DEVELOPING A LOW-COST BEER DISPENSING ROBOTIC SYSTEM FOR THE SERVICE INDUSTRY

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ABSTRACT

As the prices of commercially available electronic and mechanical components decrease, manufacturers such as Devantech and Revolution Education have made encoded motor controller systems, sensors and microcontrollers very accessible to engineers and designers. This has made it possible to design sophisticated robotic and mechatronic systems very rapidly and at relatively low cost. This paper will discuss the restrictions involved in building a Heineken DraughtKeg beer serving robot around 'off-the-shelf' components, and the issues arising from making the human-machine interaction intuitive, whilst only using low-cost sensors.

Keywords: Beer, Autonomous, PICAXE, Heineken DraughtKeg, Service Robot, Bartender.

1 INTRODUCTION

A recent project within the Autonomous Systems Lab at Middlesex University, UK was to design and build a small, autonomous, robotic bartender based around the 5 litre Heineken DraughtKeg© system, which is capable of patrolling a bar and dispensing beer when signalled to by a customer.

Because the system was designed as a commercial product, design constraints focused on keeping the build cost down, and so electronic components were sourced from outside companies and interfaced with a bespoke chassis and custom mechanical parts designed and manufactured on site at the University. All the programming was conducted using the proprietary PBasic language, which is available from the PICAXE© supplier at no cost.

This paper will discuss the restrictions involved in building a robot chassis around 'off-the-shelf' components, and the issues arising from making the human-machine interaction intuitive, whilst only using low-cost sensors. Programming issues will also be discussed, such as the control of accuracy when interfacing a PICAXE microcontroller with a Devantech MD25 Motor Controller board. Public live testing of the system was conducted at the Kinetica Art Fair 2010 [1] in London and has since been picked up by gadget websites such as Engadget, Trendhunter, Gizmowatch and many others. Feedback on the system will be described, as well as the refinements made as a result of these tests.

2 SERVING ROBOTS

Mankind has been relying on robotics to perform dull, dirty or dangerous tasks in industry for several decades. Robotic systems have therefore inevitably found their way into the consumer market. Robots in the home have been dreamt of for many years and have been projected in films and cartoons for tasks such as cooking and cleaning; however, this dream can often seem far away. This chapter will review some of the existing robots which are created with one mission: to serve us.

2.1 Cleaning Robots

In 2002 the iRobot® company which is responsible for delivering Unmanned Ground Vehicles (UGVs) to the military and civilian market for surveillance and bomb disposal, introduced the first mass produced consumer robot. The iRobot Roomba® is a small robot the size of a large pizza which drives around your house vacuuming any dirt in its path (see Figure 1). After just two years on the market, they sold over a million units which made it the biggest selling consumer robot of all time. Now with more than three million units sold, the Roomba® offers features such as dirt detection, self returning to base to charge and very low maintenance. iRobot has also introduced other home robots such as the iRobot Dirt Dog® in 2006, which is a larger industrial version of the Roomba®, along with Scooba® in 2005, which is the world's first floor washing robot. To tackle outside of the house iRobot have introduced Verro™ which is a Pool Cleaning Robot alongside Looj®, a gutter cleaning robot [2].

Figure 1: iRobot Roomba®.

2.2 Food Serving Robots

The food industry has also had assistance from robots to serve food. A chain of sushi bars called 'Yo Sushi' have been using a conveyor belt which is laid out around the seating area and the food preparation area since 1997. This method of impersonal fast food experience was developed by a Japanese restaurateur in the 1950s [3]. Once the food is prepared, it is placed in a bowl on the conveyer by the chef, which then travels around the seating area until it is picked up and consumed by a customer. This has introduced a very interesting interaction between the consumer and the product and has changed how people eat out. It has also sped up the waiting time for food.

Figure 2: Yo Sushi Conveyer Belt System.

