Improving Robotics Competition Autonomous Operation by Using Sensors

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Abstract — *The field of robotics has been growing rapidly in the last few years and is expected to continue rising. Therefore, we need to provide our middle and high school students with the tools and experiences to gain the necessary knowledge in order to take full advantage of their skills once they complete their post-secondary degrees and enter the workforce. The most challenging part in a robotics competition is to put together the hardware and software and create an artificial intelligence like behavior so that robots can help humans in tasks that range in complexity. Using sensors will provide a more accurate operation of robots when in autonomous operation that will provide information about its environment and will allow robot operation to adjust accordingly. The purpose of using sensors in the autonomous operation is to increase the score obtained when competing or provide better results when used in real life scenarios.*

Key Terms —*Autonomous operation, Robotics in education, Sensors, Vex Robotics Competition.*

INTRODUCTION

An area that is rapidly growing in today's technology driven world is robotics. The use of robots provides designers and researchers the ability to perform critical tasks in many areas that humans are yet unable to do themselves such as extra planetary exploration. Take for example the Curiosity rover sent by National Aeronautics and Space Administration to explore the Mars surface to obtain more data on the composition of the planet before sending humans on its planned trip of 2030 [1]. Another benefit to using robots is to maximize the use of resources such as materials, time and money, just like Amazon, Google and even UPS who are testing robots as part of their near future strategies [2] [3]. Many organizations are relying on robotics to help them on several aspects of their operations, therefore requiring personnel with the skills and knowledge in the area of robotics to design, build, program and test them.

Training and development of technical skills cannot be left alone to universities and colleges and must begin with elementary and secondary school students who are in the development stages capable of acquiring more rapidly new skills and knowledge. Many students also need the explore and be motivated in the areas of science, technology, engineering and mathematics (STEM) which have traditionally had less exposure than sports and performing arts.

Just as the design, structural components, mechanical and electrical parts programming is critical to a robot's operation. Without a proper set of instructions a robot is useless to the user by either not working properly or not functioning at all. This brings the operation of a robot which can be performed in one of several ways, operated directly by the user via hardware or software controls, autonomously performing predefined tasks or a combination of both operator controlled and autonomous operation.

For the past seven years the Robotics Education and Competition Foundation (REC Foundation) have provided middle and high school students the opportunity to compete on the VEX Robotics Competition. Here students are able to learn about robotics and develop technical skills through a series of challenges that provide them the opportunity to learn about programming among other areas. Therefore students learn critical thinking, logical reasoning, team work and interpersonal relations in a fun and exciting way.

BACKGROUND

The reason to pick this research topic as a design project is a personal one. For the past five years I have been involved in teaching several aspects of robotics at the middle and high school level as part of the VEX Robotics Competition. Students are provided with tools to develop technical skills related to robotics in which programming plays a very important role.

Being a teacher at a magnet school for science, mathematics and technology has given me the opportunity to introduce students to many computer science related topics. Among these topics we find programming, in which students use programming structures to make the robot perform several tasks during the competition. Many of the aspects learned at the Artificial Intelligence course have been very helpful to provide the students guidance when programming their robot.

This year marks our fifth season at the VEX Robotics Competition and third time that we will be participating at the World Championship. Throughout the years we have been improving the way students are selected to be part of the robotics club and participate in the competition. The five roles that were identified as a way to improve students' selection and development are: driver, mechanic, programmer, designer and coach.

For many students this opportunity is their first experience that involves any programming at all. To give an equal opportunity regardless of previous experience in computer programming we identified a set of skills that are directly related to programming and given all interested students a try out in activities that involve critical thinking and logical reasoning, mainly through puzzles and games. Also taken into consideration for students' selection are the following traits: behavior, teamwork, responsibility and academic performance.

Overall our teams have performed in an outstanding way during the robotics competition and have been tournament finalist on four different events and tournament champions on two other

occasions. Also the judges have recognized all our efforts by selecting our students as recipients of the Judge's Award at the national level. We have been presented the Design Award on eight different events and the Excellence Award, highest honor on the competition, on a total of four events including one at the national level this year.

PROBLEM

As mentioned before, programming is a very important part and plays a critical role in the robotics competition. Providing students the necessary tools to create an autonomous period where the robot performs several tasks is probably the most challenging task of all the ones related to the robot construction, design and operation. Students need to learn not only about mechanical and electrical aspects of the robot but they also need to learn how to program it to perform its intended tasks. In the following sections I present what tools related to the programming part of the process we have used in order to give the students all they need to successfully perform this task.

