Application of Intelligent Control to the 2007 FIRST Robotics Competition

Garrett Dicken, Nathan Butler, Michael E. Kutch,
and Jeffrey E. Erickson, *Graduate Student Member, IEEE*

***Abstract*— FIRST (For Inspiration and Recognition of Science and Technology) is a non-profit organization that organizes several robotics competitions for pre-college students. The FIRST Robotics Competition (FRC) is a high school level competition wherein high school students work with engineers to design and control a device to compete in the competition.**

The 2007 FRC presented a control problem centered on collision control and target tracking. Our strategy for the competition required the automated acquisition, tracking, controlled contact, and pushing of the opponent robot during the autonomous period. For acquisition of the target, data gathered from ultrasonic range sensors provides information related to the location of target robots. Following processing of the raw input data, and artificial neural network decides which target to pursue.

Once this target is acquired, the contact is controlled using a fuzzy controller. Using range to target and closing speed as inputs, a fuzzy controller determines motor drive. This allows intuitive adjustment of the controller, varying the number, center, and shape of membership functions.

The fuzzy collision controller has been preliminarily tested. The key to this control is to approach the target with sufficient speed to close the distance quickly, make contact with slow closing speed to avoid ramming, and then maximize the motor drive to push the opponent. Using Gaussian membership functions allows smooth transition between the classes while allowing easy modification of the controller. This method has given the appropriate outputs in controlled calibration and experimentation.

I. INTRODUCTION

FIRST (For Inspiration and Recognition of Science and Technology) is a non-profit organization which promotes interest and education in STEM (Science Technology Engineering and Mathematics) in pre-college environments. The principal mode of this effort at the high school level is the FIRST Robotics Competition (FRC), a competitive event whose season runs from January to April each year.

In the program, high school teams pair with sponsors and engineers to design a robot to compete in the competition. For six weeks, from early January to mid-February, the teams build the robot using a kit of parts provided by FIRST supplemented with other materials and commercial off-the-shelf (COTS) parts.

At a competition event, teams are pseudo-randomly paired with two other teams to form an alliance. These alliances face off in two minute fifteen second matches to qualify for an elimination round. The elimination round is a bracketed tournament to determine the winner of the competition event.

Each match begins with a 15 second autonomous period, during which the robot must operate without human controller input. Following the autonomous period, two minutes of human controlled teleoperation conclude the match. This structure requires the teams to build robots that have sophisticated programming, potentially intricate mechanisms, and accurate controls [1].

II. THE 2007 FIRST ROBOTICS COMPETITION

For the 2007 FRC game, dubbed “Rack-n-Roll” by the FIRST Game Design Committee, robots were to compete on a field 54 feet by 27 feet. Near the center of this field was a “rack” consisting of three levels of 8 spokes, providing 24 locations for teams to place inflated toroidial pool tubes to score. Scoring in this manner was calculated by taking the number of consecutive tubes and applying a power law to it. Each lone tube was worth two points, two adjacent tubes 4 points, three 8 points, etc to 8 consecutive tubes (a complete level) being worth 256 points [1].

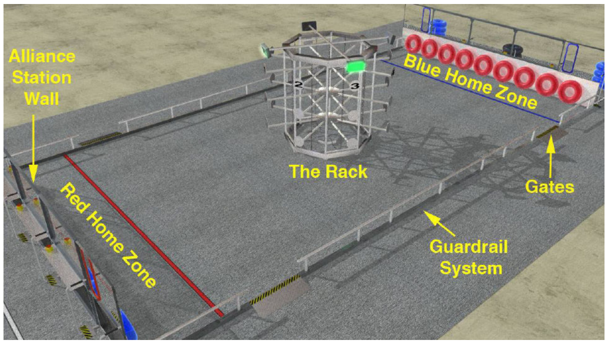

Fig. 1. Layout of the 2007 FRC field, from the 2007 FRC Manual. Teams start at opposing ends of the field. The structure in the center is the scoring rack.

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All the authors are members of FRC Team 41 for the 2007 season.

G Dicken and N Butler are students at Watching Hills Regional High School, 108 Stirling Road, Warren, NJ 07059 USA.

M. Kutch is a teacher in the Department of Science and Technology at Watchung Hills Regional High School, 108 Stirling Road, Warren, NJ 07059. (e-mail: mkutch@whrhs.org)

J.E. Erickson is a doctoral candidate with the Computational Intelligence Laboratory, Department of Biomedical Engineering, Rutgers University, 599 Taylor Road, Piscataway, NJ 08854. (e-mail: jee7s@eden.rutgers.edu)

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In addition to this method of scoring, which hereinafter will be referred to as “finesse scoring,” there was a method of “strength scoring.” For each alliance partner elevated off the floor, independent of the field, by a partner robot received points. For each robot located 4 inches to 12 inches off the floor, the alliance received 15 points, and 30 points for 12 inches or more off the floor.

Further, the FRC rules promote “gracious professionalism” and “co-opertition.” FIRST promotes the sportsmanship of the teams’ interactions within themselves and with other participants. Also, because the alliance partners change each match, it is an advantage to promote clean play and teamwork with a variety of teams and machines.

