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Towards Semantically Intelligent Robots

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1. Introduction

Approaches are needed for providing advanced autonomous wheeled robots with a sense of self, immediate ambience, and mission. The following list of abilities would form the desired feature set of such approaches: self-localization, detection and correction of course deviation errors, faster and more reliable identification of friend or foe, simultaneous localization and mapping in uncharted environments without necessarily depending on external assistance, and being able to serve as web services. Situations, where enhanced robots with such rich feature sets come to play, span competitions such as line following, cooperative mini sumo fighting, and cooperative labyrinth discovery. In this chapter we look into how such features may be realized towards creating intelligent robots.

Currently through-cell localization in robots mainly relies on availability of shaft-encoders. In this regard, we would like to firstly present a simple-to-implement through-cell localization approach for robots even without a shaft-encoder in order to empower them to traverse approximately on the desired course (curve or linear) and end up registered properly at the desired target position. Researchers have presented ways including fuzzy- and neural-based control systems for correcting the navigation deviation error. By providing a formulation for deviation error, especially during turning curves, and then applying reverse formulation to correct it, our self-corrective gyroscope-accelerometer-encoder cascade control system adjusts the robot even more. When the robot detects that it has yawed off course, the system affects the requisite maneuvering and its timing in order to correct the deviation from course.

Next step is to facilitate robots with ability of Friend-or-Foe (FoF) identification for cooperative multi-robot tasks. Mini-sumo team robots are well-known case-in-point where FoF identification capability would be most welcome whereas absolute positioning of teammates is not practical. Our simple-to-implement FoF identification does not require two-way communication as it only relies on decryption of payload in one direction. It is shown that the replay attack is not feasible due to high computation complexity as the communication is encrypted and timestamp is inserted in the messages. Our hardware implementation of cooperative robots incorporates a gyroscope chipset and rotary radar which is able to sense the direction and distance to detected object. Studying dynamics of robots allows finding solutions to attack even stronger enemy from sides so they will not be able to resist. Besides, there are certain situations that robots must evade or even try escaping instead of facing a fight. Our experimental work here attempts to illustrate situations of real battlefields of cooperative mini-sumo competitions as an example of localization, mapping, and collaborative problem solving in uncharted environments.

Source: *Advances in Human-Robot Interaction*, Book edited by: Vladimir A. Kulyukin,
 ISBN 978-953-307-020-9, pp. 342, December 2009, INTECH, Croatia, downloaded from SCIYO.COM

Simultaneous localization and mapping (SLAM) is another feature we wish to discuss here. Within this respect, robots are not only able to identify friends from foes but also they construct a real-time map of the situation without use of expensive equipments as laser beam sensors or vision cells.

There have been a lot of change and improvement in robotics within current decade. Today, humanoid robots such as ASIMO are able to talk, walk, learn and communicate. On the other hand, there are new trends for self-adjustment and calibration in wheeled robots. Both humanoid and wheeled robots may be able to identify friends or foes, communicate with others, and correct deviation errors. Researchers have provided quite acceptable balance mechanisms for any type of inverted pendulum based robots from a range of humanoids holding themselves on one leg to wheeled robots standing on a wheel or two while moving. Yet they cannot jump, nor run on irregular surfaces like humans do. However, there are many other features including speech synthesizing and video processing enabled on more advanced robots.

Advanced robots should be equipped with further human-like capability to reason and base it on knowing the meaning of its surroundings. At this point, we tend to introduce the subject of Semantic Intelligence (SI) as opposed to and in augmentation of conventional artificial intelligence. Better understanding of environment, and reasoning necessarily through SI fueled by the intelligence of knowing the meaning of what goes around. In other words, SI would be enabling robots with the power of imagination as we do. As future study, we aim to shed some light on bases of robotic behavior towards thinking, learning, and imagining the way human being does through Semantic Intelligence Reasoning.

In next section, we will discuss self localization of robots with limited resources while they have neither shaft encoders nor gyroscope. Consequent section will represent more advanced family of robots where they are able to correct deviated errors with use of gyroscope, accelerometer, and shaft encoder in a triple cascaded loop. Section 4 presents our formulations and algorithms for identification of Friend or Foe and responding accordingly in battle of multi and collaborative robots. Then we will present Simultaneous Localization and Mapping for multi collaborative robots in section 5. Section 6 will cover a brief introductory on Semantic Intelligence and application example for solving a robotic problem. Finally the chapter is concluded in section 7.

2. Through-cell self-localization

Line following is one of the simplest categories of wheeled robots. Line following robots is mainly equipped with two DC motors for left and right wheels and line tracking sensors which is a set of 1 to 6 Infrared transceiver pairs. (Notice that using only one sensor to follow a line makes the robot able to only follow edge of a connected and simple path without extra loops). Microrobot Cruiser robot (Active-Robots) were selected for this section due to the simplicity of design. In addition, there is neither shaft encoder nor gyroscope on this robot. It is aimed to enable even such robots to traverse the desired curve or path.

As can be seen in Fig. 1 (A), the front side of the robot is equipped with 6 IR sensors (3 at left and at right side) each one consisting of an infrared transmitter LED and an infrared receiver transistor read by ADC port of the microcontroller. The ADC port output is a voltage between $[0, V_{max}]$ presenting the reverse relation with distance to reflector (an obstacle, for example, walls in labyrinth platform). Sensors provide V_{max} approximately when the robot so close as to touch a wall. Initial calibration may be performed by keeping

the sensors as close as possible to reflector and then recording the captured voltage. The output of 6 sensors is presented by the $[(F_l, F_r), (S_l, S_r), (B_l, B_r)]$ tuples where subscripts l and r are respectively for sensors placed at left and right side of the robot. F is for front sensor, S shows side sensor and finally B indicates the sensors installed to watch 45° towards backside of the robot on both sides (i.e. S_l is the voltage level of left side IR sensor). When a robot is in the center of a cell with approximately same distance from either side walls, we end up with $S_l \approx S_r \approx V_n$ s.t. $V_n \in [0, V_{max}]$. Notice that V_{max} stands for maximum voltage captured from sensors and let's assume that v_{max} represents the maximum velocity of motors.

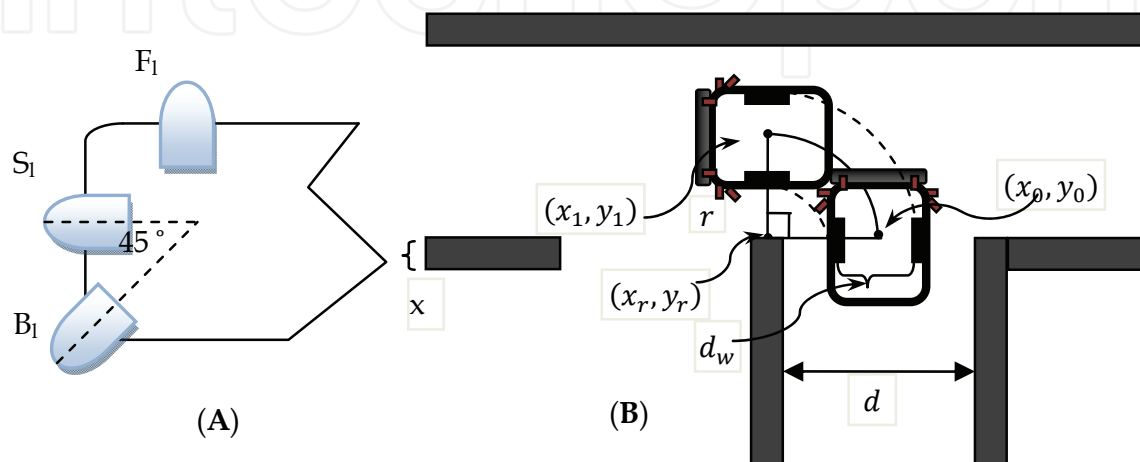


Fig. 1. left section of sensor boards of Microrobot Cruiser robot (A), and Turning left over the perimeter of the circle in a labyrinth: representation of a situation where the decision maker has decreed that the robot is to turn left (B).

For a robot turning toward a direction, its starting position is important. The radius of the curve and its length need be calculated. The main points are deciding on which curve (radius defines it) is the best choice, and when the turn has been accomplished. It is assumed that the best curve is the one which keeps the robot straddling the middle line of the next cell.

Practically, if $V_n - \alpha \leq S_l \approx S_r \leq V_n + \alpha$, where α is a small threshold value and $V_a - \alpha \leq B_l \approx B_r \leq V_a + \alpha$, $V_a < V_n$ then the robot continues moving straight so that $S_l \approx 0$ or $S_r \approx 0$ (depending on the direction of turn) until $(B_l < V_a - \alpha$ or $B_r < V_a - \alpha)$. It indicates that the center of axes of wheels is approximately on (x_0, y_0) . Now on the robot can start turning over the desired curve with defined radius. Therefore, it traverses a quarter of perimeter of the circle with radius r ($r = \frac{x}{2} + \frac{d}{2}$) in which its initial point is (x_0, y_0) and its destination point is (x_1, y_1) . Notice that x is the thickness of a wall and d is the distance between two walls or the cell width. We assume that $(x_0, y_0) := (0, 0)$ as initial point before turning and $(x_1, y_1) := (-r, r)$ is the point after turning left, whereas (x_1, y_1) would be (r, r) for turning right. As a result, traversed distance over the perimeter of inner and outer curves is calculated by the following formula (1). Additionally, we require adjusting the speed of motors as shown in (2); it's clear that the robot does not need shaft encoders in order to measure the traversed distance. Turning is continued until $B_l > V_a - \alpha$ (for turning left) or $B_r < V_a - \alpha$ (while turning right).

$$\begin{cases} \text{Turning Left: } P_l = 2\Pi\left(r - \frac{d_w}{2}\right), P_r = 2\Pi\left(r + \frac{d_w}{2}\right) \\ \text{Turning Right: } P_l = 2\Pi\left(r + \frac{d_w}{2}\right), P_r = 2\Pi\left(r - \frac{d_w}{2}\right) \end{cases} \quad (1)$$

$$\begin{cases} \text{Turning Left: } v_l = \frac{P_l}{P_r} v_{max}, v_r = v_{max} \\ \text{Turning Right: } v_l = v_{max}, v_r = \frac{P_r}{P_l} v_{max} \end{cases} \quad (2)$$

Now let's consider more advanced robots which are widely used in real-life where not only pushing the robot to follow a specific curve is intended but also error detection and correction is considered simultaneously. Autonomous Guided Vehicles (AGVs) are highly used everywhere. Next section presents a solution to error detection and correction in situations that the machine works properly however, problems such as slippage causes deviation.

