**Mechatronics: Automated Process Control**

Granite Hills High School

Full year

“d” 11th,12th (Physics)

Integrated Academics/CTE (CTE: Energy and Power Technology

Course Overview:

This is a year-long Laboratory Science course for 11th-12th graders focusing on the scientific principles of physics, energy conservation, electronic sensing, computerized data acquisition, and automated process control.  The course also meets the requirement of a career technical education course for the energy and utilities pathway focusing on environmental resources.   In this inquiry-grounded, project-based learning course, students become engineers, designing, analyzing, and building systems that automate processes.  Students learn about the fundamentals of physics.  An understanding of systems is emphasized, as students consolidate abilities with regard to appropriate selection, operational commissioning, and careful maintenance of automated technical systems.  Students are encouraged to apply basic design and operational principles to express themselves intelligibly and precisely using correct technical terms and symbols.  Students learn about electromechanical systems through experience with all the senses.  Students use program logic controller, sensors, manufacturing components, and computer models to study how product can be collected, measured, and processed by coding and designing efficient automated electromechanical systems.  Using their understanding of environmental stressors and concerns, students identify the inefficiencies in local industrial electromechanical systems and develop plans to mitigate them.

Prerequisites:

Conceptual Physics (Required)

Co-requisites:

Integrated Math III (Required)

Course Content:

**Unit 1: Fundamentals of Control Technology**

**Essential Questions:** How can automated process control improve energy efficiency and environmental sustainability?  What are the different types of process control?  What are the elements of an automated control system?

This unit introduces students to the fundamentals of control technology.  Students research different types of control systems and compare the benefits and disadvantages of open-loop vs. closed-loop systems.  Students build simple open-loop systems and identify their limitations and how automated technology might improve their efficiency.  Student define the basic control elements of a closed-loop system including monitoring, data collection, communication, and diagnostics.  Students build a small-scale electromechanical system to use as a learning module.  As they build these learning modules students learn about the components and how each contributes to the fundamentals of process control.  Students use the modules to explore the fundamentals of programming and controlling automated systems.  They learn basic circuit diagramming of mechanical and electrical systems. They practice manual and automated control of the module elements and program basic logic functions to control the automated system.

**Laboratory Assignment:**

Actuating DC Motors - In this lab exercise students build familiarity with the mode of operation of DC motors, incorporate them into circuit diagrams, and practice changing the direction of motion.  Students investigate different types of pushbuttons and switches, comparing normally open and normally closed contacts to one another.  Students use FluidSim to create a circuit to switch a DC motor on and off and have its polarity reversed via relays.  Students build and test their circuit.

**Unit 2: Sensors**

**Essential Questions:** What are the different types of sensors and how do they communicate information?  How can sensors be used to improve the efficiency of electromechanical systems?  What scientific principles govern the basic flow of electricity and explain the function of various materials used as conducting, semiconducting, and insulating devices in the construction of standard electrical circuits?  What basic tools and test equipment is used to construct, troubleshoot, and maintain standard electronic circuits and systems?  What are standard circuit configurations and component types used to build functioning electronic circuits?  What are the general operating principles of electronic components such as switches, relays & contactors, photoresistors, capacitors, transformers, inductors, transducers, diodes, and transistors?

This unit is designed to extend student understanding of the role of sensors in automated electromechanical systems.  Students use and learn about the differences between mechanical and electronic sensors while exploring the role of solid state electronic components.  Students explore the value of sensors in automated control and the functional links between sensors and drives.  Students build and test a variety of electric circuits that incorporate sensors.  They use these circuits to explore Ohm’s law, Power law, impedance, and electrical resistivity.  Students practice practical electronics as they build circuits, soldering connections and measuring values using a multimeter.  Students construct simple circuits with interchangeable components to test the effect of these components on voltage, resistance, and current.  Students reconfigure those circuits to test how series vs. parallel configurations contribute to those measures.  Students build and test circuits that incorporate relays, photoresistors, capacitors, transformers, transducers, diodes, and transistors.

**Laboratory Assignment:**

AM/FM Integrated Circuit Radio - Students expand their soldering skills and understanding of circuit design by building an complex circuit that includes an integrated circuit, transistors, diodes, resistors, capacitors, coils, and misc. parts. Students explore the theory of operation for each section of the circuit before the assembly is started. This will provide the students with an understanding of what that section of the circuit has been designed to accomplish and how it actually works. As students complete the assembly of each section they will complete tests and measurements to prove that each section is functioning properly.

**Unit 3: Controlling the Flow of Matter, Energy, & Information**

**Essential Questions:**  How does a system act on information to change the activity of that system?  What solid state electronics can be used to control of automated systems?  How are electromagnetic principles useful to automated systems?