Following the description of the hardware and software used in programming the autonomous period operation of the robot I present how the use of the sensors available have greatly improved the autonomous period operation and overall performance of the robot in the competition. The following analogy, which I often tell my students might describe in simple words the importance of using sensors in the autonomous operation of the robot: performing a task in the autonomous period without the use of sensors is like a human performing a task without being able to see, smell, listen or touch its environment. Hence the great importance of teaching students how they can program the sensors and use them when operating in the autonomous period.

The level of complexity is higher when sensors take part in robot autonomous operation. This provides the students enough difficulty to develop critical thinking and logical reasoning that are key to computer science majors.

EQUIPMENT AND MATERIALS

Hardware Components

The materials described in this design project are created by VEX Robotics which makes all mechanical and electrical parts that are used in the construction of the competition robots. Other mechanical and structural components are available and essential for a robot operation but only those that have a programming involved are discussed here due to the relevance to the project scope. A comprehensive list of parts and materials available for robot construction can be found at http://www.vexrobotics.com/vex/products/accessories [4]. Let me begin by describing the "*brain*" responsible for the operation of the robot to be design and built. As taken from VEX Robotics website the microprocessor is described as follows:

- **ARM Cortex™-M3 processor:** The processor is the industry-leading 32-bit processor for highly deterministic real-time applications, specifically developed to enable partners to develop high-performance low-cost platforms for a broad range of devices including microcontrollers, automotive body systems, industrial control systems and wireless networking and sensors. The processor delivers outstanding computational performance and exceptional system response to events while meeting the challenges of low dynamic and static power constraints. The processor is highly configurable enabling a wide range of implementations from those requiring memory protection and powerful trace technology to cost sensitive devices requiring minimal area.

- **2 Wire Motor 393:** Is the primary actuator used in the VEX Robotics Design System. Build rotational mechanisms using this motor. Drive bases, rotational joints, conveyor belts, anything that spins can be built using the 2-wire Motor 393. The 2-Wire Motor 393 does not have an internal motor controller. The motor connects directly to 2-Wire Motor Ports (Ports 1 & 10 on the Cortex Microcontroller). For 3-Wire Motor Ports (Ports 2-9 on the Cortex), a Motor Controller must be used in between the Microcontroller and the motor.

- **Line tracker:** A line tracker mostly consists of an infrared light sensor and an infrared LED. It functions by illuminating a surface with infrared light; the sensor then picks up the reflected infrared radiation and, based on its intensity, determines the reflectivity of the surface in question. Lightly colored surfaces will reflect more light than dark surfaces; therefore, lightly colored surfaces will appear brighter to the sensor. This allows the sensor to detect a dark line on a pale surface, or a pale line on a dark surface. The line tracker enables a robot to autonomously navigate a line-marked path. By drawing a line in front of a robot outfitted with a line tracker, one can dictate the robot's path by showing it where to go without using a remote controller. A typical application uses three line trackers, with the middle sensor aligned directly above the intended line.

- **Ultrasonic range finder:** An ultrasonic range finder sensor enables a robot to detect obstacles in its path by utilizing the propagation of high-frequency sound waves. The sensor emits a 40 KHz sound wave, which bounces off a reflective surface and returns to the sensor. Then, using the amount of time it takes for the wave to return to the sensor, the distance to the object can be computed. The sensor can be used to determine distances to objects. It can be used as a tool to determine if any objects are in the robot's path at all. To increase the sensing range, the sensor can be mounted to a servo to allow it to rotate.

- **Optical Shaft Encoder:** The optical shaft encoder is used to measure both relative position of and rotational distance traveled by a shaft. It works by shining light onto the edge of a disk outfitted with evenly spaced slits around the circumference. As the disk spins, light passes through the slits and is blocked by the opaque spaces between the slits. The encoder then detects how many slits have had light

shine through, and in which direction the disk is spinning. The optical shaft encoder can be used to track distance traveled, direction of motion, or position of any rotary component, such as a gripper arm.

- **Bumper Switch:** The bumper sensor is a physical switch. It tells the robot whether the bumper on the front of the sensor is being pushed in or not. SPST switch ("Single Pole, Single Throw") configured for Normally Open behavior. When the switch is not being pushed in, the sensor maintains a digital HIGH signal on its sensor port. This High signal is coming from the Microcontroller. When an external force (like a collision or being pressed up against a wall) pushes the switch in, it changes its signal to a digital LOW until the switch is released. An unpressed switch is indistinguishable from an open port.

