AC 2009-809: A MECHATRONICS (AND MATERIAL-HANDLING SYSTEMS) COURSE: CLASSROOM TOPICS, LABORATORY EXPERIMENTS, AND PROJECT

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A Mechatronics (and Material Handling Systems) Course – Classroom Topics, Laboratory Experiments, and Project

Abstract

The material handling and logistics industry encompasses the movement, control, and storage of products in both manufacturing and distribution environments. The mechatronics field, which integrates concepts from traditional engineering disciplines, has been extensively applied within material handling systems to achieve precise product movement. The presentation of mechatronic system concepts, within a material handling framework, allows practical classroom exercises, laboratory experiments, and design projects. In this paper, the multi-disciplinary mechatronics (and material handling systems) course will be presented. The classroom materials introduce sensors, actuators, control theory, human factors, electric power, electronics, electric motor, and systems integration as encountered in typical manufacturing scenarios. Further, students learn and practice leadership, team building, collaborative learning, and project management skills to help accomplish the laboratory and project activities. A series of laboratory assignments have been developed for students to gain hands-on experience with electronics, programmable logic controllers, industrial robots, conveyors, instrumentation, and data acquisition. The initial exercises establish a basis to program and network multiple PLCs, command the movement of a robotic arm, and then integrate these elements into a smart conveyor system under automated control for product distribution. The remaining laboratory activities focus on electronic circuits, and vibration experiments with accompanying data acquisition and theoretical analysis. Lastly, a design project offers an open-ended multi-faceted opportunity to apply a robotic arm, conveyors, bar code reader, color sensor, and networked PLCs to accomplish the tasks of identification, sorting, and conveyor transport to fulfill product orders.

1. Introduction

Modern industrial systems and components typically feature various sensors, actuators, and controllers integrated into complex configurations that incorporate skills from various engineering disciplines. To design and service this equipment, global companies often use engineering teams familiar with mechatronic system technologies (refer to Figure 1). Some of the key technical skills include mechanical, electrical, computer, and industrial engineering as well as control systems, computer simulation, robotics, and human factors. Although the term "mechatronics" may be widely applied to engineering systems, it certainly describes material handling processes which encompass the controlled movement of items through a define sequence of events. For example, different types of conveyor and robotic elements may be applied to transport materials, assemble components, and then move the finished goods within a manufacturing facility. Due to the prevalence of material handling systems and accompanying mechatronics expertise requirements, this industry segment may be emulated in a laboratory setting to offer students real world challenges. A fundamental understanding of various system components and their integration into a functional process is an important objective for laboratory accomplishments.

A number of universities have established classes and laboratories that focus on mechatronic systems. Khan[1] highlighted the importance of international abilities in mechatronics while discussing micro-controllers, programmable logic controllers (PLCs), transducers, and mechanical/manufacturing engineering. Merckel and Fisher[2] offered a two-week hands-on PLC experience at Rose-Hulman with two different laboratory demonstration stations. Chiou *et al.*[3] discussed an internet-based mechatronics course created at Drexel University that featured industrial robots, machine vision systems, PLC modules, webcams, and sensors. Lee and Park[4] utilized a computer controlled robotic laboratory in an undergraduate course at Purdue University to teach system integration concepts. Marsico[5] reported the availability of three Pennsylvania State University courses that covered fundamental topics in manufacturing, materials processing, and production design. Erickson[6] presented four scaled industrial processes at the University of Missouri-Rolla that featured robotic arms, conveyor assembly and inspection, pH neutralization, and operator interfaces. Stormont and Chen[7] discussed the use of mobile robots in a mechatronics course at the Utah State University. Ghone and Wagner[8] reviewed a multi-disciplinary mechatronics laboratory created at Clemson University which contained electronic circuits, PLCs, servo-motors, and pneumatic/hydraulic actuators. A materials handling system with robotic arm experiment was introduced by Bassily *et al.*[9] to accompany the existing mechatronic laboratory activities. Vermaak and Jordaan[10] summarized a mechatronics course at the Central University of Technology, Free State that focused on material handling systems with accompanying laboratory. Finally, the Material Handling Industry of America (MHIA)[11] periodically offers educational activities in collaboration with the College-Industry Council on Material Handling Education (CICMHE).

Today's engineer must be able to function in a global industrial environment as a team member responsible for a product, process, or intellectual activity[12]. A multi-disciplinary mechatronics (and material handling systems) course was created that allows students to learn and experience mechatronics engineering within the context of material handling systems. As shown in Figure 1, mechatronics incorporates aspects from different engineering fields such that product teams are typically composed of many individuals. Consequently, contributing as a team member is crucial. In this course, students have an opportunity to review and practice personal skills through classroom activities, laboratory experiments, and design project. The paper is organized as follows. Section 2 offers an overview of classroom topics that provide the technical knowledge and skills needed to create a mechatronics system. Section 3 describes six laboratory experiments which explore electronic circuits, PLC networks, and robotic/conveyor systems. Section 4 examines an integrated material handling system environment which facilitates student design projects. Lastly, a summary is presented in Section 5.

