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A new approach in Mechatronics Education through Project Based Learning by International Collaboration

Dr. Devdas Shetty, University of District of Columbia, DC

Dr. Shetty is the Dean of the School of Engineering and Applied Sciences at the University of DC. Previously he held academic and administrative positions at the University of Hartford, CT, Lawrence Technological University, MI and the Cooper Union New York. He is the author of 3 text books and more than 200 publications. Dr. Arunkumar Giriyapur is a Professor at the BVB College of Engineering and Technology, Hubli, Karnataka Stae, India. He is also the Head of Robotics Program at BVB College of Engineering and Technology.

Prof. Arunkumar Chandrashekarappa Giriyapur, B.V.Bhoomaraddi College of Engineering & Technology

New Approach in Mechatronics Education through Project-based Learning, an effort in International Collaboration

Abstract

The field of "Mechatronics" has changed from being an integrating vehicle for multiple disciplines, into a design philosophy. In the emerging scenario, mechatronics plays one of the key roles in innovative engineering. Because of the integrated multidisciplinary approach, the scope for innovation in product engineering is ever increasing. With rapid changes in technology and more applications becoming real-time and embedded, teaching the mechatronics course only through laboratories or course projects is not sufficient. The leap from the traditional sequential design approach to the mechatronics philosophy is very big. Added to this are the various definitions that have evolved and the various methodologies developed for the mechatronics system design. Mechatronics is at a stage of evolutionary process of modern engineering design and involves systems thinking. "V-cycle" is a prescribed industrial process for mechatronics. It is a graphical construct used to communicate a model-based design and development methodology. If mechatronics system design is accepted as an evolution of engineering design, then a formal perspective design process can be developed and the course delivery can be effective with project based approach. This paper outlines the results of international collaboration between the two institutions on the perception of mechatronics as a modern design philosophy emphasizing team dynamics, project based learning and integration of disciplines. The collaboration was initiated by Indo-US Collaboration for Engineering Education (IUCEE), a US based non-profit organization promoting quality and collaboration in innovative engineering education.

1. Introduction

Mechatronics as a multidisciplinary approach has been attracting contributions from different disciplines which have led to a wide variety of developments and interpretations. Millibank[16] has stated that 'By definition then, mechatronics is not a subject, science or technology per se- it is instead to be regarded as a philosophy – a fundamental way of looking at and doing things and by its very nature requires a unified approach to its delivery'. It is of the opinion of many a researcher that mechatronics is still evolving and none of the many existing definitions can be said to be the best way of describing mechatronics [Bradley][4]. Rapid changes in technology and more applications going the cyber-physical way it has become more important to use an evolutionary approach to the mechatronics system design process. More important is the student experience if they are to become industry ready. In this paper an attempt has been made to evolve a prescriptive approach to mechatronics system design for engineering undergraduate students.

2. Background

Four years ago, the B.V.B. College of Engineering and Technology, India had started a School of Automation and Robotics with the intention of developing engineering graduates with a multidisciplinary experience in system development. The new integrated curriculum was introduced in this programme. In addition, a project mechatronics course was started at the third year level to give the students an experience in mechatronics system design before they move to the final year capstone project. This course is of two semester duration to give the students a complete system design experience. In this respect a collaborative effort was established with University of District of Columbia, USA for the development of the course based on the authors experience in teaching similar courses at the University of District of Columbia, University of Hartford and the Cooper Union, USA. This paper describes how the coursework was developed and how it is being delivered to the students and what will be the expected outcome at the end of the course and how the assessment will be made. The main challenge of the course is to achieve a complex task yet keeping the integrated methodology simple for the students to understand and implement.

3. Scope

In an industrial background the design process starts with existing designs or previous knowledge base, while in an academic environment students do not have any previous experience on design and have to work on theoretical knowledge. Hence the emphasis of the course would be to provide a good foundation on computer-aided conceptual design and system architecture overlaid on the V-model of mechatronics product development. The industrial guideline VDI 2206 specifies the V-model for the development of mechatronics products. The flow of the whole process would be established and divided into lecture classes, laboratory and independent work. To complete all the activities in the given timeframe essential resources for rapid prototyping would be identified so that the students can complete the given task within time. In view of the rigorous nature of the project work the duration of the project has been fixed at two semesters. In the first semester the students complete the system architecture and the component design culminating in the virtual model of the system. The integration and the physical model and testing are done in the second semester. It is decided that the coursework should end in a student competition and a common theme would be announced. Student teams would be formed and the scope of the coursework would be explained.

