Introducing the Guided Design Experience in the Engineering Education

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***Abstract* — The design skills in engineering students can be best achieved using an integrated learning approach which consists of structured, guided, and open-ended design experiences. This paper presents a description of the guided design experience in terms of main objectives, implementation mechanisms, and assessed outcomes as applied to courses in the area of control engineering at the undergraduate level in department of electrical engineering at the American University of Sharjah. The courses in the area of control engineering are developed to introduce guided design experience which is extremely critical for developing students confidence in their design skills and preparing them for the open ended design experience which they exercise in the elective courses and the capstone projects in the final year of study.**

***Index Terms* — Engineering education, Design skills, Control courses**

I. INTRODUCTION

The initiation of the design experience only in the senior year is inadequate to prepare the students for the engineering industry after graduation. Development of design skills requires continuous exposure to design concepts and skills throughout the engineering curriculum. Traditionally, design skills are incorporated within a curriculum in a scattered manner [1]-[7], resulting in a limited exposure to design practice [8]. These efforts attempt to improve the design experience for the engineering students, but focus only on the development of individual courses of a specific engineering discipline. Introduction of design skills at the junior and senior years [9] has been made to overcome the above mentioned limitations; however, these changes did not provide an overall vision and lack strategy to cover and distribute the required design skills in a comprehensive manner throughout the entire curriculum.

Recently, a strategic integrated learning approach [10] consisting of three stages: (1) structured design experience, (2) guided design experience, and (3) open-ended design experience, has been introduced. This integrated process allows the development of design skills in engineering students in a homogeneously distributed manner, where students continuously experience design practice and gain design skills but at an involvement and complexity level compatible with their study year. These design stages should be carefully distributed when developing the curriculum, such that students gain a solid base in each stage while having a smooth transition from one stage to another. Therefore, some of the courses fundamentally serve one single stage, while others serve as transitional courses from one stage to the other. In terms of study years it is suggested that freshman courses should primarily focus on the structured design experience, whereas the sophomore year courses provide either purely structured design experience or a transition from structured to guided design experience. Similarly, junior year courses deliver purely guided design experience, while senior year courses may have the transitional phase from guided to open ended or only open ended design experience. Lastly, capstone courses should be developed to deliver the open ended design experience. The instructors can use these guidelines and check how well various aspects of design experience are covered in different courses making sure that the students achieve the necessary skills by the time they finish their undergraduate studies.

The delivery of design experience in the engineering education without an integrated approach will affect the learning abilities of the students and will leave them unprepared for the open ended capstone design projects which represent the major initiation to the real industrial environment.

The delivery of structured design experience has been presented in detail in reference [11]. This paper presents the delivery of the guided design experience during the junior year of studies which is required to prepare the students very well for the open ended design experience that the students have to exercise during the senior year's capstone projects. It has been well documented in the literature that junior students usually start to work on their first open ended design project without being well prepared for it. The proposed work will enable the educators to overcome this problem and will help them introduce and develop the needed skills for the design process.

II. THE INEGRATED LEARNING APPROACH

This section presents a description of the integrated approach for the development of design skills and other attributes that would ensure skilled graduates who are well prepared for further education as well as for industry. This strategy first of all carefully introduces the design process and shows how the above mentioned design skills are to be developed during the engineering education.

Stage 1: Structured Design (SD) Experience

The main objective of the structured design experience is to bring students' attention to the concept and practice of engineering design at the early stage of freshman and sophomore level courses. Thus, the delivery of the structured design experience should be limited to motivate and excite students' interest in the design practice of the engineering profession. The main components of the design skills are introduced to the students by taking them through the design steps to accomplish the assigned tasks.

The implementation mechanism of this stage utilizes comprehensive and well defined step-by-step procedures and instructions, which are delivered through carefully developed hands-on tasks and contrived experiments and projects. These tasks span a wide range of topics determined by the course material and include, but not limited to the concepts of measurement, calibration, application of knowledge, system characterization, and utilization of design tools.

The main outcome of this stage is the realization of the engineering design practice through hands-on experiments and simulations. The development of teamwork and communication skills is other important outcomes of this stage, thus, all communication modes i.e., written, verbal, and visual communication are exercised through written reports, oral presentations, and visual aids. The detailed implementation of the structured design experience has been already demonstrated via two freshmen lab courses in [11].

Stage 2: Guided Design (GD) Experience

The main objective of the guided design experience is to get students start exercising the design skills by themselves in contrast to the structured design experience where they are given the complete guidance to accomplish the required tasks and the objective is mere realization of the design steps and the process.

