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2. Abstract

This design project involved undertaking the construction of a machine to accomplish certain tasks. On a black and white grid half the size of a tennis court were located a maximum of seven randomly placed 6-inch square metal plates. The objective of the machine was to follow an inputted path of nodes, while detecting the plates situated on the lines and depositing a pop can vertically onto the plate. Moreover, the machine was not allowed to come into contact with any plates, and had to have the capability of being loaded easily with a maximum of seven cans for dispensing purposes. In essence, the machine was to act as a waiter.

To accomplish these tasks the machine had the following characteristics. The machine was built on a square plastic platform and used DC-motors to propel itself along the grid. It was loaded with seven metal pop cans onto an aluminum slide terminating in a turnstile mechanism. The path was input into a keypad, which was then displayed on a small LCD screen. The machine used line sensors to follow the grid and metal detectors to find the plates. The turnstile then dispensed a can vertically onto the plate, before driving off and completing its run at the end line.

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4. Notations and Abbreviations

Symbols/Abbreviations	Designation/Meaning
KISS	Keep it super simple
MISS	Make it super simple
AAAI	American Association for Artificial Intelligence
DC	Direct Current
LCD	Liquid Crystal Display
PIC	Peripheral interface controller
Rpm	Rotations per minute
DPDT	Double pull, double throw
Op Amp	Operational amplifier
LED	Light emitting diode
PC	Personal computer

5. Introduction

Soft drink companies sell billions of dollars worth of pop every year, and these companies have invested billions in delivering their products to customers. Pop companies sell their products in grocery and convenience stores and for decades have sold their beverages in stationary vending machines. Conceptually, the waiter machine is a mobile vending machine.

The waiter machine, to be henceforth referred to simply as the machine, followed a grid that was half the size of a tennis court and dispensed pop cans onto a maximum of seven metal plates, but without touching any of the plates. After receiving the input path at the beginning of a run, the machine ran entirely autonomously until stopping on the end line where it displayed the number of cans dispensed.

6. Project Concept and Design Parameters

The design project consisted of a square shaped Lexan base with an aluminum slide structure affixed to the center of the machine to hold pop cans. At the back terminus of the slide, a hole had been cut in the base to allow pop cans to drop to the ground during dispense. Differential drive was used to move the machine, which means that two drive wheels were located along the center horizontal axis of the machine. The machine went straight, turned, or spun on a point, depending on which direction each wheel was spinning.

To traverse the grid of black hockey tape on a white background, five photo sensors were placed on the machine. Two were located near the wheels along the axis and were used in turning, while the other three were located in a row close to the center of the machine, and would send signals to the microchip to determine whether the machine was straying from the lines, causing the microchip to alter the speed or direction of the motors.

At the very front of the machine centered along the front and just hanging over the edge was the metal detector. The metal detector would detect when the machine passed over a metal plate and would then send a signal to the microchip notifying it that a plate had been detected. The machine then traversed over the plate and aligned the pop can exit hole over the center of the plate. A turnstile then deposited a single can onto the plate before pulling away.

The path along the grid was input into a keypad interfaced with the microchip and was displayed on a small LCD screen. After a completed run, the LCD screen displayed the total number of cans dispensed.

7. Perspective: Theory, History, Survey, and Applications

7.1. Theory

The overall design philosophies used in this project were KISS and MISS. These were chosen to keep the project as simple as possible, but still have all the necessary functionality and reliability. Often as the complexity increases, so does the cost, as well as risk of system failure.

In the design of circuitry and choice of components for the circuits, Kirchoff's voltage law was often used. Kirchoff's voltage law is shown in equation 1 below:

$$V = I * R \quad \dots\dots\dots\text{Equation 1}$$

where V is the voltage across the device, I is the current through the device and R is the resistance of the device.

To determine which motors to use in the device it was necessary to determine the weight that would need to be propelled by the motors and thus the torque that the motors would be required to provide. To determine the weight of the device, Newton's second law was used, given below in equation 2, and the torque was determined as in Equation 3:

$$W = m * g \quad \dots\dots\dots\text{Equation 2}$$

$$\tau = r * F * \sin \theta \quad \dots\dots\dots\text{Equation 3}$$

where W is the weight in Newtons, m is the mass in kilograms, g is the acceleration due to gravity in m/s^2 , τ is the torque in Newton-metres, F is the force acting and θ is the angle between the normal and the force. The weight was also needed to determine the required strength of the base and slide materials. Lastly, in choosing motors, a motor with sufficient speed and torque was needed. In conjunction with the estimate for the total

weight applied on the motor shaft, the required torque was calculated using the formula for torque in equation 3

7.2. History

Until 1939, vending machines functioned with a column-and-drawer system. The goods would be stacked in a column. When money was inserted, the lock on the drawer released and a package could be removed from it. When the drawer was closed, the column would be pulled down into the drawer by gravity, readying the next one for vend. Moreover, vending machines have the drawback of immobility. Customers must seek out a machine to buy a drink. At restaurants, waiters deliver drinks directly to customers. However, over longer periods of time hiring a waiter can be costly and inefficient when compared to the one-time cost of a machine.

7.3. Survey

After intensive research, no existing commercial product was found that acted as a mobile drink dispenser. However, the AAAI holds an annual robot competition called Robot Host/Hors D'oeuvres. The objective is to create robots that can offer hors d'oeuvres to people at a reception. These machines have artificial intelligence making them extremely expensive, and are not currently available for widespread distribution. A few small communities have created their own systems to order drinks remotely. A person could order a drink from a vending machine connected to a local area network. The inconvenience of this system is the requirement of a credit system, computer network and terminal, as well as the fact that vending machine and thus the drink, remained stationary.