2.3 Drinks Serving Robots

Various attempts have been made over the years to try to serve alcoholic drinks using robots. The most common method used is a robotic arm with a manipulator on the end which is already used widely in industry and can easily be reprogrammed to perform such tasks. Serving drinks is a relatively simple task which a robotic arm can perform at ease. The arm introduces a fun and exciting way of interacting with machines. A more personal approach would be a humanoid robot which looks like a human and also talks back to the user. A popular robot which serves beer called 'Mr. Asahi' which doesn't pour the beer into a glass but does pop the bottle lid open for you. It also pulls a half a pint of beer whilst holding a glass underneath the tap.

Figure 3: Mr Asahi Beer Serving Robot.

The Japanese robot was developed by AA Robotics Ltd for the beer company Asahi Beer for marketing purposes and was demonstrated to the public in 2008. The 670 kg robot sits on a computer which controls the pneumatic pumps and actuators to control the robotic arms. The robot consists of two Denso robot arms which can both simultaneously pull pints or work together to open a bottle of beer. This beer pouring robot is reported to save time standing at bars for a drink, but costs around £150k [4].

Another drinks delivery method is by flying vehicle. The idea was thought of by Applied Dynamic Machinery Inc in the US. This used an Unmanned Aerial Vehicle (UAV) to deliver the pressurised beer to the customer by flight. Unfortunately, the flying vehicle crashed as soon as the drinks mechanism was engaged. The project which was known as 'BeerEagle' would have been capable of serving over 150 twelve ounce cups of beer per hour from an altitude of 200 feet [5].

3 THE HEINEKEN DRAUGHTKEG©

The Heineken Draughtkeg© system was originally conceived of as a miniaturised product, which included a pressure-tap system for personal use, whilst providing a "throw away" solution. Development started in 1997 and went through numerous stages before it's first full commercial release in Europe during 2005.

3.1 How it works

The DraughtKeg system (see Figure 4) is a miniaturised keg containing 5 litres of beer and provides a small but effective tap system which easily breaks the seal and pours beers without the need of a standard pouring station. The keg relies on an internal $C0_2$ canister with a food-grade coating, which regulates the internal pressure. Therefore, once a beer is poured the canister releases CO_2 to keep the internal pressure constant at 2 bar [6].

Figure 4: Cutaway showing the Heineken DraughtKeg© system [6].

3.2 Temperature Control

As indicated on the packaging there is a requirement to cool the keg for 10 hours at a constant temperature of around 4°C. There are two main reasons for this, the initial one is to serve a cold beer for better enjoyment, whilst the more important is the issue of reducing the amount of foam produced by the keg. Maintaining the storage temperature provides the beer with no foam [7].

3.3 Shaking

Shaking during transportation can also be a major issue and can lead to excess foam production during the pouring of the beer. This is due to the CO_2 being released from the beer and providing too much pressure within the keg [7].

3.4 Pouring angle

Serving the perfect pint is often described as a very precise technique depending on the beer type the individual desires. In this instance, Heineken is considered a pale lager and therefore requires the correct amount of "head" to preserve the taste of the beer. Heineken states that to pour a correct beer the tap pipe has to be opened quickly and completely with the glass held at an angle of 45 degrees relative to the keg, guaranteeing a good beer ratio between beer and "head". The fact that the first beer poured is of pure foam is supposedly caused due to the air bubbles caught inside the piping system [6]. During tests at Middlesex University, it was found that the pouring speed is correct whilst the pouring angle depended on the overall shape of the glass used and we preferred reasonable angles above 45 degrees. The number of glasses poured before a good consistency could be achieved varied from keg to keg, with some kegs producing nothing but foam until empty.

3.5 Inaccuracies in the tap construction

The tests at Middlesex also showed that inaccuracies in the tap design affected the pouring of the beer. On the underside of the piping at the tap, a hole is located for the addition of foam. This affects the rate with which the additional foam is produced and provides the first leakage point. The construction of the tap provided a second leakage problem at the protrusion which resulted in flooding the head with beer. The head of the robot was designed with this in mind to provide a safe consumer electronic device. Whilst the downside of this is the cleaning the user will have to do once emptying the keg.