2. Classroom Topics

A multi-disciplinary mechatronics engineer should ideally have a set of technical talents to accomplish the given engineering task and accompanying business and interpersonal skills. The required engineering skills include mechanical, electrical, and industrial engineering with computer programming and testing experiences. Given that students may have a range of backgrounds, the course focuses on both systems engineering and general professional skills. The technical content includes control systems, PLCs, robots, actuators, sensors, electronics, circuit reading, mechanical systems, electric power, electric motors, material handling, pneumatics, hydraulics, system integration, and human factors. When covering these concepts, emphasis is placed on the practical aspects of the technology as motivated by typical manufacturing and material handling environments. The completion of these topics ensures that the students have sufficient information to complete the laboratory experiments and design projects.

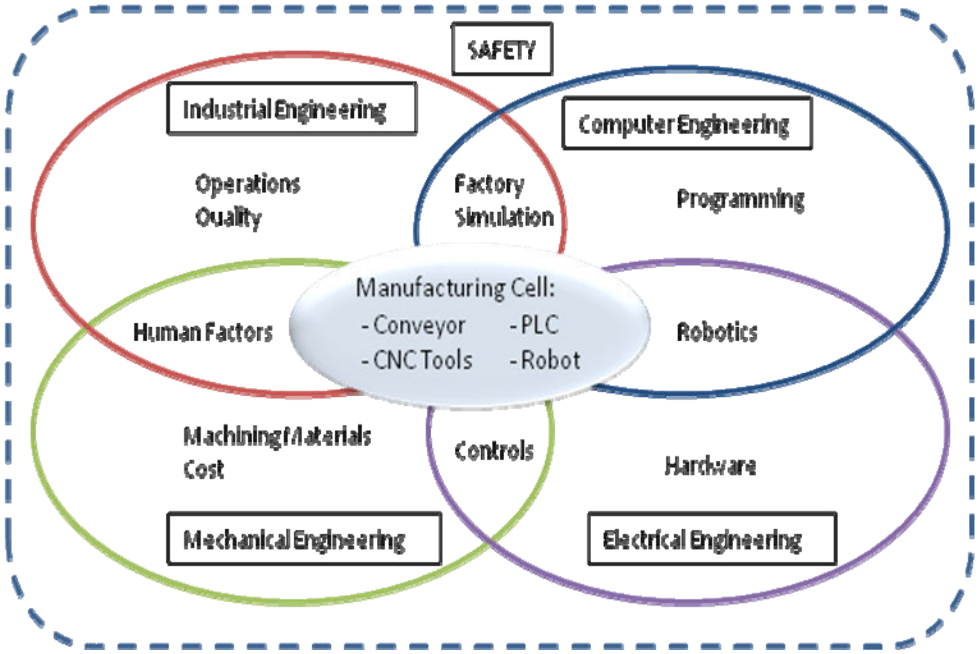

Figure 1: Engineering compentencies and technical skills to support a general purpose robotic manufacturing cell with conveyor system for material handling

The course also presents important professional (non-technical) skills to better prepare students for successful careers in the workplace. As shown in Figure 2, some of these topics include team building, collaborative learning, leadership, communication skills, project management, procurement, and ethics. The first lecture cluster focuses on team dynamics such as team building activities, project management, proper communication techniques, and leadership. Next, students learn how to properly procure materials and equipment, and review general ethics. Finally, the classroom introduction of professional skills can be practiced and utilized in the team-based laboratory experiments and projects.

To reinforce the learning concepts, periodic multi-week homework assignments have been assigned for completion by student teams. Although not currently required, the student teams might be changed for each assignment to facilitate team building skills. Lastly, a midterm exam features an in-class test, laboratory practical, and take home open ended problem. To assess the general performance of student learning throughout the course, frequent surveys and pre/post course questionnaires may be administered.

3. Laboratory Experiments

The mechatronics laboratory allows students to explore sensors, actuators, robotics, PLCs, conveyors, and system integration. A representative sampling of the experimental modules will be presented with learning objectives, procedure, and materials list.

3.1 Programmable Logic Controllers

PLCs are used in most industrial processes to control product manufacture and movement. Two laboratory modules are available that feature PLC programming basics and networked PLCs targeted for conveyor system control.

