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Introducing Automation Concepts in a "Mechanisms and Robotics" Course

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Introduction

Manufacturing processes are becoming increasingly reliant on automation to improve efficiency and output. The growing use of automation in industry suggests a need to incorporate automation topics within the mechanical engineering curriculum. A specific challenge of doing so is finding places for automation topics within an already full to overflowing curriculum.

Multiple pathways exist for the introduction of automation concepts in a Mechanical Engineering (ME) curriculum. Many ME curricula contain courses such as Mechatronics, Robotics, Instrumentation, and Mechanisms and Machines, all of which are compatible with automation.

This paper presents one pathway for the introduction of automation topics within a "Mechanisms and Robotics" course. The course provides coverage of planar mechanisms and an introduction to robot kinematics. Since both mechanisms and robots are common to automated systems, the course provides a natural environment to introduce automation topics.

One new element that is introduced to the Mechanisms and Robotics course described in this paper is the Arduino microcontroller. The use of the Arduino allows the course to bridge the gap between a traditional mechanisms course and an automation-based mechanisms course.

The Arduino platform is commonly used in Mechatronics courses. Grover et al [1] use an Arduino platform for a semester-long project to build a mobile robot using Arduino controllers. Chancharoen et al [2] describe the use of Arduino-based learning kits to provide hands-on learning experiences in a mechatronics course. Other examples of Arduino use in Mechatronics courses include Asato et. al, [3], and Riofrio and Northrup [4].

Arduinos also appear in various other contexts. They are used for teaching basic concepts in introductory Robotics courses [5] [6]. Project specific examples of Arduino systems include: use in a CNC plotter [7]; combined with a joystick for robot control [8]; to create a Spirograph style drawing machine [9]; and combined with LabView and SolidWorks to create virtual simulations of mechanisms and robots [10].

The Mechanisms and Robotics course discussed in this paper is a 4-credit, semester-long course. The course presents traditional topics in the design and analysis of planar linkages along with an introduction to robot kinematics. This paper focuses on the integration of electrical control and measurement with the traditional mechanisms content. The mechanisms content of the course provides the kinematic geometry of common industrial machines, while the electronics provide a means to automate (power, measure, and control) the machines.

The Mechanisms and Robotics course introduces automation through a sequence of five course projects. The projects begin with the design and construction of a manually operated offset slider-crank mechanism. The second through fourth projects build on this design by adding an Arduino interface, motor, on/off control, and measurement systems to the design.

The fifth project introduces path-planning concepts by using the Arduino to control a planar manipulator. Students build a planar five-bar linkage that uses an Arduino to control two stepper motors to draw a prescribed path. This introduces students to the automation concepts of stepper motors and path planning.

The following sections detail the above projects. The first section presents the use of the offset slider-crank mechanism as an introduction to Arduino electronics. A second section looks at the development of the planar manipulator. The final section introduces some additional projects currently under development.

Starting Point – The Offset Slider-Crank

The slider-crank is one of the fundamental geometries in the realm of mechanisms. The slider-crank provides a simple method for converting linear motion to rotary motion, and vice-versa. These mechanisms are commonly found in manufacturing operations such as stamps and presses. In addition to its widespread use, the slider crank has relatively simple geometry and provides a suitable platform for introducing the connection between mechanisms and automation.

The current version of the Mechanisms and Robotics course has students progressing through a series of four "design-build-test" projects based on the slider crank mechanism, as described in the subsections below.

Project 1 - Building a Basic Slider-Crank Mechanism

The first of the slider-crank projects requires students to build an offset slider crank mechanism, similar to the one shown in Fig. 1. This mechanism introduces students to the slider-crank mechanism and provides a baseline geometry for their slider-crank automation projects.

Requirements for this first build include the following:

- The mechanism must operate in the horizontal plane. (eliminates the effect of gravity when acceleration is measured in a future project)
- The slider displacement should be between 4-6 inches. (provides students with an approximate scale for their design)
- The mechanism should be made from readily accessible materials. ("hobby wood" such as popsicle sticks, dowels, etc. are common – the goal is to minimize the need for special tools or machines)
- The mechanism needs to have appropriate structural stiffness and relatively tight joints. (students are not allowed to use "slop in the system" or "flexing of links" as an excuse for unexpected data in future projects)

Students are required to calculate the timing ratio and critical pressure angles for their mechanism. This provides them with predicted performance characteristics of their mechanism and its operational capability when they move to the second project – motorizing the mechanism.