4 MIDDLESEX UNIVERSITY'S BEER SERVING ROBOT

4.1 Microcontrollers

There are two PICAXE microcontrollers in the robot. These microcontrollers, produced by Revolution Education, are inexpensive and easy to program using the PBasic programming language, which allowed for very fast integration into the system. They were programmed to carry out the following tasks:

PICAXE 28 pin project board with PICAXE 28X1 microcontroller in the base unit:

a. Communicates with the MD25 motor controller board using the I^2C bus.

b. Controls the drive pattern.

c. Receives pulsed communication signals from PICAXE 28X2 Module in the head of the robot.

d. Reads the infra-red sharp sensors.

PICAXE 28X2 module in the head of the robot:

a. Communicates with PICAXE 28X1 board by sending pulses.

b. Reads the ultrasonic (customer signal) sensor.

c. Operates the pouring servo and tilt servo.

4.2 Drive System

The drive system consists of two 102 mm diameter pneumatic wheels, independently driven by geared motors and two trolley-style casters. The two motors are controlled by a single Devantech MD25 Dual H-Bridge motor controller board, which reads the EMG30 360 Counts Per Revolution (CPR) Hall Effect encoders mounted on the motors. These encoders allow the board to measure the distance travelled and regulate the speed of the motors to keep the robot driving in a straight line. The I^2C bus allows the PICAXE microcontroller to adjust the speed and direction of the motors and to monitor the distance travelled, allowing a predetermined route to be programmed into the robot. The MD25 also provides a regulated 5V supply which is used to power the PICAXE microcontroller.

4.3 Sensors

The sensor system of the robot was the determinate for the multiple actuators within the beer serving process and subroutines within the PICAXE program. The core sensing systems used were for obstacle avoidance, customer interaction, beer actuation and for the alignment of the drive train.

For the obstacle avoidance and the customer interaction process the first prototype (previewed at the Kinetica Art Fair 4–7 February 2010) initially used three Devantech SRF10 ultrasonic sensors. The obstacle avoidance system used dual SRF10 sensors, mounted low down in front of the drive wheels, and the customer interaction system used a single sensor mounted in the top of the head, pointing upwards. These small and lightweight ultrasonic sensors are integrated with the system using the common I^2C bus and have an adjustable detection range of 6 cm to 6 m. They operate at 40 kHz with an active power requirement of 5 V at 15 mA (typical). This specification made these sensors a perfect fit for the robot’s first public presentation. When the system was developed into a more commercially viable product, cost implications were at the heart of the design and system changes were required. Since the SRF10 sensor costs £30 per unit, a more cost-effective component was needed for the obstacle avoidance system.

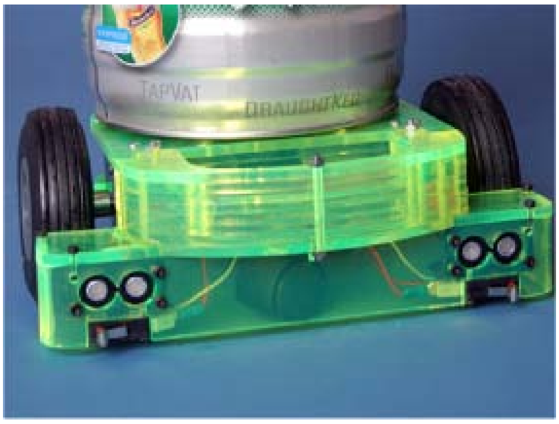

Figure 5: Old version using SRF10 sensors. Figure 6: New version using Sharp IR sensors.

The substitute component used was the Sharp infrared GP2D120 sensor. Although the ultrasonic ranging method of the SRF10 is the superior technology for the task of obstacle avoidance, the GP2D120 offered a competitive pricing of £12 per unit and fulfilled the necessary criteria.

Since the beer actuation process was the fundamental incentive of the robot’s design, the sensor used to detect the glass needed to be reliable and consistent. The SPST IP67 rated waterproof micro switch was used for this task. The components operating force required and the high Ingress Protection rating made this micro switch suitable for placement in the cup holder. The attributes of using this particular sensing method over infrared or ultrasonic comparative systems was primarily the durability of the mechanical switch system, pricing per unit at £1 and the simplicity of component replacement.