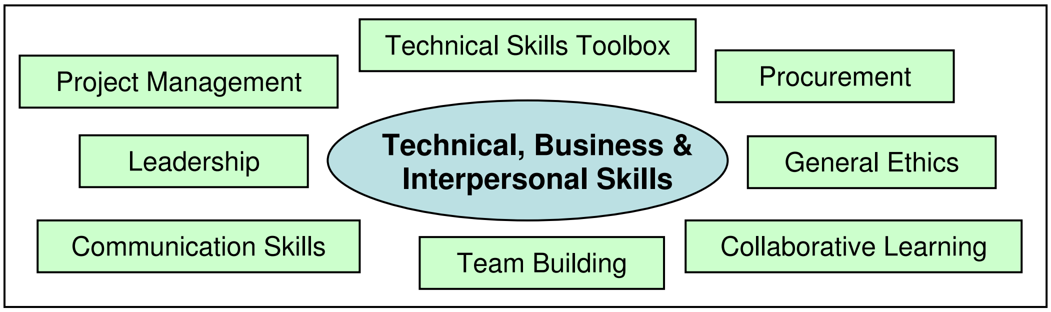

Figure 2: Select topics introduced in mechatronics and material handling system course

3.1.1 Physical Security System

The students create an alarm system (refer to Figure 3) through the wiring of security components and designing ladder logic to accomplish prescribed security functionality. This module allows students to gains hands-on experience with PLCs using common safety hardware. An Allen Bradley Micrologix 1000 PLC has been selected. The system features four inputs - motion detector, magnetic contact, vibration detector, and panic button. All four devices are wired internally as a normally closed (NC) circuit. Once a device is activated, the internal contacts open and power stop flowing back to the PLC. These sensors are pre-mounted and wired to a second terminal block. Four on/off toggle switches emulate an input keypad for the security system. The system outputs include one light stack unit (green, yellow, and red lamps).

Learning Objectives: The student will understand how PLCs operate and typical signal configurations. A selection of input and output devices will be introduced, wired, and integrated into ladder logic instructional blocks. With these skills mastered, the second laboratory module will create a network connecting multiple PLCs.

Laboratory Procedure:

1. Design an alarm system to detect an introducer while offering the home or business owner conveniences for arming and disarming it as needed.
2. Connect the inputs and outputs using terminal blocks and wires.
3. A ladder logic program will be created to function in the following manner:
   (a) System armed by placing all toggle switches to ‘open’ position with green light illuminated.
   (b) Once an input has been triggered, the yellow light will turn on for a period of 5 seconds. Before this interval is completed, the toggle switches must be changed to a ‘code’ that will deactivate the alarm (e.g., 1010).
   (c) If the proper code is entered within 5 seconds, the yellow light will turn off.
   (d) Once the switches are put back to 0000, the system will arm itself again.

(e) If the proper ‘code’ is not entered in a timely manner, the red light on the light stack will switch on and the alarm will sound.

(f) Once the alarm has been tripped, the system cannot be reset by the switches.

4. RSLogix500 and RSLinx will be used to create the ladder logic and download the program to the PLC. The security inputs will be monitored with “Examine If Open” (XIO) instructions, while the ‘code’ will require both XIO and “Examine If Closed” (XIC) instructions. The lamp outputs will use “Output Enable” (OTE), “Output Latch” (OTL), and “Output Unlatch” (OTU) instructions. Also, timers will be introduced and their respective status bits set for a five second period.

Materials: The laboratory materials include a motion detector (Optex #FX-40), panic button (Omron #A22-MR-01M), MicroLogix 1000 (Allen-Bradley #1761-L32BWA Series E FRN 1.0), magnetic contact (Honeywell #943WG-WH), vibration detector (Enforcer #PAT-14658), switches (McMaster #7343K184), and light (Patlite #XEFB-D).

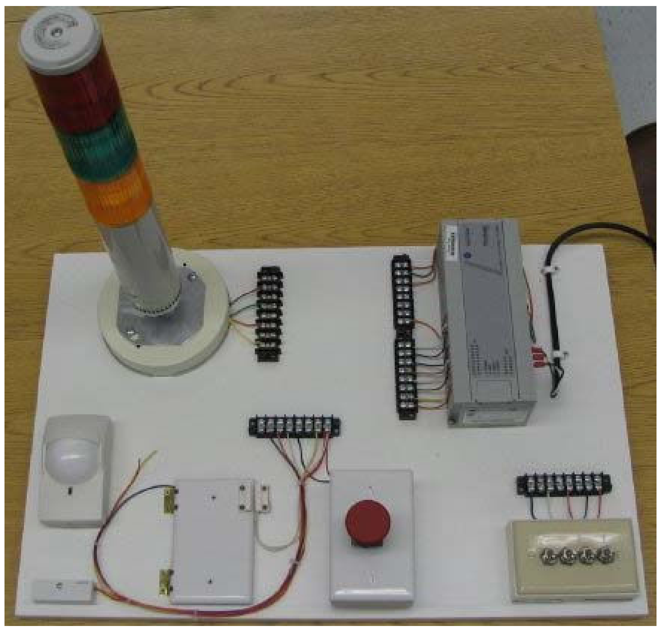

Figure 3: Security system with motion, vibration and entry sensor, light stack, horn, panic button, four binary switches, and programmable logic controller