In this unit, students focus on the role of switches in directing change within electromechanical systems and the response of electric drives.  Students explore the physical fundamentals of drive and sensor technology; how to physically integrate them to allow efficient communication between them.  Students explore how sensors and drives interact with one another and the role of switches in controlling the direction and movement of physical parts, energy, and information.  Students build on their understanding of sensors from the previous unit and explore how signals from sensors can be used to direct change in electrical or mechanical drives.  Students explore electromagnetic induction and its relevance to drive operation and electrical generator design.  Students use modeling software and physical components to design and build electrical relays and mechanical switches.  They use modeling software to program logic operations to control those switches and relays to respond differently to the same input and determine the most efficient way to integrate those switches within automated systems.

**Laboratory Assignment:**

Hydroelectric Power Generation - Students demonstrate how falling water generates electricity using the energy transfer generator.  Students investigate the relationship between height of the water reservoir and the performance of the generator.  Students also explore the effect of nozzle size and angle on the efficiency of the generator.

**Unit 4: Moving Matter/Material**

**Essential Questions:** What are the general relationships between position, velocity, and acceleration for the motion of an object?  How can the rectilinear motion of an object be analyzed to make predictions about position, velocity, and accelerations?  How can the curvilinear motion of an object be analyzed to make predictions about position, velocity, and acceleration?  How can Newtonian laws of motion be used to analyze the motion of objects acted upon by forces that are constant?  How can the principles of conservation of energy be used to predict and describe the motion of single body or connected bodies in motion?

This unit builds student understanding of the physical forces involved in moving matter.  Students build a small-scale electromechanical modules that simulates a conveyor system.  They use this module as a learning platform to investigate kinematics.  They program drives, solenoids, electrical motors, electrical and pneumatic actuators as they study and test the laws of physics that govern movement.  Students study the relationship between force, mass, and acceleration through the interaction between these electromechanical systems and plastic pucks that are processed within the module.  Experimentation is focused on defining the mathematical relationships that describe motion and using those mathematical relationships to efficiently program automated systems to move product in very precise and predictable ways.  As students extend their understanding of motion and forces they also build knowledge of electromechanical components that enable motion and how they function and are controlled.  As students integrate electrical motors into their projects they learn about DC drives, three-phase motors, servo drives, and stepper motors.  They use these electrical motors to investigate the relationships between gears, power, and torque.

**Laboratory Assignment:**

Position, Velocity, and Acceleration - Students use the electromechanical conveyor module they previously built to study the mathematical relationships between distance, time, speed, and acceleration.  Students use their understanding of these relationships to reprogram the module to deliver pucks precisely given strict parameters.  As students build and demonstrate competency using the mathematical relationships to predict and program motion more complex parameters are introduced to continue building their understanding of these relationships.

**Unit 5: Fluid Dynamics**

**Essential Questions:** What are the physical properties of fluids and how do those properties contribute to flow?  What are the dynamics of fluid flow and what are the governing parameters?  What are the conservation principles of mass, linear momentum, and energy for fluid flow?  How can an understanding of fluid dynamics improve the design of automated electromechanical systems and extend their capabilities?

This unit is focused on investigating and developing an understanding of fluid dynamics and how fluid flow can be integrated into automated electromechanical system control.  The focus is on pneumatics and water flow.  Students build and test a pneumatic control system using a compressor, tubing, pneumatic control valves, and pneumatic actuators.  Students investigate the relationships between and effect of force, surface, volume, volumetric flow, and pressure on air flow.  Students learn about and test the properties of fluids including buoyant force, streamline flow, and Bernoulli’s principle.  Additionally, students measure and test the mathematical relationships between pressure, temperature, and volume described by Boyle’s law, Gay-Lussac’s Law, and the combined gas law.  Students redesign electromechanical modules from the previous unit to integrate pneumatic control elements and reprogram relays to interface with these components.

**Laboratory Assignment:**

Controlling Single Acting and Double Acting Cylinders - Students use small-scale electromechanical modules to practice integrating pneumatic components into automated process control.  Students select the components of and design an electropneumatic circuit.  FluidSIM software is used to explore the fundamentals of actuating pneumatic single and double acting cylinders and to test their circuit designs.

**Unit 6: Programmable Logic Controllers (PLCs)**

**Essential Questions:** What is the role of programmable logic controllers in automated process control?  How can PLCs improve the efficiency of automated electromechanical system?  What solid state electronics can be replaced by PLC technology.  How do logic functions dictate PLC function and control?

This unit builds the foundations of programming used in automated process control.  Students wire programmable logic controllers (PLCs) to interface with virtual and real world electromechanical systems.  Using EasyVeep and Codesys software students build knowledge in Ladder Logic Diagram language used to program PLCs.  Students use standardized programming for the configuration, commissioning, and maintenance of automated systems.  Students practice controlling pneumatic and electrical circuits using logic operations with the PLC.  As students build and test PLC controlled circuits using the electromechanical modules from previous units, they learn about the role of programmable logic controllers in automation and how elements of their solid-state electronics can be replaced with a PLC.  Student work includes drawing and interpreting ladder logic diagrams, assigning input/output sources and connections, programming relay outputs signals, programming both normally open and normally closed instructions, and PLC timer and counter concepts.

