An Approach in Mechatronics Teaching

Dr Milan Simic

Computer Systems and Telecommunications
SIEBS, RMIT, Australia
Milan@rmit.edu.au

Abstract: This paper is a short review of an approach adapted in introducing students to Mechatronics engineering. Mechatronics systems are introduced as complex engineering and physical systems that can be modelled using ordinary linear differential equations. The use of the same equations for different systems is just another proof of the unique nature of the world around us. Energy in a complex system is carried by different physical quantities and using current technology can easily be transferred between systems without great loss. It is transferred across physical systems according to known and yet unknown laws of physics.
Those systems are a great example of the Transformations of the discipline. Traditional engineering disciplines like Mechanical, Manufacturing, Electrical, Electronics, Computer and Information Systems are all integrated in a Mechatronics System design. Students are made aware of a vast variety of simple and complex systems used in everyday life: a car, camera, washing machine, CD, DVD, hard disk, printer, but a production line as well…They are instructed to research on the future of engineering disciplines and across the boundaries. A car of the future is a great example: it is going to be more electrical / electronics / computer system than just mechanical. That future has already started.

From the first year of study, students are prepared for an interdisciplinary practice and new ideas and relationships in engineering. Teaching methods are combinations of lectures, delivered face to face and online, self paced research on selected study topics, tutorials and labs. In addition to being educated as future experts in a number of discipline areas, students are practising team work, as members of multidisciplinary teams, as well as exercising leadership skills, while conducting project based practical learning activities. LabVIEW, MATLAB and Simulink are used as simulation tools for teaching and practical exercises.

Study material is delivered using a variety of mediums; Learning Guide as a starting point, custom prepared and printed textbook, other books and printed or web published material, and using an online delivery system, i.e. Online@RMIT, Blackboard.

Assessment is an ongoing activity and it is done online in addition to the assessment of practical skills, done through project completion and professionalism assessment in lab and/or simulated environment.

Finally, students have their say during the study through online discussion forums and submitting an online subject feedback at the end.
Keywords: Engineering, Complex Physical Systems, Control Systems, Mechatronics

Introduction

In the first year of Bachelor of Engineering study (Automotive, Mechanical, Manufacturing) at RMIT University, students are enrolled in a subject called *Professional Practice 2* (coded as *MIET 2094*). *Professional Practice 2* introduces students to the following aspects of engineering:

- Mechanical Engineering
- Mechanical Design
- Mechatronics
- Workshop Practice

A Comprehensive Learning Guide[1] is available to students and covers all four aspects of engineering in the forms of learning modules. Mechatronics is a multidisciplinary field of engineering that integrates mechanics, electronics, computer and control systems. Pneumatics, acoustics, or other systems, may be included in complex systems, as well. We could also say that mechatronics systems are complex physical systems that are manage a variety of physical quantities and are controlled by a processing unit. The processing unit could be one, or a few of the following:

- Microprocessors
- Microcontrollers
- Microcomputers
- or Computers.

Sensors, actuators and feedback devices are used to transform signals and energy, carried by a physical quantity of one kind into signals and energy carried by a physical quantity of another. There are many different varieties of sensors and actuators in use. Smart sensors are taking place as well[2].
Since Mechatronics covers a wide range of engineering disciplines, there is a significant pool of literature that could be used in education and application design. Good introductory books[3, 4] cover few different areas, while specialised texts can be used for distinct study, such as: Electrical[5, 6], Electronics[7] and Digital[8] Electronics, Microcontrollers[9, 10], Robotics[11], Control Systems design[12] and Manufacturing Computer Control[13]. Mechanical and Manufacturing Engineering section is covered by the first two modules of the course and appropriate literature is given. In order to support students, apart from producing the Learning Guide, course development team has compiled a custom designed textbook: *Topics in Mechanical and Mechatronics Engineering*[14].

Multidisciplinary Approach

Ordinary differential equations (ODE) are used in science and engineering for modelling physical systems. Based on the similarities of the equations forms, we can establish analogies among physical quantities (such as voltage and velocity, or electrical current and mechanical force). Due to these similarities, we can use solutions and models developed in one scientific discipline for system modelling and solutions in other areas. For example, software tools developed for one system are easily used in another system. Electrical circuit models are commonly used as a good example of system modelling that could be applied to many other systems.