3. Self-corrective cascaded control

Self-corrective gyroscope-accelerometer-encoder cascade control system adjusts the robot if the host vehicle deviates from its designated lane. In case the vehicle detects that it has yawed away, the system calculates a desired maneuvering moment in order to correct deviation. The calculation is simply addition/subtraction from the desired value of movement expected from shaft encoder sensors of both wheels. This is done by steering the host vehicle back on course in a direction that avoids the host vehicle's lane deviation. The system compensates for the desired yawing moment by a correction factor or a gain. Manufacturing a new generation of AGVs with ability of self-corrective gyroscope-accelerometer-encoder cascade control system will improve current AGVs and cooperative robots to overcome their major difficulties and improve their utility.

When measuring odometry errors, one must distinguish between 1) *Systematic* errors and 2) *non-systematic* errors. Systematic errors are caused by kinematic imperfections of the mobile robot (i.e. unequal wheel-diameters). Another systematic error caused in many researches is simplifying kinematic control properties by default values (i.e. $d = 0$, d is distance from new referenced point to intersection of rear wheel axis and symmetry axis of mobile robot). Extending the kinematic control into dynamics level, the majority of researchers consider the general case of $d = 0$ in dynamic model of mobile robot, whereas the restriction of $I = 0$ is mostly imposed by the kinematic controller (Pengcheng & Zhicheng, 2007). On the other hand, non-systematic errors may be caused by wheel-slippage or irregularities of the floor. University of Michigan Benchmark test (UMBmark), is a test method for systematic errors prescribing a simple testing procedure designed to quantitatively measure the odometric accuracy of a mobile robot (Borenstein & Feng, 1995). Non-systematic errors are more difficult to be detected. Cascade control systems for localization are more reliable in this sense.

J. Borenstein et al (Borenstein et al., 1997) defined seven categories for positioning systems based on the type of sensors used in controlling the robot. 1) *Odometry* is based on simple

equations which hold true when wheel revolutions can be translated accurately into linear displacement relative to the floor. However, in case of wheel slippage and some other more subtle causes, wheel rotations may not translate proportionally into linear motion. The resulting errors can be categorized into one of two groups: systematic errors and non-systematic errors. 2) *Inertial Navigation* uses gyroscopes and accelerometers to measure rate of rotation and acceleration, respectively. Measurements are integrated once (or twice, for accelerometers) to yield position. 3) *Magnetic Compass* is widely used. However, the earth's magnetic field is often distorted near power lines or steel structures. Besides, the speed of measurement and accuracy is low. There are several types of magnetic compasses due to variety of physical effects related to the earth's magnetic field. Some of them include Mechanical, Fluxgate, Hall-effect, Magnetoresistive, and Magnetoelastic compasses. 4) *Active Beacons* navigation systems are the most common navigation aids on ships and airplanes, as well as on commercial mobile robot systems. Two different types of active beacon systems can be distinguished: trilateration that is the determination of a vehicle's position based on distance measurements to known beacon sources; and triangulation, which in this configuration there are three or more active transmitters mounted at known locations. 5) *Global Positioning System* (GPS) is a revolutionary technology for outdoor navigation. GPS was developed as a Joint Services Program by the Department of Defense. However, GPS is not applicable in most of robotics fields due to two reasons, firstly, unavailability of GPS signals indoor; and secondly, low accuracy in small prototype single chip GPS receivers used in cellular phones and robot boards. 6) Landmark Navigation is based on landmarks that are distinct features so a robot can recognize from its sensory input. Landmarks can be geometric shapes (e.g., rectangles, lines, circles), and they may include additional information (e.g., in the form of bar-codes). In general, landmarks have a fixed and known position, relative to which a robot can localize itself. 7) *Model Matching* or *Map-based positioning*, also known as *map matching* is a technique in which the robot uses its sensors to create a map of its local environment. This local map is then compared to a global map previously stored in memory. If a match is found, then the robot can compute its actual position and orientation in the environment. Certainly there are lots of situations where achieving global map is unfeasible or prohibited. Therefore, solutions based on independent sensors carried on robots are more likely valued.

Some applications of cascade control can be seen in the research done by (Ke et al., 2004) where cascade control strategy of robot subsystem has been applied instead of the widely used single speed-feedback closed-loop control strategy. They provided the cascade control system such that the outer loop is to regulate speed of the wheel; the inner loop is to adjust the current passing through the DC-motor. By applying cascade control system to DC-motor, the unexpected time-delay and inaccuracy can be reduced. The dynamic features of robots motion and anti-interference of robots can be improved. At the same time, the damage of current to DC-motor can be dropped and the life span of DC-motor can be prolonged.

Various control strategies for mobile robot formations have been reported in the literature, including behavior based methods, virtual structure techniques, and leader-follower schemes (Defoort et al., 2008). Among them, the leader-follower approaches have been well recognized and become the most popular approaches.

The basic idea of this scheme is that one robot is selected as leader and is responsible for guiding the formation. The other robots, called followers, are required to track the position

and orientation of the leader with some prescribed offsets. The advantage of using such a strategy is that specifying a single quantity (the leader's motion) directs the group behavior. In followers, sliding-mode formation controller is applied which is only based on the derivation of relative motion states. It eliminates the need for measurement or estimation of the absolute velocity of the leader and enables formation control using vision systems carried by the followers. However, it creates bottleneck for message passing and decision making while it can be improved by decentralized autonomous control such as in (Elçi & Rahnama, 2009) on the other hand, situations wherein the leader dies is not considered.

Other method of cascade control in robotics is with use of multi visual elements in positioning and controlling the motion of articulated arms (Lippiello et al., 2007). In a multi arm robotic cell, visual systems are usually composed of two or more cameras that can be rigidly attached to the robot end-effectors or fixed in the workspace. Hence, the use of both configurations at the same time makes the execution of complex tasks easier and offers higher flexibility in the presence of a dynamic scenario.

Cascade control for positioning is also used in Unmanned Aerial Vehicles (UAVs). A decentralized cascade control system including autopilot and trajectory control units presents more precise collision avoidance strategy (Boivin et al., 2008).

3.1 Impact and significance of self-corrective AGVs in human life

Following information on various application areas of AGVs is presented in order to highlight wide spectrum of applicability of the results of the upgraded AGVs.

3.1.1 AGVs for automobile manufacturing

Typical AGV applications in the automotive industry include automated raw material delivery, automated work in process movements between manufacturing cells, and finished goods transport. AGVs link shipping/receiving, warehousing, and production with just-in-time part deliveries that minimize line side storage requirements. AGV systems help create the fork-free manufacturing environment which many plants in the automotive industry are seeking.

3.1.2 Hospitals

Using an AGV Automated Transport System (ATS) frees hospital employees to spend a maximum amount of their time directly on patient care. It improves safety in the hospital by minimizing the potential for hospital workers to be injured pushing heavy carts. It tracks all material movements and can prioritize jobs so that the most important tasks can be completed first (for example: surgical supplies, then patient meals, then linens, then trash, etc.) The AGV can be outfitted with obstacle detection sensors which bring it to a safe stop before contacting any obstacles that might be in its path. It is reliable, safe, efficient and cost effective.

3.1.3 AGV (Automated Guided Vehicle) systems for the manufacturing industry

Timely movement of materials is a critical element to an efficient manufacturing operation. The costs associated with delivering raw materials, moving work in process and removing finished goods must be minimized while also minimizing any product damage that is the result of improper handling. An AGV system helps streamline operations while also delivering improved safety and tracking the movement of materials.

Our aim is to create a universal AGV controller board with the abilities as explained in the previous section. Manufacturing a new generation of AGVs with ability of Self-Corrective Compass Cascaded Control System will improve current AGVs to overcome difficulties mentioned earlier.

The product is a universal robot controller board which can be produced and exported worldwide. Future enhancements were taken into account as covering more servo/stepper motors for full fledged robots serving different purposes.

3.2 Cascaded control method

AGVs are widely used in production lines of factories. They mostly track a line on floor rather than being able to accurately follow dynamics of planned trajectories of start and end positions. In more advanced cases, they are equipped with a feedback control loop, which corrects the deviation errors due to movement imperfection of actuators and motors. This section presents triple feedback loops consisting of gyroscope, accelerometer, and shaft-encoder to provide self-corrective cascade control system.

A cascade control system is a multiple-loop system where the primary variable is controlled by adjusting the set point of a related secondary variable controller. The secondary variable then affects the primary variable through the process.

The primary objective in cascade control is to divide an otherwise difficult to control process into two portions, whereby a secondary control loop is formed around major disturbances thus leaving only minor disturbances to be controlled by the primary controller.

Despite the fact that first loop (which might be implemented by a PID controller) detects and corrects deviation errors in trajectory planning, however in practice there are disturbances that are generally excluded in theoretical implementations. Nevertheless, disturbances such as friction and slippage are highly important and are frequently happening in real life robotic implementations. For instance, an oily floor in factory causes AGVs to slide however, the primary control does not recognize it.

In such a scenario, Global Positioning System (GPS) is not useful either because rotational errors (without movement of the position) are not detectable. In addition, in real life examples of factories, reading GPS signals indoor is barely possible. Besides, accuracy of GPS receptors is very low in small form factor carried by tiny robots.

On the other hand, errors caused by skidding wheels while robot has not moved or parallel deviation can be detected by a ternary control loop using not only detection of movement, but also detection of acceleration towards each axis.