7.4. Potential Applications

This machine has the potential to be modified only slightly for a variety of different purposes. A particular area of great practicality would be to modify the machine to enable it to travel on sand, thus allowing the machine to traverse a sandy beach delivering cold pop cans to holiday makers on a hot sunny day, while allowing them to quench their thirst without leaving the comfort of the sand. Moreover, after more substantial modifications this type of machine could be used to traverse the floors of buildings and with certain attachments, could be used to clean floors, or dispense mousetraps instead of pop cans as the need arises. These applications would very useful in large warehouses and schools, cutting down on janitorial expenses. Lastly, this machine has the military application of setting mines, saving human soldiers the task of setting explosives in potentially hostile territory.

8. Division of Problem

The objective of the machine was to follow lines, detect plates while following a preprogrammed path, and dispense cans onto the detected plates. This problem was divided into three subsections, each including a vital portion of the machine. The three subsystems were: Microcontroller, Sensors and Interfacing, and Electromechanical.

The microcontroller subsystem involved software and hardware aspects relating to the microchip that controlled the machine. The software aspect was programming in assembly language the processing of signals received from sensors and translating those signals into actions to be taken by the actuators. The hardware aspect involved the construction of the computer board to power the microchip and interface it with the circuits. For the purpose of interfacing, a hub was constructed on one circuit that had all inputs and outputs passing through one circuit board, as well as including buffers to protect the microchip from voltage fluctuations. The microchip used was a PIC16F877.

The sensors and interfacing aspect involved the construction and design of the circuitry that connected the actuators to the microchip (PIC). The major components of this subsystem were the fabrication of the driver circuits controlling the drive motors and turnstile motors as well as the construction of the metal detector and of all the photo sensors.

The electromechanical subsystem involved the construction of the physical frame of the machine and the selection and implementation of the actuators. The two main tasks involved in the electromechanical subsystem were the driving mechanism and the dispense mechanism. The drive system consisted of two drive motors. Each motor was

firmly attached to the base of the machine and was attached to a wheel using aluminum shaft couplers. The dispense mechanism consisted of a long aluminum slide which allowed the pop cans to stay upright, and to dispense the pop cans a turnstile with a breaker switch was used.

9. Subsystems

9.1. Microcontroller Subsystem

9.1.1. Assessment of Problem

The microcontroller subsystem's task was divided into three broad categories. First, it received and processed a variety of inputs from line sensors, metal detectors and the keypad interface. Second, the microcontroller computed the direction of travel, allowing the machine to navigate the court specified by the user. Finally, it provided control to all electromechanical actuators on the machine, more specifically, the drive wheels and the dispense mechanism. These three categories – inputs, calculations and control – were interrelated problems. For example, in order for the machine to activate the dispense mechanism, it must receive the proper signal from the metal detector. Refer to Appendix (?) for a graphical representation of the problem.

9.1.2. Solution to Problem

The software was written in the assembly program language due to its simplicity and superior control. The complete, documented program code can be found in Appendix (?) while the program heirarchy can be found in Appendix (?).

9.1.2.1. LCD / Keypad Interface

The LCD / Keypad Interface was a critical component of the machine because it was used to designate the desired path of travel, and to display the number of plates served at the end of the run.

A Hitachi HD44780 driver IC controlled the dot matrix LCD module. To print characters to the screen, the program first placed the correct ASCII code onto the data lines, set the RS pin

high and set the R/W line low. Then, the Enable bit was briefly set high to send the data. To execute a LCD instruction, the program used the same procedure as above, except it set the RS line low to specify an instruction rather than a character.

A Jameco keypad (Part # 196171) was used to enter the nodes. The pull down resistors on the keypad circuit prevented a floating signal when there was no output from the PIC. Referring to the schematic in Appendix [\(?\)](#), the NodePoll subroutine would repeatedly set pins B4 to B7 high. For each column set high, the Find routines checked the four corresponding keys for a high input signal, which indicated that a key had been pressed. For example, if column B5 was set high, and the input from B2 was also high, the program would recognize that the “8” key had been pressed on the keypad. A simple delay in the program debounced the signal from the keypad. After recognizing the keypad input, the program printed the character onto the LCD and stored it in a temporary stack. Finally, the NodesLeft counter was incremented to record the number of nodes entered. Each time the machine detected a node, this counter was decremented. When the count reached zero, the machine would stop and display the number of plates served.

9.1.2.2. Navigation and Node Detection

For convenience, the inputted nodes were converted into a new set of nodes based on the Cartesian system ([Appendix ?](#)). The user inputted the original nodes, and by pressing the “Enter” key, the program popped the top two numbers from the stack, and converted them into the new nodes. These converted nodes were pushed onto a permanent stack in memory.

The “Help” key was pressed to end the node input and to start the run. The CheckNode routine periodically checks the outer two line sensors for a high signal. If either line sensor was

triggered, the program would call the Nav Subroutine to calculate the turn needed to reach the next node. For a sample calculation of the navigation algorithm, refer to Appendix (?). Note that both sensors do not have to be activated in order for the machine to recognize a node, because at the edge or the corner of the court, there would only be one sensor activated at a node.

9.1.2.3. Line Following

The three inner line sensors were used for line following. If the machine was off-centre, the program would stop one wheel for a short delay and let the opposite wheel drive the machine back towards the line (Appendix ?). Then, before polling the line sensors again, both wheels were activated again for a short time to allow the machine to straighten out and to minimize jerkiness. The program would frequently check for metal plates and nodes during these adjustments. Only certain signal combinations from the three line sensors were recognized. For example, if all three line sensors were triggered, the machine would ignore the input and continue to drive to forwards. This becomes important when the line sensors are directly over the metal plate because all three sensors would trigger.