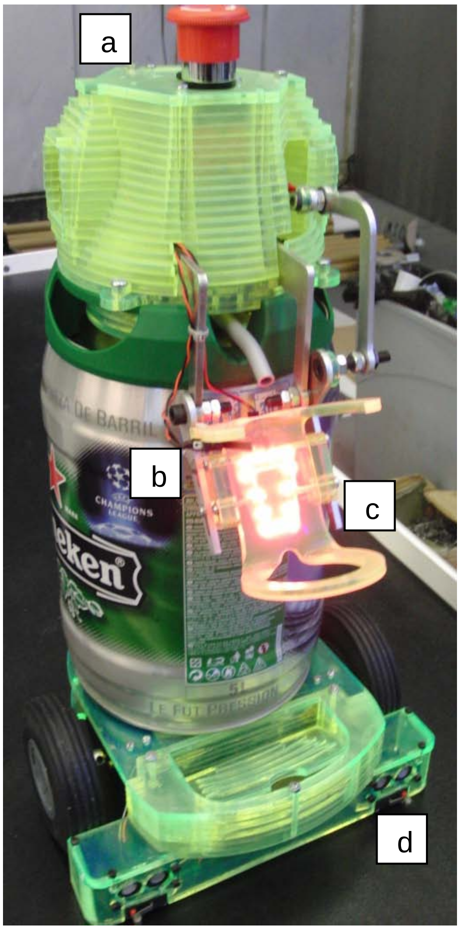

Figure 7: The first prototype beer serving robot.

Figure 7 shows the components involved in the user interaction process:

a. Ultrasonic Sensor; used as the first step when interacting with the robot. The user is simply required to hold their hand in front of the sensor in order to signal the robot to initiate the pouring procedure.

b. Micro Switch located at the base of the cup holder this is used as feedback to the microprocessor when the user places a glass in the cup holder.

c. Red LED's in the shape of a cup; these are located at the back of the cup holder and will flash when the robot is ready to receive a glass as feedback for the user.

d. Base Unit stops driving on the customer's signal.

One of the main issues with the drive system was deciphering the encoder values correctly (see Section 5). The robot demonstrated at the Kinetica Art Fair had two SPST roller micro switches that mounted just below the obstacle avoidance SRF10 sensors (see Figure 5). The system would periodically use these switches to connect with two perpendicular table edges for realignment. This meant that the first robot prototype relied upon having a table surface with a 50 mm border around its perimeter. Since the commercial robot would be placed onto unknown surfaces, the commercial system was developed to use two Sharp infrared GP2D120 sensors for robot realignment. The two GP2D120 sensors are placed at a 17 degree angle allowing the robot to realign itself with a straight table edge, and to detect the table edge whilst moving and also to prevent it from falling (see Figure 6).

4.4 Beer Actuation System

For the robot to be safe and self-contained, the servo motor for the beer actuation was placed within the head of the robot which contains the controlling microprocessor. The servo motor would only be triggered once a micro switch at the base of the glass holder was activated. This provided a failsafe in case an individual would remove the glass whilst pouring or for an incorrect placement of the glass. The mechanism works by pulling a lever which is connected to the arm of the glass holder which rotates around a joint which holds the glass holder in place.

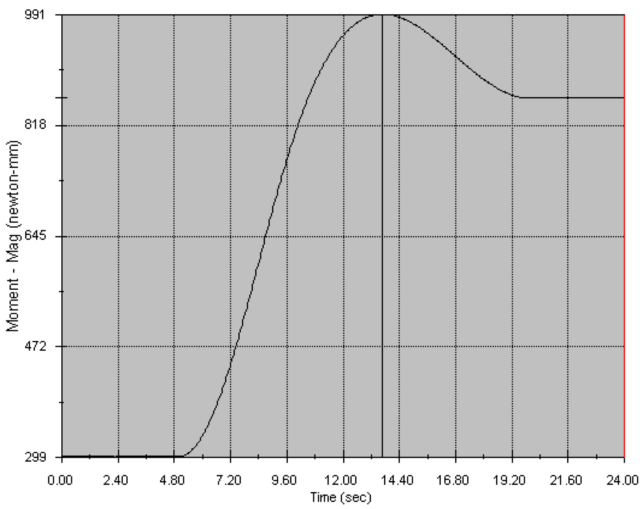

Figure 8: SolidWorks motion study results for the glass tilting servo.