During the coursework students should be able to build prototypes and quick experiments at various stages and hence the need for suitable resources. After a survey of the various software and hardware products it was found that some software and hardware were compatible with each other and would enable rapid prototyping. The following hardware and software resources have been identified for procurement:

1. List of Identified Hardware

- Rapid prototyping 3D printer – Objet 30
- Data acquisition - NI USB 6009
- Instrumentation, Design and Prototyping platform - NI Elvis II
- Embedded control and acquisition device - NI sbRIO 9632
- Embedded control and monitoring system - NI CompactRIO 9075
- LEGO MINDSTORMS NXT 2.0 kit
- Arduino microcontroller boards
- Stepper motors and drives
- AC Variable frequency drives

2. List of Identified Software

- Mechanical CAD, Motion analysis, FEA, DFM - SolidWorks 2012 Premium

- Control system modelling - NI LabVIEW 2012 including Realtime and Robotics modules
- Circuit design and simulation software - NI Multisim
- PCB layout and routing – NI Ultiboard

Software tools like SolidWorks and NI LabVIEW can communicate with each other and provide for virtual control system simulation. Virtual hardware in loop simulation can be done with LabVIEW and Multisim software. Hardware like NI Elvis II and Arduino microcontroller boards will be used for laboratory work. Both Elvis II and Arduino board can be interfaced with LabVIEW. Lego Mindstorms NXT 2.0 kits can be used for quick prototyping. The advantage with Lego kit is that it can be interfaced with LabVIEW and the modelling can be done in SolidWorks.

4. Coursework

The coursework will start with the announcement of a common theme which will end in a student competition. The overall objective will be in the form of a theme. An example of theme can be as follows:
Develop an autonomous mobile robot to participate in a maze solving challenge.

The student teams will then be formed. The process starts with the clarification of the given task or objective. The course work is prescribed using the V-cycle as the process model and is divided into number of phases as shown in the fig.1. Each phase requires inputs, has design tasks that must be performed, and produces outputs.

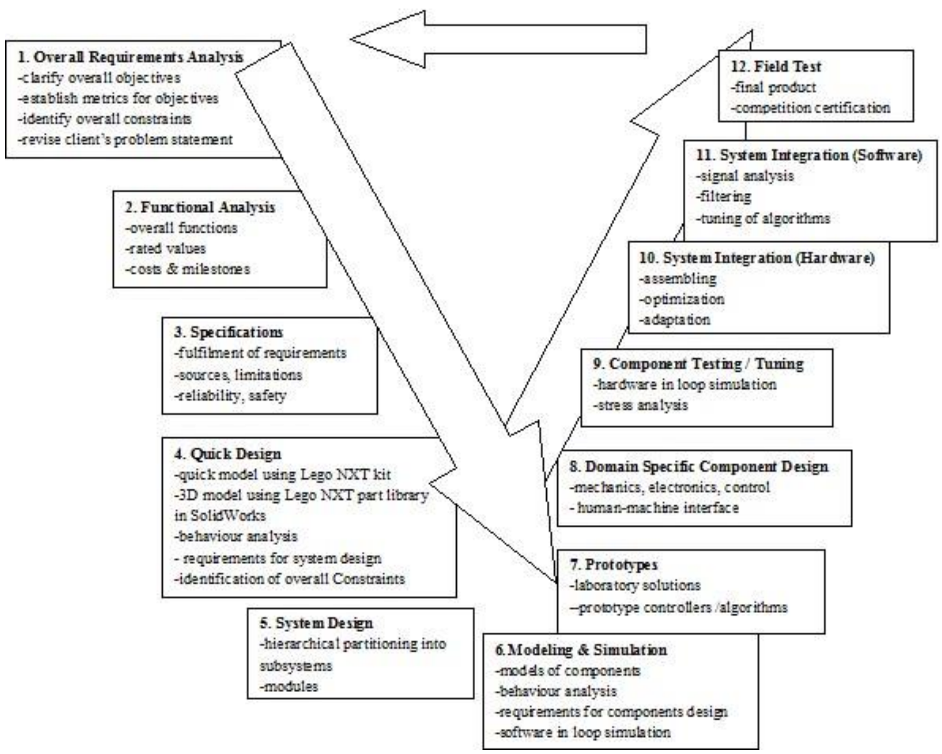

Figure 1 V-Cycle [VDI 2206]