9.1.2.4. Metal Detection and Dispense

The Metal routine was called periodically to poll for metal plates. If a metal plate was found, the Dispense routine was called. The machine would travel forward a certain timed distance, using the Follow2 routine to line follow as much as possible. After the delay, the machine would stop and activate the turnstile motor. The program would poll until the turnstile switch goes high again, indicating that exactly one pop can was dispensed, and that the turnstile motor

should be deactivated. After dispensing the can, the number of plates served counter was incremented, and the machine would continue travelling forwards.

9.1.2.5. Driving and Turning

Movement routines were called throughout the program to drive the machine properly. The microcontroller sent a two bit signal to each driver circuit. One bit was an enable bit; if high, the motors were enabled, otherwise, the motors were disabled. The second bit controlled the direction – high for reverse and low for forward. Hence, stopping, driving forwards, driving backwards, and pausing a wheel during line following were controlled simply by changing the signal sent to the drive circuit.

Turning at a node was more complicated (Appendix [2](#)). To perform a 90 degree turn, one wheel rotated forward while the other rotated backward. There was a short delay to allow the outer line sensors to clear the court line. Immediately after the delay, the program would begin polling the outer line sensors, until either became high again, indicating that the machine had successfully completed the turn. However, due to the sensitivity of the line sensors, the machine would stop turning too early, leaving the machine misaligned at the node. Therefore, a small delay was added to allow the machine to fully complete the turn, even after the outer line sensor had triggered. Finally, the machine would drive forward for a short distance before it began checking for nodes again, because if the program returned to its normal routine, it would think that it was at a new node before it even left the node.

9.1.3. Suggestions for Improvement

The designed solution satisfied the requirements of this project. However, there were two main areas for improvement. First, there were many repetitions in the program code, making it

less elegant and more difficult to read. These repetitions were necessary to perform tasks which were only slightly different. For example, there were two line following routines, Follow and Follow2. The main Follow routine was used throughout the run, except after the detection of a metal plate, where Follow2 was used. The only difference between the two subroutines was that Follow2 did not check for metal plates during the adjustments, while Follow did. This was crucial because as the machine moved forward after originally detecting the plate, the Follow routine would mistakenly detect a “new” plate every 0.5 seconds. As a result, Follow2 must be used. The point is, the code could be improved by making it more flexible to allow for special cases. This would reduce the length of the code and make it easier to read and debug.

Second, the program was dependent upon the machine staying on the line. If all three line following sensors loses the court line, the machine would be completely lost. An improved algorithm could attempt to relocate the line after the machine lost it. This would greatly increase the reliability of each run, and reduce the possibility of getting lost.

9.2. Electromechanical Subsystem

9.2.1. Assessment of Problem

The electromechanical (mechanisms and actuators) subsystem included the fabrication of all mechanisms and procurement and installation of all actuators. The two main problems faced in the electromechanical subsystem were the construction of a durable driving system capable of propelling the machine and its load, as well as the construction of a pop can dispense system to safely guide cans onto the metal plates.

The main problem in constructing the drive system was encountered in attaching the wheels and shaft coupler to the motor. Moreover, it was important that a motor shaft of sufficient strength and torque were used to handle the rigors of testing and operation.

For the dispense system, there were a variety of issues that needed to be considered. Firstly, after a can dispensed onto a plate, the mechanism had be ready to dispense another can immediately afterwards. So this part of the problem was twofold, how to dispense a can, and how to load another can into the dispense mechanism.

Moreover, there were certain restrictions on the size and weight of the machine. The machine could have a length and width no larger then 0.914m and a height of no more then 0.609m. The unloaded weight of the machine was restricted to 11.36kg. During operation, the machine was not allowed to come into contact with any plates along the lines.

9.2.2. Solution to Problem

9.2.2.1. Frame and Structure

The frame provided support for the weight of the load and machine components and served as a base for mounting and connecting the components. The base consisted of a 22-inch by 20-inch piece of Lexan of a thickness of 3/8 of an inch. Rectangular holes were cut in the sides of the machine for the drive wheels and a semi-circular hole was cut in the back of the machine to allow the cans to drop out. (See Appendix C.5) The Lexan base was chosen for two reasons. Firstly, since the base was plastic, it would not interfere with the metal detectors, and secondly due to the nature of Lexan, the base is in fact bulletproof and does not shatter except under exceptional forces.

The pop can dispensing system was situated along the horizontal x-axis of the machine. The dispense system consisted of a long aluminum slide at a slight angle terminating at the back of the machine, where the dispense mechanism controlled the output of cans. An aluminum slide was chosen for the low coefficient of static and kinetic friction with the aluminum cans. (See Appendix C.4) The slide was designed so that the cans were able to sit vertically in the slide and readily slid down the slide when a can at the bottom was removed. The advantage of this system was the use of gravity in moving the cans into position, and this eliminated the need for another actuator.

The circuits and PIC components were located at the front of the machine on either side of the slide, and were a safe distance from the can dispense mechanism in the event that a can were to explode. The circuits were attached to the machine using Velcro. The attachment of the circuits using Velcro allowed them to be easily removed for repairs or calibration if necessary. The hub

hung off of the top part of the slide, while the PIC was situated horizontally just below the hub. A vertical circuit stand was constructed, see appendix C.6., and a circuit was attached using Velcro to either side of the stand. On the other side of the slide, the circuits were attached using Velcro horizontally onto the base. However, the power board was attached to the slide using Velcro in the same manner as the hub. The metal detector circuit was screwed onto the base at the front of the machine along the horizontal x-axis. The batteries were positioned at the back of the machine with two on either side of the dispense mechanism and one immediately underneath the slide. (See Appendix C.1.)