During the study of *Professional Practice 2*, students have initially learned about mechanical engineering and design. The next step is to introduce electrical quantities and discuss analogies among different system. Here are some definitions and equations as given in the Learning Guide[1]:

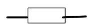
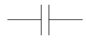
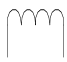
An electrical system can be presented using a circuit model, with electrical elements shown as building blocks and electrical quantities flowing through and across elements. Two basic electrical quantities are:

- *voltage* V *and*
- *current* i.

In mechanical systems we have similar occurrence, where two basic mechanical quantities are:

- *force* F *and*
- *velocity* v.

Basic electrical elements and their effect in an electrical circuit (i.e. relation that they establish between basic electrical quantities) can be shown as following:

- *R, Resistor,* $V_R = Ri$  *(1)*
- *C, Capacitor,* $V_C = \frac{1}{C}\int i dt$  *(2)*
- *L, Inductor* $V_L = L\frac{di}{dt}$  *(3)*

Graphical symbols are shown as well.

Equation (1) illustrates that a simple relation exists between two basic electrical quantities, and this is well known Ohm's Law. It is one of the keystones of electrical and electronics engineering.

Equation (2) expresses that a capacitor is an integrative circuit element, or element that "collects" electrons and build up the voltage charge across the plates.

Finally inductor, as given in the equation (3) is known as an element that differentiates instant current. So we have all possible relations in a physical system:

- *Gain, or loss,*
- *Integration and*
- *Differentiation of physical quantities.*

At this point of the course, analogies are explored by comparing an electrical system to a mechanical.

In a mechanical system, force is expressed as:

$$F = m\frac{dv}{dt} \tag{4}$$

where m is a symbol for mass and v(t) is the instant velocity of that mass.

In electrical systems, if a voltage (V) is applied across the serial connection of a resistor (R), inductor (L) and capacitor (C), such a system could be modelled as:

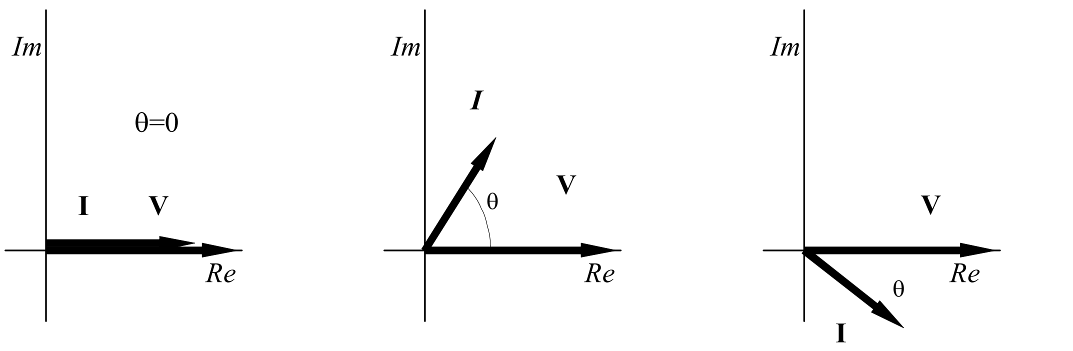
$$Ri + L\frac{di}{dt} + \frac{1}{C}\int idt = V \tag{5}$$

Similar equations, with proportional, differentiate and integrative systems elements could be derived for:

1. *mechanical translation*
2. *mechanical rotation*
3. *hydraulic systems.*

In all those physical systems, complex numbers and vectors are used as a tool to analyse systems behaviour.

Figure 1 presents complex plane diagrams for the resistive, capacitive and inductive loads.



Resistor (R) diagram; The current and voltage are in phase

Inductor (L) diagram; The current leads the voltage

Capacitor (C) diagram; The current lags the voltage

Figure 1. Complex plane diagrams

To further stress transformation, or close relations between different physical quantities and to better explain electrical current phenomena, we explain that electrical current is actually flow of charged particles. Charged particles are electrons, protons or ions. Having that in mind, mathematical expression for electrical current *i(t)* is given as follows:

$$i(t) = \frac{dq}{dt} \tag{6}$$

where dq represents changes of electrical charge in dt amount of time. Since ampere (A) is the base unit for electrical current measurement and:

$$q(t) = \int_0^T i(t)dt \qquad (7)$$

we could say that if *T = 1 sec* and *i(t) = 1A* accumulated charge is 1C (coulomb).