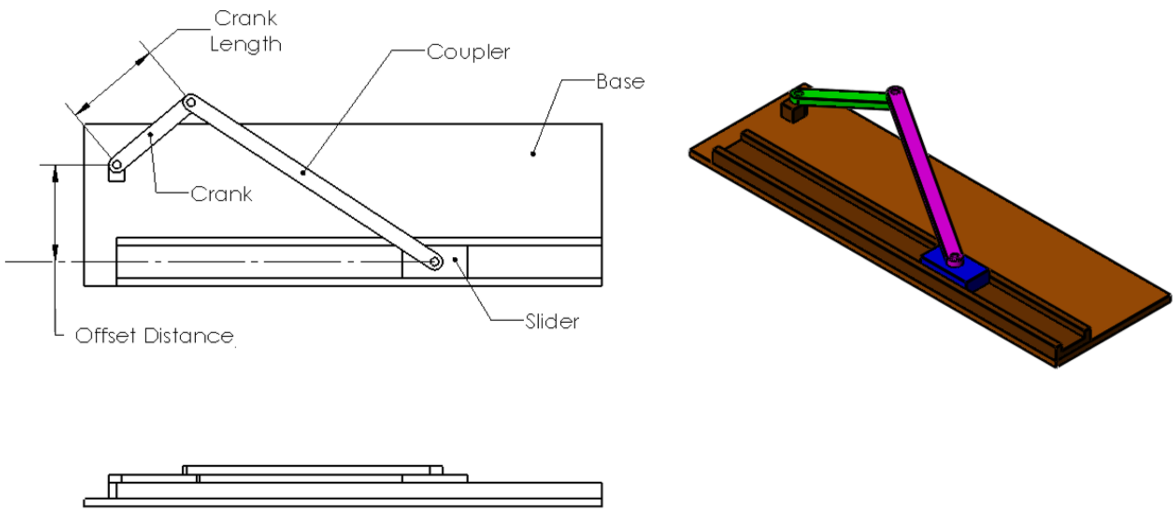


Figure 1: An offset slider-crank mechanism.

<u>Project 2 – Adding a Motor and Controller to the Slider-Crank</u>

The introduction to automation begins with the second project in the course. Students are required to add a motor to drive their mechanism, as shown in Fig. 2. Specific requirements for this project include:

1) The motor on/off control must be run through an Arduino. (This provides an introduction to Arduinos and the use of a control circuit to operate the automation process)
2) A button push activates the motor. (The power is controlled through an on/off interface).
3) The Arduino and motor operate on separate power supplies. (This introduces the concept of the use of relays to allow low power controllers to activate high power machinery)

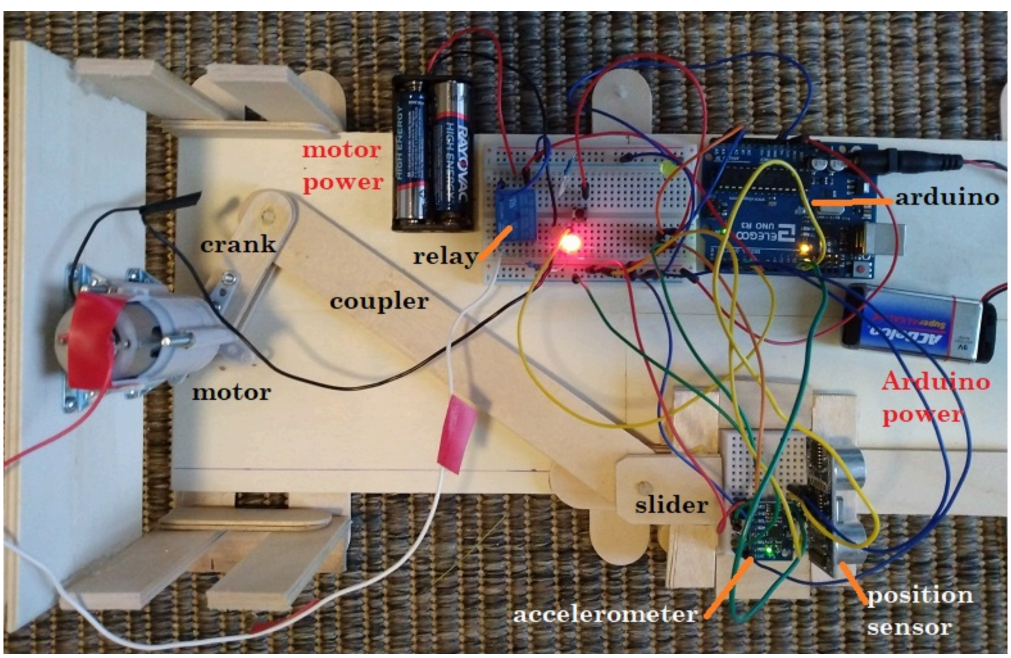


Figure 2: Motor driven slider-crank with relay and controller.