- **Limit Switch:** The limit switch sensor is a physical switch. It can tell the robot whether the sensor's metal arm is being pushed down or not. SPDT microswitch, configured for SPST Normally Open behavior. Behavior: When the limit switch is not being pushed in, the sensor maintains a digital HIGH signal on its sensor port. This High signal is coming from the Microcontroller. When an external force (like a collision or being pressed up against a wall) pushes the switch in, it changes its signal to a digital LOW until the limit switch is released. An unpressed switch is indistinguishable from an open port.

- **Potentiometer:** Incorporating the VEX potentiometer kit into your project can make it easier for your robot to perform autonomous behaviors. A robot equipped with a potentiometer becomes aware of the position angles and motion of different components, thus making it more aware of its actions. A potentiometer is an electrical device used to measure angular position. The user can therefore adjust the degree to which the potentiometer opposes electric current through it, simply by turning a shaft that is attached to

the center of the potentiometer. As the resistance of the potentiometer changes, so does the voltage, which thus causes the potentiometer to act as a variable voltage divider. This varying voltage can be measured by the VEX Controller and is directly proportional to the angular position of the shaft connected to the center of the potentiometer. This allows you to obtain an analog measurement of an angular position.

- **Accelerometer:** The sensor will measure acceleration in both directions along each of the 3 axis. Acceleration along the X or Y axis in the direction of the silkscreened arrows will produce a larger reading, while acceleration in the opposite direction will produce a smaller reading. For the Z axis, upward acceleration (in the direction of the board's face) produces larger values, and downward acceleration (toward the board's back) produces lower values. Gravity is indistinguishable from upward acceleration, so the sensor will detect a constant 1.0G while at rest. If the board is mounted horizontally, gravity will affect only the Z axis. If the sensor is tilted away from the horizontal, the gravity reading on the Z axis will diminish, and the readings on the other axis will change depending on which way you are tilting it.

Software Components

The robot and sensor programming is performed by one of two software options: RobotC and EasyC. The one we have been using with our students is EasyC V4 for Cortex by Intellitek which I will discuss into further details as we explore the programming aspect.

EasyC V4 is a graphical user interface version of C language used to create programs to control robot operation under operator control or autonomous mode. The programmer have access to building blocks that provide control over motors, servos, sensors and programming structures to perform endless possible movements of the robot mechanical components. The building blocks are

shown on Figure 1 where we can find the programming structures and sensor available to aid the robot in performing tasks when operating under the autonomous period.
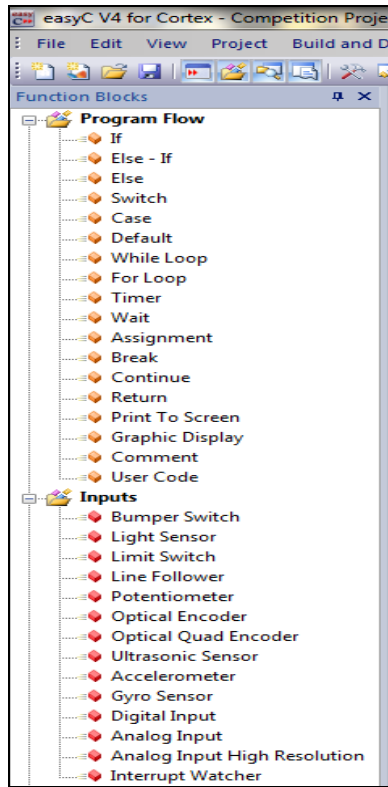
Figure 1
EasyC V4 Showing Control Structures and Sensor Input

Programmers have a flowchart diagram as seen on Figure 2 where they put their instructions to direct the robot's movement on the field. Some of the structures available are: else if, while, for, brake, continue, return, among other. The microprocessor collects input from the environment through sensors that range from light sensors, bumper switches, potentiometer, accelerometer and ultrasonic which were described on the hardware components section.