The coursework emphasises more on the integrated framework for mechatronics system design and the teams will move from overall system level specifications to specifications of subsystems and components through hierarchical decomposition. Then the definition of functional structures and behaviours of these subsystems and their interfaces will be built. Support of all the hardware and software resources will be used to complete the different phases. Some of the important phases in the course work are mentioned below:

Overall requirements analysis

Here the client is identified and the client's objectives are clarified and information gathered to develop an unambiguous statement of the client's wishes, demands and limits. The steps for a clear problem definition are as follows:

i. Clarify overall objectives
   - Expand requirements from the needs statement and do overall requirements analysis.
   - Prioritize requirements according to importance.
   - Organize requirements into an objective tree.

ii. Establish metrics for overall objectives

iii. Identify overall constraints

iv. Revise client's problem statement

The whole team will be involved as a single body and brain storming is done to gather information. The team moves from the list of desired system attributes to list of desired overall objectives. The checklist given in table 1 can be used to draw up the attributes list:

Table 1 Checklist to derive attributes list [Pahl & Beitz] [21]

Geometry	Size, height, breadth, length, diameter, space, requirement, number, arrangement, connection, extension
Kinematics	Type of motion, direction of motion, velocity, acceleration Forces Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, stability, resonance
Energy	Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion
Materials	Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations, etc.)
Signals	Inputs and outputs, form, display, control equipment
Safety	Direct safety principles, protective systems, operational, operator and environmental safety
Ergonomics	The man–machine relationship, type of operation, clearness of layout, lighting, aesthetics
Production	Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances
Quality	Control possibilities of testing and measuring, application of special regulations and standards
Assembly	Special regulations, installation, siting, foundation, transport limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of dispatch
Operation	Quietness, wear, special uses, marketing area, destination (for example, sulphurous atmosphere, tropical conditions)

Maintenance	Servicing intervals (if any), inspection, exchange and repair, painting, cleaning
Recycling	Reuse, reprocessing, waste disposal, storage
Costs	Maximum permissible manufacturing costs, cost of tooling, investment and depreciation
Schedule	End date of development, project planning and control, delivery date

K.Chen et al[19] have provided a set of guidelines for the overall requirements analysis. These guidelines will be useful to generate the function structure and the specifications. The following tables can be referred to generate overall requirements [K.Chen et al] [19]:

Table 2 Requirements from mechanical engineering point of view

1	Kinematic requirements
2	Force requirements
3	Energy requirements
4	Material properties requirements
5	Material selection requirements
6	Geometric constraint requirements
7	Manufacturability requirements

Table 3 Requirements from electrical engineering point of view

1	Collaboration requirements
2	Energy requirements
3	Control requirements
4	Installation requirements
5	Material selection requirements
6	Geometric constraint requirements
7	Manufacturability requirements

Table 4 Requirements from electronic engineering point of view

1	Electronic device requirements
2	Circuitry requirements
3	Signal requirements
4	Controller properties requirements

Table 5 Requirements from integrated mechatronics engineering point of view

1	General collaboration requirements
2	Energy requirements
3	Control requirements
4	Installation requirements
5	Maintenance requirements
6	Mechanical-Electronic requirements

Overall Functional analysis

The black box approach will be used for the overall function analysis. Fig.2 shows the overall function diagram for a example i.e. a mobile robot.

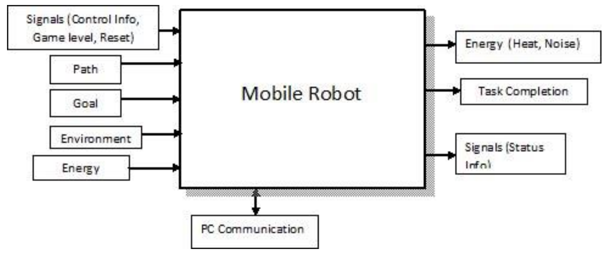

Figure 2 Black Box Diagram for a mobile robot

System level specifications

K. Chen et al[19] suggests that using a framework, integrated design of mechatronic systems can be considered from the point of view of the electrical, software, mechanical, and electronic engineers. Each discipline has its design requirements to be fulfilled. To derive the system level specifications the requirements analysis for the overall system has to be done. The following is a high-level list of requirements that should be addressed in a system level specification:

- Define the functions of the system
- Define the hardware / software functional partitioning
- Define the performance specification
- Define the hardware / software performance partitioning
- Define safety requirements
- Define the user interface
- Provide installation drawings / instructions
- Provide interface control drawings

Quick Design

Often in mechatronics the design initially starts with a defined set of general objectives. Detailed inputs, processing or output requirements are not identified at this stage. Reeves and Shipman[22] have stated that discussion about the design must be embedded in the overall design process. K.Chen at al[19] have suggested that in order to embed the discussion aspect, mechatronic products should be designed in an integrated fashion that allows for designers of both electrical and mechanical engineering domains to automatically receive feedback regarding design modifications made on either side throughout the design process. One of the approaches that can be used to gather overall requirements, get an insight into the function structure and also build a common knowledge base is the prototyping paradigm [pressman][1]. The prototyping paradigm begins with requirements gathering. The designers or the developers have to do role playing and act as internal customers. They meet and define the overall objectives for the system, identifying whatever requirements are known and outline areas where further definition is mandatory. A quick design then occurs.

The quick design leads to the construction of a rapid prototype. The prototype model is designed to assist the customer (or designer) in understanding requirements. The quick model can be either virtual, physical or both. To create a virtual model, resources like Lego digital designer or SolidWorks can be used. All the parts in the LEGO MINDSTORMS NXT 2.0 kit are available in the digital form as parts in Lego digital designer or as parts and sub assemblies in SolidWorks. Fig.3 shows a virtual model of a mobile robot created in SolidWorks while fig.4 shows a student built mobile robot using the Lego kit.

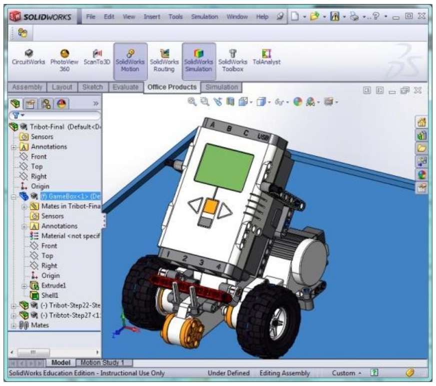

Figure 3 Model of a Lego NXT based mobile robot

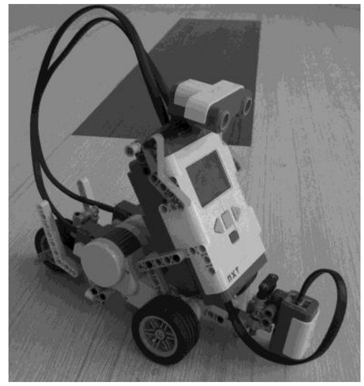

Figure 4 Student built mobile robot

System Design

In the V-model of product development, conceptual design is referred to as system architecture as a part of the system decomposition phase, in which the system-level specifications of a product are defined and hierarchically decomposed to the specifications of subsystems and components [H.Komoto et al][1]. The overall system can be divided into subsystems such as mechanical subsystem, actuator subsystem, control subsystem, etc. as shown in the fig.5.

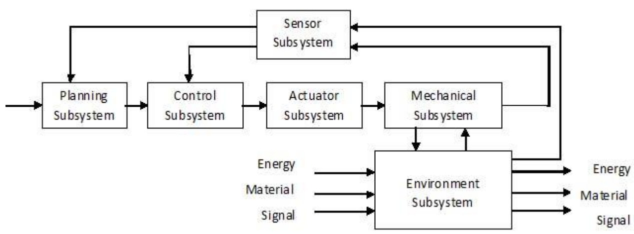

Figure 5 Typical Mechatronics System

According to Pahl & Beitz[21] "Conceptual design is the part of the design process where–by identifying the essential problems through abstraction, establishing function structures, searching for appropriate working principles and combining these into a working structure–the basic solution path is laid down through the elaboration of a solution principle."

The teams after establishing the sub functions should search for working principles that fulfil the sub functions. They have to create morphological charts, combine working principles into working structures, and select suitable combinations. The solution variants are then to be evaluated against technical and economic criteria. Fig.6 shows the use of a transparent box to show the functional details of a mobile robot.

