Autonomous Tracking and Accelerometer Validation for Intercollegiate Robotic Football

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Abstract

Every year, an intercollegiate robotic football game is held between two universities. The game is played by two teams of eight robots, where no direct human contact is allowed during each play. It consists of two twenty minute halves and is played on a course roughly the size of a basketball court (certain size restrictions apply). Scoring is handled exactly like human football, but with one exception, passes. Depending on their distance and if the ball is retained, passes can count for anywhere from three to thirteen points. This is due to the difficulty in completing passes during a game with robotic systems.

This paper is split into two parts: robotic advances and league advances. The robotic advances focus on improving the robots on offense with respect to pass completion. The football team – started in 2010 – lacked an accurate quarterback and receiver, so most points have been scored without completing passes. A new quarterback and receiver are being developed to solve the issue.

Several technological advances are made to improve the passing system. Both robots implement a visual tracking system using CMUCam5 sensors to create autonomous tracking. The two sensors track each other using a large visual target, which allows the robots to remain aligned with each other, improving accuracy. The quarterback improvements include 180-degree rotation and an improved throwing system, and the receiver's advances include a full 360-degree rotation using two Arduino boards and Bluetooth communication. The rotation allows both robots to swivel in unison, keeping the robots aligned for pass completion. The tracking, improved throwing, and rotation systems create a new strategy on offense and allow for a wider range of scoring opportunities.

The league advancement improves an accelerometer-based validation system that measures the sensitivity of the tackle sensor. The tackle sensor acts as a switch and is used to disable the robot's drive and controls whenever it is hit by another robot, simulating a tackle. The previous requirement was to implement an independently developed accelerometer, but these became too expensive. The availability and added costs act as a large barrier that prevents other interested universities from joining the league. A device was developed last year to test the acceleration thresholds of any accelerometer, but it was inaccurate. A refined model of the same design has

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been developed to provide more consistent and precise measurements. The device works as a pendulum, applying force to the robot, which in turn creates acceleration. This will allow other universities to join the league without a dependence on pre-defined custom sensors.

Introduction

The first intercollegiate robotic football match was held in 2012 at Notre Dame University between the home team and Ohio Northern University. Since then, five matches have been held between the two teams. The ONU Robotic Football team has proven successful in past performances against Notre Dame but improvements can be made to create a more balanced and effective team. The current team lacks the ability to effectively pass the ball to its receivers. This task has proven difficult in robotic football and as a result the scoring system has been adjusted to encourage passing (See Table 1 under "Rules of Play"). The large point increase given for completing passes made it a desirable goal, but the passing skills of the previous ONU quarterback were too inaccurate, too inconsistent, and lack any form of automation. These deficiencies result in a passing game that was negatively influenced by operator and system error. Fielding the pass is also a difficult process for the ONU receivers as it relies solely on human interaction for positioning and route running. The lack of catching ability of the receivers reduces the completion percentage and increases the chances of a costly interception.

Two new robots are designed with the previous problems in mind. A wide receiver robot is created to have a 360-degree rotating upper-body. This allows for more pass completion by aligning the upper body with the quarterback. The full rotation is made possible by using two Arduino Uno microcontrollers that communicate via a Bluetooth Host-shield master-slave system. A final technological advance to the wide receiver is the addition of a visual tracking system using a CMUCam5 vision sensor. This allows the wide receiver to autonomously align the upper body with the quarterback for more accurate passes. The second new robot operates as the quarterback of the team. Improvements from the previous robot include 180-degree rotation and a refined pitching system. The quarterback also uses a CMUCam5 vision sensor for alignment with the newly developed wide receiver. The pair of robots allow for more frequent and more accurate passes.

Beyond the expansion and improvement of the current team, work was done to allow other colleges and universities to create teams and enter the sport of robotic football. Currently, Ohio Northern University and Notre Dame University are the only two schools with functioning teams. While other schools have expressed interest in joining, none have fielded a full team since the creation of the league. One barrier slowing the development of new teams is the requirement to use a standardized accelerometer tackling sensor developed by Notre Dame in all of the players. This sensor is much more expensive than open-sourced accelerometer sensors and may be hindering the development of new teams. A consistent testing system is now in use that ensures all tackling sensors, Notre Dame's and open-sourced alike, result in fair playing conditions for all players. These advancements in the ONU team and the game of robotic football will extend the level of competition and will allow more teams to join and form a truly Intercollegiate Robotic Football League.

