COMPUTERS IN PROCESS CONTROL: THE RUBE GOLDBERG CHASE

Lee-Shing Chang, Michael Costa, Easwaran Cumarasamy, Pat Ho, Paul Kolb, Andrew Lee, Rajani Sharma, David Templeton, Tina Wong

Advisor: Dr. Manny Bhuta
Teaching Assistant: Justin Hotchkiss

ABSTRACT

The "Computers in Process Control" team project uses various concepts from physics, electronics, computer science, and chemistry to construct a "Rube Goldberg Machine." This is a device that performs a simple task using a complex approach. At the fundamental level, process control describes the methods by which a task or operation is regulated. In our case, process control focuses exclusively on the integration of a computer program to activate a sequence of modules. To add complexity, our team implemented a series of sensors, relays, imaginative handmade devices, and computer technology. The function of the final project is to shoot a ping pong ball at a target through a series of necessary steps that raise the target and prepare a ping pong ball launcher. However, the project also uses superfluous steps, including marble chutes, acid-base reactions, and remote control cars, to add the complexity that is characteristic of a true Rube Goldberg Machine.

INTRODUCTION

To most people, turning on a water tap is a trivial task of effortlessly turning on the water taps. Rube Goldberg, however, perceived marbles rolling, water pumping, wheels moving, gears grinding, and balls falling before he even considered the final turn of a knob. He came to believe that humans innately enjoyed making simple tasks more complex, although modern technology focuses on the simplification and refinement of many ordinary operations. Thus, Rube Goldberg dedicated his time to the creation of intricate systems of sequenced actions that would later become social fascination, societal commentary, and scientific masterpieces.

Born in San Francisco in 1883, Reuben Lucius Goldberg would grow up to be one of the most ingenious inventors, thinkers, and artists of his time. As a young boy, Goldberg followed the prescribed path that his father dreamed for him and became an engineer after graduating from the University of California at Berkley. Possessing an inherent passion for art, however, Goldberg decided to follow his own heart. He began his long career in art as an office boy in a newspaper sports department in San Francisco. With unflagging perseverance, he submitted drawings and cartoons to his editor until his work was published. Achieving rapid success, Goldberg became a well-known political cartoonist in New York. His cartoons focused on absurdly connected machines functioning in extremely complex ways to produce simple end results. He believed that although there are two ways to do things, the simple way and the hard way, a surprising number of people preferred to do them the hard way. Thus, Goldberg spent much of the rest of his life making simple tasks highly complicated through his famous Rube Goldberg devices.

Goldberg's devices serve as unique commentaries on life's complexities. Skeptical about technology, Goldberg prioritized simple human needs and values by using primitive functions to create amazingly complex processes. His amusing comments on man's ingenuity continue to affect people today, who are caught up in a high-tech world but search for simplicity. Although Goldberg's devices may seem impractical today in that they make simple tasks excessively difficult, society has developed a strong affinity for his intricate creations and values the skills involved in successfully completing a linked chain of events.

Essentially becoming engineers, the team members had to select a problem to be completed, a solution, and a means of implementing the solution. A simple task was selected: shooting a ping pong ball at a target. Applying Goldberg's principles of complicating simple functions, the team members added intermediate modules to increase complexity after extensive planning and surveillance of possible devices. As our simple task was broken down into elementary tasks, new unrelated functions were incorporated as roundabout means to accomplish certain functions, such as raising a target and providing air pressure to launch the ping pong ball. Following construction of each module, the entire apparatus was linked through circuits and sensors, ideal for the implementation of a computer program to control and initiate certain operations. Hence, process control using computer technology and the characteristics of a Rube Goldberg machine could be combined to shoot a ping pong ball at a target in the most absurd way possible, while still practically applying several scientific concepts.[1]

Each intermediate component possesses its own unique properties that when combined create a "journey" through the modules. Imagination can utilize these functions to creatively tie the devices together into a scenario that engages viewers and takes them step by step through the actual machine.

SCENARIO

Drew Police Department (DPD) Progress Report: Case 112-079-40
Suspect – Steve Surace, Professor, NJGSS
Status – IN CUSTODY

Description of Attempted Apprehension:

The culprit, a man of average height, bearded, with long, frizzy, brown, slightly balding hair, had slipped through the department's fingers on multiple accounts in the past months. Tens of thousands of dollars were being offered for information on Steve Surace's whereabouts, and warnings were on the news each night for civilians to watch for this dangerous wanted man. On August 15, 2003, early evening, he was finally identified driving a stolen green PT Cruiser convertible. A high-speed car chase ensued, with a number of DPD officers tailing the car. After hearing the police's warnings, Surace naturally declined the invitation to pull over and instead accelerated. Nonetheless, he was promptly brought to a halt by his own rash behavior.

Upon crashing into a garage, his stolen car erupting into flames. As much as this seemed the end of our criminal, the DPD had many an encounter with Surace before and knew him to be a devilish trickster, and a faked death could not be ruled out.