The implementation mechanism of this stage is realized by carefully guided design activities to perform the specified design objectives. The instructor does provide the guidance but not the step by step procedure to accomplish the desired tasks. Care must be exercised at this stage, as the course progresses the level of guidance from the instructor should be reduced because this is confidence building process that should make students more and more independent in accomplishing their design tasks. The complexity of the assignments at this stage is from low to moderate. The design activities are performed in a team environment where each member has to work on his subsystem. These subsystems are finally integrated together thus experiencing the cooperative design experience. The design tools selected at this stage and the next stage (open ended design experience) are the ones that are mostly utilized by the industry.

The main outcome of this stage is confidence building and start making students more independent while accomplishing the assigned design objectives with as little guidance as possible. Also, cooperative design experience is realized at this stage as well. This stage will prepare students better for the open ended design experience and improve both the quality and the quantity of engineering design experience. The main subject of this paper is to introduce the guided design experience and its implementation.

Stage 3: Open Ended (OE) Design Experience

This is the third and ultimate level of design experience in the engineering education, which is exercised through the senior and capstone courses. A number of capstone projects are expected to originate from the industry which exposes students to the real engineering problems. The main objective of this stage is to make students completely independent in taking all the design process decisions by themselves with almost no guidance.

The implementation mechanism of this stage engages students in the open ended learning while working in a cooperative learning environment. The students are to start from the design specifications, think and outline the design steps to execute the complete design, decide the tools that are needed, distribute the design assignments among the team, and finally integrate the overall system and test it for the design validation. The guidance from the instructor is very much limited and students learn to rely on themselves. In this implementation process the instructor becomes just a team member not the team leader any more. The author at this stage has many times dared to tell his students "well this is just my opinion, or may be one way or my way of solving this problem. I am sure that you can come up with another better solution". Once the students reach this stage, the objectives of teaching design skills to the engineering students are achieved.

The main outcomes of this stage are; students' resistance fades, their confidence to rely on them selves is built, and life long learning skills are honed.

III. CASE STUDY: IMPLEMENTATION OF GUIDED DESIGN EXPERIENCE IN CONTROL TRACK

This section presents the development of a magnetic coil levitation system for use as a class project illustrating the linear control system design process. It will include the discussion on how to introduce the guided design experience in the area of control engineering. The class project actually involves the development of a working prototype which requires the background knowledge of a broad range of concepts in electronics and circuits analysis. The class project demonstrates key issues by focusing on the linear systems concepts from modeling, to analysis and design. Some performance measures such us speed of response, overshoot, damping and stability are also addressed. Students can learn a great deal from a relatively simple example by focusing on one subsystem from the overall complex nonlinear system. Such a study work will form a good basis for further work on more advanced control systems [12-14].

The magnetic levitation system consists of an electromagnet, a steel ball, sensors, a power amplifier and a controller. The conceptual schematic diagram is shown if Fig. 1. The electromagnet provides the force necessary to lift the ball when supplied with the required current to generate the needed force and counteract gravity. When exposed to this problem, the students can easily see that the magnetic field strength and therefore the force strength depends directly on the amount of current flowing through the coil and maintaining the equilibrium of the ball suspended in air requires the judicial control of the force and hence current. This gives a good motivation to introduce them to the concept of feedback control and the need for sensors.

The search for needed sensors such as optical sensors to measure the ball position, or a current sensor to measure the electromagnetic force is a good exercise to motivate the development of the closed loop control system architecture. The relationship between force, current and air gap is nonlinear, therefore the students are advised to focus first on the relationship between voltage and current supplied to the coil and how can current be controlled by dealing only with a linear system.

The students are asked to build a model of the electromagnet and adjust it to fit experimental data. Fig. 2 outlines the circuits used in this analog system. They consist mainly of small signal operational amplifiers and a power amplifier. The current measurement device is based on the voltage measured across an additional small power resistance which is fed back through a voltage follower.

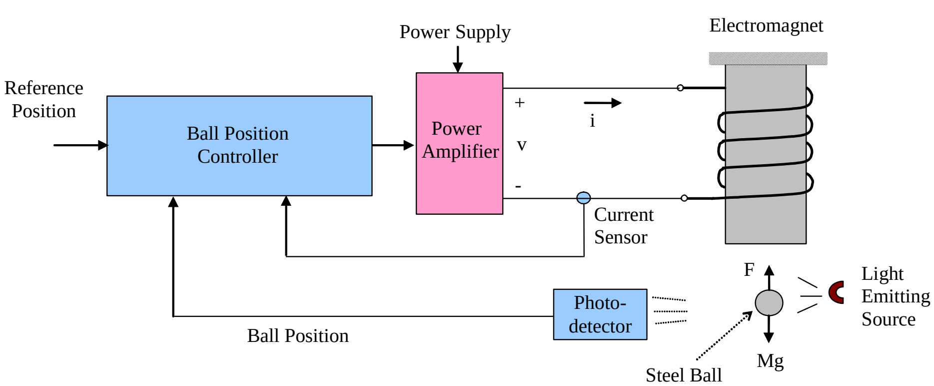

Fig. 1 Magnetic levitation system

The first part of the project covers the system modeling and open loop control of the magnetic levitation system.