Rules of Play

The game of Robotic football is similar to regular human football in how the game is played and scored, however, with remotely controlled mechatronic machines, additional new rules had to be introduced. The game is played between two teams, each consisting of eight players, and a minimum of five functioning players on the field. A violation in either of these rules results in a 1- point delay of game penalty. Since the robots are controlled remotely, human interaction during actual gameplay is prohibited except for when the balling is being placed on the Center before an offensive play or when the ball needs to be placed in the kicker on kick offs, punts, and field goals.

Regarding the actual robot, the machine cannot weigh more than 30 lbs., and powered by a DC power supply, which cannot exceed more than 24 volts. An accelerometer must be implemented on every robot that takes the field, and must provide 2 seconds of immobilization upon being tackled through an interrupt routine in the microcontroller. Regarding the physical build, there are no restrictions on the shape of the base plate, however, all players must fit within a 16 inch square, and a 24 inch tall box at the beginning of any play. Yet, these dimensions expand after the ball has been snapped by the quarterback.

The game is comprised of two 15-minute halves and a 10-minute halftime. The play clock for any offensive play is 25 seconds, which is indicated by the play clock, and starts when the referee spots the ball to initiate a play. Failure to start play after the play clock has expired is a 1 point delay of game penalty. The game clock stoppage occurs when there is a change in possession, dead-ball penalty, a score, or a time out is called. In addition, each team is allowed 2 time outs per half that last up to 1 minute, and the play clock will start from 25 after that 1 minute has expired. The game, surprisingly, can end in a tie, and no overtime will be played.

The scoring rules are very different than regular football as it reflects the difficulty in passing and catching the football. A touchdown is still worth 6 points, however, the point after is worth 2 points. If the ball is ran or passed in the PAT is then worth 1 point. A completed forward pass that is approximately 5 – 15 feet passed the line of scrimmage is worth 7 points, and anything further than 15 feet is worth 12 points. If a pass is intercepted within the 5-15 feet range of the line of scrimmage 2 points and possession of the ball is awarded to the defense, and anything after 15, 3 points and the ball would be the reward. A pass is caught or intercepted when a robot makes contact with the ball before it touches the ground. In other words, the wide receiver or safety need not actually catch the ball, but only hit the ball while it is in the air. Nevertheless, if the robot can catch the ball on either team, the robot can advance the ball.

The traditional rules of the game of football are upheld such as neutral zone infraction, pass interference, illegal contact beyond a certain distance from the line of scrimmage, roughing the passer, false start, and illegal motion on the offensive end. However, instead of yards beginning tack on based on a penalty, the distance the ball will move forward is measured in feet.

Literature Survey

In order to ensure success in the development of the new robots, a literature survey was conducted. One primary focus of this survey is to find a suitable sensor for tracking the position of other robots. The other focus is to guide the development of an accelerometer validation system.

Vision Tracking

Vision sensors are a rapidly growing and developing field in the computing and electronics industry. In the past, stereo vision has been used to compute distances of an object, but reliability has been an issue[1]. Since then, no standard camera has been used to track objects, and many different solutions have been analyzed. Various applications were researched in order to identify systems that could integrate with the existing robotic football functionality. The technologies considered viable options for the application on this project included a custom CCD (Charge-Coupled Device) camera, Microsoft Kinect and stereo vision, and CMUcam vision sensors.

The first solution researched was the integration of a CMUcam vision sensor into the quarterback and receiver to track the relative location of the robots. The CMUcam is classified as an embedded color vision sensor and was initially developed in 2002 in order to create a digital interface to track various objects[2]. The first camera allowed a robotic rover to follow a person, chase a ball, and send images back to a user interface to record what it sees. The main benefit of this camera is its lower price point and frame rate of 50 Hz[3]. It is designed to readily communicate with Arduino microcontrollers, making it an ideal tool to integrate into the robotic football team.

In previous years, the CMUCam has been used on robotic football teams. A CMUCam3 was used by a quarterback to track a receiver with a blinking LED light[4]. In initial testing, the quarterback was able to see the receiver at a 100% success rate on all distances less than 15 feet. The average error on distance tracking was less than 0.31 inches in the testing environment[4]. When tasked with in-game scenarios, however, the CMUCam3 was not effective in improving the passing capabilities of the robotic football team. Issues arose with in-game scenarios such as interference from other robots, the movement of the receiver, and the passing accuracy of the quarterback.