Master of planning ahead, DPD special agent Justin Hotchkiss had already foreseen Surace's course of action, and on the other side of town, his own plan had begun to unfold long before Surace had even stolen that car. He had purposely linked a chain reaction of seemingly random events to prevent Surace's catching on to his strategy, and so it started with a water pump from the city's water supply, which soaked a piece of toilet paper holding a weight near the sewer system. This weight then fell through, raising a ramp just outside of the city, rolling a wide, white pipe towards a teetering wall. This wall, attached at the top to a pulley, fell and pulled the string down, thereby starting the rolling of a set of boulders across the top and down the side of a hill down towards the city limits. They barreled down a street, the first three boulders falling through a man hole, with the fourth larger boulder rolling across due to its larger size. After falling through the manhole, the boulders quickly depressed one end of a catapult, which simultaneously launched an attempted shot at our suspect and released a zip line.

The shot missed. But this line led to a bucket suspended overhead, which slid down and knocks a pipe down so that seawater empties into a reservoir. This reservoir was located conveniently near the city's power supply company, from which two lines were drawn down into the reservoir, and when the seawater reached these lines, electricity surged through them, activating the plant and relaying a signal back to the supervisor Justin. At this time, the big boulder not meant for the catapult rolled into a series of walls, which fell down one by one in a domino effect, finally knocking the last one to the ground and tripping an infrared sensor. This sensor relayed this information concerning Justin's process back to his computer, and he starts the rotation of a motor in a local quarry which raises one end of a pipe suspended in the air by a crane. This pipe was filled with one of two reactants in a reaction, the other in liquid form in a tub below the pipe. The reaction occurred, naturally, and the tub, secretly wired by Officer Justin, noticed a change in resistance and again relayed the information back to him. He then activated a second motor, which tipped a box, releasing many sport balls down a ramp and into a pan, which fell and connected with a broken wire to the central power source, completing another circuit that Justin was watching. The pan was also attached to a target on the other end, an electronic target that was then pulled up by the pan's momentum over a pulley and showed the genius of such a process, to the extent that Surace's future whereabouts has been decided.

At this point, the suspect had apparently found that reports of this chain of seemingly accidental and coincidental events, as random as they were, seemed suspicious, and he decided to make his getaway, resulting in the aforementioned crash. As mentioned before, Justin was extremely wary of Surace's car chase and had told the DPD field officers to inform him of the possible crash as soon as possible, so that he could start up the second stage of his plan. Upon receiving this information, the officer tried to activate a large weather balloon filled with sodium bicarbonate fit over the opening of a huge container of acetic acid, but Surace, thinking he was one step ahead, attempted to break the balloon by towing it away with a second stolen vehicle. But, by lifting, he helped the reactants to mix and a gas was produced in the balloon, inflating it more and more until it was high enough to tip one end of a ramp, rolling a set of boulders into a nearby empty pool (which was wired, of course). Unexpectedly, at the same time, a number of other boulders were shaken by the explosion of the car and rolled zigzag down a mountain side, but did not affect Justin's process or hurt civilians. Meanwhile, the boulders in the empty pool had just enough minerals inside to conduct a weak signal across the wires, firing off a signal to the last step of the process, the take-down. All the while, the suspect had decided to abandon his car and steal a green mini cooper in an attempt to escape, but he was no match for the process set up against him. DPD officers caught up with him and herded him towards sector 22-M, where there was set up an ingenious device, the pressurized shooter of a ball which would paralyze the suspect and allow him to be taken in to the department. Justice was done in finally catching one of the most wanted men in the country, and it was all due to process control.

DISCUSSION

Marbles careen through the air while flashes of flames engulf a toy car and dominoes cascade in intricate patterns. Any ordinary person would be quite bewildered by the nature of such operations; however, Rube Goldberg would simply see them as a ping pong ball shooting a target. Adopting the principle of transforming a simple task into a complex system of modules, we created our own Rube Goldberg machine with the integration of computer process control and data collection to, simply put, shoot a ping pong ball at a target.

The Rube Goldberg machine uses both manual control and computer prompted activation. Thus, our project includes manual and electrical modules, which are connected by circuits, sensor activation, and mechanical force.

Throughout our particular Rube Goldberg machine, several sensors, and electrical devices were implemental in the collection of data and process control. Hence, it was imperative to develop a general understanding of their mechanisms in order to include computer process control effectively.

Process Control

Process control is used to monitor and control a given process or situation by programming a computer to take readings from sensors and to respond differently based on what data it receives. This is often done with If/Then statements. For example, if the temperature rises too far above a certain pre-programmed temperature value, the program turns on a cooling system.

In real life, process control is much more complex. However, it still can be broken down into several simple If/Then statements. In a nuclear power plant, the temperature inside the core is crucial. If the temperature is too low, the rods do not heat enough, and sufficient energy for fission is never received. On the other hand, if the temperature is too high the rods will melt and fuse causing a "nuclear meltdown" that could destroy a reactor. Therefore temperature is crucial; however, a human cannot physically measure temperature readings in a nuclear reactor core due to risks and process disruption.

