E1 Project title

Control Experiments using Lego Mindstorms.

E2 Aim

This document is a proposal for setting up a control laboratory course for Undergraduate and Post Graduate students. The main goals are to devise :

1. Experiments that gives students the freedom to be creative.
2. Experiments that allow for easy evaluation of the students.
3. Experiments that are upgradeable with a minimum of cost, space and time.

E3 Background

Control courses are taught across many departments in IIT Madras. In the Department of Electrical Engineering a minimum of 200 students do control courses (of these, $160 - 170$ are under-graduate students). Courses such as

1. Control Engineering (First course on Control that introduces basic concepts for under-graduate students).
2. Linear Control Systems (First course for M. Tech Students that teaches a reasonably advanced material with Control Engineering as a prerequisite).

have to be supplemented by a Laboratory module. Laboratory modules are necessary:

1. To make a student understand the gap between "theory and implementation",
2. To present the "Ahah–hah" moments that these "ideas are by and large correct in practice and can be used".

Normally, in a lab-course credited by 160 students, the students would be divided into 53 groups with 3 students in each group. Of these 53 groups 26 would be assigned an experiment, from a set of 4 experiments, on a particular day. The other 27 would do the same set on an another day in the same week. Experiments then being swapped in the following weeks such that all groups get to do all the experiments. Control Engineering and Linear Control Systems are offered once every year, with Control Engineering being credited by approximately 160 students (subdivided into two sections) while Linear Control Systems credited by approximately 40 students.

E3.1 Current Situation

Department of Electrical Engineering presents the following five control experiments for the Lab module:

1. Stabilization of pendulum on a cart, Figure 1.

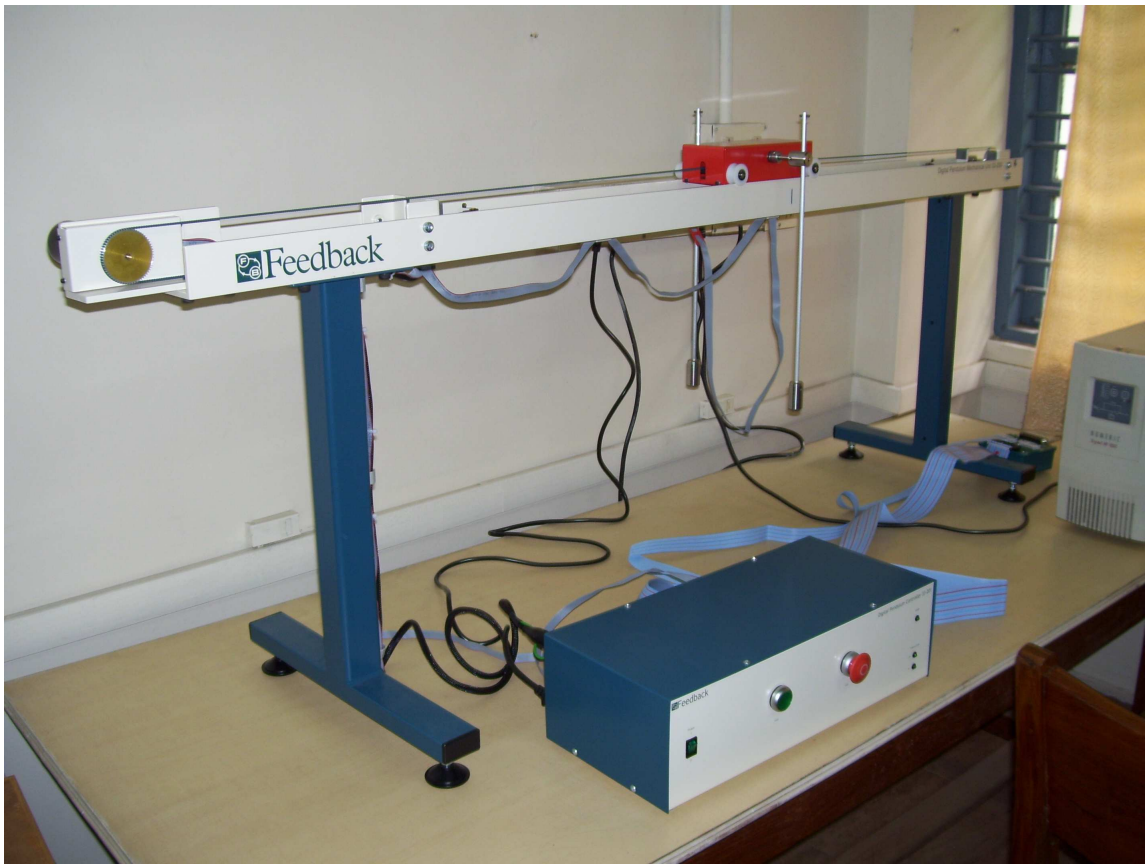

Figure 1: Pendulum on a cart

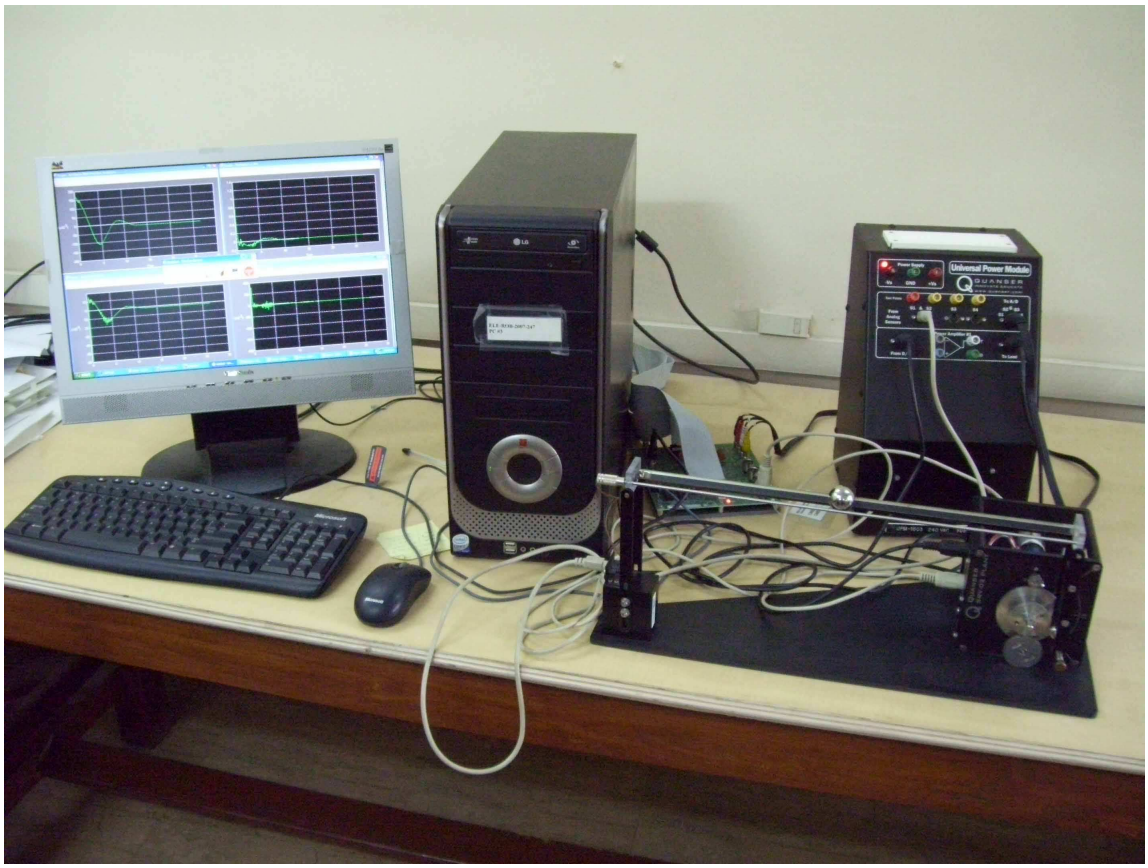

Figure 2: Ball on a beam system

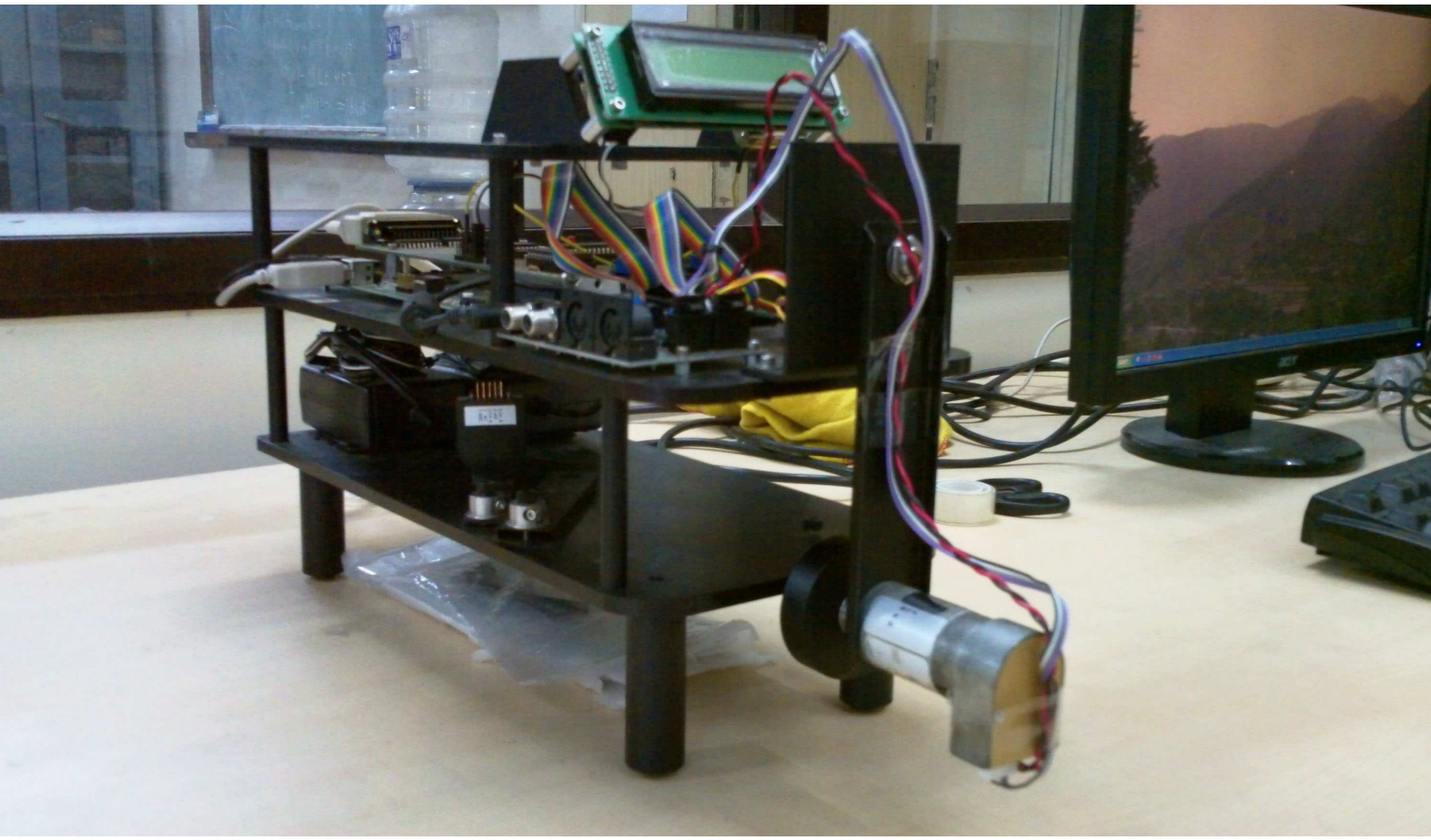

Figure 3: Inertia Wheel Pendulum

Figure 4: Twin Rotor.

2. Ball on a beam, Figure 2.
3. Inertial Pendulum, Figure 3.
4. Stabilization of Twin Rotor, Figure 4.
5. Single link manipulator, Figure 5.

There is just one equipment (experimental set-up) available for all the above mentioned experiments. This asymmetrical ratio of students to the number of experimental setups have led to demonstrations of these experiments to the students as opposed to students performing the experiments.

E3.2 Scaling Up the Current Laboratory

Increasing the number of equipments would improve the situation. However, each of the above mentioned equipments

1. Costs more than $6,50,000$ Rs (Approximately $10,000$ USD).
2. Would occupy a space of 35ft^2.

Therefore, 26 such equipments would cost more than 16900000 Rs (approximately 260000 USD) and would occupy an area of 1690ft^2 (another 30ft^2 per equipment would be required for free the mobility of the students and staff and to store other essential accessories, thus in total requiring an area of $26 \times 65\text{ft}^2 = 1690\text{ft}^2$). Thereby, making the above proposition infeasible.