3.3 Feedback control mechanism:

Essentially the movement of the robot is translated in terms of number of Pulses generated from shaft-encoders connected to each wheel. The number of Steps estimates the length of movement and rotation of each wheel. However it might face with an error in movement. Therefore, the robot is deviated from the straight line. Consequently, error on both motors at the same time do not deviate the robot from the line but it causes less or more movement on that line. Therefore, the trajectory planning of the robot movement is planned as a rectangle starting from a vertex and return to the same after passing all four edges.

This path is divided into smaller sub paths based on number of traversed pulses. And at each, the magnetic angle of the robot is read using the compass module. If the robot is deviated the correct value for control algorithm is calculated to eliminate and minimize the total error.

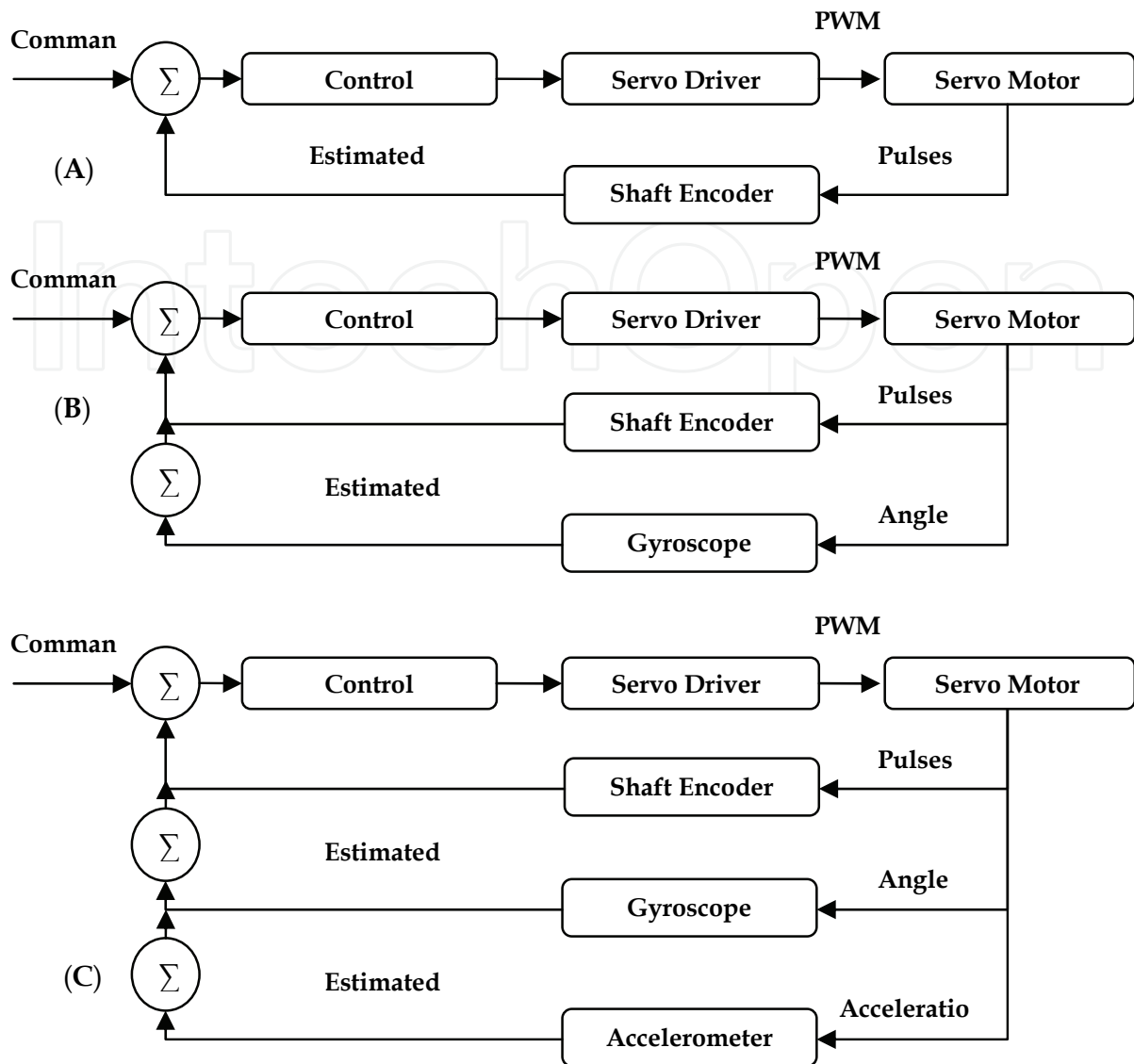


Fig. 2. Feedback control with shaft encoder (A), additional loop for gyroscope (B), and the third loop for accelerometer (C).

As shown in Fig. 2(A), the robot is only based on shaft encoder and without Gyroscope to be used in cascaded control as the second loop. The loop continues until the number of pulses coming from shaft encoders reaches the required value. For instance, the command `go_forward(1 meter)` will be translated as `Right_Servo(CW, 1000)`; and `Left_Servo(CCW, 1000)` then the shaft encoder which triggers external interrupt routines for counting left and right pulses. The encoder value will be increased at each interrupt call until it reaches the maximum value (i.e. 1000 in above example). Then it sends a stop command to pulse generator module at control unit to stop the corresponding motor.

Such system yet is vulnerable to errors caused by the environment such as slippage while shaft encoders yet present correct movement. A command might be wasted at mechanics of motor because of voltage loss etc. in Addition, the motor might work but the wheel does not have enough friction with the floor to push the robot. Therefore, gyroscope enables the robot to understand such deviations. Fig. 2 (B) presents the cascaded control with inclusion of Gyroscope. Yet, slippages in the direction of movement while both wheels having same

amount of error do not activate gyroscope. Our proposed way to detect such error is to control acceleration continuously toward direction of movement. Acceleration is zero while traversing a path on a fixed speed. Moreover, acceleration can be subtracted from output of accelerometer in situations that robot traverses a path on variable speed. Fig. 2 (C) presents the triple cascade control loop.

3.3 Practical results

In order to test the result, we developed a scenario for movement of the robot without/with triple cascade control feedback mechanism. The robot must traverse a rectangle of edge size equal to one meter and return to the home position. The error is calculated in both unmodified and modified robot assuming only one direction of rotation (CCW). Following figure presents the developed scenario.

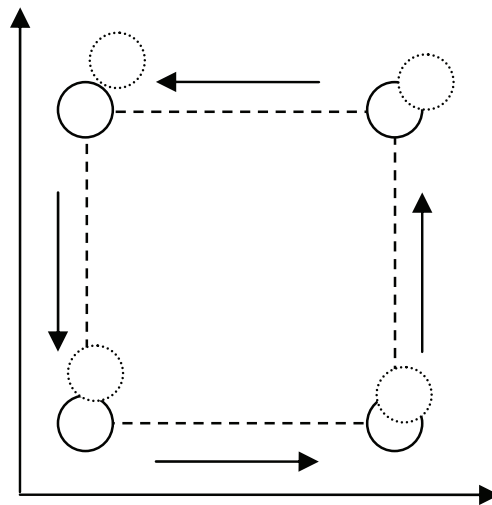


Fig. 3. Trajectory design of self-corrective cascade control robot

As shown in Fig. 4 (A), robot without second and third loop in cascade control mechanism deviates a lot from desired positions in robot trajectory. Fig. 4 (B) presents the corrected error after applying above mentioned loops to correct the deviation error.

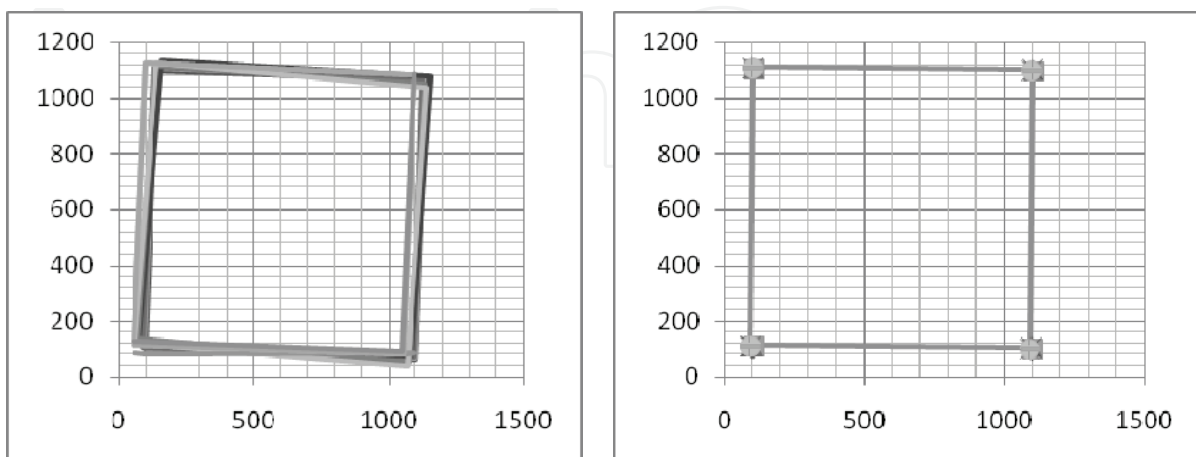


Fig. 4. Robot with only shaft encoder feedback control loop (A), and results while triple loop cascade control is applied (B).

In next section more sophisticated robots are presented while they are not only to correct the deviated errors but also they are able to identify friends from enemies in cooperative environment and help each other towards achieving the common goal.

4. Friend-or-Foe identification

In this section a novel and simple-to-implement FOF identification system is proposed. The system is composed of ultrasonic range finder rotary radar scanning the circumference for obstacles, and an infrared receiver reading encrypted echo messages propagated from omnidirectional infrared transmitter on the detected object through a fixed direction.

Each robot continuously transmits a message encrypted by a shared secret key between teammates consisting of its unique identifier and timestamp. The simplicity is due to excluding transceiver system for exchanging encoded/decoded messages. System counters replay attack by comparing the sequence of decoded timestamp. Encryption is done using a symmetric encryption technique such as RC5. The reason for selecting RC5 is its simplicity and low decryption time. Besides its hardware implementation consists of few XOR and simple basic operators which are available in all microcontrollers.

