Teleoperation of AutoMerlin by Inculcating FIN Algorithm

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***Abstract*—This work is presenting FIN algorithm, which is developed to assist the human operator in the teleoperation of AutoMerlin mobile robot. It enables the efficient teleoperation of the robot in the presence of random time delay and helps the operator in safe navigation through ill-structured environment having scattered obstacles. It is an auxiliary intelligence which has been added to already existing speed controller to avoid obstacles autonomously. FIN algorithm takes the control of robot when certain obstacle at a specified distance is detected by ultrasonic sensors and the robot gets the command from the human operator to move in forward direction or connection is lost between human operator and the mobile robot. Then, this algorithm detects the position of obstacle relative to robot and diverts the robot in the appropriate direction to avoid collision. The robot listens to the operator only for backward movement, when the obstacle is within specified range and ignores the forward motion command and avoid obstacle autonomously and shifts back the control to human operator. Servo control has been provided to steer the robot for 2D navigation. The presented results show the performance and effectiveness of algorithm during the teleoperation of AutoMerlin.**

***Index Terms*—fuzzy logic, 2D navigation, ground robot, servo control, teleoperation**

I. Introduction

Teleoperation of mobile robot is primary choice in the situations where the presence of human is undesired due to hazardous effects e.g. nuclear waste handling, explosive material transportation, landmines clearance and surveillance *et al.* Teleoperated robots also have crucial role in planets exploration, ocean floor inspection and complicated industrial constructions *et al*. In all these applications human robot interface plays the key role in successful completion of required tasks [1]-[3]. In recent years, demands for teleoperation of mobile robots controlled by human operator are increasing because they are equally useful in maintenance work in power plants [4].

The teleoperation of mobile robots is an extension to add human intelligence in the control loop, because human can send teleoperated robot appropriate instructions according to the environment and situation demand. This property of teleoperated system makes it superior over autonomous robot and also there are no harmful effects on the human operator because s/he always stays at a safe distance from operation site [5]. Bilateral control provides another dimension to the teleoperation, enabling the human operator to interact with the remote environment by force feedback. A haptic device is used for this purpose and force feedback is played over it so that operator can feel that s/he is present at operation site [6].

In many mobile robot teleoperation applications it is common to use force feedback based on obstacles in the environment. This force displayed at the master device shows how to control the mobile robot in order not to collide with an obstacle in remote environment. This obstacle based force feedback is calculated by different methods in literature but mostly it is dependent on the distance between mobile robot and obstacle. This makes mobile robot teleoperation system with obstacle based force feedback different from classical master-slave manipulator bilateral teleoperation system in which a slave robot interacting with environment is directly affected by environmental forces [7], [8].

Obstacle avoidance is the back bone of safe navigation of mobile robot which enables it to reach to destination without collision. Several algorithms have been proposed for obstacle avoidance having drawbacks and benefits. Ref. [9] presents different algorithms for robot navigation with obstacle avoidance. They have compared different algorithms and mentioned their characteristics, advantages and disadvantages. Ref. [10] the work focuses on the navigation subsystem of a mobile robot which operates in human environments to carry out different tasks without colliding with different objects, such as transporting waste in hospitals or escorting people in exhibitions. Ref. [11] they have designed a fuzzy logic system and proposed an obstacle avoidance algorithm for a path planning in unknown environment for a mobile robot. In order to safely teleoperate the mobile robot AutoMerlin the introduction of Free Intelligent Navigation (FIN) Algorithm helps to avoid obstacles in ill-structured environments as well as deals with the drawbacks from the sensors.

II. Problem Description and Method

The teleoperation of mobile robots becomes a difficult task if the environment around the mobile robot is not presented to human operator precisely. The low quality of the information delivered to the operator has a negative impact on the perception of the remote environment and

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often leads to incorrect decisions. For instance, relying exclusively on the video feedback commonly leads to disorientation, incorrect depth estimation, or failure to detect obstacles in unstructured environments. These negative effects of the separation of the operator from the point of action become even more significant in applications where precise maneuvering is required.

In order to teleoperate the mobile robot AutoMerlin the human operator sets the linear and angular velocities of it using joystick. The robot follows the human operator, but sometimes due to delay in teleoperation or incorrect vision information or operator misperception of environment around mobile robot, the robot goes close to the obstacles can collide with them before operator takes necessary steps. Therefore, an ancillary Intelligence has been added to existing speed controller to avoid obstacles autonomously present in the environment during teleoperation when they are in the critical range.