To this end, the rules prohibit actions intended to destroy or damage opponents. Also, excessive ramming and pinning of robots is discouraged to promote fair and exiting game play. However, defense is promoted as a part of the game, so ramming and pinning are permitted within reason. So long as the intent is not to damage, and the impact not excessively forceful, ramming and pinning were allowed.

III. OUR TEAM

Watching Hills Regional High School is a grade 9 to 12 secondary school located in Warren Township, New Jersey, USA. The school supports FRC 41, a FIRST Robotics team that has continuously competed for 10 years. The team consists of students at all levels, 2 mentor teachers at the high school, and 2 engineering mentors from academia and industry.

Early in the build season, our team separated into teams for each aspect of the robot: control, mechanics, power, etc. This paper focuses on work done by the control team for the autonomous period of the match.

IV. OUR STRATEGY

Early in the competition build season we decided on a defensive strategy with the aforementioned strength scoring. We designed and constructed a robot with high mobility “crab drive,” which enabled the robot to stop, rotate its wheels, and drive at right angles to the original direction. Coupled with high torque drivetrains, we hoped to force our opponents into stalls or pins that would prevent their scoring. In addition, a ramp was constructed to allow partner robots to drive up onto our robot and achieve the 12 inch height necessary to score 30 points.

In deciding on this defensive strategy, we also decided to employ a defensive strategy during the autonomous mode. This meant the design of algorithms and intelligence to locate and acquire a target, close on it, make contact, and pin the opponent. Through all these actions, in order to comply with the rules, our robot needed to be operated in a safe manner, and we could not ram our opponents from long distances or at high speed.

However, we recognized early on that speed would be a factor in tracking a target and closing on it before the target’s program had time to react. This required us to design an intelligent control algorithm to decide on a target to close on and pin, and another algorithm to control the impact with the opponent.

A. *Decision Engine*

Given the layout of the playing field, and the 3-on-3 nature of the competition, an automated decision regarding which target to pin needs to be made by the control processor in real time during the 15 second autonomous period of the competition.

To do this, we employed an artificial neural network (ANN). Taking this machine learning approach allowed our high school student members to understand the principles of the decision making process without employing excessive advanced math or intricate programming architectures.

As a means of further automation, the inputs to the ANN were fuzzy sets. The output of the network was a decision on what direction to move: left, right, or center.

After this decision on direction was made, the robot would follow a pre-programmed set of moves. First, the robot would move in the direction indicated by the output of the ANN. Then, the processor would wait to acquire a target within a certain range. If such a target was found, the robot would close on it and pin or ram it to inhibit its movement on the field. If such a target was not found, the robot would move repetitively through over a section of the field, attempting to interfere with the opposition’s autonomous strategy.

B. *Collision Control*

Both in the autonomous period and the teleoperated period, we employed intelligent collision control. Since the interaction between robots was allowed but ramming was prohibited, we employed a fuzzy controller to mitigate the collision.

This controller would override the user’s input, or supplement the intelligent decision making, to prevent any possibility of ramming. Using information from ultrasonic ranging sensors, the fuzzy controller would determine, based on the range to target, the acceptable maximum motor speed.

Fuzzy control was chosen because it would allow the high school students to intuitively understand how the controller worked, and avoided excessive advanced math or programming. Though the understanding of how the controller worked, the tuning of the controller and the use of a fuzzy controller exposed the students to intelligent control methods and their real world application.

V. IMPLEMENTATION OF INTELLIGENT CONTROLS

The specific algorithms used to control this robot were implemented on the Innovation First robotics controller. This is the only controller permitted under FRC rules. It features A/D input channels, digital inputs, relay outputs, and PWM channels for motor control. Also, the controller handles competition control and radio communications between the robot and the operator station.

A. *Intelligent Collision Control*

On each of the four sides of the robot, we positioned an ultrasonic ranging sensor (Maxbotix LV-EZ1) mounted on a small piece of polycarbonate. This provided improved directionality and an insulated mounting surface.

The analog output of the ranging sensor was converted using the software library provided by Innovation First, the company that makes the FRC controller. The controller is based on a Microchip PIC18F8722, which has 10-bit A/D conversion.

This 10-bit number corresponds to a range from 4 inches to 20 feet. This input information was converted to fuzzy sets using Gaussian membership functions. This allowed for easy adjustment of the fuzzy centers and width of each center's membership function.

A progression of speeds associated with each center was designed to slow the robot on approach, then deliver full power to the motors on contact. By slowing on approach, we avoided possible infractions of the ramming rule. Following contact, however, we wanted full power delivered to the motors to push or pin our opponent. Using a fuzzy controller allowed us to alter the centers to suit the application best, and make these changes simply in the software

Five such centers were used. Each center was associated with a power level for motor output speed limiting. Table I shows the centers, the standard deviation of the Gaussian curves associated with each center, and the power output level associated with each set defined by the center.