That amount of charge is achieved by gathering 6.25 x 10^{18} electrons.

This also means that single electron has a charge of 1.6x10^{-19} C. Now that electrical current is demystified, we could explain the difference between Direct and Alternating current.

- When *i(t) = const* over time, the current is called DC (Direct Current).
- When *i(t)* = a function of time, like *sin(t), cos(t),* then current is called AC (Alternating Current).

Once again we could relate back to the mechanical system and explain that Displacement *(x)* and Velocity *(v)* are taking the same place as Charge and Current in the same forms of differential equations.

$$v(t) = \frac{dx}{dt} \qquad (8)$$

$$x(t) = \int_0^T v(t)dt \qquad (9)$$

Similarly, for mechanical rotation we have

$$\omega(t) = \frac{d\Theta}{dt} \qquad (10)$$

And

$$\Theta(t) = \int_0^T \omega(t)dt \qquad (11)$$

Where $\omega(t)$ is Angular speed and $\Theta(t)$ is Angular displacement.
Students are asked to create a table of analogies in different physical systems, and include it in their Engineering Journal.

Continuous Learning and Assessment

From the first week of study, students are encouraged to research and recognise engineering applications used in everyday life. They adhere to the *Learning Guide* and are exposed to the combined learning and assessment experiences each week.
An example from the first week of Mechatronics learning is shown here as it appears in the Learning Guide[1]:

Perform the following activities as a member of a team and consult your tutor if needed. You will be continuously assessed on your involvement, as well as skills and knowledge acquired.

- *Recognise subsystems in different mechatronics systems.*

Your instructor will bring few of the following systems to look at: Hard Disk Drive, Laser Printer, Ink Jet Printer, Tape Recorder, CD, Floppy Disk Drive…

- *Discussion: Hard Disk construction. A useful site to help you is:*

  http://computer.howstuffworks.com/hard-disk.htm

  Some hard disk drive subsystems could be seen on the Figure 2.

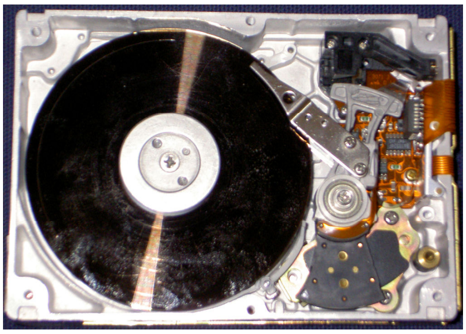


Figure 2. Hard Disk Drive

- *Identify hard disk subsystems.*
- *Participate in a discussion on different types of:*
  - *head arm assembly subsystems*
  - *motions (circular, liner) and motors used*
  - *sensors for head arm assembly positioning*
  - *feedback for head arm assembly positioning*
  - *head on sector positioning system*

Through this experience students are encouraged to take an active approach to their learning. In addition to this, students are becoming familiar to comprehensive systems consisting of various physical subsystems. Every week students are undertaking online assessment – Topic Exams. Weekly examination is a learning and assessment tool, and could be attempted many times. The emphasis is on learning, but the subject leader can moderate the contribution of the topics' assessment, and other assessment tools. This is carried out in order to achieve an optimal objective final mark.

From the beginning of study, students are instructed to keep an Engineering journal. The journal is a valuable tool for students and engineers as well. Here is another example of an activity as given in the Learning Guide.

Activity 4.12C
Analyse and Discuss in Small Teams

Analyse concepts of different numbering systems.
Practice algorithms for conversion of numbers between different systems.
Record algorithms in your Engineering Journal.
Perform exercises as specified at Online@RMIT and in this document.
Analyse and design logic circuits with digital gates (Online@RMIT).

Exercises:
The binary number 1001 0001 expressed as its decimal equivalent is:
a) 145 b) 91 c) 165

Binary number equivalent to decimal number 125 is:
a) 1000 0111 b) 0111 1101 c) 0100 1111
and so on…

Control Systems and Team Project Work

After being introduced to the following topics:
- Introduction to Mechatronics, Physical Quantities and Analogies,
- Electrical Quantities and Units, Electrical Elements,
- Magnetic Effects of a Current: Ampere Rule,
- DC Motor, The Alternator, The Transformer,
- Tesla's Experiment and AC Induction Motor, AC Power, and
- Electronics, Digital Numbers and Arithmetic,

students are learning about Control Systems.