The decision making algorithm and behavioral aspects of each robot are represented as follows.

1. *Scan surrounding objects using ultrasonic sensor.*
2. *Create a record consist of distance and position for detected elements.*
3. *Fetch the queue top record and direct the rotary radar towards its position.*
4. *Listen to IR receptor within a certain period (i.e. 100 ms)*
5. *if no message is received*
 - a. *Clear all records*
 - b. *Attack the object*
 - c. *Go to 1*
6. *Otherwise,*
 - a. *Decode the message using the secret key*
 - b. *If not decodable Go to 5.a*
 - c. *Otherwise, register the identifier and timestamp besides position and distance for detected object*
 - d. *Listen again to IR receptor within a certain period*
 - e. *Decode the message using the secret key*
 - f. *If not decodable Go to 5.a*
 - g. *Otherwise, match the identifier and timestamp against the one kept before*
 - h. *If identifier mismatches or timestamp is the same or smaller than as it was before, Go to 5.a*
 - i. *Else if detected identifier is the same as the identifier of detector, Go to 5.a*
 - j. *Go to 3*

It is assumed that the received message is free of noise and corrupted messages are automatically discarded. This can be done by listening for a limited number of times if message is not decodable. However, transmission is modulated on a 38 KHz IR carrier so sunlight and fluorescent light are not highly distorting the IR transmitted stream.

4.1 Hardware Implementation

Our first generation of cooperative mini sumo robot included an electronic compass instead of gyroscope and accelerometer so it was not able to detect skidding errors towards any axes without possibly the robot being rotated. Very common instance is when the robot is pushed by enemies. Fig. 5 (A) presents the first developed board being able to control two DC servomotors, communicate through wireless over 900MHz modulation, and having infrared sensors and bumpers to detect surrounding objects.

In the second design, an extension board suitable for open source Mark III mini sumo robots is presented. The Mark III Robot is the successor to the two previous robot kits designed and sold by the Portland Area Robotics Society. The base robot is serial port programmable. It includes PIC16F877 20MHz microcontroller with boot-loader which has made programming steps easier. In System Programming (ISP) is provided by boot-loader facility. It is possible to program the robot in Object Oriented PIC (OOPIC) framework. It includes controller for two DC servomotors in addition to three line following and two range finder sensors. Low-battery indicator is an extra feature provided on Mark III. However, there were few requirements to enhance the robot to fit our requirements for cooperative robotics. Wireless Communication, Ultrasonic range finder, infrared modulated transceiver, gyroscope, and acceleration sensors were added in extension board as shown in fig. 5 (B). In addition, the robot uses two GWS S03N 2BB DC servomotors each providing 70 gr.cm torques at 6v. However, the battery pack connected to motors is not regulated so it does not provide steady voltage while discharging. It effects center point of Servo calibration which effects servo proper movement. In extension board, a regulator is also included to fix the problem explained above.

Such robots are able to communicate and collaborate with each other in addition to benefitting from self-corrective cascaded control system. It can be easily used as a controller for intelligent robotics to solve a given task cooperatively by multiple robots.

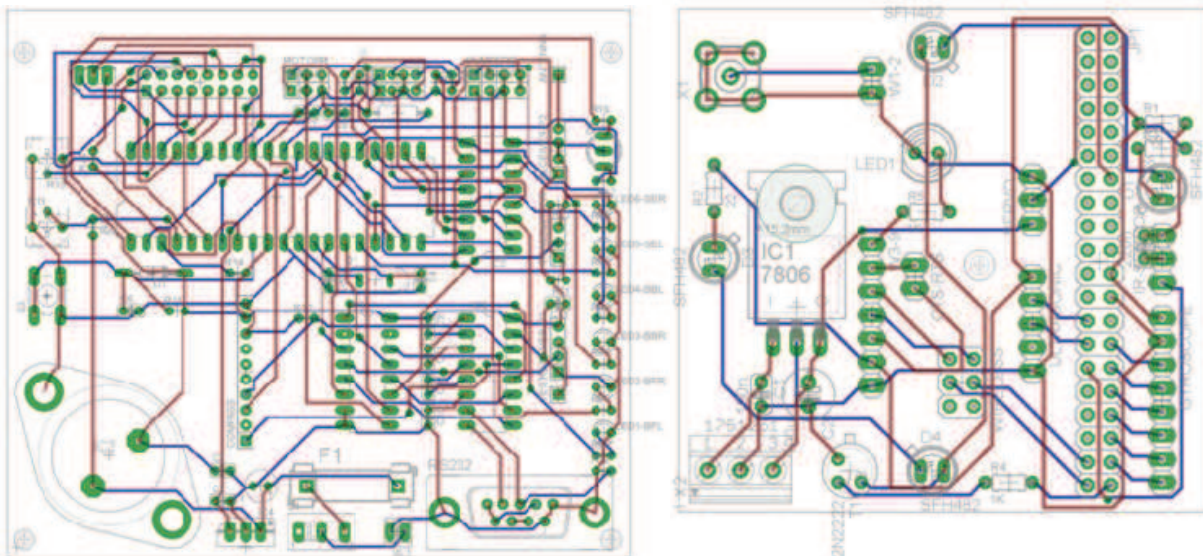


Fig. 5. The first generation of cooperative mini sumo platform robots 9×10 cm (A), and the extension board for Mark III (B).

4.2 Cipher analysis and attacking strategies

Following figure represents two of the worst cases for decision making in battlefield. These two crucial situations shown in Fig. 6 includes 1) When an enemy robot masks a

friend and enemy copies messages it receives from the masked friend to others so called reply attack. 2) Attacking an enemy by two robots from opposite sides

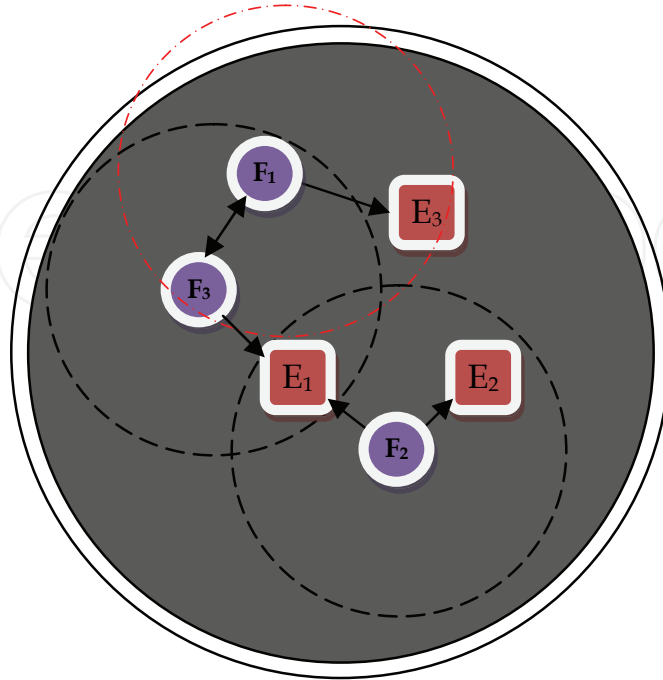


Fig. 6. An example arrangement of two teams of robots while fighting. Arrows demonstrate detection of objects.

4.2.1 Replay attack

In the first instance, E_1 stands between F_2 and F_3 covering their line of sight, so it is possible for E_1 to copy messages propagated from F_3 and replay them to F_2 and present itself as a friend and then attack against F_2 . In this situation, F_2 assumes that E_1 is friend F_3 and it will be targeting the next possible enemy detected by rotary radar however it will be attacked by E_1 . Part 6.1 of the algorithm presented in Section 2 counters replay attack. In order to avoid replay attack, the timestamp included in decrypted message is compared against the one received in advance. Besides, the other friend robot receives the same copy of its own transmitted message including its identifier. Therefore it recognizes the enemy by matching and comparing the identifier of copied message with its own unique identifier. Therefore it recognizes the enemy.

4.2.2 Opposite side dual attack

According to the algorithm represented in previous section, both F_2 and F_3 start attacking E_1 from opposite sides either towards sideways of E_1 , or one faces front of E_1 . In both cases, they keep pushing enemy until they see the boundary so they return and start searching for other enemies. However, they either stay in this situation and challenging for a long time or one of friend robots understands that it is pushed out. It is highly possible so any of friends will be detected by other enemies and they will be pushed out. Therefore, a convincing strategy is to escape if it is not able to push. Being pushed or challenging without being able to push is simply detectable by checking gyroscope and acceleration sensors. LIS3LV02DL from free samples of ST Microelectronics single chipset gyro-acceleration sensor is used to provide movement and acceleration towards x , y , and z axes.

4.3 Strategies

Escape strategy simply consists of backing off for a period or rotating around itself with maximum speed and then moving towards a direction so it can start the algorithm from beginning or attack the enemy from a better direction.

Another upgrade in algorithm is to cancel an attack if the enemy is escaped away out of detection radius. The reason is making the system more efficient and spending time on fighting against other enemies instead of an escaping robot which might not be caught in a short while.

It is assumed that the radius of detection range is adjusted to half of radius of the platform. It is due to applying Divide and Conquer (DAC) policy within cooperative robots by assuming to solve each subset of battlefield by one of the robots. In addition it reduces the complexity and collision while communicating with other teammates. Later it is shown that the radius of detection can be dynamically changed based on real-time conditions of match.

A better but more time consuming approach is to detect all enemies in range and then decide which one to attack rather than attacking against first detected enemy. For instance, E_1 and E_2 are in see sight of the F_2 . In this situation F_2 should be intelligent enough to choose the best attack. It is highly possible for robots to be at the boundary so they cannot back off or run away. Therefore the robot has to attack to the first detected enemy asking for help from other teammates.

Determining the level of power of enemy robots helps deciding to utilize escape strategy more efficiently. The problem refers to the condition that level power of enemy robots are more than ours. Therefore, in such situation having face to face attack is not desired. Instead, the only way to remedy is to attack from wheel sides of enemy robot. Consequently finding relative movement angle of the enemy robot helps friend robots to decide whether to attack or not. Following are three main concerns.