Hence, process control is a tangible solution. A temperature sensor is installed in the reactor core to takes readings every set time interval, such as once every second. The computer interprets this data, such as, if the temperature is too high the computer automatically opens a valve to let cold water flow around the core to cool it. If it is too low the computer allows the nuclear chain reaction to continue in order to raise the temperature. We have implemented this type of process control on a lesser scale with the use of various sensors and computer activated operations.

Nichrome Wire

Nichrome wire, an alloy made of nickel and chromium, has a very high resistance, and therefore, heats up when electric current is passed through it. In addition, since it does not oxidize when heated, it is very useful for producing fairly high temperatures. In practice, nichrome wire is also used in a variety of household devices, such as, hairdryers and toasters. We specifically utilized heat from nichrome wire to burn through strings that either connected modules or set off specific operations.

Motors

A motor is a simple device that utilizes electromagnetism to convert electric energy to kinetic energy. Simple motors contain an electromagnet and two permanent magnets, one with a north pole and the other with a south pole. When current is supplied from a battery or alternate power source, DC current flows through the coils of the electromagnet, causing each pole of the electromagnet to be attracted to the opposite pole of the permanent magnet. Two small pieces of metal called commutators are attached to the electromagnet and rotate as it spins. As a half-turn is completed, the commutators on the electromagnet move over to the opposite motionless brushes, attached to the encasement of the motor and connected to a power supply. As the electromagnet rotates, commutators reverse contact with the brushes and the current reverses direction which causes the poles of the electromagnet flip. After the motor completes another half-turn, the electromagnet continues to spin in one cyclical motion. Thus, the motor is useful for performing mechanical work, such as winding string to lift a lever.

Thermistor

A thermistor has special properties ideal for sensing temperature changes. It is comprised of ceramic, which inherently changes resistance as temperature changes. This ceramic thermistor is in series with a circuit so that as temperature changes, the circuit can directly detect alteration in resistance. Thus, a computer can easily detect changes in heat, as generated through endothermic or exothermic reactions, and trigger the subsequent process. This device proves to be very convenient in process control, since a computer can monitor temperature and respond accordingly through electronics.

Power Supplies

Variable power supplies are used throughout this team project. Since 120V alternating current is both dangerous and unsuitable for the components used, the power supplies provide an avenue for decreased voltage and transformation to direct current. In total, five power supplies are utilized in the project.

Even though power supplies are capable of outputting low-voltage alternating current, the items in this team project use only direct current. Regarding the internal electrical pathways used in this team project, the power supply initially stepped-down the 120VAC to 16VDC by a fixed transformer. This 16VDC was then directed to a user-operable variable resistor, which could reduce the voltage to any value. Thus, power supplies are imperative to allow the computer to operate the modules.

Relays

In its simplest form, a relay is a fancy on/off switch controlled by a computer. It has signal and device inputs through which it connects to and communicates with both the computer and device.

The circuit into which the device is wired is complete with the exception of the relay. One end of the circuit is connected to the relay's "common" input, while the other is connected to the relay's "normally open" input, or, a continuity gap inside the relay. When the computer sends a current into the signal input, a metal arm moves to fill the gap in the relay and connects the device circuit causing the next connected device to run. After the computer stops sending current, the metal arm moves back to its original position thereby opening the device circuit to stop device function.

A relay also has a "normally closed" device input. This input allows a device circuit to constantly run unless the computer sends current to the signal input, in which case the metal arm opens a gap in the circuit and breaks the circuit stopping the device.

COMPONENTS

Although our ultimate goal is to shoot a target, we have incorporated several immediate devices necessary to construct a true Rube Goldberg Machine.

Module I – Jack in the Box

A piece of aluminum foil was taped to the lid of the toy, with two connecting wires attached on the sides. Powered by hand, a jack-in-the-box opens, breaking the circuit going across the top of the box and relaying to the computer to provide power for the next step.

Module II – Water Pump and Weight

The pump we used as the second module of our Rube Goldberg machine was once a pump for windshield cleaner fluid in a car, but was removed for this project. Its purpose is to pump water onto toilet paper to disintegrate it, allowing a weight on its surface to fall. The pump has a tube to collect water and bring it to the motor as well as another one to dispense the water. It was placed in the tub on which the toilet paper is fastened and into which the weight would eventually fall. The pump would not work properly unless the tubes were filled with water prior to starting the motor. Therefore, the tub was filled with water, and the pump was submerged. Thus, when the computer activates the pump with 12V, it will pump water through both of the tubes onto the toilet paper.

The toilet paper is doubled over four times and taped taut across the plastic tub while a one kilogram weight is placed on it. When the water pump shoots water onto the toilet paper, it disintegrates and the weight slowly falls through it.

This module worked well with the toilet paper, as it is designed to dissolve in water. We initially tried using a paper towel, but it failed because paper towels are designed to remain strong even when wet.

Module III – Ramp and Block

A one kilogram weight is attached to a string which leads over a pole and is taped to the bottom of a level wooden ramp, on which a roll of duct tape lies. The force exerted on the string as the weight falls causes an upward force on the wooden ramp, lifting it and causing the duct tape to roll down the ramp.