Even if the above mentioned constraints are met, these equipments are dedicated for the experiments they are manufactured for. All the sensors, actuators and the signal conditioning circuitry are concealed in panels. Opening up these panels will invalidate the insurance. Even simple modifications such as incorporating a sensor or removing

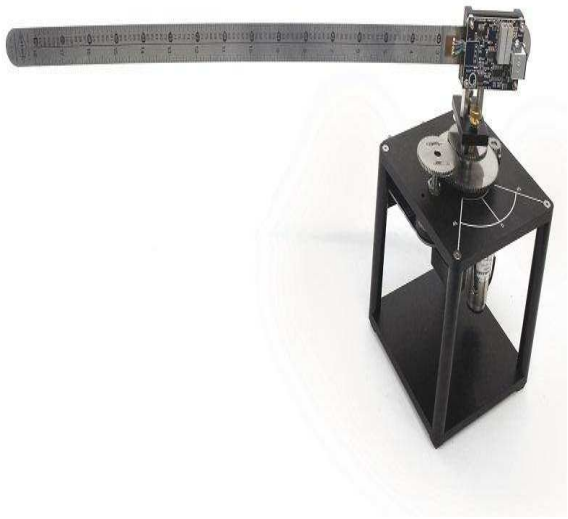

Figure 5: Single link manipulator.

a sensor from the equipment is impossible, as that would be incompatible with their dedicated signal conditioning circuitry. Furthermore, as these equipments are imported, repairing them takes an unusually long time. And phasing them out, a process referred to as "condemnation" in IIT Madras, when they become obsolete or broken down beyond repair is an arduous and a painstakingly long task.

E4 Control Experiments with Lego Mindstorms.

Lego Mindstorms is a popular Robotic educational kit. Lego Mindstorms can be reconfigured with ease to perform a variety of experiments. In [1, 2, 3] and [4], experiments have been devised (by reconfiguring the Lego Mindstorms) to teach concepts of Mechatronics, Signal Processing, Cyber Physical Systems and Control Engineering. Lego Mindstorms are relatively inexpensive and small in size (each kit occupies less than a square feet of area, can be hand held and weighs less that 0.6 Kg), Figure 6. Three control experiments have been devised using Lego Mindstorms for the proposed control laboratory. And a demonstrational/instructional video recordings of these experiments can be viewed from the following links

1. Controlling a DC Servo Motor.

   `http://www.youtube.com/watch?v=tnixTniekLc`

2. Pendulum on a cart.

   `http://www.youtube.com/watch?v=pvaGqvBqsqs`

3. Mobile Inverted pendulum.

   `http://www.youtube.com/watch?v=nhj39_Yw7TM`

These videos are self-explanatory and can be presented as Laboratory experiments to students for both Control Engineering and Linear Control Systems.

Figure 6: Lego Mindstorms kit assembled as a Cart.

E5 Last but not the Least

As the number of students increase giving them final year or final semester projects is an insurmountable problem. This situation can be alleviated using Lego Mindstorms Kit. Algorithms in research topics such Multiagent systems, Formation control, Perimeter patrolling etc are demonstrated mostly using simulation, without any physical realisation. Lego Mindstorms can be used as a rapid prototyping platform in these cases to develop scaled down versions of many of these projects. Implementation, if not research, aspects of the above mentioned problems can be presented to B.Tech or M.Tech students as projects. Additionally, in the Control Engineering Lab, a interface to control Lego Mindstorms kits using the ROS (Robot Operating System) software has been developed. ROS is an Open Source software used by all the leading roboticists in the world and has an active community with new algorithms and programs being added every day. Overall, the Lego Mindstorms kits have proved to be an excellent pedagogical tool while at the same time being an important tool for research and development.

E6 Budegt

1. 60 Lego Mindstrom Kits(Quote attached): 29,71,275 Rs.
2. Miscellaneous expenditure*: 4,00,000 Rs.

Here miscellaneous expenses refers to buying additional hardware such as Raspberry Pi, WiFi dongles and other additional sensors.

References

[1] A. Fernandez A. Valera, M. Valles and P. Albertos. *Platform for the development of mechatronic practical works based on LEGO Mindstorms NXT robots.* IEEE, 2009.

[2] N. S. Clements B. S. Heck and A. A. Ferri . A lego experiment for embedded control system design. *IEEE Control Systems Magazine*, 24(5):61–64, October 2004.

[3] S.A. Filippov and A.L. Fradkov. *Cyber-physical laboratory based on LEGO Mindstorms NXT-first steps.* IEEE, 2009.

[4] P.J. Gawthrop and E. McGookin. Lego-based control experiment. *IEEE Control Systems Magazine*, 24(5):43–56, October 2004.