Projects 3 and 4 – Instrumenting the Slider-Crank

Projects 3 and 4 introduce students to instrumentation to demonstrate the ability to monitor and measure automated systems. In this case, we are using a position sensor (project 3) and accelerometer (project 4) to monitor the position and acceleration of the system.

Both the position sensor and accelerometer are located on the slider, as shown at the bottom of Fig. 2. Students use these sensors to acquire data for multiple cycles of the mechanism. The data is compared to theoretical performance curves to ensure the system is operating as expected.

Common results of the monitoring typically show variations in the speed of the motor during a cycle, and excessive noise in the accelerations. Students are asked to explain these variations and make suggestions for how to improve their machine performance.

As described above, the first four projects focus on automation concepts that include: machine control from a microcontroller, separation of controller and machine power supplies, and the monitoring of machine performance. These exercises also provide students with a hands-on experience for the "Mechanisms" portion of the Mechanisms and Robotics course. The next section describes a fifth project used to introduce automation from a robotics perspective.

Robotics – Design and Construction of a 2 Degree-of-Freedom Planar Manipulator

The fifth project is a "capstone project" for the course. The last four weeks of the semester-long course introduce robotics, with a focus on the position analysis of both serial and parallel robots. In the fifth project, students create a two degree-of-freedom planar manipulator - a five-bar mechanism with a tracer point. The planar manipulator is a simple parallel robot that introduces students to stepper motors and the control of multiple degree-of-freedom systems.

The fifth project has several parts. The first is a CAD design and simulation. The project goal is to have the manipulator generate a designated path. The students first design their mechanism and simulate its motion using SolidWorks, as shown in Fig. 3. A Motion Study is performed on the CAD model to develop a data file of motor angles associated with the path positions.

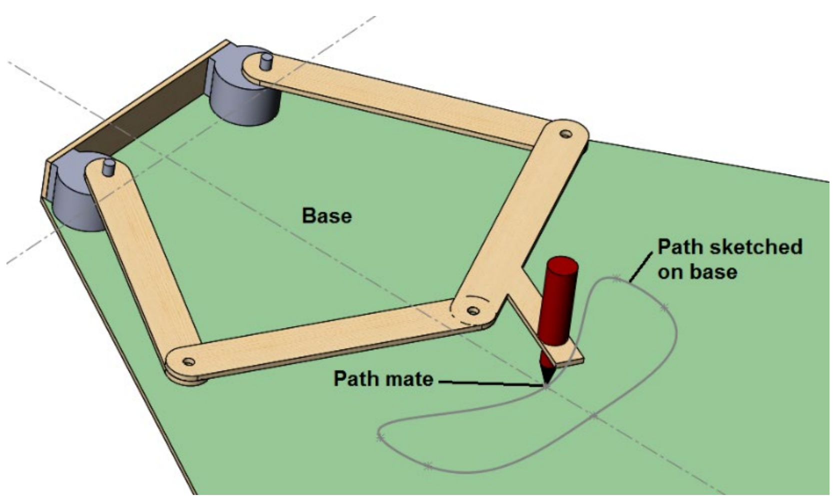


Figure 3: CAD model of planar manipulator with proposed path.

In the second phase, students build a physical model to match the dimensions of the CAD model. The angular positions of the input links from the CAD model are converted to motor steps and this information is used to program the stepper motors that drive the physical model. Students use the Arduino environment to program and drive the motors through their motion. The result typically looks something like Fig. 4.

The automation concepts presented in this project include an introduction to stepper motors, as well as the need to develop a method to "home" a system.

The five projects described above represent the current state of the course. The next section describes two additional projects currently under development for future use.