We taped down thin wooden dowels to the sides of the ramp to guide the tape down the ramp and taped a rubber balloon on the top of the ramp. When the ramp is level, the balloon ensures that the duct tape does not roll off the ramp. But when the ramp is on an incline, the potential energy of the duct tape is sufficient enough to overcome the static friction of the rubber and roll down the ramp.

At the bottom of the wooden ramp a block is attached by a string to a plastic ramp initially tilted downwards which cradles a large marble. The inertia of the rolling duct tape knocks over the block, lifting one end of the plastic ramp. The incline causes the large marble to roll down the chute towards the pachinko machine.

Module IV – Pachinko Machine

The design of this module was modeled after Japanese pachinko machines, in which multiple marbles are dropped and allowed to fall freely on metal pegs. This design is visually entertaining (the random falling of the balls), audibly appealing, and functional (Figure 1).

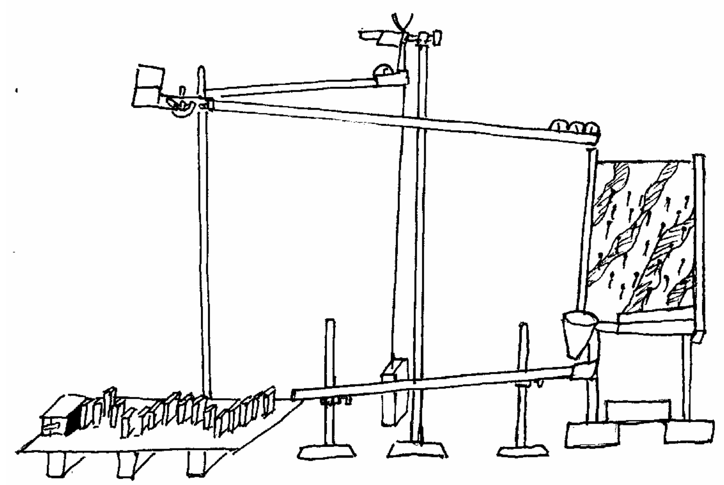

Figure 1- Marble ramps, Pachinko machine, and dominoes

Due to the randomness of the marbles, it was very difficult to predict where the marbles would fall and end up. Furthermore, we spent time adjusting the incline of the path leading into the machine and the path leading out into the funnel to ensure adequate speed and accuracy.

We constructed our pachinko board using three pieces of plywood and nails. Rubber bumpers at the edges prevent marbles from getting stuck at the edges and ensure that all marbles fit through.

The marbles escape the module through a funnel and fall onto a plastic path. Because of a hole in the path, marbles that are smaller than the hole will fall in, while a larger marble will pass over, initiating the cascading domino sequence.

Module V – Infrared Sensor and Dominoes

After one marble has successfully reached its final ramp following the pachinko machine, it approaches a system of dominos. The momentum of the traveling ball is transferred to the first domino, which prompts the remaining dominos to fall in succession. These dominos are mounted by tape on a wooden platform supported by three wooden blocks. The final domino falls into the path of infrared light passing between an infrared transmitter and receiver that face each other. Initially connected to 1.2 volts, the transmitter sends infrared light to the receiver, whose wires provide terminals for resistance readings. Thus, as the last domino disrupts the beam of infrared light, a decrease in resistance occurs at the receiver. When the resistance falls below 40 kiloohms, it is detected by the DAQ, which prompts the program to provide 1.9 volts for the next module necessary in continuing the next task.

It is imperative to set the dominos in a foolproof fashion that consistently causes a cascade reaction. Infrared sensors are also very sensitive, which in turn accounts for altered infrared detection due to surrounding lights. Thus, one must try to block extraneous light by constructing a small cover for the sensor apparatus.

Module VI – Baking Soda and Vinegar Reaction

After being triggered by the infrared sensor, the computer provides 2.7 volts to the motor to turn over a pipe and drop baking soda into vinegar. The combination of baking soda and vinegar is a classic acid-base reaction that effectively incorporates changes in pH ranges by the neutralization of H_3O^+ ions with OH^- ions. The chemical equation of

$$HC_2H_3O_2 + NaHCO_3 \rightarrow CO_2 + NaC_2H_3O_2 + H_2O$$

describes our particular reaction that produces carbon dioxide and water, as seen through the effervescence and foaming of the products. In short, baking soda ($NaHCO_3$), a base is added to vinegar, which is 5% acetic acid ($HC_2H_3O_2$), to increase the original acidic pH by neutralizing vinegar's H_3O^+ ions to create water.

By incorporating computer process control, the changes in pH can be related to changes in resistance between two electrical wires immersed in the solution. As pH rises, the resistance between two wires taped under the fluid to the beaker drops almost to zero while the reaction is occurring. Subsequently, the resistance begins to rise back up to the original value of about 40 kiloohms due to the formation of water. Using 200 ohms as a cutoff, the DAQ is once again signaled to activate the succeeding module.

It is necessary to use consistent amounts of baking soda and vinegar to obtain a sufficient drop in resistance value that can be easily detected electronically.