3.1.1 Networked PLCs for Distributed Architecture

In a typical manufacturing environment, multiple PLCs are networked together for communication and the coordination of events. Although there are different network protocols (e.g., DH-485, DeviceNet, EtherNet), an understanding of one network protocol can be extrapolated to others. This laboratory module creates a network; PLC1 governs the material handling system direction while PLC2 powers the rollers to operate a modular conveyor system. Each PLC is a MicroLogix 1500 connected to individual ENI modules via RS-232 cables. These modules convert messages sent by the PLC to the EtherNet protocol, and then translate the messages sent by the network to the PLC. The network (ENI modules, network switches, CAT5 network cable, PC) was connected to allow the PC to access the PLCs as shown in Figure 4. Using the security system experiment, the toggles switches and red/green lamps on the light stack were wired into the inputs/outputs of PLC1. For the second PLC, a single conveyor segment is connected which featured five powered rollers and seventeen gravity idle rollers. Along the edge, mounted infra-red sensors determine the position of materials. The sensors and powered rollers have been pre-wired into PLC2. A connectivity chart summarized how the rollers and sensors are connected to the PLC input/output channels.

Learning Objectives: The student will gain an understanding of PLC networks with the ability to configure a network. Specifically, they will establish communication between two PLCs over a prototype network interfaced to a conveyor system with integrated sensors to control material movement. Further, this experiment shall reinforce basic skills in the programming and operation of PLCs.

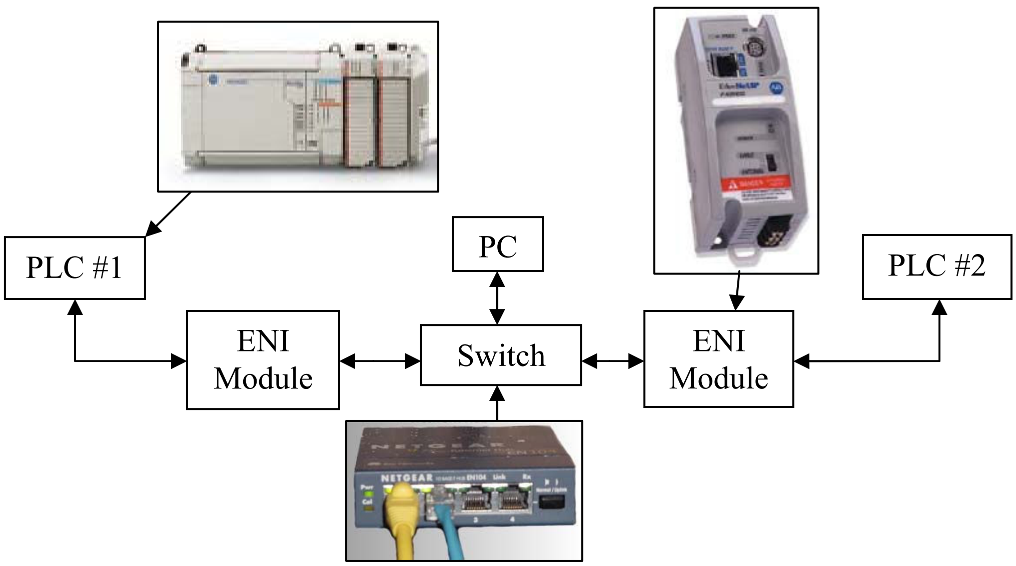

Figure 4: Two programmable logic controllers (PLCs) with Ethernet modules and central network switch connected to a computer work station for programming

Laboratory Procedure:

1. The first PLC is connected to the toggle switches and light stack. Then, PLC1 and PLC2 are connected to their respective ENI modules. Finally, the ENI modules and PC are interfaced to the network switch to permit PLC programming via PC.
2. Algorithms are created for the PLCs to perform the five tasks listed below. Most instructions are familiar. However, the Message (MSG) instruction sends data in an integer (N7) address from one PLC to another. By changing the N7 register bits, data can be communicated between two PLCs. For example, PLC1 can change two bits (based on the toggle switches) and monitor two other bits that control lights. Similarly, PLC2 will monitor two toggle switch bits and change two light bits.
   (a) When one switch (connected to PLC1) is activated, the conveyor system (powered by PLC2) will turn on and move a tool pallet down the line
   (b) While the pallet is moving, the red light (connected to PLC1) will turn on.
   (c) Once the pallet reaches the last sensor on the line, the conveyor will stop.

(d) When the second toggle switch is activated, the conveyor will switch directions and move the pallet back to its original destination.
(e) Once pallet reaches this point, the green light connected to PLC1 will turn on.

Materials: The laboratory materials include MicroLogix 1500 (Allen-Bradley #1764-24BWA), ENI Module (Allen-Bradley #1761-NET-ENI), and Network Switch (Standard 5 Port 10/100 Mbps Fast Ethernet Switch).