4.3.1 Determining the level of power of enemy robots

Utilizing gyroscope and matching it with usual speed of the robot in steady state helps measuring movement toward x, y, z axes. See fig. 7.

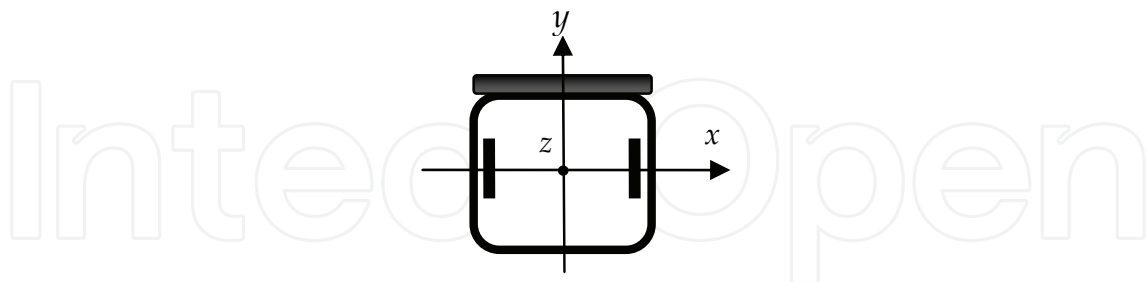


Fig. 7. The direction of axes over the robot while y showing the front of the robot.

Respectively A_x, A_y, A_z variables presents gyroscope values. The digital returning value from SPI port indicating gyroscope results follows $A_x, A_y, A_z \in (-512, +512)$. Attacking face to face with enemy robot is when $A_y < -\alpha, \alpha > 0$ or $A_x > \beta, \beta > 0$. While α and β are threshold values such that $A_y < -\alpha$ shows backward movement and similarly $A_x > \beta$ indicates side movements more than an acceptable threshold for skidding errors. Therefore, $A_y < -\alpha$ indicates that the level of power of the enemy is more than being able to repel against. In this case attacking sideways of enemy is needed. Respectively, the relative angle

of enemy should be suitable for attack so that one side of enemy could be caught. The ultrasonic rangefinder on implemented rotary radar determines the distance to detected object. The relative angle is calculated from position of DC servomotor rotating the radar. An example is represented in Fig. 8.

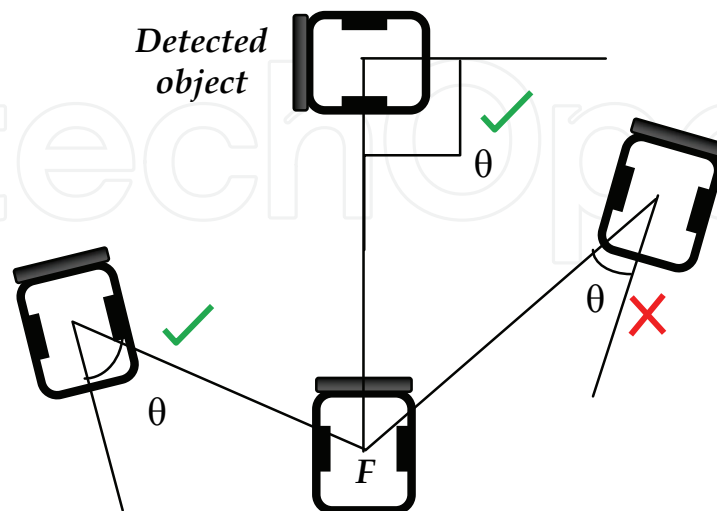


Fig. 8. θ is acceptable if $\theta > \theta_0$.

4.3.2 Determining the speed of enemy

Estimating velocity of enemy robots is done through two ways. Firstly, while the enemy attacks directly towards friend. Therefore, $v_e = \frac{l}{s}$, v_e is velocity of enemy robot, and l is the distance traversed in s seconds. Secondly, we can estimate speed of enemy robot using radar. At first detection of enemy, assuming its distance is l_1 and detecting it again in a short while as s seconds in distance l_2 with θ degrees angular rotation of rotary radar, speed can be calculated as follows using law of Cosines as shown in Fig. 9.

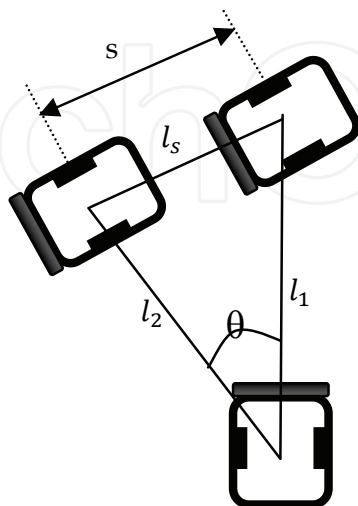


Fig. 9. Second way of calculation of the average speed of enemy.

$$l_s = \sqrt{(l_1)^2 + (l_2)^2 - 2l_1l_2 \cos \theta}$$

$$v_e = \frac{l_s}{s}. \quad (3)$$

4.3.3 Determining the relative angle of enemy robots

The relative angle is considered in both static and dynamic situations. Static situation (see Fig. 10) is while friend robot does not move. Reversely, dynamic situation declares when friend robot is moving.

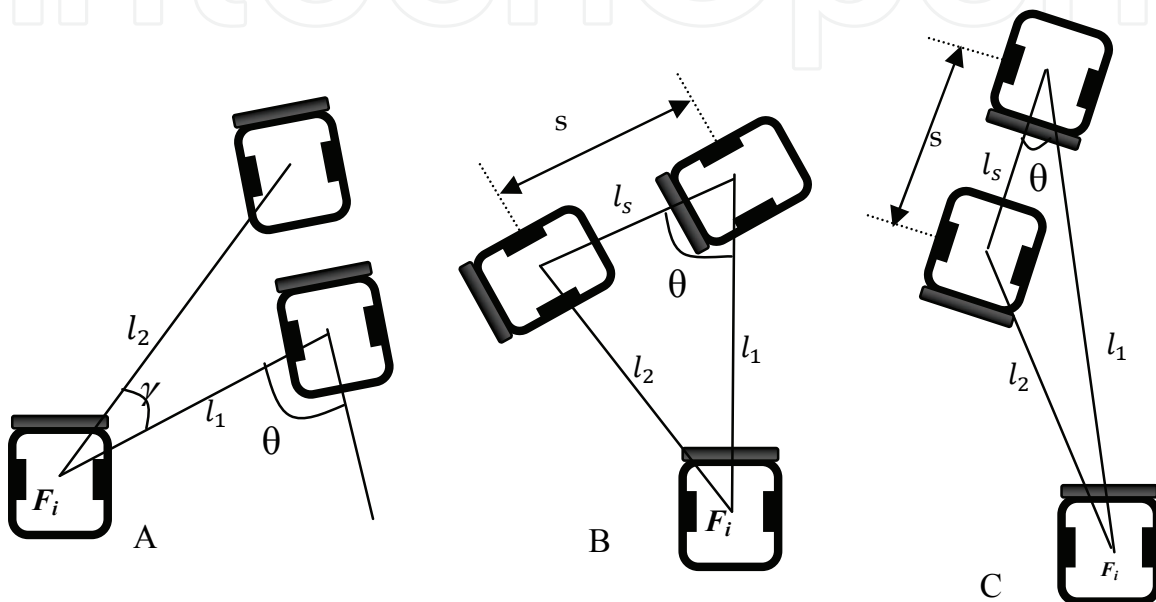


Fig. 10. While enemy is getting far from friend robot (A). The enemy gets closer with a desirable angle (B). While enemy gets closer with an angle more than threshold (C).

In fig. 10 (A) $l_2 > l_1$ then in attacking strategy it is decided to follow the enemy if it is in an acceptable range considering that the enemy would not be able to change the role of front and back side of the robot. Otherwise, leaving the target is a better decision as enemy probably has time to attack friend robot.

In fig. 10 (B) $l_2 < l_1$. $0 < \frac{l_1 - l_2}{s} < \alpha$, α is an acceptable threshold for speed of decreasing distance of enemy towards friend. Satisfying above inequality allows attacking the enemy. $l_s = v_e \cdot s$, l_s is the distance traversed by enemy robot in s seconds.

In the situation shown by fig. 10 (C) friend is not allowed to attack. Therefore execution of escape strategy is done and friend robot runs away. In other words, $\frac{l_1 - l_2}{s} > \alpha$, which shows that the enemy is in good state to attack friend.

$\bar{l} = l_1 - l_2$, $\bar{v} = \frac{\bar{l}}{s}$, \bar{v} stands for velocity of enemy moving towards friend robot. Final results of static situation are as follows.

1. If $\bar{v} \cong 0$ then the movement of enemy is octagonal to our robot.
2. If $0 < \bar{v} < \alpha$ then enemy is getting close with an acceptable relative angle for friend to attack.
3. If $\bar{v} \cong v_e$ then the enemy is able to attack straight.

Next, the dynamic situation is considered. As shown in fig. 11. $l_{s_e} = v_e \cdot s$, l_{s_e} is the distance traversed by enemy in s seconds. Similarly, $l_{s_f} = v_f \cdot s$, l_{s_f} is the distance traversed by friend in s seconds. Results of dynamic situation are as follows.

If $\bar{v} < v_f$ then enemy is going far (see Fig. 11 (A)).

1. If $\bar{v} \cong v_f$ then the movement of enemy is octagonal to our robot.
2. If $v_f < \bar{v} < \alpha$ then enemy is getting closer (see Fig. 11 (B)).
3. If $\alpha < \bar{v} \leq v_f + v_e$ then the enemy is able to attack straight.

Conditions 2 and 3 are desirable to attack. However, a better strategy in condition 4 is escaping away. Condition 1 depends on the ratio of speed of friend versus speed of enemy. This ratio can be used in decision making strategy whether to attack or leave the enemy.