The metal detector was affixed to the base using duct tape, which allowed for easy adjustability. Two photo sensors were located immediately to the inside of the drive motors and small holes were drilled through the base to allow these two sensors to be able to get readings off the ground. A long rectangular hole was cut to allow the adjustable positioning of the three line sensors, which were located in close proximity of each other. (See Appendix C.5.)

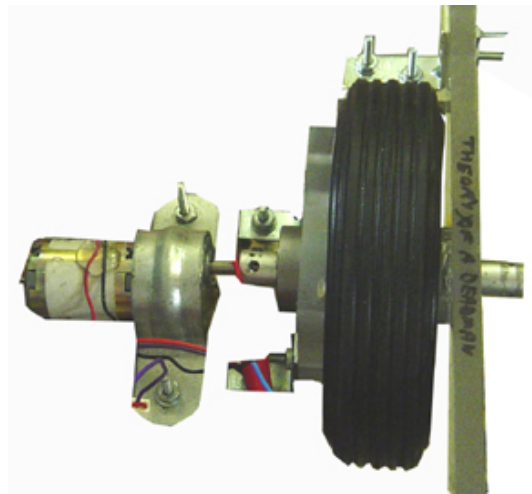
The geometrical configuration of the device was such that the majority of the weight was located very close to the ground and the symmetrical weight distribution made the machine extremely stable. The weight of the machine with no load was measured to be 23 pounds, and the weight with load was 28 pounds. These weights were used to determine the forces acting upon the drive actuators. (See Appendix C.8.1. and Appendix C.8.2)

9.2.2.2. Drive System

The drive motors used were 23.5V DC geared motors made by Buehler Motors. (See appendix C.9) These motors ran at a speed of 18 rpm, which was determined in testing to be a

reasonable rate to run the machine. Moreover, the drive motors had very high torque, which ensured that there were no problems moving the machine. The necessary torque required by the motors was calculated to be $30\text{N}\cdot\text{m}$, see Appendix C.8.3., and it was determined that the drive motors fulfilled this criterion. The advantages of these particular motors were their durability and that the motor shaft was of a large size and had a flattened portion for attaching setscrews.

Figure 9.2-1: Drive System



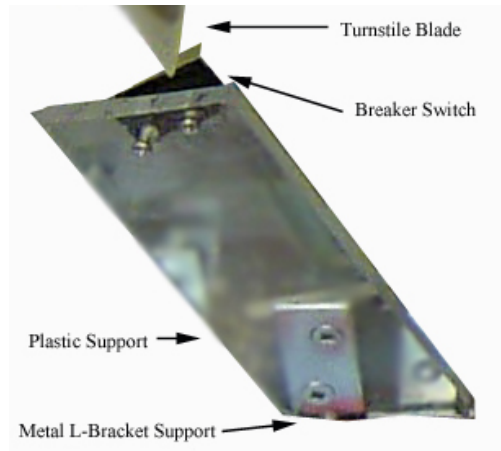
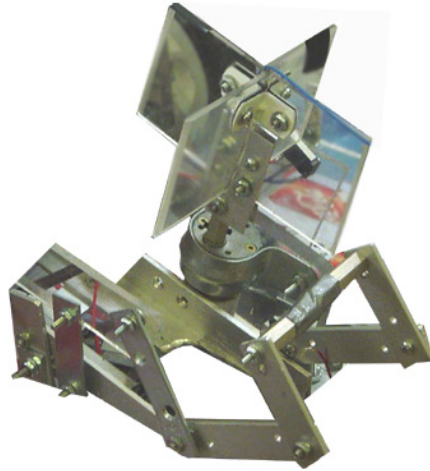
The drive motors were affixed to the base close to edge of the rectangular holes along the horizontal y-axis of the machine, used for direct drive. An aluminum shaft coupler fit snugly onto the motor shaft and was held in place with setscrews. The aluminum shaft coupler was set in two bearings and mounted on Lexan mounting pieces on the inside and outside of the wheel. (See Appendix C.3) To attach the shaft to the wheel, a hole was drilled through the wheel and shaft and it was held in place with a screw. The reason for this configuration was because the motors cannot take large amounts of axial load, so the mounting pieces with the ball bearings were used to bear the load of the machine. The ball bearings were attached to the mounting pieces by wedging them in place, and friction was used to keep them in position. The motors were held down with metal brackets and support from beneath with small plastic pieces to

ensure that the motor was perfectly horizontal. (See Appendix C.3.2) Lastly, at the four corners of the machine were located small ball casters. The ball casters were attached such that they barely touched the ground, ensuring that the load was distributed mainly to the drive wheels to ensure maximum traction.

9.2.2.3. Dispense System

To dispense the cans, a turnstile was used. As the cans slid down the slide, they would slide into place and were held by a high torque DC motor, the 23.5V DC geared motor from Buehler Motors. (See Appendix C.9) The motor supported the weight of the cans. When the PIC determined that a can needed to be dropped, the motor was activated and it would turn one-quarter revolution until the next turnstile blade came into contact with a small switch mounted on the outer side of the motor and aligned with the bottom of the turnstile blades. Once the switch was triggered, the turnstile would stop. In initial testing, it was found that if the can fell improperly that there was a risk that the strength of the motor could puncture the can and the resulting fluid flow could damage the circuitry of the machine. To correct this problem, the exit hole was made larger to ensure that cans did not catch on anything. Moreover, a guiding rail was attached immediately opposite to the turnstile. (See Appendix C.2.4) This served to ensure that the cans stayed upright during the dispensing process. To prevent the cans from falling over after dispense, an aluminum blocking mechanism was constructed overhanging from the back of the machine. (See Appendix C.2.1) The can fell into the exit hole at an angle, and the top part of the can hit the bar, which blocked its fall. The can then bounced back into an upright position into the exit hole. The bar was at such a height that the machine pulled away without knocking over the can.