The mechanism for the first prototype varies compared to the second version. For both systems a motion study in SolidWorks was conducted to analyse the magnitude of forces acting on the servo. This was crucial to determine the specifications for the servo that was required to be used in both versions. In the first version the plastic cup had a minimal weight and the addition of the 250 ml of beer presented no problem for the relatively cost effective hobby servo we used. But for the second system, where a glass with a weight of 300 grams and the addition of 330 ml of beer was used, presented a bigger problem. The solution to this was to shift the servo outside the head. Through shifting and testing a minimal value was achieved and a micro servo is used for the actuation resulting in a reduction of cost, space consumption and operating power.

The pouring procedure is divided into three different stages with varying pouring times. This is to guarantee optimal pouring and provide time for the natural reduction of foam build up within the glass.

5 COMPONENT INTEGRATION

5.1 Issues in Integration

The EMG30 encoders can read 360 CPR and with 102 mm diameter wheels this gives us potential accuracy of 1 count/0.89 mm. However, it is not possible for the robot's drive system to be this accurate in practice. The PICAXE 28X1 microprocessor operates at 4 MHz, however various factors slow it down and cause it to miss encoder counts such as; additional operations in the program, time taken for the MD25 board to translate encoder counts, time taken to send data through I^2C and the fact that the PICAXE microcontroller compiles the code during operation. Considering this it can be said that as the robot increases in speed it will become less accurate. Travelling at 0.5 m/s, the system will on average loose 19 counts.

The microprocessor in the head must communicate with the microprocessor in the base for the following reasons:

a. When a user is detected the base must be informed to face the user.

b. Just after a beer has been poured, the base must know when to turn back and continue driving.

c. If the head senses that the keg has nearly run out, the base must return to the home position for a keg changeover.

At some points in the drive program the head must ignore the user's interaction. These points are during measurement of the table, during turns and when the battery is too low. Originally the signal was sent using the command; [PULSOUT *pin, time*], where *pin* is the i/o pin used on the microcontroller, and *time* is the length of the pulse. However, this proved unreliable as it would produce only one high pulse and if the base was not searching for the pulse at the correct time it would not receive it. Therefore, we now use; [SERVO *pin* ,*time*]. This command gives out the same pulse, but it is constantly repeated.

6 LIVE TESTING

6.1 Kinetica Art Fair 2010

Kinetica Art Fair is a yearly event which combines contemporary art in motion and is held at the P3 gallery in Westminster, London. As the title suggests this event focuses on Art pieces which are combined with robotics, electronics or simple motion featuring over 150 artists from all over the world, which attracted over 10,000 people in 2010. This proved to be the ideal place for a proof of concept whilst exposing its possible problems for future development. The opportunity to present the Heineken Robot at the event resulted in large amounts of publicity, via numerous websites around the world.

6.2 User Intuition

Predicting how the general public would interact with the robot was a big challenge prior to the Kinetica exhibition, encompassing what components were selected for the first prototype and developing an ergonomically sound design. Initially we designed the system to be a simplistic and approachable robot, where the user was expected to wave in front of the head mounted SRF10, which was vertically placed, and wait until the robot turned to face them.

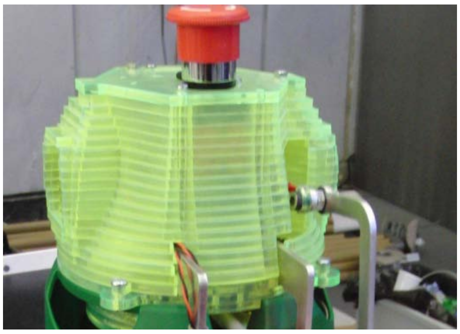

Figure 9: The original emergency stop button.