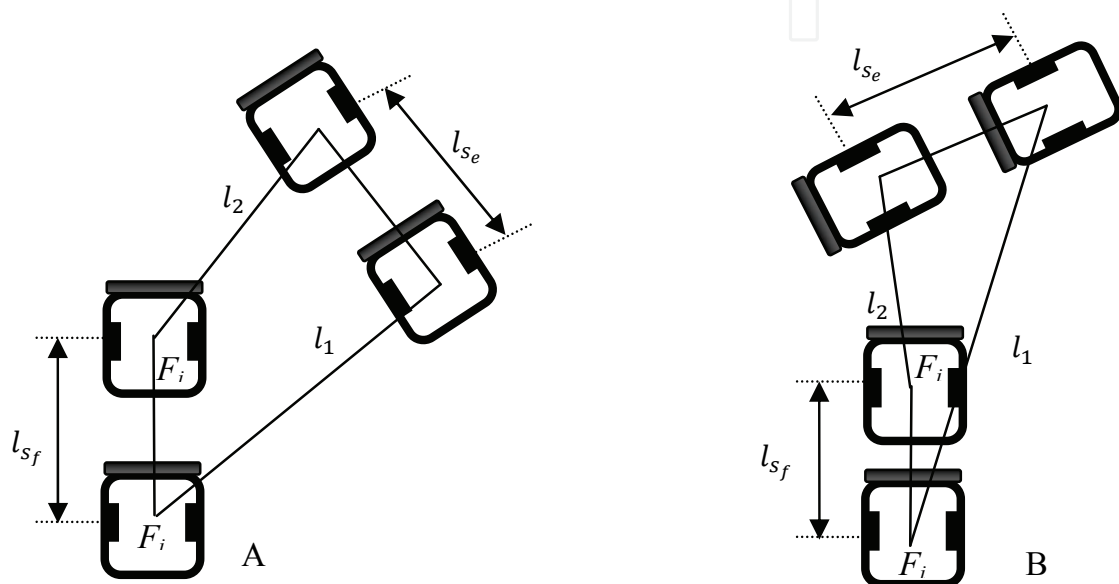


Fig. 11. $\bar{v} < v_f$ (A), and $v_f < \bar{v} < \alpha$ (B).

If the enemy comes towards friend straightly and there would be no possibility to escape, friend should start attack while announcing request for help over wireless medium. Notice, it is already known that level of power of enemy is higher than level of power of friend. Therefore more likely, friend will lose the battle. Now teammates can decide to help the challenging friend if the distance is acceptable or if friend is in the range of their radar, or leave the friend to die.

4.4 Experimental results

The developed system is tested on team of three robots. The team of enemies consists of three cooperative robots with basic abilities which include IR transceiver for FOF identification. The test is done for ten rounds. Last remaining robot(s) win the game. There were five different situations to test robots. Therefore, fifty different rounds of competition were conducted. These five situations included basic, wireless enabled, radar and wireless enabled, radar and wireless with gyroscope, and finally everything in addition to utilizing escape strategy. Wireless communication helps robots to talk to each other, share their information, and ask for help. Rotary radar is an ultrasonic range finder. Gyroscope shows movement towards all directions. Finally escape strategy is a software enhancement as mentioned in earlier section. Following figure presents five set of competitions each in ten

rounds. The absolute duration for each competition resulting loss of one team is considered separately in terms of mm:ss.

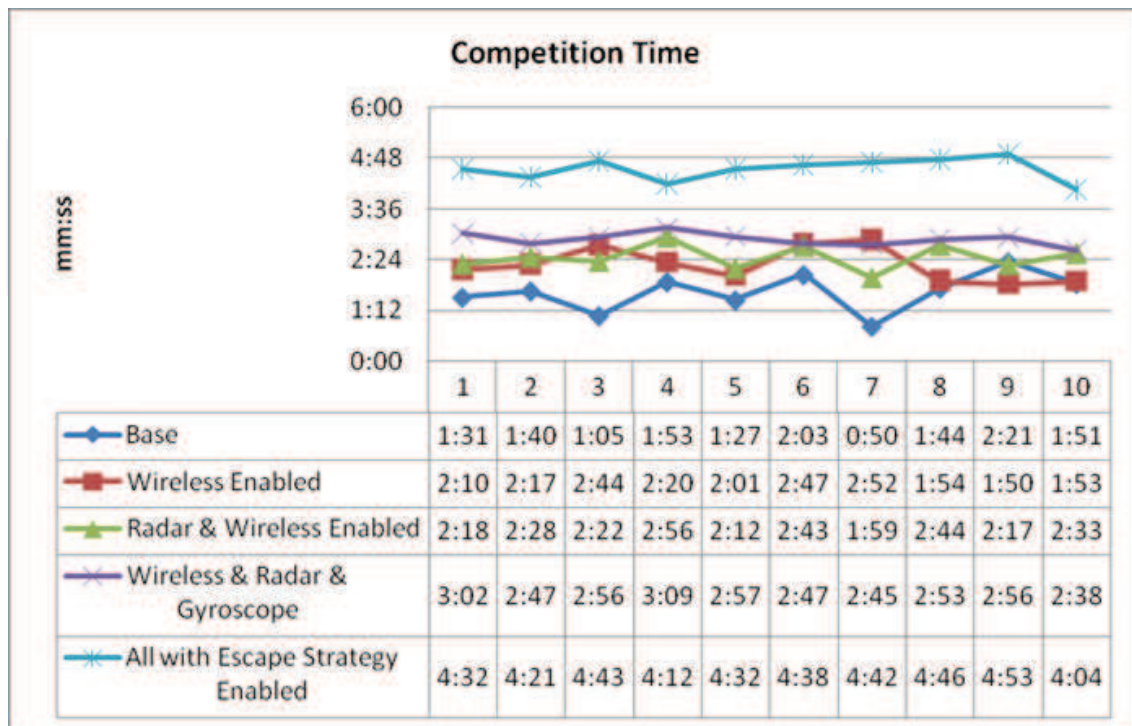


Fig. 12. Competition time for 50 different tests

5. Simultaneous localization and mapping

An unmanned aerial vehicle (UAV) is tasked to explore an unknown environment and to map the features it finds, but must do so without the use of infrastructure-based localization systems such as GPS, or any a priori terrain data. The UAV navigates using a statistical estimation technique known as simultaneous localization and mapping (SLAM) which allows for the simultaneous estimation of the location of the UAV as well as the location of the features it sees. SLAM offers a unique approach to vehicle localization with potential applications including planetary exploration, or when GPS is denied (for example under intentional GPS jamming, or applications where GPS signals cannot be reached), but more importantly can be used to augment already existing systems to improve robustness to navigation failure (Bryson & Sukkarieh, 2008)

The solution of the SLAM problem has been one of the notable successes of the robotics community over the past decade. SLAM has been formulated and solved as a theoretical problem in a number of different forms. SLAM has also been implemented in a number of different domains from indoor robots, to outdoor, underwater and airborne systems. At a theoretical and conceptual level, SLAM can now be considered a solved problem. However, substantial issues remain in practically realizing more general SLAM solutions and notably in building and using perceptually rich maps as part of a SLAM algorithm (Chanier et al., 2008) (Pathiranage et al., 2008).

The first problem is the computational complexity due to the growing state vector with each added landmark in the environment. The second problem is the data association which matches the observations and landmarks in the state vector (Temeltas & Kayak, 2008).

One key requirement for SLAM to work is that it must re observe features, and this has two effects: firstly, the improvement of the location estimate of the feature; and secondly, the improvement of the location estimate of the platform because of the statistical correlations that link the platform to the feature. So our UAV has two options; should it explore more unknown terrain to find new features, or should it revisit known features to improve localization quality. These options are instantiated into the online path planner for the UAV (Bryson & Sukkarieh, 2008).

One of the main problems with the SLAM algorithm has been the computational requirements. Although the algorithm is originally of $O(N^3)$ the complexity of the SLAM algorithm can be reduced to $O(N^2)$, N being the number of landmarks in the map. For long duration missions the number of landmarks will increase and eventually computer resources will not be sufficient to update the map in real time. This N^2 scaling problem arises because each landmark is correlated to all other landmarks. The correlation appears since the observation of a new landmark is obtained with a sensor mounted on the mobile robot and thus the landmark location error will be correlated with the error in the vehicle location and the errors in other landmarks of the map. This correlation is of fundamental importance for the long-term convergence of the algorithm and needs to be maintained for the full duration of the mission (Frese, 2005).

Recently, estimation algorithms have been roughly classified according to their underlying basic principle. The most popular approaches to the SLAM problem are the extended Kalman filter (EKF-SLAM) and the Rao-Black wellized particle filter. The effectiveness of the EKF approach comes from the fact that it estimates a fully correlated posterior over feature maps and vehicle poses. EKF-SLAM permits linear approximations of the motion and the measurement models, and it assumes Gaussian representations for the probability density functions .the solution of the EKF-SLAM is inconsistent due to errors introduced during linearization, which induces inaccurate maps with filter divergence. Therefore, the consistency issue of the EKF-SLAM has attracted the attention of the research community due to its importance, and many recent research efforts have concentrated on improving the classical algorithm (Kim et al., 2008).

5.1 Proposed SLAM method

There are N robots as friends and N robots as enemies. Friends achieve the simultaneous map presenting the position of all robots. This scheme consumes ultrasonic radar, gyroscope and wireless connection. At the beginning, the radar will present position distance of any detected object within its receptive range. It is obvious that some might be masked. We consider the matrix A with two dimensions with the size $2N \times 3$ as follows.

$$A = \begin{bmatrix} ID_1 & l_1 & \theta_1 \\ ID_2 & l_2 & \theta_2 \\ \vdots & \vdots & \vdots \\ ID_{2N} & l_{2N} & \theta_{2N} \end{bmatrix}_{2N \times 3} \quad (4)$$

ID_i presents the identification of detected object i . A fixed unique identifier is given to friends in the range of 0 to $N - 1$. ID_i is equal to N for foes and consequently undefined objects are tagged by $N + 1$. l_i is the distance between the robot and detected object. Therefore, it is equal to 0 for the Scanner robot. θ_i is the angle between North Pole and the detected robot. Thus it defines the angle for scanner robot if $l_i = 0$. All equations can be

upgraded so that perpendicular vector to connecting line of the wheels or front side of the robot would be considered as North Pole. For the time being let's consider the angle between front side of the robot and detected object as α_i . Then $\theta_i = (\alpha_i + \theta)$. $\theta = \theta_i$ if $l_i = 0$. α_i is in the range of 0 to +180 for counterclockwise rotation; and it is in the range of 0 to -180 for clockwise rotation. The radar initial state is as 0 position while pointing to front side of the robot. θ presents the shift from North Pole. Thus both θ and θ_i are positive when the angle is towards counterclockwise direction. Following figure presents three different situations while scanning the environment.