Module VII – Raising the Target

Finally, raising the target is one of two essential goals of our Rube Goldberg project. The target must be in place to receive the ping pong ball being shot from an air compressor gun. After current is sent to a geared motor obtained from a toy car, the motor winds a string attached to the closed end of a cardboard box. The generated tension lifts the closed right end, allowing marbles to pour out the left side's open end. The marbles then fall into a box attached to a pulley system that lifts the target. The pulley system has the target attached to one side of the string and a box on the other side (Figure 2). The string pivots on a bar clamped to a stand. As the marbles add weight to the box, the box's mass surpasses the mass of the target just enough to raise the target to a desired height of about 0.5 meters.

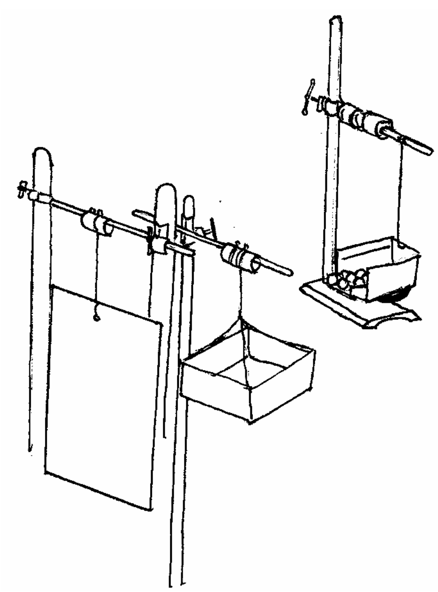

Figure 2- Raising the Target

It was difficult to determine the number of marbles we needed to cause the target to rise. Furthermore, it was difficult to predict where the marbles would end up and thus we conducted numerous tests to ensure accuracy.

Module VIII - Catapult

The catapult, started by marbles falling from the hole in the lower ramp, marks the beginning of the second section of the parallel sequence. The marbles fall through the hole and land in the basket that is extended from the end of the catapult launcher. When the basket fills with enough marbles, the launcher's supports fall down, enabling the catapult to release its energy. When the catapult is launched, a 500g weight falls down, raising one side of the catapult lever which in turn launches the ping-pong ball. The ping-pong ball is for show and will land randomly.

Several obstacles blocked the progress of the construction of the catapult and pail, in that, the module was essentially plagued by reliability issues. The catapult, pail, and electrolyte apparatuses were relatively easy to build with few difficulties. However, after the modules were initially constructed, the success rate of the catapult in launching correctly was about 30%. Extensive testing and slight modifications allowed the module to have a 75+% success rate, and triggered the pail.

Module IX – Zip-line and Pail

After the lever of the catapult goes up, a second process is activated as the lever tugs a string connected to a pail. The pail hangs from an inclined wire and, when tugged, starts its descent down the wire, the pail slides down and gains speed, it knocks over a graduated cylinder filled with salt water (an electrolyte) into a beaker. The beaker contains two electrodes which form a connection in the electrolyte; the DAQ senses decrease in resistance and proceeds with the next operation in the apparatus.

Module X – Exploding Car

A large green electric car is wired so that the completion of a circuit drives the car's motor and propels it forward. This car is then placed on a wooden board elevated by foam so that the car falls into a box on top of a frame that causes paper flames to pop up. By scoring and folding two large corners of a piece of cardboard the flames fold up easily. Then, using dowels, plastic railing, and hot glue a platform was made to achieve height from the ground. It is square with dowels at each side, propped up using the railing as legs. There are tubes on the flaps of the cardboard with stiff wire piping attached to the platform, that create the desired hinge. Thus, as the central flat part of the board is depressed, the flaps tilt to a vertical position as a result of the hinging effect of the tubes and wires. However, the platform surface is not large enough for the car to go through, so there is a Styrofoam block on the central surface of the cardboard and a box on top of that, both of which create a “garage” to be crashed into. The green car drives into this box, depressing the foam below it and the apparatus’s center below that, and lifts the flames on the sides fairly quickly due to the sudden impulse of the car’s added weight. This effect is then exaggerated using the alcohol combustion apparatus.

Module XI - Denatured Alcohol

After the PT Cruiser jumps the ramp, the computer control will complete a circuit that contains a nichrome wire, inserted inside a 1 L Erlenmeyer flask coated with denatured alcohol. As the coating of denatured alcohol vaporizes, the flask is filled with hydrocarbon and oxygen, while 12 volts is applied to the nichrome wire by the DAQ. This wire heats up and within a few seconds, fumes are ignited dropping the resistance of the thermistor in the flask from the kiloohm range to approximately zero ohms. When the computer control senses the drop in resistance in the thermistor, it signals the activation of the next apparatus.

Most of the modifications made in this module dealt with the amounts of denatured alcohol to use. If too little was used, a lack of hydrocarbon in the air around the nichrome wire, would inhibit ignition. However, if too much was used, a lack of oxygen concentration would inhibit combustion.