The information about the surrounding environment helps the program decides which functions to perform and when to start or stop doing so. More advanced structures are also available to provide a wide range of functions to the programmer to take advantage of all the robot's microprocessor capabilities.
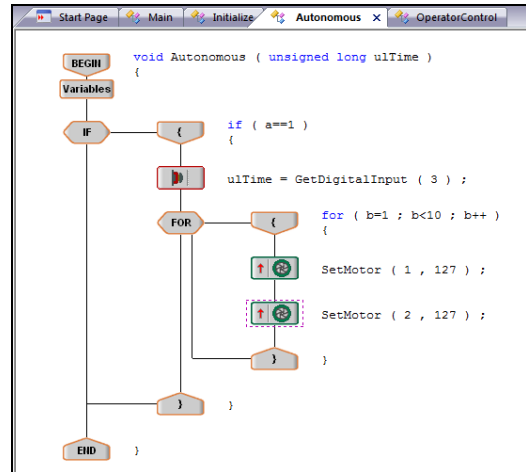
Figure 2
**EasyC V4 for Cortex Flowchart**

METHODOLOGY

The approach used on the robotics club and course is the topic to the research presented in this paper. Students learn which functions are available to control the robot operation by using different software structures such as while, for, if then else among others that are presented on Figure 1. Students use those structures to create an autonomous period program on which the robot operates without user intervention in real-time to perform the game's objective. Students have to be aware that when competing in the tournament their robot might not be the only robot on the field, depending on the competition event they are participating at the moment. Whether they are competing with an alliance or at the programming skill challenge the field configuration and purpose of the game stays practically the same.

This approach, along with the techniques and activities that were developed and implemented to teach students about robot autonomous programming are appropriate for their academic level. Students are capable of using the software tools that are available including sensors to improve the autonomous operation of their robots.

Every year students face a new robotics challenge or game. New field objects are introduced along with different ways to score objects or obtain bonus points so students have to design a

completely new robot every year. This year's game is called Toss Up which is shown on Figure 3 [5]. The purpose of the game is to score buckyballs that are five inches in diameter and large inflated balls that average a diameter of sixteen inches. Robots must manipulate those objects and put them into a scoring position that range from one point to ten points for each individual ball.
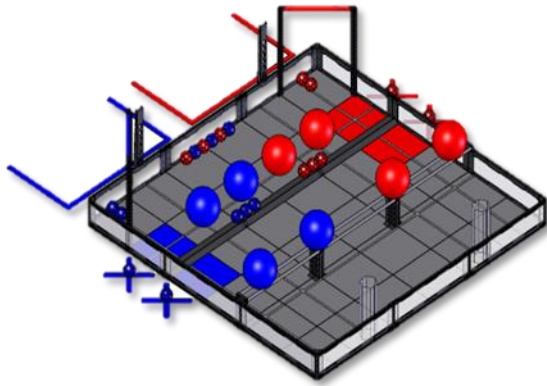
Figure 3
**Field View with 2013-2014 Season Game Toss Up**

Let's go deeper into the robot's operation under autonomous programming. The robot's autonomous period code can be performed when activated by one of the following events. If the robot is connected to the field controller it will start performing the actions once the enable switch is activated and autonomous period is selected either by software or hardware activation. The autonomous actions will start and continue until manually disabled via the switch or software controlled, a predetermined time counter following competition rules is used, or if all program code is executed. The microprocessor starts reading the code and performing the actions following the control flow determined on EasyC V4. When the flow demands to read an input (one of the many sensors available) it will determine the signal/state of the sensor and use it to determine the action to follow, which can be exiting/entering a subroutine or continue/stop the flow structure of the program.

Among the various sensors available to provide the microprocessor's program information about the robot's environment are the line tracker, ultrasonic range finder, optical shaft encoder, bumper switch, limit switch, potentiometer and accelerometer. These sensors allow the program code to produce behavior (action) based on the information gathered in real time about the environment, allowing the robot to perform tasks more precisely and efficiently.

Students usually develop a systematic programming of their robot's functions. The desired operation of the robot is first presented as a flowchart. Then the program is created on a step by step basis. They start by adding a little step of their routine and test it on the robot, preferably on the field, to determine if the function is working properly. If the test does not perform as expected a recoding/debugging is necessary and then tested again until the desired operation is achieved. Students keep adding more actions as long as the time allowed for the autonomous period is exhausted, which is 15 seconds for the tournament part and 60 seconds for the programming skill challenge. Afterwards, the code is verified to determine if a more efficient use of time is possible and to improve the program accordingly.