The magnetic coil designed in first assignment will be supplied with a power amplifier to adjust the supply voltage. A current sensing circuit will be designed to measure the current flowing through the coil which will be used for feedback in the current control system. The students will build at this step the coil with a given length and number of turns. They next measure its resistance and will connect it to the power amplifier as shown in Fig. 2.

In the second assignment, the students are asked to find the transfer function between the voltage command and the coil current. This is achieved by going through the following steps:

1. Measure the step response of the system by applying a square wave input voltage v_{in} and displaying the current as shown in Fig. 3.
2. Identify the dc gain and the equivalent time constant of the system.
3. Determine the inductance of the electromagnet.
4. Represent the total system in block diagram form and find the total transfer function including the current sensor $\frac{V_m(s)}{V_{in}(s)}$.

The student will use in this phase of the project the concepts learned in class related to first order systems and transient response characteristics as well as block diagram representation of open loop and closed loop systems.

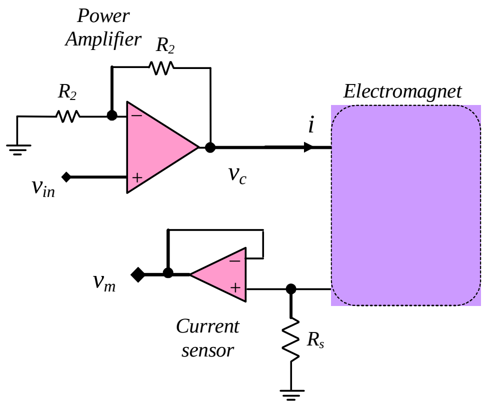

Fig. 2 Electromagnet system

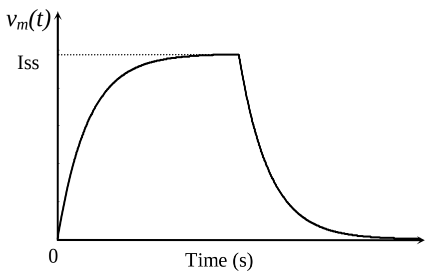

Fig. 3 Step response of the electromagnet

In the third and last assignment, the goal is to design and study the performances of an analog controller for the magnetic levitation system. The specifications are to design the analog controller such that the closed loop system has zero steady state error for step inputs, a maximum overshoot less than 10% and a settling time less than 0.1 sec. The controller implementation using analog operational amplifiers is shown in fig. 4.

The students will have to pick the correct values for the resistances and the capacitor C to get the suitable PI controller transfer function.

$$K(s) = K_p + \frac{K_i}{s} = \frac{R_4}{R_3}\left(\frac{R_2}{R_1} + \frac{1}{R_1 C\, s}\right) \qquad (1)$$

The students will derive the controller transfer function and will use MATLAB to design the controller gains based on the Root Locus design method.

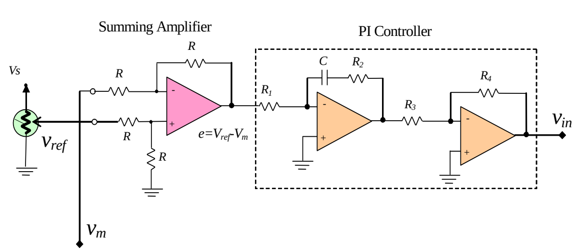

Fig. 4 Analog implementation of the PI controller

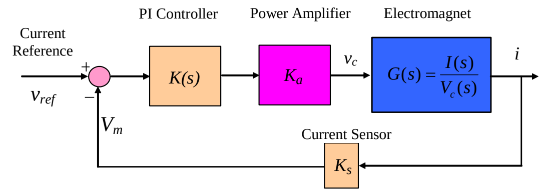

Fig. 5 Closed loop current control system

At the end, the students will demonstrate the functionality of the system and check the design specifications through simulation and through the experimentation.

IV. CONCLUSION

This paper has presented an important element in the development of students' design skills i.e. the guided design experience and its implementation is demonstrated in the area of control engineering. The paper also detailed how the guided design experience is useful for developing students' confidence in the students' design skills and prepares them for the open ended design experience which they are to exercise in the elective courses and the capstone project in the final year of study.

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