Determining the lengths of nichrome wire to use also caused problems. There was also trouble in determining the length of nichrome wire to use. If the length was too short, the wire would heat up too much and burn out, due to low resistance and high current. On the other hand, if the length of the wire was too long, the wire would not heat up sufficiently to ignite the vapor inside the flask because of high resistance low current. Extensive testing was completed to determine the appropriate length.

Originally, pure methanol was used for the module but it was determined that the ethanol/methanol mixture in denatured alcohol produced an identical flame at a lower price, so denatured alcohol was used in the final machine.

Module XII - Towing Car

The electric toy car wired to the DAQ is activated and set into reverse motion. It is set upon an inclined ramp so that it can easily lift the weight on the other end. The car is attached by nylon string at the front and hangs over a horizontal bar approximately the same

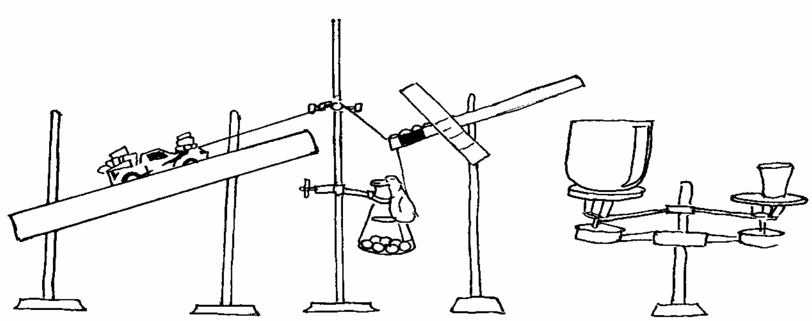

Figure 3- Car Towing the Balloon

height from the ground as the car's initial position. Its other end is attached to the top of a balloon filled with baking soda. The horizontal bar and two plastic ties act as a pulley to guide the string. This, along with the inclined slope, makes the act of pulling the balloon and its contents upwards easier (Figure 3).

Module XIII - Vinegar/Baking Soda Balloon and Seesaw

A balloon is attached at its mouth to an Erlenmeyer flask. The opening is then sealed, making the flask airtight. There is 200 mL of 5% acetic acid ($HC_2H_3O_2$) vinegar in the beaker and 10 g of baking soda ($NaHCO_3$) in the balloon. When the balloon is lifted by the car, the baking soda empties into the flask and causes the following reaction:

$$HC_2H_3O_2 + NaHCO_3 \rightarrow CO_2 + NaC_2H_3O_2 + H_2O$$

The CO_2 produced by this reaction then inflates the balloon attached to the flask slowly lifting a seesaw above it. After the seesaw, which is placed on top of a ring stand, is lifted by the inflation of the balloon, five marbles at one end, and roll off of the seesaw into a bowl on a scale that acts as a weight sensor.

Module XIV - Marble Chute and Weight Sensor

Seven marbles are held at the top of a marble chute by a piece of string that is weighted at one end and attached to a nichrome wire. As the computer sends current through the nichrome wire burning the string, the weight pulls the rest of the string over the chute to let the marbles fall. These marbles then fall down the chute into another container triggering the next module.

Module XV - Pressure Cannon

The ping pong ball firing mechanism is a pressure cannon or air rifle that is modeled after a "spud gun." A large pressure accumulator was built using PVC sewer pipe and end caps. Before the accumulator was sealed, an air valve which was cut out of a bike's inner-tube was installed in the side. One end of a T-connector on the end cap connects to the triggering piston, a mechanism that seals the hole in the end cap while a compressor fills the accumulator and then released the hole to allow the air pressure to run up the barrel and fire the ping pong ball.

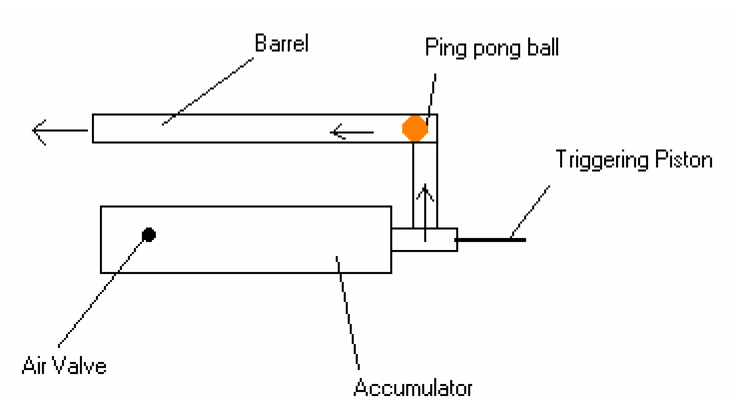

Figure 4- Pressure Cannon

The other end of the T-connector is attached to the barrel, made up of a long piece of 1' 1/2" PVC pipe that bends ninety degrees at an elbow joint in order to meet the T-connector. Since the ping pong ball doesn't fit through the elbow joint, it confined to the barrel. When the pressure cannon is triggered, the air from the pressurized accumulator rushes through the T-connector, out the ninety degree part, up and through the elbow joint, and then carries the ping pong ball out the barrel.

