop a product that is able to satisfy the customer's needs. It also strengthens the design phase as it seeks for new approaches at problem solving, permitting the multidisciplinary team to facilitate the manufacture, avoid delays and reduce costs. Statistical engineering is also used during the creative phase of the project since it helps to evaluate the design problems quantitatively and guarantee the quality in the design, manufacture and final product. Total design philosophy of Stuart Pugh [3] is to be used for the identification of the market-user need, and the synergy between process, product, people and organization. Best practices for customer information through the market, competition analysis as well as design and repair centres that allow engineers to take a broad overview of the expectations placed on a product.
- The second step is focused on the application of technical and engineering tools through the creation of the product by considering the distinct areas that integrate a multidisciplinary project. In this stage, it is important to take into account the importance of statistical methods such as the Design of Experiments (DOE) [4] and linear regression. Simulations can be performed with specialized software that allows the user to understand the behaviour of the product (output) by modifying subsystem variables (inputs) such as the materials. The usage of these tools allows the designer to identify key problems in the project performance by evaluating different points of failure and creating a robust design and product with the minimal risk exposure.
- The third and last step consists in the manufacture of the final design or prototype. In this stage the students have the opportunity to apply their knowledge from previous courses such as Material Mechanics, Electronics, Digital Systems, among others. By using their mechatronics knowledge, the design engineers become able to combine the work that was developed in each of the mentioned areas. It is important to orderly follow the suggested sequence in this document; starting from the design phase by generating innovative ideas, verifying and validating the design in different ways to minimize risks and problems, securing the success of the product, finding points of failure and the application of the involved areas in mechatronics. By applying in order this set of steps, the success probabilities of the project will increase considerably, since the integration of every single tool within the project is aimed to secure the design and product acceptance.

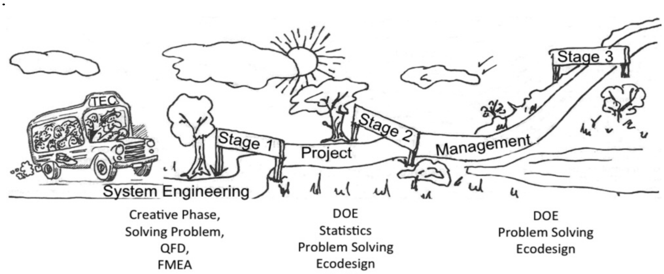

Figure 1. Steps for the execution of mechatronics projects

Figure 1. explains easily the precise sequence in which the stages have to be followed in order to make an adequate use of the propose methodology and thus to create a robust design. The significance of following these stages in the specified order lays in the fact that it has been idealized in such a way that it allows the user of the methodology (designer) to complete a whole process of creation that starts with the generation of an idea through the completion of a functional prototype. Specific tasks have been assigned to each stage in order to clarify to the designer the method so he is able to perform his design as if reading a recipe.

The innovation of this method lays in the potential impact and efficiency that it causes when applied at an early point in projects that are to be started. The teaching of this method to engineering students in the mechatronics field is recommended given that it offers a new approach of how a mechatronic design has to be created since it has a broader vision of all the areas that are involved and that usually are not taken into account. This method allows students, teachers and engineers to think beyond the three main fields that compose a mechatronic model as it studies the integration between its areas, as well as its integration and combination with other engineering disciplines.

The steps of the model proposed in this paper are based on the Mechatronic Model described on Figure 2. Three sets represent knowledge disciplines that intersect: Mechanics (A), Electronics (B) and Computer Systems (C) [5]. The intersection A∩B studies motors and sensors, A∩C analyzes computer aided and mechanical design, B∩C works interfaces and digital & analog control. This focus reduces the effort and stress of students as it helps them to keep in mind the main objective: the construction of the Mechatronics Project (MP), which is represented by the intersection A∩B∩C. The model reflects the necessary use of System and Concurrent Engineering.[1], [6] System Engineering unifies the product (finished project) [7] and process issues in the design and manufacturing approach of the robot. Concurrent Engineering reduces the project lead time based in the simultaneous focus. Industrial engineering techniques are written on the left and right of the sets because without the use of these techniques the Mechatronic Project would present delays and lack of quality. Systemic Vision makes the model work efficiently.