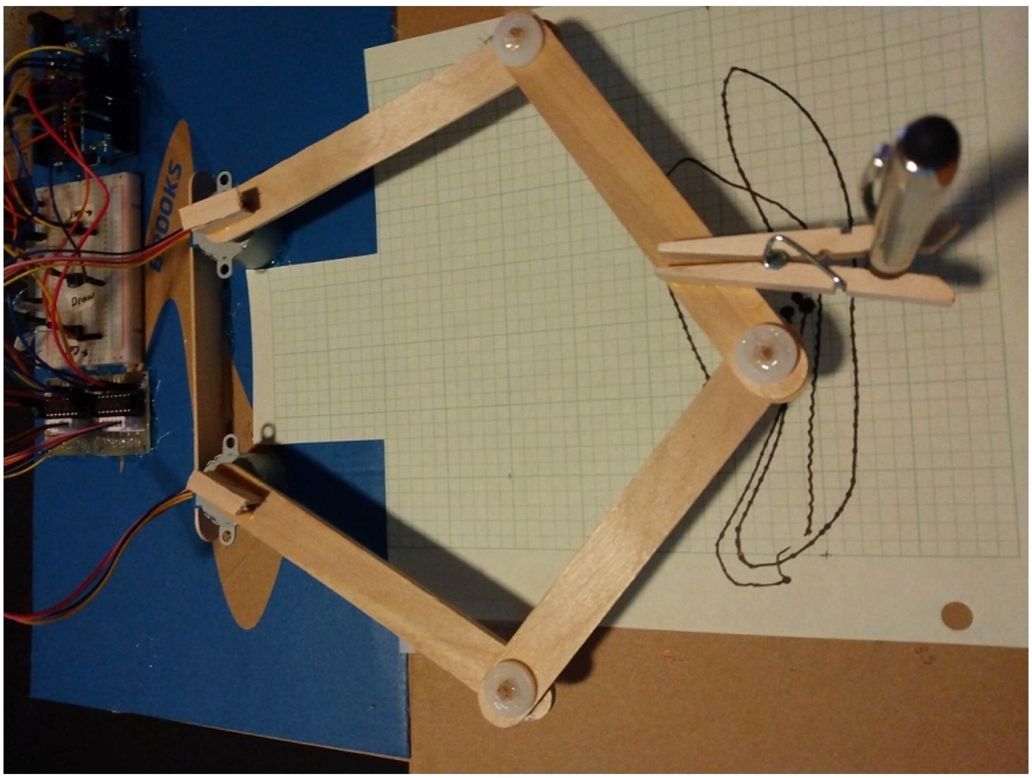
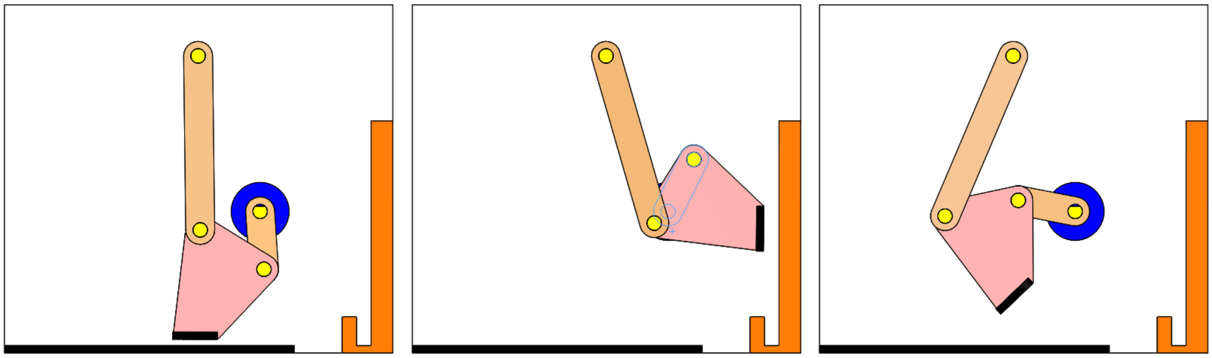


Figure 4: The physical mechanism with its traced path.

Future Development

Two new projects are under development for the course. These projects are planned to extend the automation principles by requiring the machines to interact with external objects.

Both projects under development are "pick-and-place" style machines. The first is a single degree-of-freedom four-bar linkage as shown in Fig. 5. The mechanism uses an electromagnet to pick an object from a simulated assembly line, and then drop the object into a slot to the side of the assembly line. Students will design the mechanism (an existing assignment in the course) and then test and verify the design. This project requires the students to coordinate the timing of the device with the pick-and-place operations. This slightly higher level of automation is a natural progression from the existing slider-crank projects.