3.2 Robot Programming and Sensor Integration Experiments

Many factories use fixed base and/or mobile industrial robots with computer controlled actuators to accomplish a variety of manufacturing and material handling applications. Some typical operations include part "pick and place" operations and general component assembly. In the next two laboratory experiments, students gain experience with programming and utilizing a standard industrial robot. The students move the robotic arm to specific points and assemble a piston (piston, connecting rod, wrist pin) for an internal combustion automotive engine.

3.2.1 Industrial Robot Programming

The Staubli RX-130 robot features six degrees-of-freedom. The control cabinet contains a pendant for manual programming and a terminal for software programming. The teaching pendent allows the student to define specific points needed to control the robot's movement. The controller allows the user to move the specific joints of the robotic arm through the V++ programming language. Using a few basic commands such as OPENI, CLOSEI, MOVES, and DELAY, and by defining points using the pendant, the robot can be controlled to perform various operations. A pneumatic end effect gripper (refer to Figure 5) has been installed to grip different objects. This module also introduces students to robot safety issues.

Learning Objectives: The student will understand robot fundaments such as movement (pendant and language programming), motion limitations, and safety concerns. It will be observed that the robotic arm may select different paths between operating points which reinforces the need to remain alert.

Laboratory Procedure:

1. Students need to review the safety requirements for the robotic cell.
2. After ensuring that power is disconnected, students enter the cell to stage the necessary parts to assemble and ship the pistons (i.e., pistons, rods, pins, pallet).
3. The appropriate end effect gripper should be installed on the robotic arm and the compressed air supply turned on.
4. The students program the robot to accomplish four tasks which results in a fully assembled piston. First, the arm retrieves a connecting rod from a part storage platform and places it on the assembly jig. Second, the arm moves a piston from the platform and places it on the assembly jig with the wrist pin holes properly aligned. Third, the robot retrieves a wrist pin from the platform and inserts it into the piston and connecting rod. Fourth, the arm picks up the assembled piston and places it into an empty pallet located on the conveyor.

Materials: Staubli robot (CS7 RX-130) with control pendant and computer terminal.

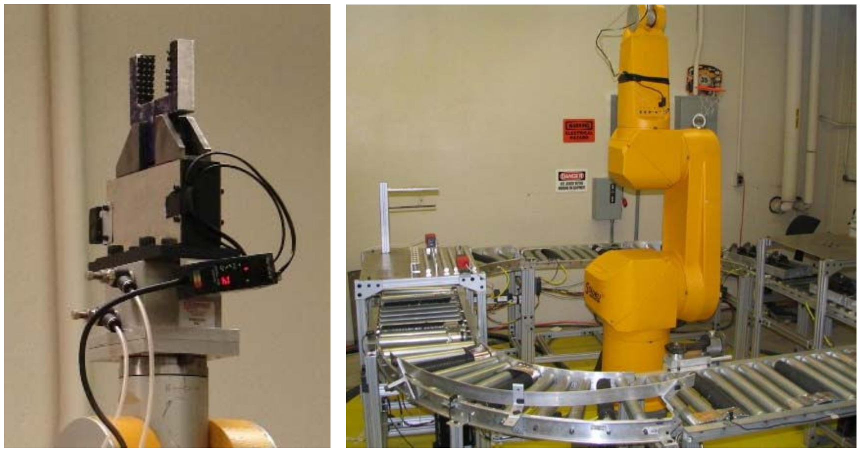

Figure 5: Staubli RX-130 industrial robot with (a) end effect gripper for part manipulations, and (b) conveyors in enclosed manufacturing cell

3.2.2 Robot and Conveyor System Integration

This module builds on the knowledge gained regarding the Staubli robot and previous PLC modules to integrate the equipment into a material handling system. A series of conveyor segments, featuring distributed electrical powered rollers with driver modules, are constructed of inner/outer aluminum rails mounted on an aluminum frame with casters. The infra-red sensors, mounted on the edge of the conveyor, permit the position tracking of materials on the conveyor rollers. The Staubli control cabinet features input/output terminal blocks to allow the robotic arm to be integrated into surrounding environment for closed loop operation. The dual PLCs, controlling the conveyor segments, will be interfaced to the robot, for coordinated material movement studies.

Learning Objectives: The student will understand the integration of robotics with material handling systems for product fabrication and transport. A unified architecture will be introduced and implemented which permits multiple PLC interactions with robot arm to assemble and move goods based on user defined algorithms and sensor feedback.

Laboratory Procedure:

1. Two robot outputs (e.g., 1 and 2) are connected to PLC1 thereby replacing the two toggle switches used in Section Module 3.2.1. Similarly, two robot inputs (e.g., 1010 and 1011) are wired to PLC1 to replace the lights.
2. In module 3.2.1, the robot assembled a piston. The robot is now programmed to wait before placing the piston in the pallet until a signal is sent from PLC1 which indicates the pallet is in the proper position based on the infra-red sensors.
3. Once the assembled automotive piston is properly secured in the pallet, another signal is sent to PLC1 by the robot to move the pallet to the end of the conveyor system for subsequent operation by another manufacturing resource.
4. When the pallet reaches this terminal conveyor position, the robot is programmed to return to the “ready” position to resume operation.