This process is easier said than done. Everything worked exactly as planned except the triggering piston. It is very difficult to create an air tight seal when using crude materials. Originally the accumulator was sealed on the outside so it could easily be fixed with the pressure working against the seal but this proved to be unreliable. Since the original plan failed the next option was to create a seal with the pressure helping, from inside the accumulator.

The accumulator was hence sawed in half and the triggering piston was installed this time so that the seal pressed up against the inside of the end cap hole and the pressure in the accumulator helped to hold it there. The accumulator was then sealed again with a connecting sleeve and this time the system worked perfectly. The only problem that could occur was if the triggering piston broke. The piston's seal was inside the accumulator and as a result was inaccessible without cutting open the accumulator. And unfortunately, after the 7^{th} trial, the triggering piston broke. Consequently, the trigger had to be fixed by cutting the accumulator open and using a stronger glue. Certainly, although the glue is stronger, the possibility of the trigger breaking again under repeated stress still exists.

The Computer's Role

The computer, detecting changes in properties such as weight, temperature, and light through relays, can act as a regulator to initiate and terminate processes. Indeed, functioning a checkpoint for a multitude of the components in a process, the computer plays an important role in process control.

There are many different computer languages that can be used for programming. In our project, a version of BASIC known as High-Tech BASIC (HTBASIC) is used (Appendix A). The program is designed to control the relays but as it could not access the relays directly, an intermediate device called Data Acquisition Unit (DAQ) is used to connect the computer to the relays (Appendix B). The DAQ contains two multiplexers, or devices that organize multiple input/output signals, which consist of ten relays each. The computer sends commands to DAQ in order to access the relays, such as measuring the resistance or providing voltage. In the past years, the DAQ only contained one multiplexer, which limited the number of computer control that could be done. However, one advantage in this year's project is the presence of two multiplexers; it not only provided more ports for computer input/output, but it also allowed for parallel processing where multiple commands could be executed simultaneously. This new feature enabled us to further add on to the complexity of the process.

CONCLUSION

Although the purpose of the project was to teach us and the audience about the role of a computer in regulating multiple processes, the most tangible aspect was of course the aesthetic or "coolness" of the device to the audience. Consequently, our project was unique in that it necessitated not only a degree of erudition and understanding of concepts but also a great deal of creativity and showmanship.

By physically constructing the modules and realizing plans that we had theorized on paper, the team learned the importance of planning and the process by which one accomplishes a planned task. On numerous occasions we found ourselves coming up with new ideas or methods to complete different tasks and ultimately we found that our project, though exhibiting aspects of the original plan, was different from what we had originally designed, and accordingly learned to keep an open mind free to accept novel ideas whilst keeping a deadline. Furthermore, while constructing the modules, we tried to keep in mind the impression that an audience member might perceive and thus most of the modules were set up in such a way as to be discernable and entertaining.

However, the most important parts of this project were probably those that the audience would never really be able to see such as teamwork, project coordination, and patience. Over an innumerable number of trials, we discovered that because of the magnitude of the project, there existed a multitude of malfunctions, errors, and other unexpected mishaps that we had to overcome. Many of the ideas that worked perfectly on paper failed when it came to real world experimentation and thus we all assumed the role of educated guessers, applying concepts that we had learned in class but unsure of how they would result in the real world. Thus, we came to realize the amount of precision and constant testing required in the real world when running process control mechanisms especially in dangerous situations such as in nuclear power plants, space shuttle launch sequences, and in subway systems. Through repeated mistakes we began to appreciate especially the breadth of the computer's role in regulating the systems that preserve our safety and to appreciate the people who designed the systems. Inspired by this, with unfaltering determination and with several adjustments and alternations, we were able to see even the most outlandish of our designs vitalized and were able to breathe life into our own manifestation of process control.

REFERENCES

[1] "Rube Goldberg Biography." http://www.rube-goldberg.com/bio.html.

[2] "How Electric Motors Work." http://electronics.howstuffworks.com/motor.htm

APPENDIX A – COMPUTER COMMANDS

- REM *text*
  statement !*text*
  The “Rem” and “!” command allow for the use of comments throughout the program. The *text* contains information that is not read by the computer during execution; it is simply written as a reminder/remark for the programmer. Although not part of the executable code, this is still an essential part in computer programming.
- ASSIGN @*io-path* TO *resource*
  This statement assigns the computer to a specified port; it provides for the connection between the io-path name and the DAQ. With this, the computer is able to access the different relays in the DAQ through the io-path name.
- TIMEDATE
  The “Timedate” command returns the internal time and date of the computer. This, combined with the “Wait” command, could be used as a timer in the program.
- WAIT *numeric expression*
  This tells the computer to wait for some time (in seconds) before executing the next command.
- REPEAT
  program statements
  UNTIL *condition*
  This command tells the computer to repeat a section of the code until a certain condition is satisfied.
- OUTPUT @*io-path*; “*command*”
  This sends a command to the io-path; it receives the desired information and stores it inside the path location. The following are some commands used in this program:

cls<x>	closes relay x and opens all other relays
opn<x>	opens relay x
two<x>	measures the resistance across channel x; measured in ohms

- ENTER @*io-path; variable*
  This command retrieves the information stored in the io-path and saves it in a variable for further usage.
- DISP *variable*
  DISP “*text*”
  This displays the information stored in the variable or the text in the quotes onto the computer screen.
- GOSUB *line number*
  Go to the subroutine whose start is given by the line number.
- STOP
  Indicates the end of the main code so the computer does not go on to execute the subroutines.
- RETURN
  Indicates the end of a subroutine.
- END
  Indicates the end of the program.