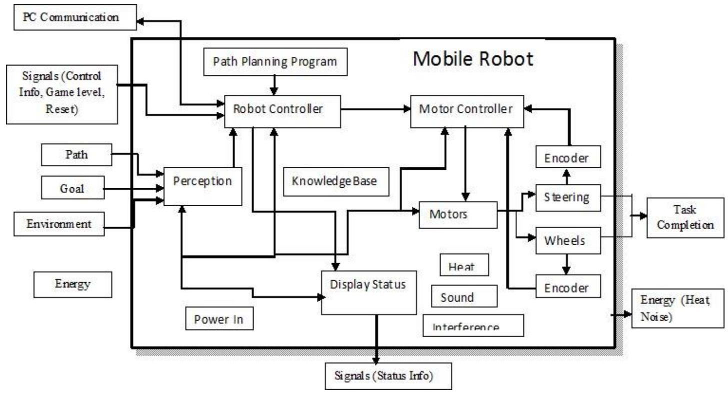

Figure 6 Transparent block diagram for a mobile robot

Constraints Mapping

It can be summarized that even on conceptual design level, mechanical and electrical design aspects of mechatronic systems are highly intertwined through a substantial number of constraints existing between their components [K.Chen at al] [19].

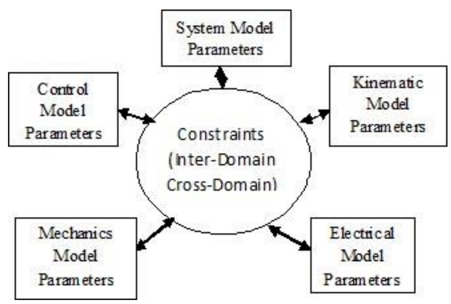

Figure 7 Constraints mapping

The constraints have to be identified and classified. The classification will be based on whether the constraint is within a domain or between two domains. The cross domain constraints are important since they provide a path for feedback. The following are some classifications given by K.Chen et al[19].

1. Constraints in the mechanical domain
   - Geometric constraints
   - Kinematic constraints
   - Force constraints
   - Energy constraints
   - Material constraints
   - Tolerance constraints

2. Constraints in the electrical domain
   - Electrical characteristics like resistance, capacitance and inductance
   - Motor torque
   - System control

Domain specific design

It is important that during the component design at the domain level team members receive feedback from the other domains whenever a constraint is changed. This can lead to better integrated designs. The design tools selected will assure that a common database gets developed and the data can be ported between different systems using the standard product data exchange formats.

Table 6 identifies various integrated tools which will be made available for domain specific design of components.

Table 6 Integrated Tools

Design and Modelling Activity	Integrated Tools
Mechanical Design: Mechanics and Kinematics	SolidWorks for part design, assembly design, stress analysis and motion analysis
Electrical Design: Motor sizing, Motor drivers, Sensor interfaces	NI LabVIEW, NI Multisim & Ultiboard
Control Design: PID, Model based control	NI LabVIEW control design
Integrating mechanical and control design	SolidWorks motion study with NI LabVIEW motion
Electromechanical simulation	SolidWorks with NI motion

Modelling and Simulation

The learning can be enhanced by using a coordinated approach for model building. The teams will be conducting experiments, building models both physical and virtual along with the design. Fig.9 shows a couple of student project models in Solidworks.