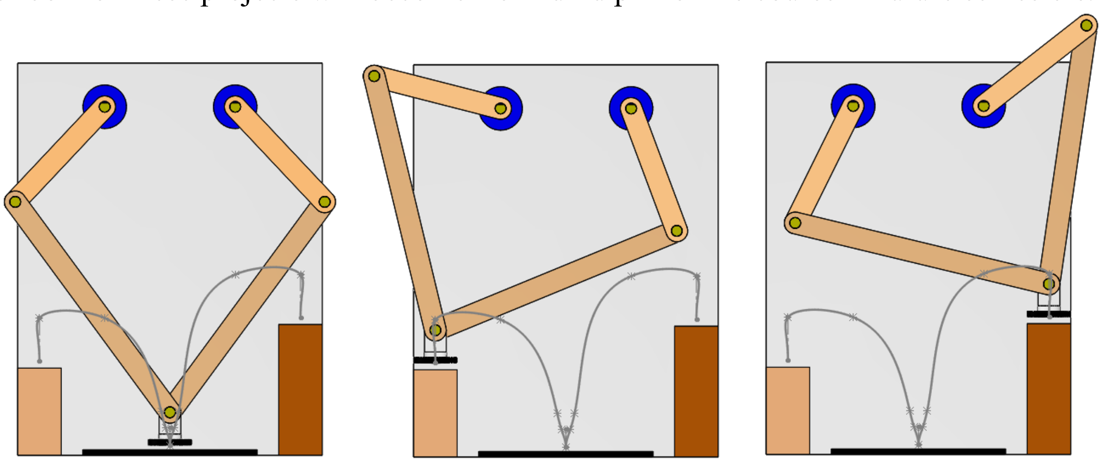


a) Pick b) Place c) Return

Figure 5: Four-Bar Pick and Place Mechanism

A second developmental project is similar to the planar manipulator from project 5. The new project asks students to use a planar manipulator as a pick-and-place mechanism. Students program the mechanism to pick an object from a simulated conveyor belt and place it in one of two storage locations, as shown in Fig. 6.

Both pick-and-place projects are currently under evaluation as extra credit projects for students. One or both of these projects will become a standard part of the course in future semesters.



a) Pick Position b) Left Side Place c) Right Side Place

Figure 6: Five-Bar Pick and Place Mechanism

Conclusions

This paper has outlined a series of projects that introduce automation concepts in a "Mechanism and Robotics" course. The projects are design-and-build projects to demonstrate the control and monitoring of common kinematic systems. The projects are deemed to be useful because they provide a means to incorporate automation topics more broadly within a mechanical engineering curriculum. Automation is becoming a major factor within industry, so it behooves us as educators to adapt to these evolving needs.

The question remains open as to the impact of the projects on the overall student experience. Readers may have to decide for themselves if the ideas presented are worthwhile, but here is some anecdotal evidence of how the projects impact student learning:

- In project 1 the students build a mechanism and in project 2 they put a motor on the mechanism. About 50% of the students have to rebuild their mechanisms moving from project 1 to project 2 when they realize they have no method to allow for the attachment of a motor. This demonstrates that the projects are making students think about the physical geometry of mechanisms.
- Even after redesign, about 25% of students find that their project 2 has a point in its motion where the mechanism either hesitates or stalls. The hesitation is caused by a real-world combination of friction and less than ideal pressure angles. Students need to decide if they want to introduce a bigger motor to overpower the hesitation, or redesign the mechanism.
- In projects 3 and 4, the sensor data can be relatively noisy. This is particularly true for the accelerometer data. For the data to make sense, students must figure out a way to either filter or smooth their data. This provides an introduction to working with noise in a system.

The most important learning outcomes that students realize through the projects are:

- The ability to move from theoretical representations of machines to machines that can be actuated, controlled, and measured.
- The ability to build and program basic electronics to interface with machines.

The primary premise of this paper is that the set of projects provide students with a hands-on learning experience to introduce automation concepts. Students enjoy the addition of hands-on projects to complement the course theory. The biggest hesitancy from the students lies in their lack of confidence working with Arduino programming and assembling the electronics. The successful completion of the projects bolsters their confidence and prepares them to tackle more complex automation challenges.

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