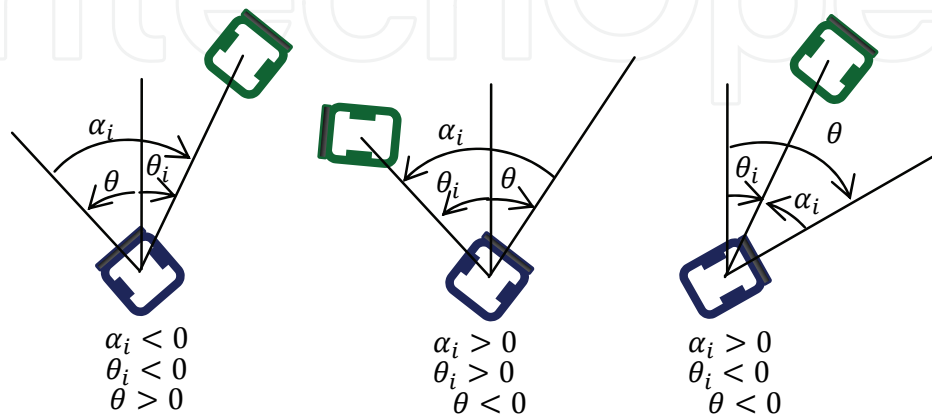


Fig. 13. Different situations while scanning the environment by ultrasonic radar

The matrix A is broadcasted and thus the most recent SLAM information is propagated among all robots. There are three conditions while aiming to find position of friends: 1) A friend is detected, 2) A friend is masked by another friend, and 3) A friend is masked by foe. First case is straightforward, therefore, second and third situations are considered as follows. In second condition, as shown in Fig. 15, the robot at the bottom of figure (scanner) cannot detect the robot which is masked behind the robot in the middle.

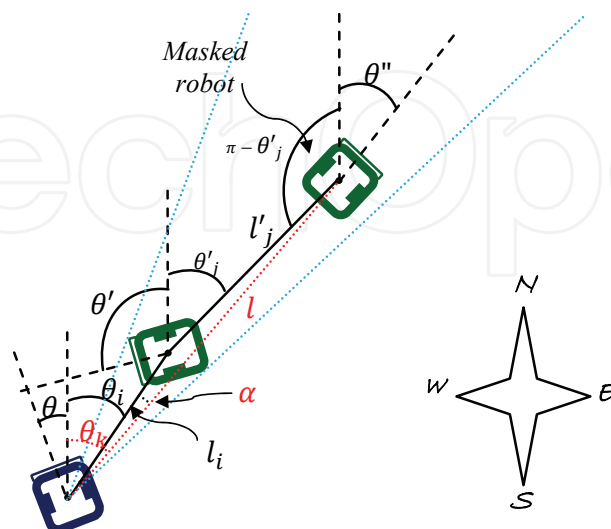


Fig. 15. A friend is masked by another friend.

In this condition l is the distance between the robot at the bottom and the masking robot. The masking robot is having θ_k degree with scanner considering to North Pole. Therefore, l and θ_k are calculated as follows.

$$l = \sqrt{(l_i)^2 + (l'_j)^2 - 2 l_i l'_j \sin(\pi - |\theta_i| - |\theta'_j|)} \quad (5)$$

$$\theta_k = \theta_i + \alpha$$

and, by the sine rules on triangle

$$\frac{l}{\sin(\pi - |\theta_i| - |\theta'_j|)} = \frac{l'_j}{\sin \alpha} \Rightarrow \alpha = \sin^{-1} \left(\frac{l'_j \cdot \sin(|\theta_i| - |\theta'_j|)}{l} \right) \quad (6)$$

then scanner robot updates l and θ_k of record corresponding to the masked robot. In third condition as seen in the following figure, two situations are considered.

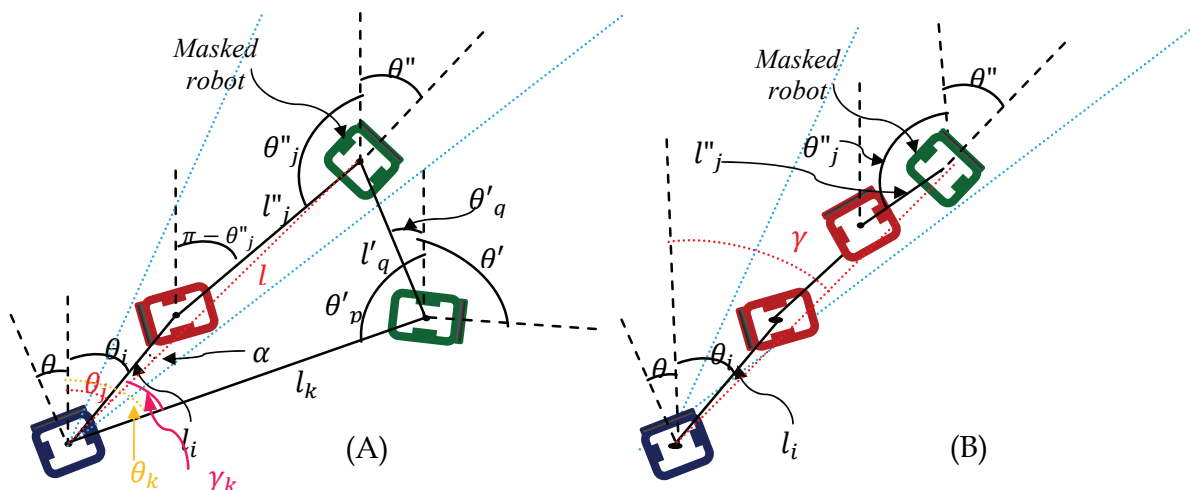


Fig. 16. Third situation while a friend is masked by an enemy. Blue robot is scanner, Friends are shown in green color, and Enemies are shown by red.

In the Fig. 16 (A) a friend is masked by an enemy. In this condition l and θ_k are calculated as there is only one enemy between scanner and the masked friend. However, Fig. 16 (B) presents a worse situation while a friend is masked by two consequent enemies. In such case calculation of SLAM will be done at another robot where both current scanner and friend are not masked by two enemies in the middle. Therefore, at least three robots are needed at each side. Consequently, l and θ_k of the masked robot are calculated accordingly.

$$l = \sqrt{(l_k)^2 + (l'_q)^2 - 2 l_k l'_q \sin \beta}$$

$$\beta = \theta'_p - \theta'_q \quad (7)$$

$$\frac{l}{\sin \beta} = \frac{l'_q}{\sin \gamma_k} \Rightarrow \gamma_k = \sin^{-1} \left(\frac{l'_q \cdot \sin \beta}{l} \right) \Rightarrow \theta_j = \theta_k - \gamma_k$$

In case of having no friend in a proper position to solve the problem presented in Fig. 16 (B), the record and estimation of position of friends are considered. θ is known for all friends. Comparing SLAM records generated at both scanner and masked robot at certain timing which is base on subtraction of timestamp of two consequent records provides an estimated record for the masked robot. The angle is approximately equal to the angle which the masking enemy (γ) exists. A very accurate detection is done by searching among θ_i and comparing them against $\pi - \theta_i$ of angle of masked friend in addition to keep tracking of previous position of friend at Δt period of time.

6. Reasoning through semantic intelligence

Semantic Web Services provide a new approach to communication, situation- and context-awareness, and knowledge representation for reasoning by multiple agents. Collaboratively working multiple robots on a mesh acting autonomously require a universal platform in order to merge data processed by each agent for perception and map building while gathering possible answers to a query.

In the foundation of semantic Web reasoning engines and communication platforms rests Open World Assumption (OWA). This is due to 'openness' of web where absence of entities being searched should not entail negative response rather simply treated as a fact "not available at the moment." While, that sets the base in anticipation of future enhancements of the fact base, it is not preferred in situations where a definitive answer is needed. Closed World Assumption (CWA) alternatively returns definitive yes/no answers even in situations where future enhancements are inevitable (Elçi et al., 2008). It is also essential to derive partial results from a set of cooperative agents/robots based on Locally Close World (LCW) settings (Doherty et al., 2000).

Robots currently apply CWA for decision making and learning. They could also utilize the huge mass of information available on semantic web in order to deduct new knowledge using standard or extended OWA. Consequently, robots cannot only cooperate and communicate using semantic Web platform but also be able to retrieve much more realistic and acceptable answers to queries. This is even more so where unsupervised learning plays the main role where our knowledge about task is incomplete; and that is true for the most of real life situations.

Systems with distributed processing and control require distributed coordination in order to achieve a shared goal. Such systems may be realized using self-actuated agents donning semantic capability such as that of an autonomous semantic agent (ASA). Implementation of an ASA (Elçi et al., 2006) as a semantic Web service possibly offered by a robot provides the required features. In a multi-agent system, one of the ASAs may indeed assume as well the duty of a common site acting as the central registry of web services in the field. We devised new software architecture for distributed environments using autonomous semantic agents (ASAs) (Elçi & Rahnema, IWSC2005, 2005). Multiple ASAs can act collaboratively serving the same goal. One of the applications ASAs can serve is Traffic network Management System (TMS).