TABLE I
FUZZY CENTER INFORMATION

Center (range to target)	Width (Standard Deviation of the Gaussian)	Power Output Level (127 is neutral/stopped, 255 is full speed)
60 in	10 in	255
48 in	10 in	200
30 in	10 in	180
20 in	5 in	163
8 in	14 in	255

Following the calculation of membership in each set, the centroid method was used to determine the output of the controller [2]. This is a standard means of calculating the output of a fuzzy controller.

This output was then used in control statements to override the user input speed or autonomous script speed and limit the speed of collision.

B. *Intelligent Decision Making*

The automation script was to be written to have the robot move down the field at full speed to a point beyond the rack at the center of the field, then turn inward to move to the center of the field. At this point, the following intelligent decision engine was used to decide on the robot's next move.

When considering inputs, we decided that angle to target and range to target would be the two most intuitive values. Our machine should choose a target opponent that was attempting to score, so this one chance move would not be wasted. Also, if multiple targets were in range, we would want to select the targets closest to square with our orientation.

Our intention was to mount an ultrasonic ranging sensor on a servo, which would sweep across our "frontal view" (the region between our robot and our opponents), collecting distance and angle data.

Angular data was calibrated so zero degrees was the left side of the robot, 90 degrees was the frontal face, and 180 degrees was the right side. Given these inputs, the angular data would be preprocessed by doubling the angle and taking the cosine of the result. This produced peaks at our front and sides, with zeros at our corners. In doing so, we could maximize neural network response when the target was in positions easy for our robot to attack.

Distance information was preprocessed using a linear decay, having a value of 1 at 0 distance and a value of zero at 10 feet (120 inches). Distances beyond 120 inches received a zero value.

A neural network was constructed using feed-forward 2-5-3 architecture. The two inputs were the processed distance and angle values, and the outputs indicated left, right, or center. Inputs to each node were combined using a weighted average. The output of each node was limited using the hyperbolic tangent function.

After initializing the weights using a random number generator, the network was trained by modifying the weights using the algorithm of pattern extraction (ALOPEX) [3], with a learning rate parameter of 1.0, and noise variance of 0.1. The response function was mean squared error of the output of the network. Training proceeded using ideal data in MATLAB, and was intended to drive one of the three outputs to 1 while suppressing the other two to zero, an all-or-none response.

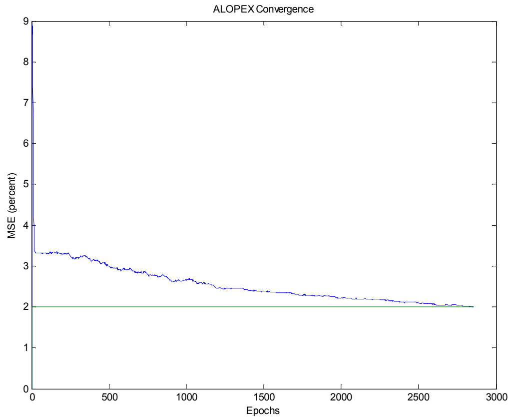

Fig. 2. Reduction of Mean Squared Errror as a result of training with ALOPEX. The lower line indicates target error. The upper line is the error at the epoch (iteration) indicated by the y axis.

Training was completed in less than 3000 iterations to within 2% MSE. Training sets were a selection of 10 possible target locations. Subsequent testing showed these 10 locations were properly classified. A set of 10 other ideal locations different than the training set were used for verification. All 10 of these were properly classified.

VI. TESTING

The fuzzy collision controller was tested on the control platform using targets at several distances, and recording the motor limiting outputs. Monitoring the sensor input values and motor limited values on Innovation First's proprietary dashboard (a monitor for the state of the controller), control values were recorded at 12 points, three times each. Identical values were found each time the data were recorded. (see Fig 3.) This validated the design of the controller.

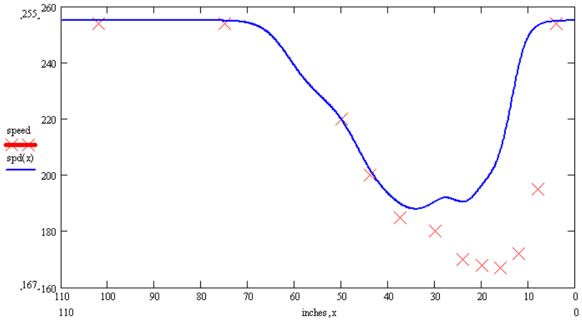

Fig. 3. Fuzzy controller data. Solid line is the theoretical response of the controller, as calculated and graphed continuously. Discreet crosses are observed controller values during testing.

Unfortunately, due to time constraints, the restraints of the competition, and equipment failures that have yet to be resolved, we have been unable to test the collision controller on an operational robot.

In addition, due to similar restraints, we were unable to test the neural network we designed, implemented, and trained in MATLAB on the competition platform. However, MATLAB results did verify the performance of the neural network.

VII. CONCLUSION

Designing these intelligent control methods set the foundation by which we could remove obligation from the human controller without significant loss of performance. While we were unable to employ this system in competition due to unrelated design problems and mechanical failures, testing indicates this method would provide an intuitive and effective means of controlling sophisticated machines. Further, this control can be implemented without knowledge of high level mathematics or control theory, making it ideal for a pre-college setting.

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