Figures 9.2-2: Dispense System and Switch



The guide rail was made from a piece of plexiglass and was affixed to the base using a metal L-bracket. To attach the turnstile onto the, an aluminum shaft coupler was used to attach to the motor shaft and was held in place with a setscrew. Flat aluminum couplers were used to attach the turnstile blades to the hexagonal shaft coupler. (See Appendix C.6) The tops of the turnstile blades were braced with small L-brackets. The motor was attached to a Lexan mounting piece using the same semicircular metal mounting bracket used to attach the drive motors. This mounting piece was affixed in position to the base using small metal L-brackets. The switch was mounted on top of a piece of plexiglass and was set in position so that the bottom edge of the turnstile blade would push the switch as it passed by. (See Appendix C.2.2 and Appendix C.2.3)

9.2.3. Suggestions for Improvements

In the drive system, there were a few minor improvements that could have increased the efficiency and reliability of the machine. Instead of using setscrews to attach the motor shafts to the shaft couplers, a small hole could have been drilled straight through the shaft and coupler and then put in place using a pin or small screw. This would have ensured that the motors did not slip if a setscrew came loose. However, this method was not chosen due to the difficulty in drilling through the steel motor shaft. Moreover, the use of faster motors would have had a twofold

benefit, firstly it would have completed its tasks faster, and secondly, in completing a run faster it would save the batteries from being used for long periods of time and thus allowing more runs based on the same power. Faster motors with sufficient torque were not used since none were found to be available.

An improvement could have been made in the placement of the photo sensors. The photo sensors, currently located in the center of the machine close to the axis of the drive wheels, should have been located closer to the front of the machine, allowing the machine to correct faster and thus stay straighter than a sensor placement near the wheel axis.

9.3. Sensors, Circuits and Power

9.3.1. Assessment of Problem

For the robot to function properly, the brain of the machine (PIC) must be connected in a feedback loop with its mechanical limbs. This was done by the sensory and circulatory systems of the machine, adequately dubbed sensors and circuits. Some circuits were required to send the PIC's commands to mechanical components. These included the generation of movement forwards or backwards through drive motors and rotation of the turnstile to dispense cans. Other circuits were required to send information to the PIC regarding the surrounding environment through the use of sensors. Such information provided whether the robot was aligned with a black grid line, whether there was a metal plate ahead and whether a can had be dispensed. Finally, there was the requirement of energy to keep the system functional. The machine required sustenance in the form of batteries. Hence one of the major problems was to determine the right amount of power required to keep systems functioning optimally.

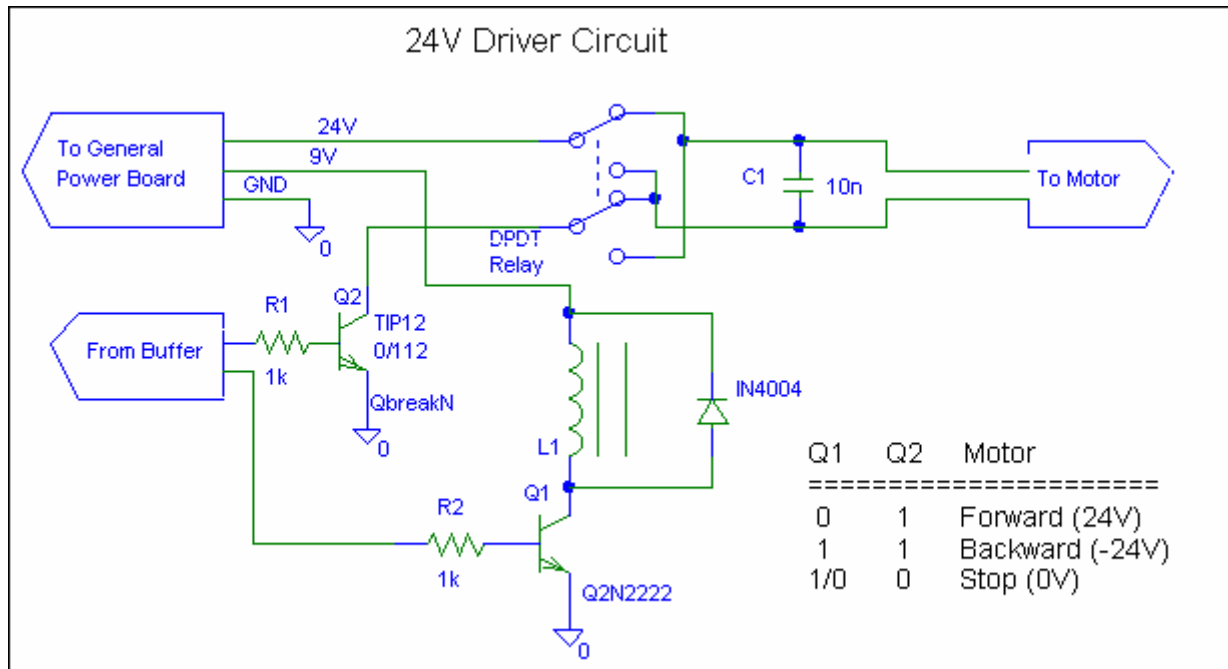
9.3.2. Solution to Problem

9.3.2.1. Drive

The final drive system for the Kart consisted of two 23.5 V motors mounted along the center axis across the horizontal, supported with 4 caster wheels at the 4 corners (Appendix A?). Since the speed of motor rotation was only 18 rpm, there was no need for a fast and slow speed setting. The drive system's tasks included driving forward, stopping and turning. Hence the circuits had to control each motor such that they would turn forward, backward and stop individually. Hence a double pull, double throw relay circuit was chosen (Appendix B3). The each driver circuit was controlled by two inputs from the PIC. One input was the enable/disable, which determined whether the motors were stopped or turning. The NPN

transistor controlling the enable/disable was Q2 (see Figure 9.3-1), which allowed current to flow through the motor when PIC sent a high and stopped the current when PIC sent a low. The second input controlled the direction the wheels were to turn via another NPN transistor which flipped the DPDT Relay.

