Development of a Mechatronics Course Using a Robotic Platform

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ABSTRACT

The Electronic Systems Engineering Technology (ESET) department at Texas A&M will offer a new course in Mechatronics including fundamental mechanical and electronic topics through combined lab and lecture. The lab offered with this course uses a second-generation Articulated Suspension Exploratory Platform (ASEP II) robot as the focus of this experiential learning process. The labs provide students with the opportunity to analyze statics, dynamics, four-bar linkages, energy conversion and control systems, by manipulating, instrumenting, and measuring subsystems of the ASEP II robot. These labs are planned in combination with other lab assignments on electronics hardware, embedded intelligence and software development to support multiple course projects completed by student teams. This paper describes the strategy and process of developing the mechanical portion of this course and the strategies used to teach phenomena by directly working with the robot. The paper also shares lessons learned, recommendations for improvements for the course, and plans for the development of the follow-on Mechatronics II course.

INTRODUCTION

There is a growing need in a number of industry segments as indicated in [1] for entry-level employees to understand a broader spectrum of engineering, specifically combining mechanical, electronics, embedded intelligence and control. Known in many circles as Mechatronics, the Electronic Systems Engineering Technology (ESET) program at Texas A&M University chose to expand its undergraduate curriculum by developing and offering a new course in this area. The course was developed over the Fall 2015 semester and will be offered for the first time as a technical elective to ESET students in Springs 2016. Because the majority of the students are focused on electronics, and embedded microcontroller-based monitoring and control design and development, this new course will have a significant component dedicated to mechanical principles and concepts. In addition, based on industry input, the ESET faculty plan to incorporate robotics and vision systems into the course. As presented in [2] the first focus area is to more fully motivate students and allow for the application of real-time embedded systems, and the second is to differentiate this course by including such an advanced topic.

The selection of the robotic platform was based on past work that has been undertaken by members of the Mobile Integrated Solutions Laboratory in partnership with faculty and students in the Mechanical and Manufacturing Engineering Technology program. The Articulated Suspension Evaluation Platform (ASEP) was originally designed to meet a NASA mission requirement and was discussed in [3] and [4]. The mobile platform has been recently modified and improved to provide the ASEP II design, shown in Figure 1. Some of the major changes include the redesign on a number of the mechanical members so that they can easily be printed using a 3D Printer. Shock absorbers and improved four-bar linkages are also part of the newly designed platform. The Mechatronics I course is intended to concentrate on the embedded aspects of mechatronics. Using the ASEP II platform will allow just that. Sections of the robot will be analyzed and be the basis of a number of experiments during the first third of the course. Each two-person team will study the apparatus and collect, analyze, display and record data using the myRIO module available from National Instruments and the LabVIEW graphical programming environment [5]. Once the characteristic data have been collected, the two-person teams will assemble their robot. The myRIO will then be installed as the embedded system for the ASEP II interfacing with a number of sensors and the four DC brushed motors via appropriate interfacing and power amplification circuitry.

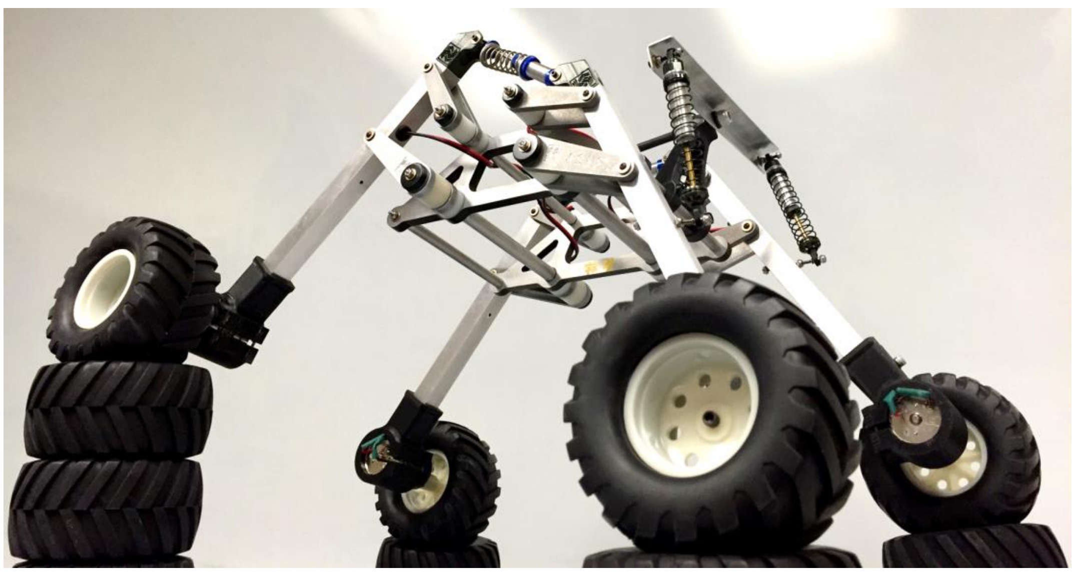

Figure 1. ASEP II robotic platform.