Materials: The materials for this laboratory include Holjeron 24VDC brushless dc motor driven rollers, Holjeron #ZL-DK100 driver modules, 8020 T-Slot extruded aluminum, and Takex #GS20SN infra-red sensors.

3.3 Electronic Circuits

Electronic circuits are common in manufacturing environments and consumer products which should encourage engineers to understand their basic electronics. Consequently, electronic components and integrated circuits will be introduced and reviewed to acquaint students with the general operation and connectively. In the next two modules, several basic circuits will be presented which offer breadboarding opportunities with signal test points. The two circuits feature 'electronic dice' which mimics a real dice using IC chips and a rotational sensor to count rotations of a flywheel.

3.3.1 Electronic Dice Circuit

The electronic dice module introduces integrated circuits with the creation of an electrical system that emulates the functionality of a six sided dice with a digital display. The circuit features a general purpose timer chip, a counter chip, assorted resistors, diodes, a switch, and six LEDs as shown in Figure 6.

Learning Objectives: The student works with a 555 timer chip and learns how to test basic circuit features. Specifically, they learn how to use breadboards, wire chip inputs/ outputs, and validate circuit functionality using oscilloscopes and multi-meters.

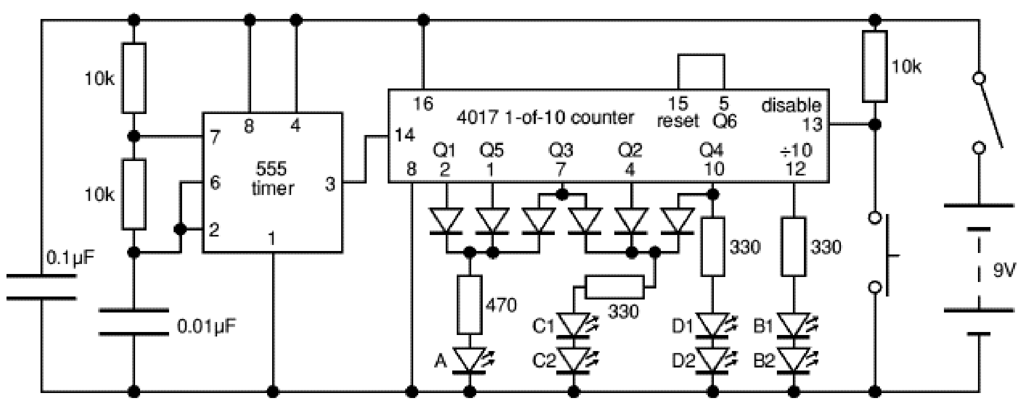

Figure 6: Circuit diagram for electronic dice experiment which features a 555 timer, 4017 decade counter, and multiple light emitting diodes (LEDs)

Laboratory Procedure:

1. Insert a 555 timer chip into the breadboard with the number 1 pin in the top left. Connect Pins 8 and 4 to +5VDC and connect pin 1 to ground. Connect one side of a 10kΩ resistor to +5VDC and the other side to Pin 7. Take another 10k Ω resistor and connect pin 7 to pin 6. Use a piece of wire to connect pin 6 to pin 2. Place a .01uF capacitor between pin 2 and ground.

2. The timer circuit is now fabricated to operate as an oscillator. Check to determine whether the circuit is properly functioning by connecting the onboard speaker to pin 3 and ground. If you hear a ringing note, it is functioning as expected.
3. Place the 7 LED's and arrange them on the breadboard in a standard dice configuration (three rows by two columns). Make sure the cathode and anode are not on the same rail and that no LED shares the rail with another. There should be three sets of LED's in series with the middle LED being alone.
4. Wire a 330Ω resistor to points A, B, and D. Next, connect a 470Ω resistor to point C. Apply +5VDC through the resistors to the LED's and verify that all seven are illuminated. If so, then this circuit section is properly completed.
5. Place the 4017 counter with pin 1 oriented in the top left corner. Connect pin 16 to +5VDC and pin 8 to ground. Wire the 1N4148 signal diodes to pins 1, 2, and 7. Bring the diodes together on one rail and connect this rail to point C using the 470Ω resistor. Connect the 1N4148 signal diodes to pins 4, 7, and 10. Bring the diodes together on one rail and connect this rail to point D using the 330 Ω resistor. Wire pin 10 to point B using a 330 Ω resistor. Connect pin 12 to point A using a 330Ω resistor.
6. Use a 10kΩ resistor to connect +5VDC to pin 13. Wire the switch from pin 13 to ground. Connect pin 14 of the 4017 chip to pin 3 of the 555 timer. Connect a 0.1 uF capacitor to between ground and +5VDC to smooth the power supply.
7. When the circuit is energized, all 7 LED's should be illuminated until the switch is pressed again. At that point, there should be a different number displayed via the LED configuration which resembles the behavior of a thrown dice.