Figure 9.3-1: 24V Driver Circuit Schematic

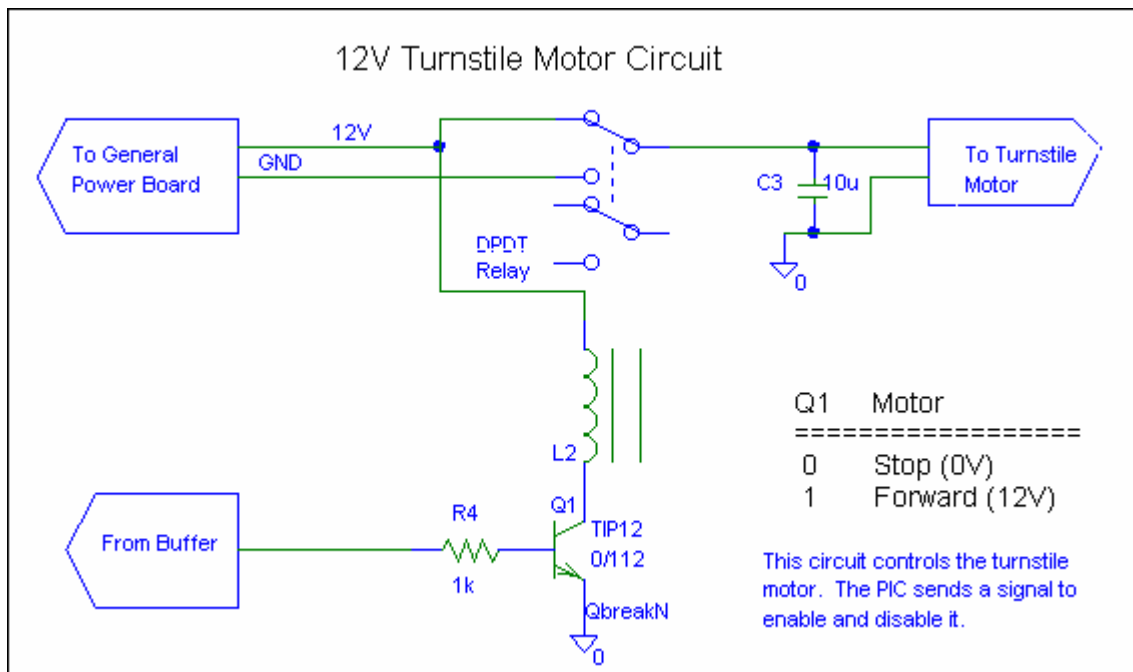


Initially, the Kart ran using fast 12V motors with less torque. An op amp driver circuit was designed and a separate circuit for speed control was also required (Appendix B6). However due to unforeseen circumstances, the motors were switched to a set of slower 23.5V motors, hence the driver circuit changed to the relay one described above. A benefit of the relay circuit was that relays could handle quite a bit of current (>5A), which was more than sufficient to run the motors with its load. The new motors also drew less current than the old ones. The old motors and op amp driver circuit caused a 2V drop across the 12V power supply, which affected the metal detector's 9V regulator that required a minimum input of 11V to regulate properly. Hence the new motors and circuit was better suited for the system.

9.3.2.2. Turnstile

For the problem of dispensing the pop can onto the plate, a motor was fitted with a custom made turnstile of lexan plates (Appendix A?) that sectioned off one can at a time for dropping. The motor used for the turnstile was the same 23.5V motor used for drive. Hence the circuit also resembled each other. The difference was that this motor only needed to either turn slowly in one direction or stop altogether. This circuit only required one signal from the PIC, telling the motor to go or stop, hence a combination of transistor and relay was used as seen in Figure 9.3-2.

Figure 9.3-2: 12V Turnstile Motor Circuit Schematic

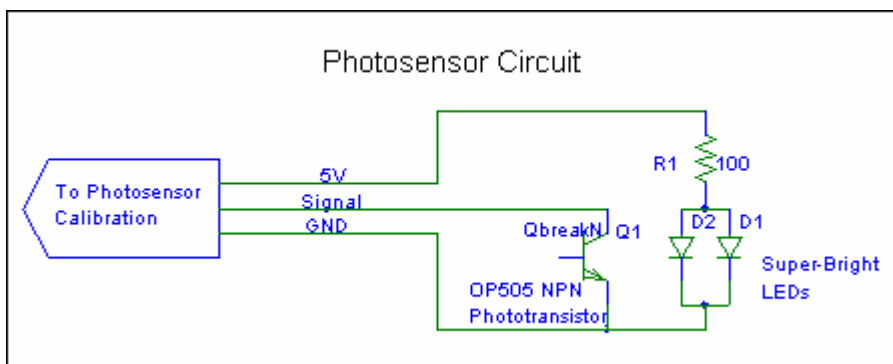


When the lexan turnstile rotated 90°, one can was dispensed. A switch was depressed at that point by the turnstile, which was filtered through a debouncer circuit and sent to the PIC. The PIC at that time stopped the motor's turning, thereby readying it for the next dispense. The debouncer circuit (Appendix B3) was a simple latch that prevented false triggering due to the spring-like bouncing of the metal switch.