The teams will then take on the course project to meet a new NASA space exploration mission requirement addressed in [6] which is to create a small group of robots that can travel and work together with limited man-in-the-loop requirement. A former NASA program manager will be providing a mission briefing during the first week of the course and will act as a technical liaison during the course project. Teams will have to work collaboratively to establish the concept of operation and wireless communications protocols necessary for the independent robots to travel in a group. Finally the course will include oral presentations and demonstrations of the robots, lessons learned and recommendations for future work. From this first offering of the course, the ESET program will integrate feedback from the students and industry partners to improve the course and lab for future offerings

MECHANICAL LABS

The Mechatronics I course integrates all of its mechanical lecture topics into hands-on lab experiments. This section explains the content of the labs, associated hardware and overall procedures used in each lab.

Statics Lab

The first statics experiment is depicted in Figure 2 below, which illustrates the ASEP II robot sitting on offset heights left to right on top of weight scales. Prior to this lab, the students will learn the concepts of normal forces, summation of moments about a point, and be able to perform a slipping versus tipping analysis for the robot. Examples for these problems are drawn from a statics textbook by Hibbeler [7].

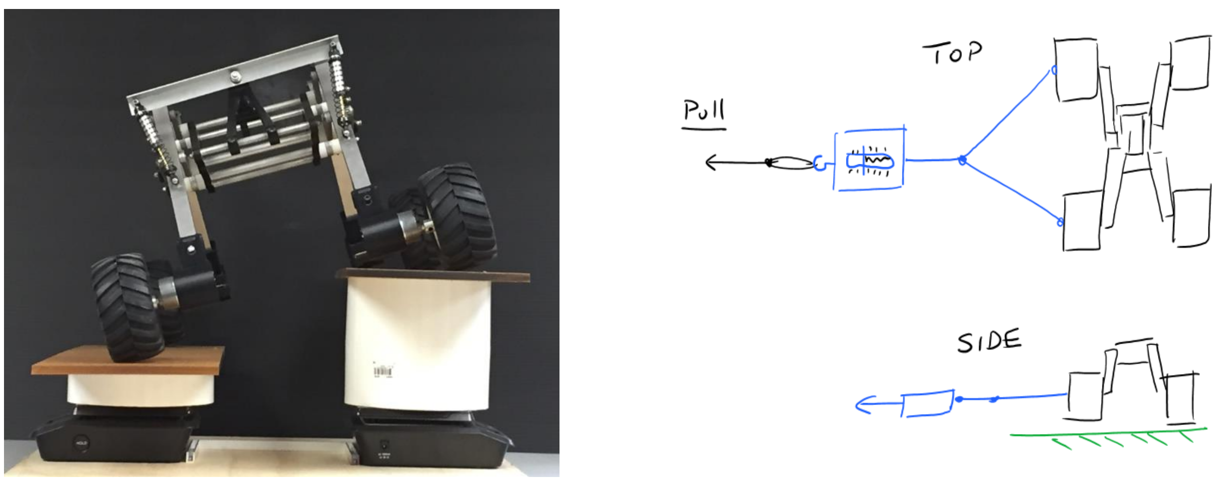

Figure 2. Statics Experiment with ASEP robot

Using the setup in Figure 2 (left), the students will be able to use the geometry and the differential reading in the two scales (reading the left and right sides of the robot) to find the robot's center of mass. The right side of 2 shows how the static friction coefficient is found for the robot. The students place the ASEP II on tile, carpet, concrete and other surfaces to measure the pulling force required to overcome the static friction with a handheld meter. They then use summation of forces as in Eq. (1) to find the static normal force, and Eq. (2) to find the static friction coefficient.

$$\Sigma F_y = 0 \tag{1}$$
$$F_s = \mu_s N \tag{2}$$

After evaluating the friction coefficients, weight, and center of gravity for the ASEP II, the students are able to find the maximum gradient or tilt the robot can handle before losing stability. In further projects, the students may modify the center of mass by changing the payload configuration to achieve a performance metric.