Since the inception of the CMUCam, five models have been created. The most recent model, released in November 2013, is called the CMUCam5 and is designed to track color markers “taught” to the vision sensor. The primary benefits of this model is its affordability, color precision, and number of signals it can track. The newest model uses the color and hue differences the camera sends to the interface to track various objects. This model has the ability to track up to seven different color sources at a time[2]. This will allow for future expansion, where each receiver would be designated a different color, allowing the quarterback to know where seven different robots are at once.

In many robotic tracking systems, stereo triangulation has been used to track both positioning and depth. For the cited project, the Microsoft Kinect vision sensor was researched. The Kinect uses two lenses and infrared body position to track an object’s movement. This is a widely known and used sensor, and it has an in-depth SDK. One document researched the depth sensor in Kinect for use in Mobile Robotics. The author concluded that while Kinect has issues with reflections, it was much more successful at calculating depths of objects than the standard stereo vision[1].

A final solution for vision tracking was to develop a custom Charge-Coupled Device (CCD). This technique was used to develop a camera to pinpoint coordinates of objects relative to the camera which continuously analyzes image snapshots. The CCD develops two coordinate planes for vision development: a Vision Frame and a Robot Frame. The vision frame is used to track objects within the CCD’s scope. The robot frame tracks objects outside the scope and maps the position of all targets in the Robot Frames. This is used for guiding movements[5]. The benefit is the strong coordinate planes this develops, but it requires a lot more work to develop in comparison to other systems. Using a modular system that has already been developed would be more beneficial, cost effective, and potentially successful method.

The vision sensors observed are all potential solutions to the difficult process of visually tracking one robot or object from another. The CMUCam5 has the ability to track based on color, is cost effective, and is simpler than the other technologies researched[2]. Microsoft Kinect has a built in depth sensor which would help track the overall location of the wide receiver and quarterback[1]. Finally, the CCD develops a strong mapping system for the quarterback and receiver to follow in order to communicate[5]. Each tracking system has distinct advantages and disadvantages for the application to robot football. However, it was determined that existing technology is more than capable of accomplishing the intended objective of visually tracking other robots. After using a decision matrix, weighting accuracy, depth, initialization, and speed of tracking, it is decided that the CMUCam5 will be used for the tracking system.

Accelerometer Validation

In order to create a universal system for a Robotic Football League, a standard accelerometer test needs to be created which will allow for open-sourced accelerometer tackling sensors to be developed by individual teams. This will reduce the cost of participating in the games and also maintain fairness between the individual teams. The current solution of having all robots use the same accelerometer board is costly and ineffective as the boards can only be purchased from

Notre Dame at a price that is greater than the cost of implementing an open-sourced system[6]. The current testing system, developed by the 2013-2014 Robotic Football Capstone team, has undergone limited testing and requires modifications in order to be used as a functional and consistent testing tool. This device swings a sledge against a slide that holds the robot in place. The robot is mounted on a weighted base so that all robot/sled combinations weigh the same and are oriented in the same manner in order to maintain a constant swing distance of the sledge[7]. It was found that the implementation of this device resulted in inconsistent acceleration values. The accelerometer testing device is a close solution, but is not precise enough for widespread application. Due to a lack of structural integrity, the device moves unpredictably during the swing and does not always give accurate measurements[6]. Due to these limitations, the device requires modifications in order to function as desired. After completing a decision matrix, using consistency, accuracy, and mobility as criteria, it is decided that a swinging arm design will continue to be used for the accelerometer validation system.

Robotic Advances

To ensure the success of this and future teams, technological advances needed to be made to the robots. These advances give a tactical advantage each year, since the team enters the match with a new advancement that the other team is unaware of. The technological advances to this team revolve around a wide receiver (WR) and quarterback (QB) pass and completion system to optimize the amount of points received. Each completed pass awards a minimum of four points, allowing for the possibility of a large number of points on one possession.

Vision Tracking

The primary technological advance, implemented to both the wide receiver and the quarterback, is a vision tracking system. This is done using a CMUCam5 on each robot. At the beginning of each play, a mast can be raised on both the WR and the QB that holds both the CMUCam5 and a vibrant "color code." The mast rises higher than the limitations of a resting robot, allowing the two robots to see each other's position without the interference of other robots. Once the cameras are locked on to each other's "color code," the robots pivot synchronically, creating an ideal passing scenario.