9.3.2.3. Line Sensors

For the Kart to orient itself in the right direction, it had to keep track of where it was at all times. This was accomplished by a coordinate system within the PIC that counted the nodes traveled by Kart. To detect nodes, sensors were required that distinguished black grid lines from the white floor. Similar line-detecting sensors were also required to straighten the Kart's trajectory since the two motors were not rotating at exactly the same speed. A simple circuit of composed of an OP505 phototransistor and two super-bright LEDs provided this sensory information for the PIC (Figure 9.3-3). 5 of these photosensor circuits were required, 3 placed close to the center for line following and 2 placed on the outer edges for node detecting. The photosensor changed its resistance depending on how much light is detected. The level of light detection was calibrated via a potentiometer (Appendix B7) and the signal was passed through a 7414 Inverter with Schmitt Trigger (Appendix B8), which has a small ambiguity range (where it will not definitively output a high or low), to filter the signal before sending it to the buffer. A 4049 Inverting Buffer (Appendix B9) was used instead of the 4050 Non-Inverting Buffer (Appendix B10) used for everything else. The signal was reverted back to the original signal before the Schmitt Inverter so that it matched with the PIC code as well as intuition of black sending a high and white sending a low.

Figure 9.3-3: Photosensor Circuit Schematic



Two super-bright LEDs were placed beside the OP505 to light up the spot directly beneath the phototransistor. With this constant source of light, the ambient conditions surrounding the robot were insignificant. Through testing, it was found that difference in signal between a fully lit room compared to a dark room was less than 0.02V, which was insignificant. The only drawback to the use of super-bright LEDs was that it drew more current than normal red LEDs, hence requiring a separate power source.

9.3.2.4. Metal Detector

One of the major objectives included finding metal plates to dispense the pop cans on. Hence a metal detector was required. The one used was a modified version of Velleman Metal Detector Kit (Appendix B11), which added a potentiometer to boost the signal before sending it to the buffer such that it was well above the high threshold range, leading to a clean signal of high or low to the PIC. The sensitivity of the detector was adjustable through potentiometers R7 and R8 in Figure 3.2.4, up to a maximum range of around 1 inch.

Figure 9.3-4: Metal Detector Schematic

To power the entire robot, two separate power boards were required; one for photosensors, and another for everything else. Through testing, it was found that the super-bright LEDs from the photosensor circuits drew a lot of current. The 5V regulator could not handle the large current draw from the photosensor circuits concurrently with all other subsystems, a majority of which required 5V as well. Hence a separate power source of three 9V batteries in parallel was fed through another 5V regulator to provide the photosensors with power (Appendix B4). The PIC board was also powered separately by its own 9V battery. All three power sources were connected with a common ground.

9.3.3. Suggestions for Improvement

Given more time, a possible improvement could be made to the power system such that only one power source would be used for all subsystems, including photosensors and PIC. This may have been accomplished if the current draw from the photosensors were reduced, possibly by pairing only one super-bright LED to each phototransistor instead of two. Another possible improvement was to bundle the wires together in a way such that less crossovers and less tangles appeared on the Kart.

10. Integration

10.1. Sensors onto Machine

The line following sensors were mounted on the topside of the base with the phototransistor and LEDS pointing towards the ground through a custom made hole in the base for each photosensor circuit. The two photosensors for detecting nodes were placed as close as possible to the edge of the machine without interfering with the drive motors. They had to be lined up along the horizontal axis between the wheels since the Kart turned on the spot using differential drive and the sensors must be able to tell 90° turn intervals. The three photosensors for line following were placed in the middle of the machine in a long rectangular hole along the same horizontal axis (Appendix C?). This allowed small adjustments between the spacing of photosensors, which is a benefit since the thickness of the grid lines were not known.

The metal detector was placed at the front center of the machine with the ferrite rod coil taped to the edge of the base with duct tape. The height of the base off the ground (1 inch) fit perfectly with the range of the metal detector (also 1 inch) such that the 0.5-inch thick metal plates were easily detectable. Initially, the rod was mounted on a movable piece of plastic, however it was found that adjusting the rod too much caused the copper wiring to break. Taping in one spot created a much sturdier mounting and required less calibration.

10.2. Circuits to Actuators

Long wires were soldered onto the motor leads so that they could easily reach and plug into the sockets of the driver circuits. The leads were tested for the correct driving direction of the motors before being plugged in. The speeds of the motors were tested with the circuit to determine whether the set speeds were reasonable. With the initial 12V motors, it was determined that different speed settings were required; with the final 23.5V motors, it was

decided that only directional control would be sufficient since the speed was slower. The turnstile motor speed was tested so that it did not throw the cans down the ramp too quickly. A mechanical touch switch was mounted horizontally on a piece of lexan such that the turnstile plate would depress it as it turned (Appendix C?). This switch informed the PIC of when to stop the turnstile motor.

10.3. Power to Actuators

Depending on the drive circuit and type of motors, a different power arrangement was used. Initially when the 12V motors and Op Amp driver circuit was used (Appendix B6), the batteries were arranged in such a way that +12V and -12V were supplied to the circuit – two 12V batteries in series with the connection between them taken as the common ground for the whole machine. However, when the motors changed to the present 23.5V motors, the power source arrangement was changed such that two 12V batteries were placed in series, with the common ground taken from the low end of one battery (the one that was not connected to the high end of the other battery). The 24V power supply for the new motors and drive system turned out better than the old one since there used to be a 2V drop across the op amp drive circuit that lowered the power supply down to about 10V from its original 12V. This caused current fluctuation problems through the 9V regulator for the metal detector, which required a minimum input of 11V to regulate properly. After switching to the 24V power supply arrangement, the metal detector required a lot less calibration and performed optimally.