III. Free Intelligent Navigation FIN

Obstacles avoidance algorithm called Free Intelligent Navigation FIN detects the obstacles in the vicinity of robot takes the control of robot and avoid them and then shifts back the control to operator. The obstacle avoidance algorithm detects the objects and then adjusts the servo and speed of the robot to avoid them using proximity sensor mounted in front of robot. FIN Algorithm enables us to teleoperate the robot in the presence of random time delay. The robot will follow the human operator and in case of connection loss the robot will not collide with surrounding objects but instead self obstacle avoidance algorithm FIN will take over and would set a constant speed and suitable steering value to drive it to avoid collision with the objects and when the connection is resumed then robot will again follow the human operator provided there is no obstacle in critical range. However, in some emergency cases the collision monitoring is also realized on the front infrared sensors. If a very near object is detected by the IR sensor the robot is instructed to stop. The security distance, verified by the IR sensor is about 40 cm for usual objects in the lab. The sonar measurement distances are in the range from 0.3m up to 2m.

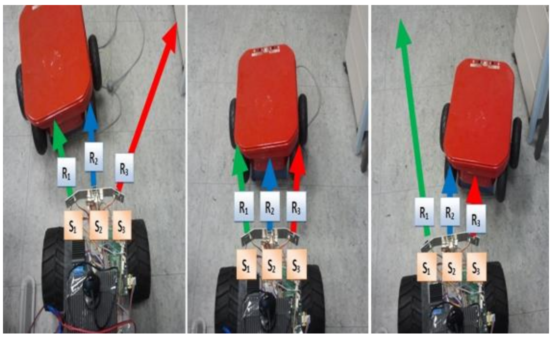

Figure 1. Sonar sensors mounted in front of the robot to determine the position and distance of obstacle relative to robot

The FIN Algorithm has been designed for the obstacle avoidance and it is described in Table I. The front sensors S1, S2, S3 as shown in Fig. 1, provide the distance readings R1, R2, R3. The algorithm aims to find the shortest distance SD among these three readings, and then find if the obstacle is on the right, middle or left side of the robot. As a result the algorithm should turn the robot for the best orientation to avoid the obstacle. The estimation of the FIN_{Final} in order to change the servo for the AutoMerlin robot is shown in Fig. 2.

TABLE I. The FIN Algorithm

Input Sensor Readings	**$(S_1,D_1), (S_2,D_2), (S_3,D_3)$**
	Correct Sensor readings by Fuzzy set Model. **Obtain** New Distances: $(S_1,D^{1*}), (S_2,D^{2*}), (S_3,D^{3*})$ **Calculate** the shortest distance ***SD***. **$FIN_{initial}$**= ***{min(D1, D2), min(D1,D3), min(D2,D3)}.*** **FIN_{Final}**= ***min { D}.*** **While**: Navigate. **IF**: ***SD*** > Safety Distance. *Navigation.* **Else**: Find $FIN_{initial}$. Then estimate the FIN_{Final}. **End IF**. **END WHILE.** **Return** Navigation. **Control** the Servo.

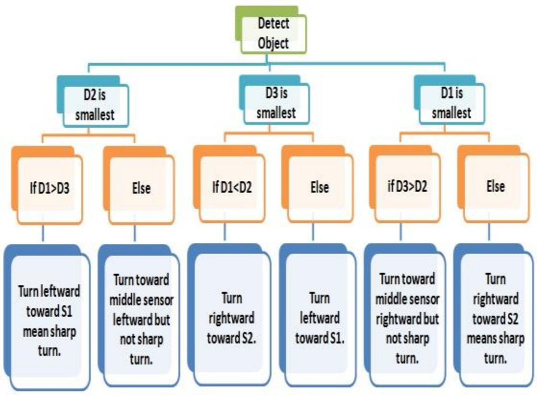

Figure 2. Execution of the FIN algorithm

However, the most well-known characteristics of Ultrasonic sensors are the uncertainties and drawbacks information. Motlagh demonstrated that fuzzy sets systems might model the uncertainties information using linguistic rules [12]. Cliff Joslyn introduced a method to construct possibility distribution and fuzzy logic from the empirical data by collecting the data and constructing the interval set statistics with random sets [13], [14]. Therefore, FIN algorithm has two main stages that have been designed and implemented. The first stage is the sub-fuzzy set model that deals with the drawbacks in sensors, then using the proper fuzzy set to find the shortest distance between the AutoMerlin robot and the obstacles based on the sonar sensors. The second stage uses the output of the sub-fuzzy set model as well as to generate the main behavior of the robot.

A. Sub Controller

In order to reduce the drawbacks in sonar sensors a fuzzy set model was modeled by using possibilities distribution theory. However, the experimental data show the values of these errors related to the range of view $\boldsymbol{\beta}$ as well as the distance between the sensor and objects. As a result, these errors can be reduced and modeled by fuzzy sets and possibility distributions as it is shown in Table II. The vectors of endpoints, cores and support for possibilities distribution are shown in Table III.