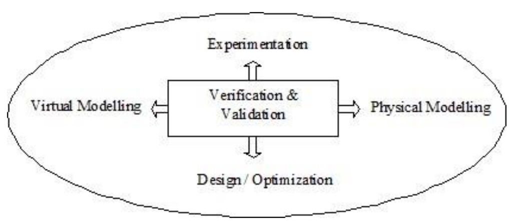

Figure 8. Coordinated approaches for model development

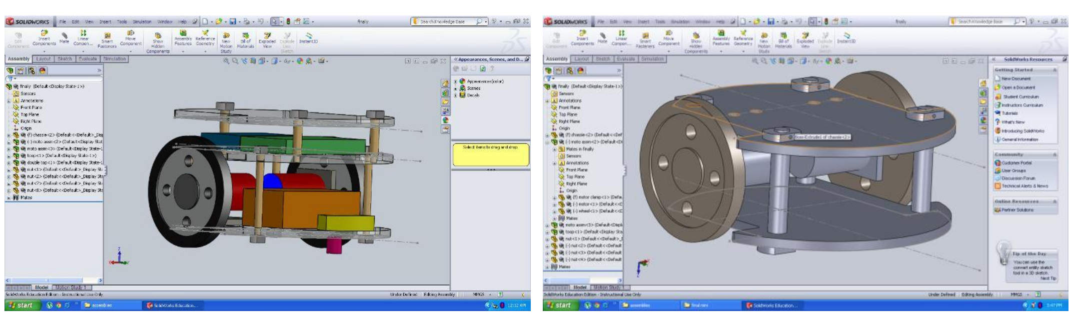

Figure 9. Student project models in SolidWorks

Rapid control modelling and simulation can be done with the help of tools like NI LabVIEW and Multisim. Co-simulation can be done using tools like SolidWorks, NI labVIEW and NI motion module. Modelling and simulation can also be done in the NI robot model and simulation environment.

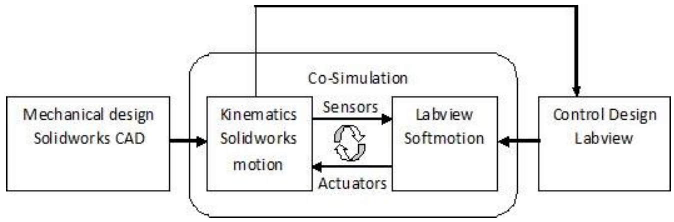

Figure 10. Mechanical and control system co-simulation

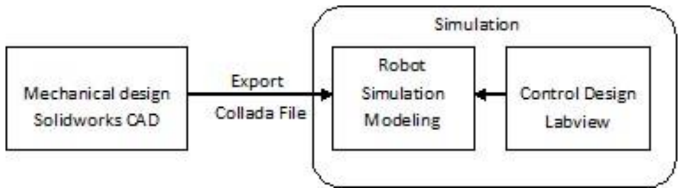

Figure 11. Simulation modelling environment in LabVIEW

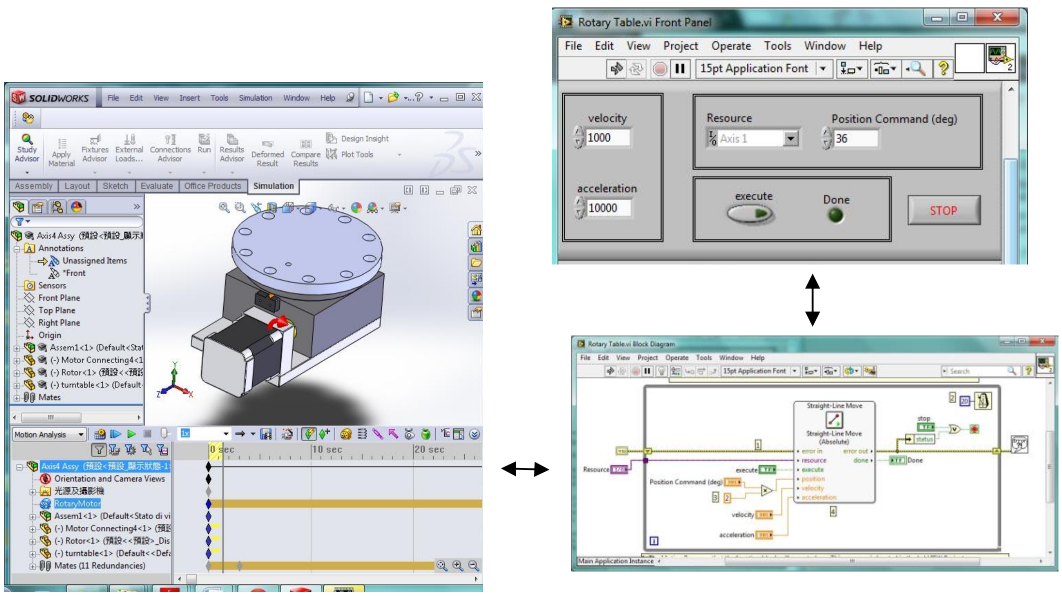

Figure 12. Modelling and co-simulation in SolidWorks and NI LabVIEW motion module

5. Assessment

Assessment will be done at the end of each phase so as to keep track of the work done and to facilitate the teams in problem solving. Each team has to participate in the final competition with their device. Each team will get a certificate at the end of the competition based on the performance of their device.