Let us start with a sample task where the robot begins to move until it reaches the end of the field. The corresponding code would look something like that presented on Figure 4.
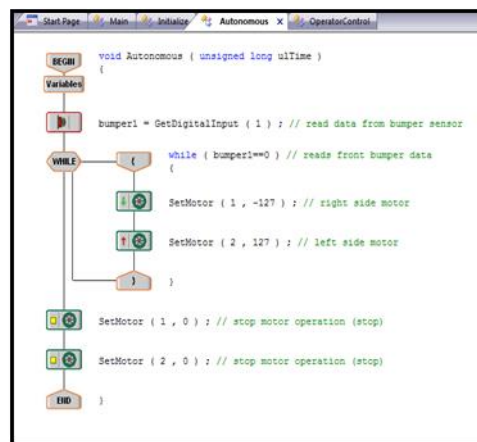
Figure 4
Flowchart and Code Corresponding to Robot Moving Forward until Bumper is Pressed

This behavior is similar to the robot learning about its environment, such as that described in artificial intelligence [6]. This line of thinking provides enough challenge to the tasks performed and add enough complexity to the students' academic level. The robot can use either a bumper switch or ultrasonic sensor to determine if it has reached a wall on the field. The code will activate the sensor and keeps reading its input value. Using a control structure (while), the program will send power to the corresponding wheels to move the robot forward. This motion will continue until the bumper switch is pressed or the distance from the ultrasonic sensor reading nears zero. Once the condition to exit the while structure is met the microprocessor will stop sending power to the robot's wheels and will stop at that time. The use of a bumper switch is recommended only when the robot's speed is low because a sudden stop/crash might damage the mechanical components.

RESULTS AND DISCUSSION

The results obtained have changed during the five years we have been working with the programming of the robots, especially the autonomous operation and sensor use. Results have been more consistent during the past two years when we have put more effort into the programming aspect with emphasis on the autonomous operation of the robot. Upon including sensors in the autonomous operation, we have increased the robot performance and scoring in the competition has been higher.

When sensors are not included on the robot's autonomous programming its performance is very low and inaccurate. Among the factors that affect autonomous period execution are battery level, robot positioning and orientation on the field. Even some slight changes in these variables just mentioned the robot struggles to complete its task as intended and the success rate is much less than half of all attempts.

As of February 3, 2014 the school's team that will participate on the VEX Robotics World Championship (2252C) is tied at rank 65 worldwide on the programming challenge out of over 4,000 registered teams [7]. Our target is to be on the top 30 of the world rank when the current season ends. The other teams are currently working on their autonomous period using sensors and will also try to finish on the top 30 ranked positions worldwide in order to qualify for the World Championship as well.

Beyond scores and rankings the greatest result is that students develop a profound and genuine interest in computer science and engineering. The experience working with their teammates is something that will be valuable wherever they end up studying and whichever career they decide to pursue. Should it be related to computer science they have many skills and knowledge that will set them apart from the rest.

These results are the ones that make all the effort and dedication put into it worthwhile.

CONCLUSION

The impact that the use of sensors has made on the autonomous operation in the robotics competition is evident on the performance our teams have had during the past and current years. Students have been provided with a varied skill set that range from programming, robot construction, design process, teamwork, time management and many others. This experience has equipped them for a future where all this skills are valued and will give them an advantage over other students. Among the skills that they have learned, the ones that stem from programming such as critical thinking and logical reasoning will be the ones that will make them shine when they become professionals in a not so distant future.

They will be the future scientists and engineers that will shape the world and guide us to next technological revolution that is taking shape with robotics. They already have the necessary skills to be successful once they become professionals. I can rest assured that I have contributed to their future

success and provide a little push in the right direction.

FUTURE WORK

There are several ways to provide a more comprehensive analysis of how using sensors help improve the autonomous operation of a robot in a competition. The relationship between the use of sensors and the robot performance can be measured quantitatively to determine if a correlation is present. This analysis can provide more concrete evidence of what our experience has taught us.

A future work will be to develop guidelines and tutorials along metrics to measure effectiveness of the programming of the robot. We have to start by determining specific objectives and activities that meet the competition criteria. Measurements must be aligned to that criteria and will provide a method of evaluation and assessment on how effective the tutorials are. A separate focus group can be taken to validate this approach and improve the results that we have seen so far.

Another area to investigate further is the impact that programming robots have on students overall school performance and how this helps motivates more students to pursue careers in science, mathematics, technology and engineering. This latter option can be determined once our students start graduating and enter post-secondary institutions and decide to pursue careers in STEM related fields.

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