Torque, Work, and Energy Balance Lab

This lab ties together several concepts that are critical to the operation of any robot. The students need to understand energy balance in a sense that energy can be quantified in terms of stored energy in the battery, potential energy changes in the mechanical system, and work done by forces or torques. Losses that take place in the electrochemical processes, in electric motors and through mechanical friction also should be grasped. The students will learn how energy is converted by machines and be able to estimate the efficiency of some processes.

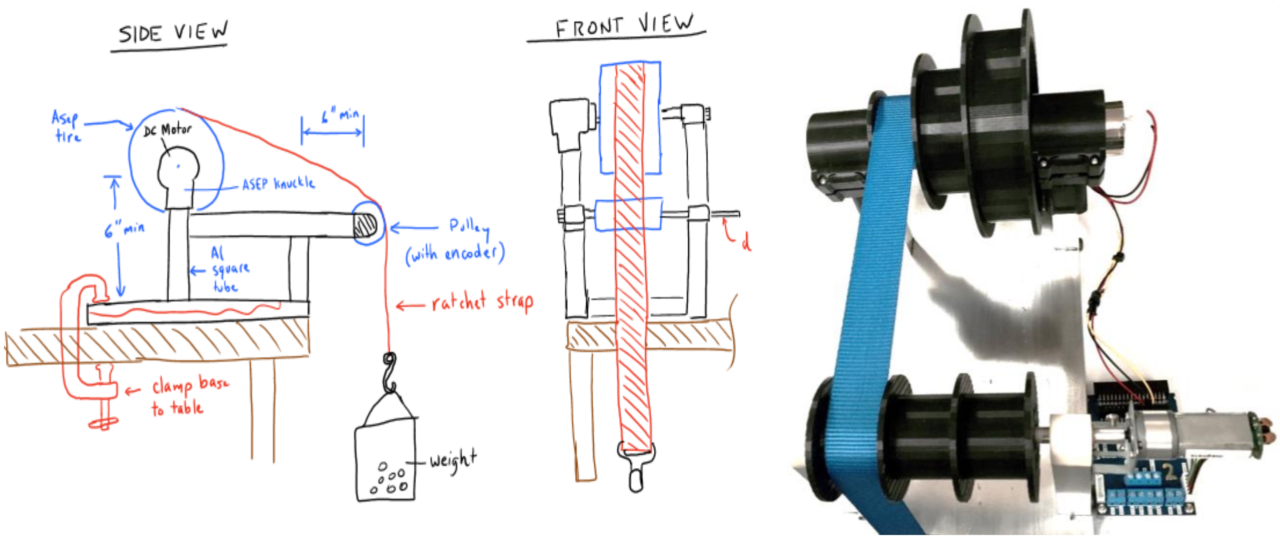

Figure 3. Apparatus for Torque, Work, and Energy

Figure 3 shows the apparatus planned for this torque-based lab. When quantifying the work done by the motor, they will consider the torque and rotation output by the DC motor as well as the change in potential energy of the hanging mass. When quantifying the power output by the motor, there is an encoder attached to the apparatus to find the velocity of the hanging mass. Equation (3) will be used to find the rate of work output by the system, then the current supplied to the motor will be measured and the electrical power consumption can be calculated by Eq. (4).

$$\dot{W}_{out} = mg\frac{dh}{dt} \tag{3}$$

$$\dot{E}_{in,\ electrical} = VI \tag{4}$$

By comparing the power measured at the input and output of the system, the losses will become evident. The efficiency of the system will be discussed using chapter two from the thermodynamics text by Cengel, et al [6]. Then, Eq. (5) will be used to find efficiency, η, from the incoming electrical power to the rate of work being done on the hanging mass. The lab also offers more instrumenting experience using a hall-effect encoder.

$$\eta = \frac{\dot{W}_{out}}{\dot{E}_{in}} \tag{5}$$

During labs such as the torque lab the students will program their own LabVIEW VI. The "front panel" for a torque bench VI is pictured in Figure 4.

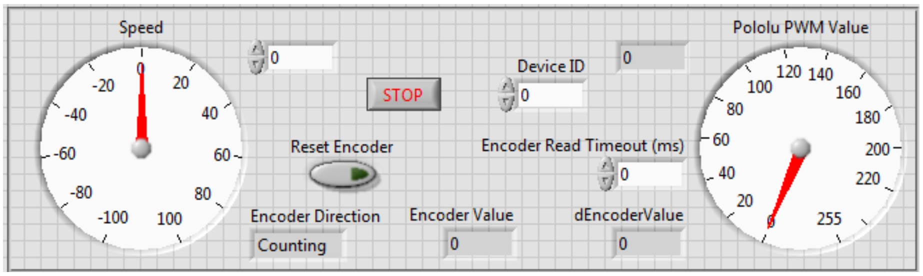

Figure 4. Labview VI for Torque Bench

4-Bar Linkage Lab

The lab for evaluating four bar linkages uses a linkage system directly from the ASEP II robot. One leg assembly from ASEP II is connected to a static platform allowing for a simplified analysis of this four-bar linkage, shown in Figure 5 (left). A DC powered actuator has been added to the linkage system to automatically push the leg through its range of motion. In lecture, concepts for four bar linkages from [7] will be presented.