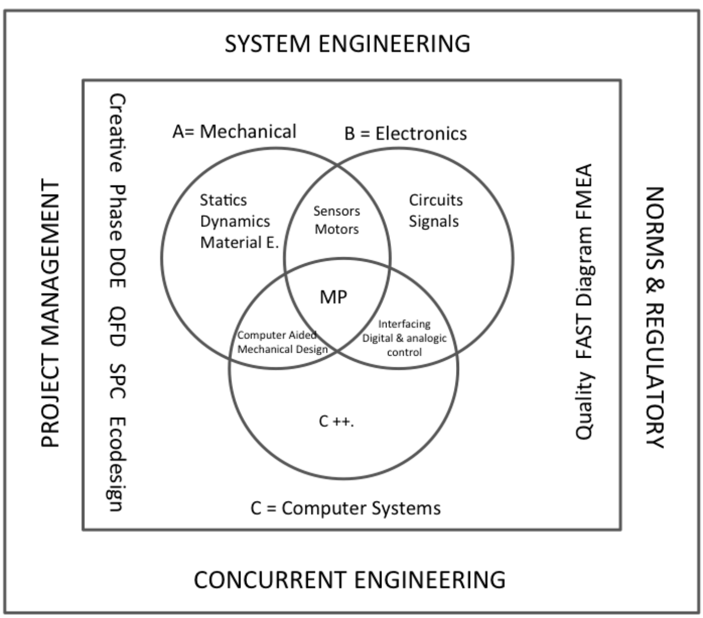

Figure 2. Mechatronic design model

It is important to note that what enriches this model is that it considers other essential engineering disciplines and industrial techniques as part of the systemic vision besides the three core fields that compose a mechatronic model. Once every area involved in a mechatronic project has been identified and clearly understood, it is necessary to show up the steps that need to be followed in order to reach the completion of a high quality mechatronic project.

Step 1 is based on Creative Phase and Problem Solving Techniques, total design model, the use of tools as the Quality Function Deployment (QFD), Statistical Process Control (SPC), Failure Mode and Effect Analysis (FMEA), so the students are capable of defining product requirements. The customer's concept could be materialized in sketches and prototypes, necessary elements to define the product specifications, raw material requirements, process and dimensional studies. This phase demands the use of techniques such as brainstorming, mind maps and QFD simultaneously in order to clearly translate customer needs into technical specifications and keeping in mind that the product is technically and economically viable. In the same survey cited before, professors mentioned that they believed poor design is the most recurrent cause for average and unsatisfactory projects. Students normally do not spend the necessary time to design their projects and jump immediately to the stage of manufacturing, finding out as they move forward that the process is difficult to actually carry through. Step 1 covers this gap: lack of planning and weakness of the principal idea. The Creative Phase helps students go from reality to abstraction by using primarily brainstorming, mind maps and thinking engineering. In this way, they make an efficient conceptualization of the requirements, taking the necessary time to discuss each of the ideas and making a selection that results in the most technically feasible proposal.[2]

In Mechatronics, the QFD is considered a planning tool because it lists the wants and needs of the costumer, which build-up the design, technical and functional requirements. The main question that this tool is capable to answer is: "What does the costumer absolutely need?" Costumers are used to define the product using only their own desires and qualitative expressions, and most of the time the definition rarely carries any technical support specification. QFD is the translator. The other significant advantage of using the QFD technique is the improvement gained in the overall design process, which greatly impacts on the customer's satisfaction.

Step 2 begins with the preliminary approach and prototype analysis. In this phase, the use of Statistics and Design of Experiments is used for the selection of appropriate raw materials and parameters for every subsystem, but how do students find the correct variables? The answer is simple: doing research about the materials used in robots from previous projects. In this way, students save time and just tune up the range of the parameters' necessaries. Problem Solving is a fundamental tool because even though students are confident using Design of Experiments in theoretical problems, they are insecure of making abstractions of real problematic situations and designing a mathematical model that represents them. The preparation of students in this process will result in a simple and successful DOE.

The use the Statistical Engineering is fundamental. Students can find out descriptive statistical about former research and projects, but it's necessary to apply inferential statistical to find out critical parameters, particularly for raw material. The statistical treatment is critical in the whole construction process project. Statistics is a mathematical science enclosing the collection, analysis, interpretation or explanation, and presentation of data.[8] Since its discovering it has been very useful because through this technique, the behaviour of systems and processes can be predicted in order to define the best parts and practices from the beginning of the production process without spending valuable resources –human, time and money– in doing so.

A satisfactory deliverable for this stage is a robust design, with the total of variables and their parameters defined. In this part of the project development, students begin to design the robot in a formal way, making a selection of materials and defining the appropriate parameters and the critical variables. For robot construction, one of the best manufacturing processes is thought subsystems, in other words, in modules. The achievement of these objectives is based on previously acquired knowledge in areas of Mechanical Engineering, Electronics and Computer Systems, and complemented with engineering techniques such as Design of Experiments, Statistical Process Control and Engineering Statistics. Mathematical simulations performed have made it possible to eliminate waste of time, lab materials and human resources.