10.4. Circuits to PIC

All inputs and outputs between the PIC and mechanical systems or sensors were buffered. The buffer circuit had plugs for every circuit's input/output including systems that were not buffered, such as the keypad and LCD. Every plug on that board was labeled with the

appropriate PIC port and pin number to which the input/output signals were transferred. The physical connection between the buffer circuit and PIC board was through a neat 40-pin ribbon cable. This allowed easy connection and disconnection of the PIC board from the rest of the system for testing and repairs.

11. System Operating Procedure

11.1. Preparing the Grid

- 1) Black hockey or electrical tape, 1"-2" in width was placed on a lightly coloured ground surface in the shape of a grid with 4 columns and 4 rows.
- 2) 6"x 6"x 0.5" Metal plates were placed at arbitrary locations on the inner grid lines. Plates were not permitted to be placed on top of a node, or within 24" of each other.

11.2. Preparing the Kart

- 1) Made sure the power supplies were fully charged.
- 2) Hooked up all wires into its appropriate plugs on every circuit.
- 3) The power switch for the General and Photosensor Power Boards were switched on.
- 4) The metal detector was calibrated such that it could detect metal plates lying on the ground from its 1" perch on the base of the Kart.
- 5) The line sensors were calibrated for sensitivity through the use of the Photosensor Test Circuit and by adjusting each potentiometer. These sensors were adjusted such that the corresponding LEDs, as well as the signal to PIC, were high when the phototransistor was directly over the black tape. When they were over the white ground surface, the sensors would send a low to the PIC.
- 6) The machine was positioned such that its center and outer line sensors were directly over the black line of a node.
- 7) The power for the PIC was turned on.
- 8) Nodal coordinates for the Kart to travel were entered via the keypad by keying in the node number and hitting 'Enter' to store it in memory.
- 9) To start the machine, the 'Help' button was keyed in.

12. System Improvement Suggestions

The Kwik-E-Kart provided the basic functionalities for the robot waiter to navigate the grid and dispense pop cans on plates. However, it only had the bare essentials and could not handle some special cases, hence it had little advantage over the other robot waiters. There was possible areas of improvement that would have gave Kart an edge over its competitors.

One of the extreme cases that the Kart could not handle was that if it over shot the line while turning, the line sensors located at the center of the machine may completely lose contact with the black grid lines, which would confused the Kart. A possible solution to this was to space out the line sensors such that there would be a larger width for correction (i.e. larger width under which the black line would be detectable.) Another viable solution was to mount the line sensors closer to the front of the machine. Doing this would reduce the PICs need for a time correction factor to attempt to straighten the Kart since the turning radius would be larger for the sensors.

Other special cases that the Kart could not handle included several possible plate arrangements along the grid that would prevent the dropping of cans without running over a plate (for example, if a plate was placed within the wheel radius of the Kart on all 4 sides of a node.) Impossible situations like that would be minimized for the Kart if it had other functions such backing up towards a plate rather than running over it going forwards, or by travelling off the grid lines completely. However, to compensate for such cases a lot more complication would have been added to the system, hence violating the KISS (keep it super simple) philosophy.

Another plausible area for improvement would have been the implementation of a shortest algorithm either by the PIC or through another PC program. With such a program, the shortest distance to travel would have been found for the Kart, minimizing the time to travel the course.

13. Conclusions

- summarize work and concentrate on results
- how may project be improved
- in what areas would the study best be extended
- limitations/restrictions imposed by using presented methods
- what specifications are most limiting or where could they be modified to
simplify/improve the design

14. References

Borenstein, J. “Where am I?” Sensor Technology for Mobile Robot Positioning.
<http://aerospace.utoronto.ca:8900/aer201y/support/Robot_Navigation.pdf>

Buehler Motor GmbH. Buehler Motor Group. Last Update: October 8, 2002.
<<http://www.buehlermotor.com>>

Cook, David. Robot Room: Light Detection Using A Phototransistor and Voltage Comparator. Last Update: 2002. <<http://www.robotroom.com/Comparator.html>>

Emami, Reza. Engineering Design: Course Manual Third Ed. UTIAS, September 2002.

McComb, Gordon. Robot Builders Bonanza. McGraw Hill, Toronto, 2000.

University of Western Australia Computer Club. The UCC Drink Machine. Last Update: 2002. <<http://www.ucc.gu.uwa.edu.au/services/drink.ucc>>

Yanco, Holly. AAAI-2002 Mobile Robot Competition and Exhibition. Last Update: 24 April 2002. <<http://www.cs.uml.edu/aaairobot/>>

15. Budget

23.5VDC motors	\$60
Plexiglass	\$3
Lexan	\$24
Aluminum bar	\$5
Aluminum corner pieces	\$9
Wheels	\$5
Large L-Brackets (corner braces)	\$5
Small L-brackets (corner braces)	\$3
Lock Washers	\$2
Washers	\$2
Screws	\$5
Nuts	\$5
Photosensor Circuits	\$15
Photosensor Test Circuit	\$1
Buffer Circuit	\$6
24V Driver Circuit	\$9
Metal Detector Circuit	\$6
Turnstile Motor and Latch Circuits	\$7
PIC Circuit	\$28
LCD	\$6
Keypad	\$2
Power Board Circuits	\$8
Three 12V Batteries	\$21
Four 9V Batteries	\$3
Wires	\$5
Plugs	\$5
<hr/> <hr/> Total	<hr/> <hr/> \$250

16. Appendices

Tables