Figure 5. 4-Bar Linkage Lab Components

In the procedure for this lab, the students will use machine vision to capture points on the links and the velocity and acceleration of the points. A Basler Ace camera (shown in Figure 5– right) will be connected to the myRIO to capture the motion while the actuator is driven up and down. The vision analysis data can be used to check the accuracy of the hand calculations done before lab.

In order to understand four-bar linkage systems, some topics from [8] will be presented in lectures. Students can then answer questions such as: What is the motion of the shock mounting point when the wheel is displaced vertically by a given amount? Performing this analysis gives insight to the robot's range of motion and dynamic characteristics.

Shock Evaluation (Dynamic Systems) Lab

This lab will illustrate a real world example of a simple spring and damper system. Figure 6 shows one of the shock assemblies from the ASEP II robot in a fixture that is used to extract the spring and damper constants.

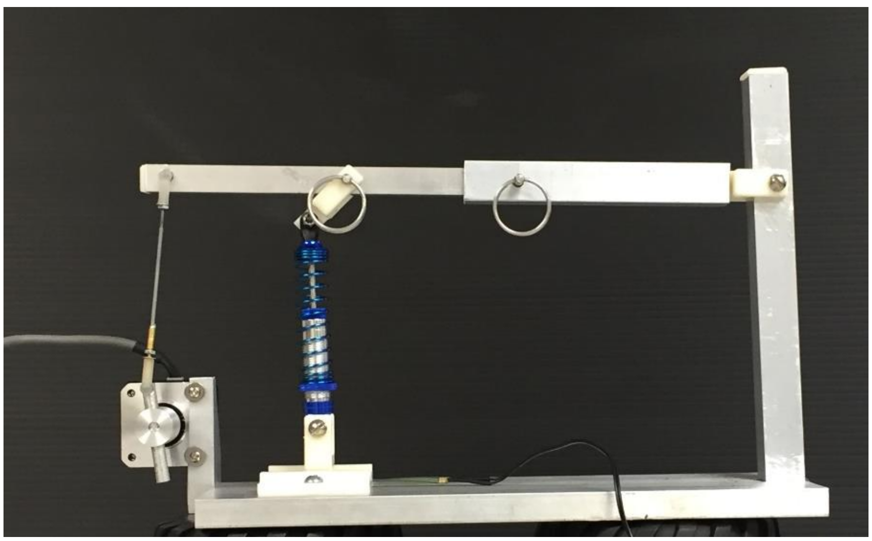

Figure 6. Shock Evaluation Lab Apparatus

A Stepper motor and linkage are connected to the shock and are controlled by a LabVIEW VI. A pressure transducer is mounted below the shock which returns force data to the user. With the spring compressed in a static configuration, it exhibits force proportional to Eq. (6). When the shock is moving through its stroke with some velocity x, then the force is given by Eq. (7). This experiment will return the coefficient for spring rate, k, and damping coefficient, b.

$$f = kx \tag{6}$$

$$f = kx + b\dot{x} \tag{7}$$

For additional steps in this lab, the students may replace the spring from the shock with a different stiffness, change the valve inside the shock, or change the weight of the damping oil. They then can see the effect of this hardware on the dynamics.

With knowledge of the robot's linkages as well as the shock characteristics, the students can consider the robot suspension as a dynamic system and evaluate metrics such as the natural frequency or the settling time of the suspension with an induced motion. In class, there will be discussions of the simplifying assumptions required to calculate these metrics with basic formulas.

Heat Transfer Lab

Mechanical instrumentation would not be complete without a consideration for energy balance and heat transfer. The heat transfer lab will follow a lesson on convection, conduction and radiation and an overview of common methods of temperature measurement.

The subject to be measured is a Pololu High Powered Motor Driver board shown in Figure 7 (middle & right) which is used on the ASEP II to drive each pair of DC motors. With current passing through the board, the elements on the board will be monitored using a thermocouple, thermistor, and lastly an infrared thermal imaging device called a FLIR-1, which is shown in Figure 7 (left).