However, this process proved to be partially flawed in multiple areas. Firstly, when the customer signalled to the robot that there was a beer required, which involved the waving of a hand over the robots head in a specified area, the customer would tend to expect the system to react instantaneously to any hand movement. Unfortunately, placement of the ultrasonic sensor (which ended up being counterintuitive) frequently missed the hand signal and the robot continued with its predetermined route.

Coinciding with the signalling process problem was the placement of the emergency stop switch, which was placed next to the ultrasonic sensor (see Figure 9). Because the stop switch was one of the only objects that could be viewed as mechanically interactive on the robot's exterior, it was a common misconception that this was the beer actuation button. On numerous occasions the robot would be switched off by the user on route, due to this design flaw.

Another issue with the user interaction process was the robot's movement sequence once it had recognised there was a customer signalling it. Initially, when designing the robot's public interfacing procedure the Middlesex team decided it would be appropriate for the robot to continue facing the direction that it was going when stopped by a customer for a beer. In practice this, alongside the other design faults, accounted for misconceptions that the robot had recognised the customer but was waiting for further commands. The general feedback from the event concerning this matter was the robot failed to give sufficient notice that the customer was recognised, and the recommendation from this was that the sequence should include the robot facing the signalling customer.

The design of the cup holder for the robot was relatively successful during the Kinetica exhibition. The system poured over 900 drinks within the 4-day period and on the whole proved to be an intuitively designed function. The cup holder was one of the only components that used lighting and movement to engage the customer to complete the beer actuation process. Beckoning the consumer to place their cup into the cup holder with a flashing LED cup sign (integrated into the cup holder), that would then switch to a vertical waving motion to show the completed process. However, the design was specifically fabricated with one-cup size in mind, which for the Kinetica exhibition was suitable, but for the commercial robot had to be assessed to encompass multiple glass sizes.

Figure 10: The redesigned Heineken Robot.

Figure 10 shows the latest robot design, encompassing the changes made resulting from testing at the Kinetica Art Fair to aid user interaction and feedback:

a. Emergency stop switch was removed and replaced with two small on-off switches in the base and head units.

b. Major redesign to the head unit. It is now possible to quickly remove the shell of the head without affecting any of the components. A smaller PICAXE board is now being used and there is no battery in the head, allowing for a smaller and more aesthetically pleasing package.

c. The ultrasonic sensor in the head was moved to the front and angled forward as this will catch movement above and in front of the head unit and a green "searching” light" was installed next to the sensor to show when it is searching for an object.

d. The glass holder was redesigned to hold a wider range of glasses and to make it easier to place the cup in the correct position and slimmer, surface mount LED’s are used for illumination. The servo was upgraded to lift the weight of a real glass and half pint of beer, as opposed to a plastic cup.

e. Red warning lights were installed in the base to show when the battery or keg are running low.

f. The original two micro switches and ultrasonic sensors are replaced with three Sharp IR sensors. The benefit of this is that the robot can now run on a table without sides, as an added advantage cost is also reduced.

The drive program was changed for functionality on a standard table with no border. The robot now measures the table using the IR and motor encoder sensors, so can be used on any sized table. When a user is detected the robot now turns 90 degrees to give the user easier access to place their glass in position. Various LED's were also added to the base and head unit to help to draw attention to the robot during use.

7 CONCLUSION

Assembling a custom robot to carry out the task of serving real customers has proven to be challenging, but not impossible, when using off-the-shelf components. The flexibility of the communications protocols such as I^2C mean that components from different manufacturers can work together almost out of the box.

The overall reaction of the Heineken Robot has been extremely positive with a lot of requests for the robot to be available commercially. The main negative aspects towards the robot were user interaction (waving, red button and non-intuitive), sudden behaviour and the range of DraughtKeg beers. For the user interaction and sudden movements the robot has been updated to be more intuitive and to provide more acceleration and deceleration stages for each movement. Some users have expressed an opinion that Heineken is not the preferred beer brand, but with six other beers becoming available within the DraughtKeg system as of 2010, there is potential for the Heineken Robot to gather a wider market [8].

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