**Laboratory Assignment:**

EasyVeep Simulations - Students use EasyVeep software to write logic sequences using Ladder Logic Diagram language to control virtual electrical and pneumatic circuits using a physical PLC unit connected to a computer running the simulation.  Students start with a simple circuit with a single input and a single output and then progress through more complex simulations.  Students are allowed to select which simulations to attempt depending on their comfort level and success.  The series allows for spiral review of foundational concepts in PLC control that will build new skills and provide opportunities to review and practice existing knowledge.

**Unit 7: Process Automation**

**Essential Questions:** How are cost, resource availability, and process requirements integrated in designing an automated system?  How can automated closed-loop control options/variations be appropriately matched to application?

This unit is designed as a capstone to the course where students demonstrate their understanding of and their ability to integrate the elements of process control.  Students are challenged to design and build an automated fill level water system.  Given specific economic, physical space, and component parameters students are challenged to design, install, and commission an efficient system.  Student first study a process description to understand what the system should be able to do within the parameters established by the assignment.  Students then plan, install, and commission the system.  Students are given specific problems to solve and parameters to follow in function testing the system.  Student projects require they consider energy and design efficiency and that they provide electrical and mechanical circuit diagrams of their projects.  Once electrical and mechanical components are built and tested, students automate the system using PLC controllers.  Automation includes measurement of pressure and flow using electronic sensors, pump control, and controlling fill level.  Students are challenged to demonstrate fill level control using a pneumatic actuator, two-step controller, continuous controller, proportional controller, integral controller, and proportional-integral controller.

**Laboratory Assignment:**

Automated Closed-Loop Control Circuits - Students integrate and function test several automated closed-loop control systems into a fill level process.  Control systems include two-step, continuous, proportional, integral, and PID  (proportional-integral-derivative) controllers.  Students test them to define the advantages and disadvantages of each.  Students are challenged to consider cost and reliability in order to select which control system to integrate into their plant design project listed above.

Course Materials

Textbooks

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| Physics Principles and Problems | Zitzewitz | Glencoe | 1st Ed./ 2013 | <https://www.mheonline.com/programMHID/view/0076592529>  (primary text – yes) |
| Engineering Your Future: A Project-Based Introduction to Engineering | Gomez, Oakes, Leone | Great Lakes, Incorporated | 3rd Ed./ 2011 | <http://www.glpbooks.com/titles/engineering-your-future-project-based-hs.html>  (primary text – yes) |
| CK-12 Engineering: An Introduction for High School | D. Baker | CK-12 Foundation Flexbook | 2nd Ed./2012 | http://www.ck12.org/book/Engineering%253A-An-Introduction-for-High-School/ |
| Fundamentals of Automation Technology | F. Ebel, S. Idler, G. Prede, D. Scholz | Festo Didactic GmbH & Co. KG | 1st Ed./2008 | http://www.festo-didactic.com/int-en/learning-systems/technology-for-schools/media/technical-book-fundamentals-of-automation-technology.htm?fbid=aW50LmVuLjU1Ny4xNy4xOC4xMTIwLjU0ODI |
| FluidSim Pneumatics | A. Systems | Festo Didactic GmbH & Co KG | 1st Ed./2007 | http://www.festo-didactic.com/int-en/learning-systems/technology-for-schools/media/technical-book-fundamentals-of-automation-technology.htm?fbid=aW50LmVuLjU1Ny4xNy4xOC4xMTIwLjU0ODI |
| EduKit PA | B. Schellmann, H. Kaufmann | Festo Didactic GmbH & Co. KG | 1st. Ed./2009 | http://www.festo-didactic.com/int-en/learning-systems/process-automation/accessories/edukit-pa-workbook.htm?fbid=aW50LmVuLjU1Ny4xNy4xOC41NzcuNjgyMw |
| EasyVeep | U. Karras | Festo Didactic GmbH & Co. KG | 1st Ed./2009 | http://www.festo-didactic.com/us-en/links-and-downloads/software/software-licences-trial-version/easyveep.htm?fbid=dXMuZW4uNTc5LjE3LjMyLjgyNS41NjU5 |
| CODESYS Installation and Start | CODESYS/Festo | 3S-Smart Software Solutions GmbH | Not Available | http://www.festo-didactic.com/int-en/learning-systems/software-e-learning/programming-software/codesys-provided-by-festo.htm?fbid=aW50LmVuLjU1Ny4xNy4xOC41NjYuNzYwNA |

Supplemental Materials

Websites

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| NEED Info books |  | National Energy Education Development Project | http://www.need.org/secondary |
| CNN Student News |  | CNN | http://www.cnn.com |
| EPA |  | United States Environmental Protection Agency | http://water.epa.gov |
| National Center for Case Study Teaching in Science |  | NSF | http://sciencecases.lib.buffalo.edu/cs/ |
| PhET Interactive Simulations |  | University of Colorado | http://phet.colorado.edu/en/simulation/gas-properties |