6. Conclusion

All the hardware and software tools identified have been procured. The theme for the competition has been announced and the teams have been formed. The model library of the Lego NXT components in SolidWorks has been deployed. Time to market is an important concept which any mechatronic engineer should be well aware of. A reduction in project duration and time to market can be achieved by concurrent and simultaneous engineering for design, optimization and operation [B.Vogel-Heuser] [20]. Proper workflow can be established by providing a prescriptive approach to mechatronics system design and all the phases from concept phase to the integration phase can be tightly integrated and lead time shortened. In this respect identification of proper tools and tool integration has to done and should be available to the students. Also the students should be trained on these tools at the right time.

References

1. H. Komoto and T. Tomiyama, "Computer-Aided Design A framework for computer-aided conceptual design and its application to system architecting of mechatronics products," *Computer-Aided Design*, vol. 44, 2012, pp. 931-946.
2. Gómez-de-Gabriel, J.M., Mandow, A., Fernández-Lozano, J., García-Cerezo, A.J., Using LEGO NXT Mobile Robots With LabVIEW for Undergraduate Courses on Mechatronics, IEEE Transactions on Education, vol.54, no.1, pp.41-47, Feb. 2011.
3. T.J. Beek, M.S. Erden, and T. Tomiyama, Mechatronics Modular design of mechatronic systems with function modeling, Mechatronics, vol. 20, 2010, pp. 850-863.
4. D. Bradley, Mechatronics Mechatronics – More questions than answers, Mechatronics, vol. 20, 2010, pp. 827-841.
5. A.A. Cabrera, M.J. Foeken, O.A. Tekin, K. Woestenenk, M.S. Erden, B.D. Schutter, M.J. Tooren, R. Babuška, F.J. Houten, and T. Tomiyama, Mechatronics Towards automation of control software : A review of challenges in mechatronic design, Mechatronics, vol. 20, 2010, pp. 876-886.
6. S.J. Choi, D. Shetty, J. Poduraev, and W.Y. Lee, J.H.Lee, International Collaboration and Improvement of Mechatronics Education based on Simulation and Virtual Instrument .
7. R. Mchugh and H. Zhang, Virtual Prototyping of Mechatronics for 21 st Century Engineering and Technology,.
8. D. Shetty, J. Kondo, C. Campana, and R.A. Kolk, Real Time Mechatronic Design Process for Research and Education, Engineering Education.
9. R. Isermann, Mechatronic Systems – Innovative Products With Embedded Control, IFAC Symposium on Mechatronic Systems, 2005.
10. V.S. Vasić, Standard Industrial Guideline for Mechatronic Product Design, Mechatronics, 2008, pp. 103-108.
11. C. Koch, A. Spröwitz, and T. Ströhla, Project course - Design of Mechatronic Systems, ICM 2006, 2006, pp. 2-5.
12. J. Bathelt, C. Bacs, S. Dierssen, and M. Meier, "Applying the new vdi design guideline 2206 on mechatronic systems controlled by a plc," International Conference on Engineering Design iced 05 Melbourne, August 15-18, 2005.
13. S.K. Gupta, S. Kumar, and L. Tewari, A Design-Oriented Undergraduate Curriculum in Mechatronics Education , Int J of Engg Ed, vol. 19, 2003, pp. 563-568.
14. R. Rothfuß, M. Lasa, H. Heinkel, and P. Tirgari, Systems engineering in the design of mechatronic systems, 1997.
15. S.M. Qureshi, Introduction to Mechatronics : A Graduate Engineering Course, Engineering, 1997.
16. Millbank J., 'Mecha-what', UK Mechatronics forum newsletter, Summer; 1993.
17. Chee Khiang Pang, Tsan Sheng Ng, Frank L. Lewis, and Tong Heng Lee, A Systems Design Approach to Manage Mechatronics R&D.
18. P.R. Anderl, D.R. Nattermann, and D.T. Rollmann, The W-Modell – A Systems Engineering based Approach to Active Systems Development.
19. K. Chen, J. Bankston, J.H. Panchal, and D. Schaefer, A Framework for Integrated Design of Mechatronic Systems.
20. B. Vogel-Heuser, Integrated modeling of complex mechatronic systems to increase dependability.
21. Pahl G, Beitz W., Engineering design, a systematic approach, Springer; 1995.
22. Reeves, B. and Shipman, F., Supporting communication between designers with artifacts-centered evolving information spaces, In Proceedings of the 1992 ACM Conference on Computer-supported Cooperative Work, pp. 394–401.