The vision sensor is designed to work well with Arduino computing. It works by seeing a digital array of "blocks," where it recognizes different color hues as different signatures. Each block is approximately twenty pixels, and the lens can see an array of 200x320 blocks. The current vision sensor can recognize up to seven different colors and react to them. Data about each "block" is then sent to the Arduino board via I2C communication. The data includes the x- and y-position, width, height, and color signature of each item read.

Once the data is processed, a proportional-integral-derivative (PID) control system provides error correction to the position. This was created internal to the Arduino code, and helps to set the pivot position for proper tracking. The QB receives servo-motor positions because of its 180-degree rotation. Due to the wide receiver servo motor for pivoting being modified for 360-degree rotation, speeds are sent based on the error correction instead of positions.

Pivot System / Bluetooth Communication

The previous quarterback has a major limitation to its passing ability, since it cannot rotate. In order to aim for a pass, the user must drive the entire robot at an angle to position itself for the pass. This is a slow and difficult process, making pass completions nearly impossible from the beginning. A pivoting system is needed for the new quarterback to make the vision tracking feasible. However, the two robots have different rotational needs. The quarterback needs 180-degrees of freedom, whereas the wide receiver needs a full 360-degree range of mobility.

To make pivoting possible on the quarterback, one servo and pivot system was needed. An electric servo motor was added to a pivot stand which has a weight distributing bearing. The addition of a single motor and pivot system allows the top to spin freely. Due to the 180-degree rotation, all electronic hardware and batteries are mounted on the bottom to free the top of unneeded weight.

In order to have a successful wide receiver, it needs to be able to continuously align with the quarterback no matter where it is on the field. This means that a full 360-degree rotation of the top is needed. This desire for full rotation proved to be challenging due to the hardware limitations of the top. It is not possible to have hardware on the top and bottom connected with wires. Therefore, an alternative solution was needed. To solve the issue, a top was fitted with a second Arduino Uno microcontroller. Then, both microcontrollers were given a Bluetooth transmission shield. The two microcontrollers can then communicate data without the need for wires. The wide receiver was also fitted with the same pivot stand as the quarterback, but with an electric servo motor that is modified for continuous rotation.

The two robots, although having similar pivot functions, are designed very differently to fit the needs of the system. Both designs proved to compliment the tracking system, and the two additions made much more viable passes.

League Advances

In the previous rules of the league, a standard tackle sensor was required for every robot to create a league-wide standard for setting tackle thresholds. These tackle sensors were very expensive, and they made it unfeasible for other teams to join the league[6]. In order to encourage other leagues to join, teams needed to be able to supply their own open-source accelerometers and prove their sensors are functioning properly on the day of the match via comparative testing.

To solve this issue, the previous team developed an accelerometer testing stand. This stand worked by swinging a sledge at a sled in which the robot rides on. Their stand was made hastily and with scrap materials, so the overall quality and precision was very poor. This lack of consistency made the stand unusable for the match.

A new test stand was developed using the same design, but with more precision. The scrap metal was replaced with Aluminum T-slot, and the sledge was given a weight-displacing bearing, making it resemble a Charpy test stand. This test stand is also designed to be portable and simple so that other teams can replicate it to test their own robots prior to the match. The portability also allows it to be moved to the match location for on-site testing prior to the game.

The goal of the league is to create a large, nationwide mechatronic football league, where matches could be held year round, or a large tournament could determine a national champion. The accelerometer validation system makes fielding a team much more economically feasible.

Conclusion

The solutions for robotic advances and league advances are proving to be successful. The technological advances to the new quarterback and wide receiver meet our criteria for more accurate and precise passing plays. The automated tracking allows the user to focus on the location of the receiver down field and the maneuverability of the robot in general. The robots prove to increase the ability of passing, which in turn creates more scoring opportunities within the same drive. The accelerometer validation stand creates the opportunity for new teams to join the league by allowing open-source accelerometers, which is much more feasible. The combination of technological advances to the robots and league advances with the validation stand created strong advances for the team and the league as a whole. Future work includes statistical data proving the effectiveness and accuracy of the robots and accelerometer validation stand.

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