APPENDIX B – PROGRAM CODE

```
10 REM NJ GOVERNOR'S SCHOOL IN THE SCIENCES
20 REM Drew University - 7/20/03 - 8/16/03
30 REM TEAM Project 8 - Computers in Process Control
40 REM Instructor: Mr. Manny Bhuta
50 REM Assistant: Justin Hotchkiss
60 REM TEAM members: Lee-Shing Chang, Michael Costa, Eashwaran Cumarasamy,
70 REM                    Pat Ho, Paul Kolb, Andrew Lee, Rajani Sharma,
80 REM                    David Templeton, Tina Wong
90 REM Purpose: Build a Rube Goldberg Machine - shoot a ping pong ball at a target
100 ASSIGN @Hpib;"cls11" !turn left
130 OUTOPUT @Hpib;"cls10"      !go
140 REM wait for circuit break in jack-in-the-box -> start water pump
150 T=TIMEDATE
160 REPEAT
170    OUTPUT @Hpib;"two29"
180    ENTER @Hpib;Jb
190    DISP "Jb=";Jb
200    WAIT 1
210 UNTIL Jb >1000 OR TIMEDATE>T+10
220 OUTPUT @Hpib;"cls26"       !water pump
230 WAIT 7
240 REM photo gate -> start chemical reation (activate motor)
250 T=TIMEDATE
260 REPEAT
270    OUTPUT @Hpib;"two22"
280    ENTER @Hpib;Pg
290    DISP "Pg=";Pg
300    WAIT 1
310    UNTIL Pg<12500 OR TIMEDATE>T+30
320    OUTPUT @Hpib;"cls18"    !motor (baking soda)
330 WAIT 3
340 REM measure change in resistance -> tilt marble box (turn on motor)
350 T=TIMEDATE
360 REPEAT
370    OUTPUT@Hpib;"two23"
380    ENTER @Hpib;Rs
390    DISP "Rs=";Rs
400    WAIT 1
410 UNTIL Rs<200 OR TIMEDATE>T+10
420 OUTPUT @Hpib;"cls16"       !motor (tilt box)
430 WAIT 3
440 REM************************
450 REM wait for two signals -> send timed current to blow-up car (5 secs)
460 T=TIMEDATE
```

```
470 REPEAT
480     GOSUB 870
490     GOSUB 930
500     UNTIL (Ccl<100000 AND Cc2<100000) OR TIMEDATE>T+5
510     OUTPUT @Hpib;"cls17"       !send current
520 WAIT 5
530 OUTPUT @Hpib;"opn17"
540 REM send voltage through to burn wire -> light alcohol chamber
550 OUTPUT @Hpib;"c ls19"          !burn wire
560 WAIT 5
570 REM check temperature -> starts towing car and opens marble gate
580 T=TIMEDATE
590 REPEAT
600     OUTPUT @Hpib;"two27"
610     ENTER @Hpib;Tmp
620     DISP "Tmp="Tmp
630     WAIT 1
640 UNTIL Tmp<5000 OR TIMEDATE>T+5
650 OUTPUT@Hpib;"opn19"
660 T=TIMEDATE
670 OUTPUT @Hpib;"cls20"           !marble gate
680 OUTPUT @Hpib;"cls21"           !towing car
690 WAIT 3
700 OUTPUT @Hpib;"opn20"
710 WAIT 20
720 OUTPUT @Hpib;"opn21"
730 REM check resistance on weight sensor (see-saw) ->air pump (12 secs)
740 REPEAT
750     OUTPUT @Hpib;"two24"
760     ENTER @Hpib;Wt2
770     DISP "Wt2=";Wt2
780     WAIT 1
790 UNTIL Wt2<1000 OR TIMEDATE>T+30
800 OUTPUT @Hpib;"cls15"           !air pump
810 WAIT 12
820 OUTPUT @Hpib;"opn15"
830 REM mini cooper goes straight -> falls -> stops
840 OUTPUT @Hpib;"opn11"           !go straight
850 OUTPUT @Hpib;"opn10"           !stop
860 STOP
870 REM ****************************
880 REM check for completion of circuit (pan to floor)
890 OUTPUT @Hpib;"two25"
900 ENTER @Hpib;Cc1
910 DISP "Cc1=";Cc1
920 RETURN
```

```
930 REM *****************************
940 REM check for completion of circuit (salt water)
950 OUTPUT @Hpib;"two28"
960 ENTER @Hpib;Cc2
970      DISP "Cc2=";Cc2
908 RETURN
990 REM *****************************
1000 END
```