Laboratory Materials: The electronic supplies for the experiment include 330Ω resistors (3), 10kΩ resistors (3), 470Ω resistor, 0.01μF capacitor, 0.1μF capacitor, 555 Timer (Texas Instruments #TLC555CP), 4017 decade counter (Texas Instruments #CD4017BE), toggle switch (C&K Components #GT12MABE), signal diodes (6) (Diodes Inc, #1N4001-T), and LEDs (7) (Panasonic #LN81RCPHL).

3.3.2 Rotation Sensor Electronic Circuit

An electronic sensor circuit will be created to count the rotations of a metal flywheel connected to a servo-motor. A metal test stand holds the dc motor, metal disk with single through hole, and light emitting diode (LED) with photo-resistor sensor as shown in Figure 7. An accompanying breadboard circuit (refer to Figure 8) interfaces to the LED and sensor to count the flywheel rotations with test points to validate during construction.

Learning Objectives: The student will gain experience with op-amps (compare measured sensor voltage against established threshold value) and a combined counter and display driver integrated circuit (4026 chip) for multiple segment LED display. In addition, a sequential building process that emphasizes frequent validation will reinforce the need to test each subsystem for operation prior to the complete build.

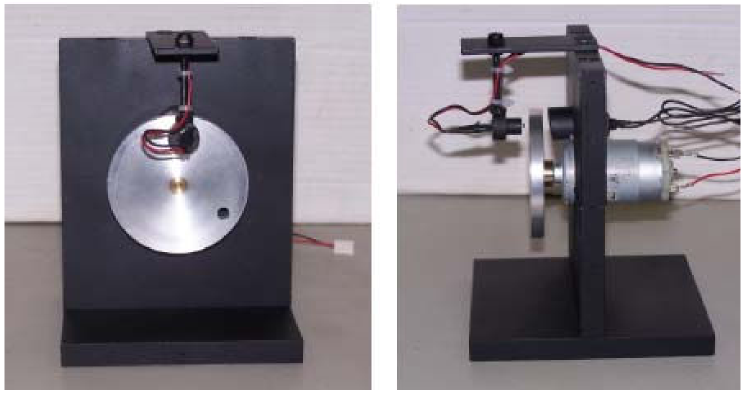

Figure 7: Servo-motor driven wheel featuring a single thru-hole with LED lamp and photo-resistor components for rational sensor experiment

Laboratory Procedure:

1. Insert the 741 operational amplifier into the breadboard with the number 1 pin in the top left. Connect Pin 7 to +9VDC and connect pin 4 to ground. Take the leads coming from the LDR and connect one to +9VDC and connect the other to pin 3 of the 741 amplifier.
2. Use a 3kΩ resistor to connect one side to +9VDC and the other side to pin 3 of the 741 chip. Connect a 330Ω resistor to +9VDC and connect the other end to the positive lead for the white LED. Attach the other LED wire to ground.
3. Test the circuit. Place a LED with 330Ω resistor to pin 6 of the 741 amplifier. Spin the wheel and check to ensure the LED is flashing when appropriate. If the LED fails to light, increase the resistor to pin 2. If the LED is always on, decrease the resistor to pin 2. Once the circuit is verified, remove the LED and resistor.
4. Place the 4026 IC into the breadboard with the number 1 pin in the top left. Next, connect pins 3 and 16 to +9VDC. Now connect pins 2, 8, and 15 to ground. Finally, place the seven segment display onto the breadboard and follow the diagram to connect the pins. Please include 330Ω resistors in each connection.
5. The 4026 IC pin 1 should be connected to +9VDC; ensure that it counts up one. If the circuit successfully counts up one, then connect pin 1 of the 4026 IC to pin 6 of the 741 op-amp chip.
6. The circuit has been successfully constructed. Connect the servo-motor to a variable output dc power supply to spin the attached flywheel. As the wheel rotates, watch the circuit count the total number of rotations.

Laboratory Materials: The supplies include 330Ω resistors (8), 3kΩ resistor, 741 op-amp (Fairchild Semiconductor #LM741CN), 4026 IC chip (Texas Instruments #CD4026BE), 7 segment display (Lite-On Inc #LSHD-5503), light dependent resistor (Chartland #N5AC501085), LED (Panasonic #LN81RCPHL), and dc motor test stand.