On successful completion of the final, Control Systems Topic students are able to:
- describe control systems and the function of the feedback: positive and negative,
- describe elements of a control system: input signal, response signal, comparator, actuators, and sensors,
- describe the features of actuators: DC servos, brushless servos, stepping motors, linear motors, microstepping motors, induction motor drives, hydraulic systems,
- describe the features of feedback devices: digital encoders, synchros, resolvers, inductosyns, encoders, and
- sketch control systems for simple applications.

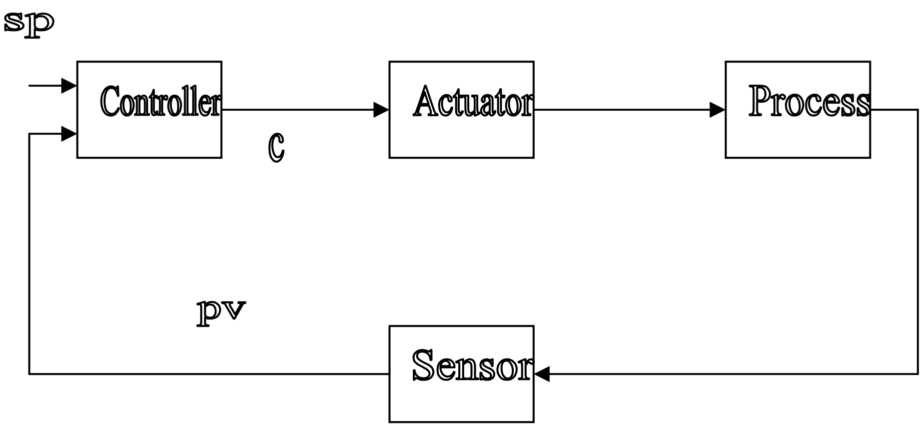
One way to look at control systems is as systems with:
Closed –loop control (feedback control)
- Positive: used when rapid change is desirable, speed up the process,
- Negative: used to stabilise the system, slow down the change.

Open-loop control
- *Traffic lights,*
- *Talking toys,*
- *Vending machines…*

Control system design issues are as the following: Speed of the response, Steady state error and Stability.
A PID (Proportional Integral Derivative) control system, as shown in the Figure 3 is a widely used method of process control. A mathematical expression of the system is:

$$c = K_p e + K_i \int e dt + K_d \frac{de}{dt} \qquad (12)$$

where variable *c* and *e* are as per figure 3 and K_p, K_i, K_d, represent proportional, integral and derivative gain respectively.



c is a Controlled Variable

sp is Set Point or Desired Response

pv is a Process Variable

e = sp - pv, error or difference

Figure 3 Feedback Control Systems Structure

Towards the end of the formal study students are performing lab/simulation activities based on the number of different simple projects, either specified by the lecturer, or suggested by students and endorsed by tutors or lecturer. Projects involve some kind of Mechatronics systems as following:

- Hard Disk Head Arm Positioning Control
    - Positioning System has two modes: Course and Fine, depending on the number of cylinders to go;
    - Voice Coil Actuator is a precise positioning DC motor: can be Linear or Rotary;
    - Position tracking is done with the use of Servo Record[15];
    - Data is recorded as file per disk, but other methods can be used as well, such as RAID, bit per disk recording[16].
- Floppy R/W Disk Heads Positioning Control
    - Step Motor and Screw are used for positioning;
    - Microswitches and Optical sensors are in place as well.
- Printer Print Head Positioning Control;
- House Fire and Security Alarm System;
- Step Motor Control;
- Solar Ponds Salinity Gradient Measurement and Control;
- Other, approved, student-defined Mechatronics projects.

Students can use RMIT electronics labs' resources or simulation software available in RMIT computer labs.

Design and Simulation Tools

More than 25 years ago software toll known as ECAP (Electronics Circuits Analysis Program) was successfully used, not only for electronics circuits, but for other systems modelling, as well. It was used for mechanical, hydraulic, acoustics systems design. Nowadays we could chose from the vide range of simulation and modelling tools, but for our particular requirements that include education as well, we found that LabVIEW, MATLAB and SIMULINK are the most appropriate.

Delivery Methods

Course material is delivered using Learning Guide[1], Custom Designed Book[14], on line delivery through Online@RMIT and of course face to face teaching i.e. lecturing, tutorials and lab activities. Lectures, tutorial material, design project instructions are all available on RMIT site. At the end students are encourage to perform online satisfaction survey.