Engineering Value Analysis is used to increase the value of products or services by considering the function and benefits of individual items and balancing them against the costs incurred in delivering it. Industrial Engineering is very resourceful as it includes various tools that enable engineers to make processes faster, better and cost competitive. One of these tools is the FAST diagram, which is a

Quality Assurance technique. Through this method the functions and characteristics of a product are deployed and separated so they can be managed separately and treated individually [9].
Finally, Step 3 is the project execution itself. The robot manufacturing process is easily done because students rely on a robust design. They know the necessary materials, characteristics and dimensions in order to build the robot without any, or little uncertainty. The students apply process design techniques and define, for every module, the manufacturing processes. They have access to machinery and laboratories available at ITESM. Following this methodology, students learn other abilities different from engineering techniques, such as team-work, problem solving, creative phases, working under stress, and project management.

3 APPLYING THE MODEL

The control project consisted on the construction of a helicopter prototype using "Meccano" [10] as raw material. The requirements to be met were:

- The 3Volts engine must be powered with solar energy
- It must use sensors in order to know external conditions
- All the electronic needs (as power amplification) should be accomplished using analogical and digital electronics
- It must move along 0,3 m lineally and independently sorting the obstacles through the use of sensors and must power off with a voice command.

The group formed by twelve students was distributed into two teams. Each member had a specific task, and the Project Manager role was rotated every week. The students established communication between them using social networks like Facebook and Twitter as well as they developed a website using the Google tools for project management, where they placed the documents so they could be attainable online for each member and the professor.
Using the creative phase techniques, the students built a robotic engineering sketch, based in aeronautic and Mechatronics research and practicing with laboratory experiments. By using these tools, they could define the variables and critical parameters for every single piece of the robot. They applied QFD and Engineering Value Analysis in order to make a robust preliminary design.
Finally, the students designed statistics experiments in order to define the most suitable parameter for wheels, gears and materials as well as dimensions of the solar cells to ensure the helicopter would be compliant with the task that must be done. Following the methodology and without the faults typically carried from design stage, students saved approximately four months of work because the last step became so smooth that test and error proved useless and the manufacturing was completed in two days. Figure 3 shows two different views of the functional prototype that was designed and created by students using the methodology described in this document (helicopter); it also includes a view of a robot that was implemented on a subsequent course (Mechanical arm) where the methodology was not applied as specified and where the students took more time and resources to develop the project due to the lack of organization, thus causing the un-completion and failure of the designed model of mechatronic project.

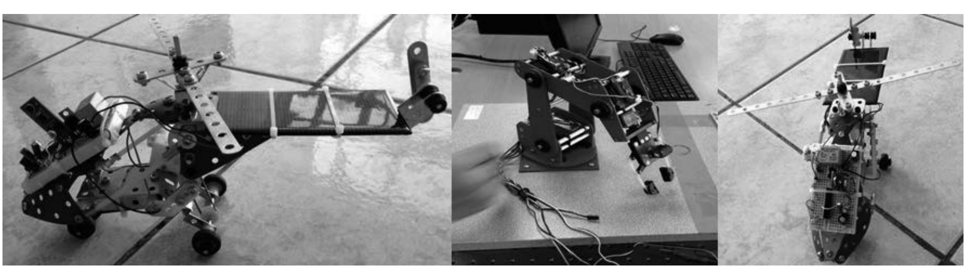

Figure 3. Views of the prototypes that were implemented using the proposed methodology

4 CONCLUSION

The System Engineering approach is an important means to the development of Mechatronics systems and helps students overcome two important challenges: reduction of the development time and correctness of design. Eco explained in his book, "How to write a thesis" [11] that not all research is based on new knowledge, also is based on the compilation of techniques or knowledge. Mechatronic projects are defined by the systematic integration of mechanical, electronics and computer sciences; this integration can be performed with Industrial Engineering tools such as project management, concurrent and systematic engineering as well as a robust theoretical frame. The application of the proposed model helps students clarify the project requirements on a robotic design. Consequently, a structured methodology can guarantee reduction of time on the research and feasibility stage of design, as well as in the total product lifecycle. The best way to reflect the students' learning process is by sharing an abstract of the group conclusion, where they explain how they used the model and the advantages gained during the academic period:

The development of a project, which requires mechatronic design, can be analyzed and developed by applying different Industrial Engineering techniques as the seen above. These tools form a process divided into specific stages such as identification, feasibility, design, development and industrialization of a product or a service. A tool like the QFD can be enhanced with the previous knowledge of students, because now they only have to involve on the needs of the customer instead of acquiring complex technical skills. By using these techniques it'll be easier to identify errors on the design phase so the faults carried in all the process can be avoided.

The advantages given by the usage of the Industrial Engineering techniques can be easily identified, since the savings produced on execution time through the reduction of time and cost during design are just a few of them. By combining mechatronics engineering (which is a versatile and multidisciplinary science) with Industrial Engineering which is made for improving processes and products, we can obtain high quality projects which can be used in a wide range of industrial and daily applications."

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