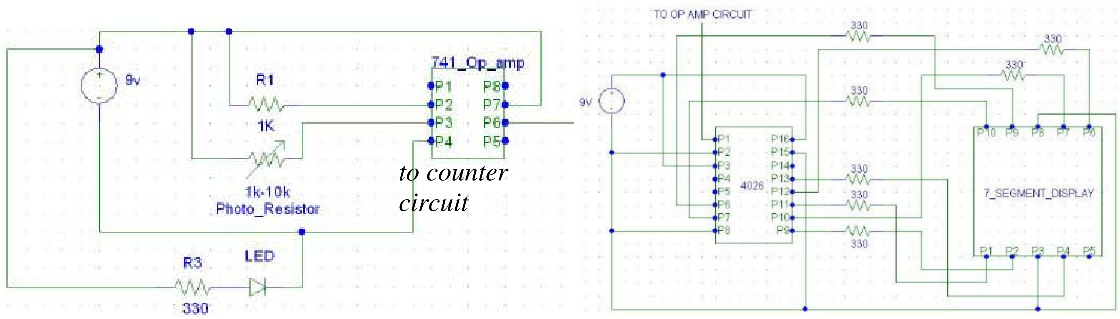

Figure 8: Rotational photoelectric sensor circuits - (a) sensor and (b) counter elements

4. Design Project - Material Handling System with Order Fulfillment

A semester long experimental based design project has been introduced to supplement the classroom activities and laboratory modules. In the laboratory, the robot and conveyor system have been combined on a somewhat ‘microscopic’ level to execute a specific well-defined task. In contrast, the design project requires student teams to create a larger ‘macroscopic’ system that encompasses tasks including order identification, fulfillment, and movement in preparation for shipment from the manufacturing facility. The project emphasizes the need for students to divide into teams to accomplish singular objectives that may then be integrated into a collective material handling system which achieves a larger objective. For instance, some of the groups may focus on sensing and sorting, conveyor systems, PLC programming, or robot interaction The team approach allows students to experience how real world problems may be solved with typical group and organization challenges. Finally, the project allows the application of class room and laboratory technical and interpersonal skills to create a mechatronics system.

The design project requires the sorting and packing of colored (blue, green, red, and yellow) multi-sized plastic balls for order fulfillment at a toy distribution center. Specifically, the students use the Staubli robot, conveyor segments, and sensors/actuators to create a small scale material handling system per Figure 9. In terms of operation, a bar code on the pallet box side lists the number of colored balls and destination (one of three points) on the conveyor system for subsequent pallet placement. The system reads the bar code using a bar code scanner (Keyence #BL-160). A color sensor (Keyence #CZ-H32) determines the ball color loaded in the main hopper and places the correct number in the proper container (refer to Figure 10). The box is then sent down the conveyor and routed to one of three spurs as commanded by the PLC network.

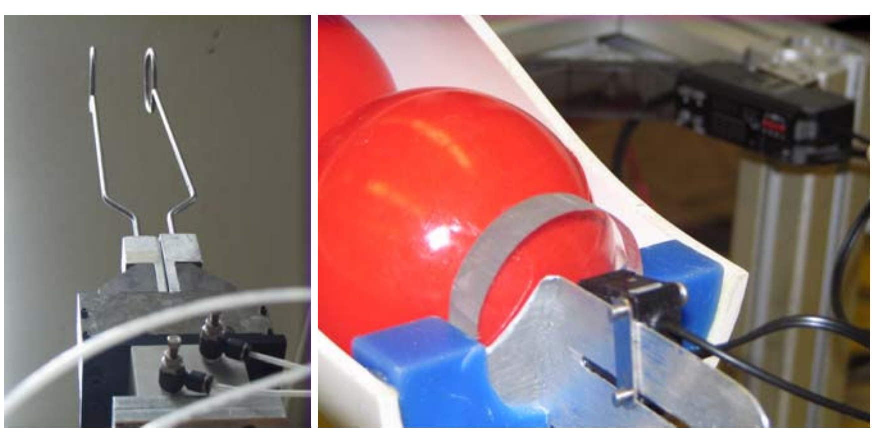
Figure 9: Staubli robot with end effector and color balls with sorted single color bin

5. Summary

The growing sophistication and complexity of engineering systems requires broad knowledge of mechatronics (sensors, actuators, and controls with application to consumer products, specialized equipment, and manufacturing environments) as well as general business and interpersonal skills. In this paper, the mechatronics (and material handling systems) course has been described which offers students an experience composed of classroom activities, laboratory experiments, and semester long design project. First, the technical, business, and personal skills covered include electrical, industrial, mechanical, and systems engineering, project management, procurement, team building, and leadership. Second, laboratory experiments allowed students to program networked PLCs, integrate conveyor system components including industrial robot for material movement, and breadboard electronic circuits. Third, a challenging material handling design project offered a learning opportunity for students to synthesize class and laboratory materials in a hands-on team-based endeavor. A comprehensive mechatronic course should help prepare graduates to meet the product design, manufacturing, material transport, and research needs of the 21st century.

Figure 10: Shipping container with ball order fulfilled and complete sorting system

Acknowledgement

The authors would like to thank the National Science Foundation (Grant No. NSF-DUE-CCLI-0632800) for the financial support of this project.

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