Recent research on traffic and transport systems has been concentrated on vehicle and driver safety through fitting vehicles with onboard IT systems. TMS takes control over traffic flow and reports possible incidents in an urban area. An intersection network can then serve to improve the quality of life in mobile municipal communities (Elçi & Rahnema, 8-9 June 2006), (Takahashi et al., Dec. 2004). Traffic junctions can be replaced by MASAs

rather than to be controlled through a centralized architecture. An instance of such structure is a security scenario concerning tracing and tracking of missing vehicles was considered and shown how to implement it over so called Traffic network Management and Information System (TMIS) network. Simulation results showed promising outcomes. Further research involving similar development base was also suggested (Elçi et al., TEHOSS 2006, 09-13 October 2006). Cooperatively responding to a query by intelligent intersections in TMIS is in some essential ways similar to a multi-agent robotic system discovering a way out of a labyrinth. Communication-wise, each robot should talk to its neighbors and share its information. Furthermore, we aim at effecting coordination and cooperation among MASAs towards realizing intelligent behavior in order to achieve a shared goal through processes benefiting from semantic web technologies (Elçi & Rahnama, ROMAN 2007, August 26-29, 2007) (Elçi & Rahnama, 30 Nov - 1 Dec 2006). Within this respect and for simplicity in referring to these robots, and in order to convey their capability better, we will call them as the Cooperative Labyrinth Discovery Robots (CLDRs).

Researchers have worked in various categories of cooperatively solving problems by robots. For instance, to recite a few, Takahashi et al. (Takahashi et al., Dec. 2004) studied autonomous decentralized control for formation of multiple mobile robots. They covered formulations for forming a group of robots following the same goal. Chia-How Lin et al. (Lin et al., 10-12 Oct. 2005) represented an agent-based robot control design for multi-robot cooperation in real time control. Their system is suitable for cooperative tasks with capability of controlling heterogeneous robots. Finally, Xie Yun et al. (Yun et al., 5-8 Oct. 2003) have prepared a communication protocol for their soccer robots.

In cooperative robotics, such as Cooperative Labyrinth Discovery (CLD) (Elçi & Rahnama, 30 Nov - 1 Dec 2006), (Elçi & Rahnama, 2009) in an uncharted labyrinth, conventionally, the probability and the estimation were used to select one path among a set of possible but as yet undiscovered ones. In order to overcome naïve decision making, according to (Elçi et al., 2008) a hybrid scheme is needed to serve as decision maker. Following algorithm is a revised and simplified version of the one presented at (Elçi & Rahnama, 2009) to suite the limited capacity CCLDRs by dividing it into two phases running cooperative decision making on SCLDRs and local standalone decision making on CCLDRs.

Team of CLDRs consists of an SCLDR and some CCLDRs start discovering an unknown labyrinth trying to find the correct exit. (i.e. an entrance should not be distinguished as exit if it is not defined so). The only information they have is the position of entrance they start from and position of exit in labyrinth matrix but not the way through. As mentioned earlier a counter is defined for each cell presenting the number of times that a robot has visited it. Therefore, value 0 presents an undiscovered cell. In SCLDR in addition to copy of local counters, another counter indicates shared value as sum of all local counters concerning a cell.

The a / β algorithm is an undeterministic version of minimax algorithm widely used in AI. Our algorithm applies a / β algorithm as entire labyrinth data is not known for each individual. Assuming a CLDR at a junction with 4 possible ways (left, right, forward and backward), a / β finds the minimum of counter values of respected neighboring cells. For instance, assuming 3 for value of local counter of cell at left side, 4 for front and 8 for the cell at backside, and 0 for the cell at the right side, the minimum of 0, 3, 4, and 8 which is 0 (right) is chosen. Following is the detailed algorithm.

1. CCLDR is on a cell in the labyrinth. It is to decide on its next move: advance to neighboring cell forward, left, right or backup?
2. Has the current cell been visited before?
 - 2.1. Read walls of the current cell if not visited
 - 2.2. Update local counter at CCLDR and request SCLDR to update the shared counter
 - 2.3. Request SCLDR to update shared memory of paths (Actually it is done as consequence of 1.2. at SCLDR)
3. Run Decision-Maker based on CWA (Local Counters) obtaining the next-move-to cell.
 - 3.1. Has the next-move-to cell been visited before?
 - 3.1.1. If yes, run shortest path algorithm
 - 3.1.2. Otherwise wait for the answer from SCLDR based on following situations
 - 3.1.2.1. Finding results of running α / β algorithm based on shared counter of visited cells
 - 3.1.2.2. If α / β algorithm returns more than one minimum, run OWA based on local counters
 - 3.1.2.3. If OWA results in an unknown answer, then infer from labyrinth ontology based on LCW by limiting shared ontology to just neighboring cells.
 - 3.1.2.4. If LCW reasoning contradicts CWA results, select a solution randomly or based on a move priority
4. Move the robot to the next-move-to position and update position value.
5. Check if the selected cell is an exit cell.
 - 5.1. If not, repeat from Step 1.

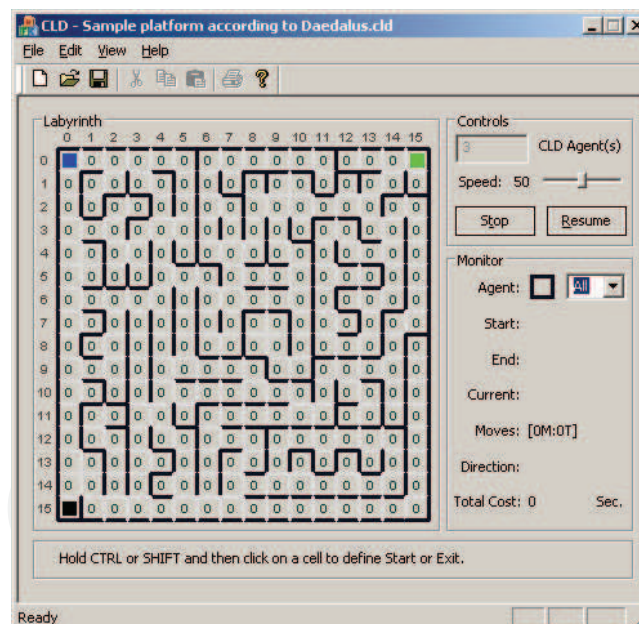


Fig. 17. Screenshot from the Semantic Intelligent Reasoning Engine on three cooperative labyrinth discovery robots.

The experience with this algorithm proved that there are some cases for which CWA alone cannot answer the query so OWA returns a better estimation of a possible answer. Therefore, utilizing open / locally-closed / open world assumptions simultaneously is necessary side-by-side. It is not possible to avoid any of the world assumptions but having them together leads to better answer sets to queries in some domains such as robotic platforms. This powers the robot with better estimation and answers where CWA alone

would have returned negative result. The following screenshot presents the SI software developed to act as core of decision making according to the given algorithm.

7. Conclusion

This chapter draws a beginning to end framework for design and implementation of more intelligent robots in different aspects such as self-localization, deviated error correction, Friend or Foe identification, simultaneous localization and mapping, and finally semantic intelligence. Line-following robots were used to illustrate simple modification without necessarily hardware improvement and making them able to localize themselves while traversing a curve or a straight line. Mini-sumo robots were the example case self-corrective cascade control and friend or foe identification robots while absolute positioning of each teammate was not possible. Our designed friend or foe strategy does not require two-way communication as it only relies on decryption of payload in one direction. The replay attack is not feasible time wise as the communication is encrypted and timestamp is inserted in the messages.

There were two sets of hardware implementations for the test robots. The second version is equipped with rotary robot able to detect direction and distance to detected object in addition to gyroscope chipset. There were several facts that could be enhanced in decision making algorithm of fighter robots. There were situations that robot were losing the game against more powerful enemies. Although studying dynamics of robots allowed finding solutions to attack such enemies from sides so they will not be able to resist. There were certain situations that robots must escape instead of fighting. These states were based on the relative position, speed and other properties of enemies which could be calculated by friend robots helping them to act more intelligently in cooperative environments. Such improved robots can be used within the scope of industry standards and they that can be applied in manufacturing industries, hospitals, and automated seeking products in chain shops.

Finally, design and implementation of client cooperative labyrinth discovery robots (CCLDRs) were presented especially addressing severe restriction or lack of resources. Decision making is performed through a semantic intelligence approach incorporating Open / Locally Closed / Closed World Assumptions in its algorithm. The algorithm was retrofitted from earlier research in order to fit into limited capacities of client CLDRs. On the other hand, decision making algorithm was optimized to perform autonomously leaving only more complicated calculation to SCLDR.

CCLDR hardware architecture was enhanced by inserting an extension board accommodating modulated IR receivers for Friend or Foe determination, wireless communication capability, and allowing multiplexing of line tracing and sides detector sensor boards. Robots are able to localize themselves based on the mathematical formulations relying on distance measurements by side sensors but without needing shaft-encoders. They act as clients of more advanced CLDRs with ability of processing ontology files, and providing Semantic Web Services (SWS), etc. Within this environment, each agent is autonomous complex system acting based on its sensory input, information retrieved from other agents, and suitable form of converted ontology files from SCLDR.

8. Acknowledgement

We wish to thank Mr. Hamid Mirmohammad Sadeghi from EMU for his valuable contribution in mathematical formulating of proposed algorithms provided in this chapter.

The material in Section 3- Self-Corrective Cascaded Control was drawn from our project proposal "Self-corrective compass cascaded control system for AGVs" in the Project Competition to support young entrepreneurs by GMTGB Teknopark, Famagusta, North Cyprus. Our project proposal was awarded the fourth place on 24 October 2008.

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Advances in Human-Robot Interaction

Edited by Vladimir A. Kulyukin

ISBN 978-953-307-020-9

Hard cover, 342 pages

Publisher InTech

Published online 01, December, 2009

Published in print edition December, 2009

Rapid advances in the field of robotics have made it possible to use robots not just in industrial automation but also in entertainment, rehabilitation, and home service. Since robots will likely affect many aspects of human existence, fundamental questions of human-robot interaction must be formulated and, if at all possible, resolved. Some of these questions are addressed in this collection of papers by leading HRI researchers.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Atilla Elçi and Behnam Rahnema (2009). Towards Semantically Intelligent Robots, *Advances in Human-Robot Interaction*, Vladimir A. Kulyukin (Ed.), ISBN: 978-953-307-020-9, InTech, Available from:
<http://www.intechopen.com/books/advances-in-human-robot-interaction/towards-semantically-intelligent-robots>

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