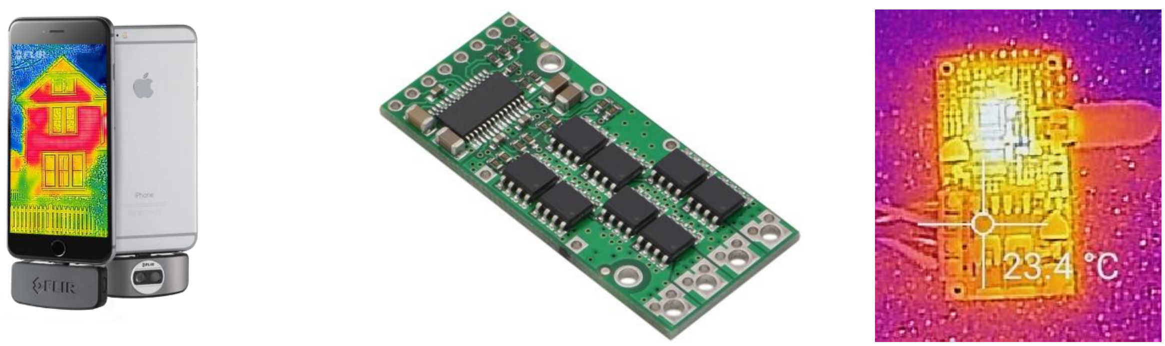

Figure 7. Heat Transfer Lab Components

Students are able to see the difference in readings coming from different instrumentation types in this lab. Heat transfer topics from [9] are to be presented while teaching the students to estimate the junction temperature of a transistor by measuring the case temperature. Important assumptions will also be discussed in class. Estimations that may create errors are related to emissivity of different surfaces, heat dissipation due to a thermocouple itself, and heat transfer effects of minor airflow changes or ambient temperature changes. Completion of this lab gives the students the ability to monitor temperatures of the ASEP robot and create a control system to adjust power levels to counteract overheating of critical components.

ELECTRONIC TOPICS

The ESET students will bring a significant amount of expertise and experience in the areas of electronic systems design and development including sensors, actuators, interfacing circuitry, control and associated wired and wireless communications. In addition, ESET students will have taken a three-course sequence in embedded microcontroller architecture, software development and interrupt/real-time operating systems. As part of the course, each team will select an advanced technology sensor/actuator to present to the class with a complete demonstration using the myRIO and LabVIEW. Each of these presentations will provide all of the students with the tools they will need to fully implement their robot for autonomous and group operation.

COURSE PROJECTS

As indicated, each two-person team of students is expected to fully understand the operation of their four-bar linkage, articulated suspension robot. The team will then fully assemble the mechanical portion of the mobile platform and integrate the myRIO embedded hardware into the platform and interface it to the selected sensor technologies and signal conditioning circuitry necessary to control the motion and operation of the unit autonomously. Each team will be free to pursue different approaches to meeting these requirements

Once operating, groups of two to three teams will then work together to create a tracking capability that will allow them to follow the path of a lead robot as it travels along some path which is communicated wirelessly from a base station.

SUMMARY AND CONCLUSIONS

As mechatronics continues to increase in its importance to the private sector, the ESET program at Texas A&M is moving to meet this demand with new technical elective courses. By providing significant focus on mechanical concepts in the early part of the course, the students will have an opportunity to better appreciate and use these principles to understand the operational envelope and capabilities of the mechanical structure. Using these new tools and techniques, the ESET students will be much better prepared to define and add to the electronics, embedded intelligence, and control algorithms to develop a complete robotic system. The use of the NI myRIO will allow the teams to rapidly integrate the various subsystems and iterate through a number of design approaches. The use of LabVIEW as the graphical programming environment will result in straightforward embedded software that can take full advantage of the on-board FPGA for design implementation. Finally, the availability of on-board wifi and the ability to quickly integrate other wireless communications technologies should allow the students to modify their robots for operation in a vehicle following scenario.

Follow-on activities include the creation of a second course, Mechatronics II. This course will leverage the lessons learned, understanding of mechanical principles and the NI RIO architecture to study mechatronics from an industrial manufacturing approach. In this second course, students will move from the myRIO embedded platform to the higher performing CompactRIO monitoring and control architecture. This two-course sequence will be used to establish a new program in mechatronics in the near future. The new program will merge the essential educational elements of both ESET and its sister program in Mechanical and Manufacturing Engineering Technology. With the fundamentals provided by these two programs, the mechatronics students will complete their senior year by taking Mechatronics I and II and their mechatronics-oriented capstone projects.

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