Course Evaluation

RMIT is continuously monitoring, evaluating and improving course delivery. There are many surveys and feedbacks conducted on and off line: Student Satisfaction Survey, Program Survey, Course Survey …
In order to evaluate this course, all students are required to submit course feedback. All answers and comments are confidential and are used only for course improvement. Students can select one of five options, or write a comment in the space provided, and submit at the end of survey.
Survey has content (i.e. topics related questions), delivery and assessment related questions. Answers to topic questions do not influence student's final mark. They are only be used for improvement of delivery and assessment tools.
Firstly students are asked for their opinion of the capability level achieved in each of the topic areas.
The next set of questions relates to the delivery and finally to assessment.
There are questions like:

- The teaching staff was well prepared?
- The teaching material is well written and easy to follow?
- Teaching staff was easy to approach and was supportive?
- The teaching staff motivated you to achieve best result?
- You improved your capabilities thanks to this T&L (teaching and learning) experience?
- Would you like to have another course with the same teaching staff?

Finally students can write their comments to open questions like:

- Your comments about assessment tools used.
- What did you like mostly in this course?
- What should be changed or improved in this course?

Conclusions and Follow Up

Design of this multidisciplinary course and the use of different tools like simulation software and online delivery has been a great experience.
The course will run for the first time, in this form, in semester 2, 2005 and feedback results will be available after. They will be used for the course improvement and in the preparation of another Mechatronics course, advanced one, that will be delivered in the second year of the engineering study. Emphasis will be on control systems, so topics covered in that course will be more related to the modern control systems design.

Bibliography

1. Gregory P., Aleksandar S., Milan S., Andrea B.,(2005) MIET2094 Professional Practice 2 Learning Guide, RMIT University
2. http://www.ni.com/pnp/
3. D.G. Alciatore, M.B. Histand (2003), *Introduction to Mechatronics and Measurement Systems,* Second Edition, Mc-Graw-Hill.
4. D. Shetty, R.A. Kolk (1977), *Mechatronics System Design,* PWS, International Thomson Publishing
5. G.Rizzoni (2004), Principles and Applications of Electrical Engineering, Revised Fourth Edition, Mc-Graw-Hill.
6. J.Jenneson (2004), *Electrical Principles for the Electrical Trades*, 5th Edition, Mc-Graw-Hill
7. T.L. Floid (2001), Electronics Fundamentals, Fifth Edition, Prentice Hall.
8. T.L. Floid, Digital Fundamentals, 6th Edition, Prentice Hall
9. M. Predko (2002), *Programming and Customizing PICmicro Microcontrollers*, Second Edition, Mc-Graw-Hill.
10. T. Fox (2000), *Programming and Customizing HC11Microcontrolle*, Mc-Graw-Hill.
11. M. Predko (2003), *Programming Robot Controllers*, Mc-Graw-Hill.
12. J.Dorsey (2002), Continuous and Discrete Control Systems, Mc-Graw-Hill.
13. Y. Koren (1983), *The Computer Control of Manufacturing Systems,* Mc-Graw-Hill.
14. Gregory P., Aleksandar S., Milan S., Andrea B.,(2005) *Topics in Mechanical and Mechatronics Engineering,* A custom Publication by Mc Graw Hill
15. Milan S., (1990) *Honeywell MSC (Mass Storage Disk) Head Alignment Based on Data, Instead of Servo Record and CE Tool Disk,* Ei Honeywell Innovation Procedure, Nis, Yugoslavia
16. Milan S., (1989) *Honeywell L6 and DPS6 Computers Bit per Disk Recording System,* Ei Honeywell Innovation Project, Nis, Yugoslavia

Biography

Dr Milan Simic holds BScEE, MScEE and PhD in Electronics Engineering, from University of Nis, Serbia, and Graduate Diploma of Education, from RMIT, Australia. Dr Simic is also a Cisco Certified Academy Instructor for CCNA. He spent 13 years in Honeywell, as a Research Fellow, Test Engineer, Consultant, Scientific Consultant and 12 in education as a Lecturer, Teacher and Project and Program Manager. He has 23 research and educational papers published. For his contributions Dr Simic was awarded a RMIT Award for Education, as well as few awards for R&D from Honeywell.