The possibilities histograms are shown in Fig. 3, which could be converted to fuzzy membership functions as it is shown in Fig. 4, where C_i are the core for the histograms, P_i are other points, S_1 and S_2 are the start and end point for the support, MC is the mid-point for the core for each histogram.

TABLE II. FREQUENCY DATA ANALYSIS

A_i	S_i
A_1= <[0,1],[1,3],[0,3],[-1,4]>	S_1={[0,1]=0.25, [1,3]=0.25, [0,3]=0.25, [-1,4]=0.25}
A_2= <[-1,4],[0,5],[2,7],[3,10]>	S_2={[-1,4]=0.25, [0,5]=0.25, [2,7]=0.25, [3,10]=0.25}
A_3= <[3,10],[4,11],[5,11]>	S_3={[3,10]=1/3, [4,11]=1/3, [5,11]=1/3}

TABLE III. POSSIBILITIES INFORMATION ANALYSIS

E_i^L	E_i^R	$C_i(\pi)$	$Supp_i(\pi)$
{1-,0,0,1}	{1,3,3,4}	[1,1]	[{-1,0},{0,1}, {1,1},{1,3} {3,4}]
{-1,0,2,3}	{4,5,7,10}	[3,4]	[{-1,0},{0,2}, {2,3},{3,4}, {4,5},{5,7}, {7,10}]
{3,4,5}	{10,11,11}	[5,10]	[{3,4},{4,5}, {5,10},{10,11}]

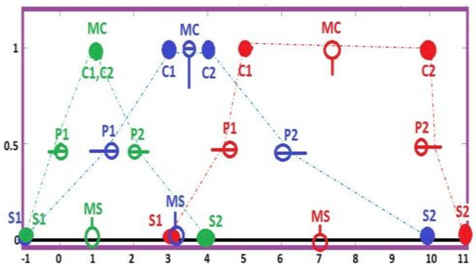

Figure 3. Possibilities histograms.

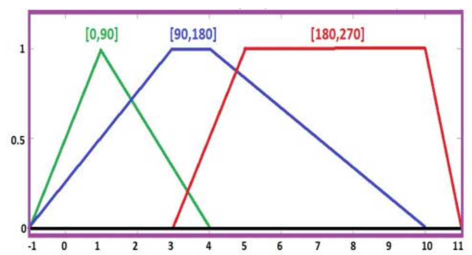

Figure 4. Fuzzy membership functions for fuzzy sets model.

As a result, the FIN algorithm can decide which sensor has the smallest distance reading with known radial errors and view angle as given in (1). Then, rotate the reading distance (short of "RD") to the original axis coordinate to find the shortest distance (short of "SD") as given in (2). Finally, to estimate the shortest distance the T-norms should be used as given in (3).

$$\mu_{SD}(x) = Supp\{\mu(\varepsilon,\beta)\}, \alpha^1 < \beta < \alpha^4 \tag{1}$$

$$SD_X = [\varepsilon \pm RD]\cos(|\beta|) \tag{2}$$

$$Supp(\mu) = \sum_{\mu=1}^{4} \min(SD) \tag{3}$$

For simplicity, assume the **R1** is the shortest distance and it is 80 cm, then, the **R1** has the green membership function as it is shown in Fig. 4, because **80 є [0, 90].** The radial error here has four values **Ɛ= {[-1, μ=0], [1, μ=1], [1, μ=1], [4, μ=0]}**. Therefore, **SD={ [80-1, μ=0]* cos(β1), [80+1, μ=1]* cos(β1), [80+1, μ=1]* cos(β1), [80+4, μ=0]* cos(β1)}.** Then**, SD= {[80+1, μ=1]* cos(β1)}.**

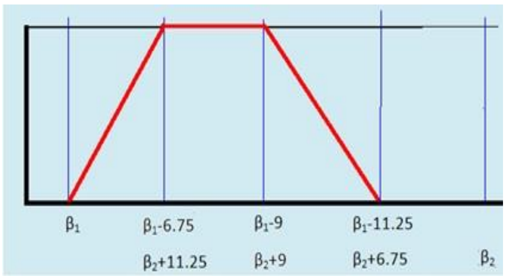

Figure 5. Fuzzy membership functions for β, case R1.

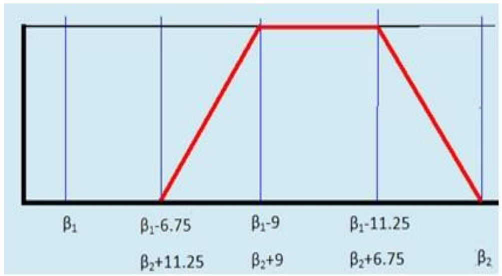

Figure 6. Fuzzy membership functions for β, case R3.

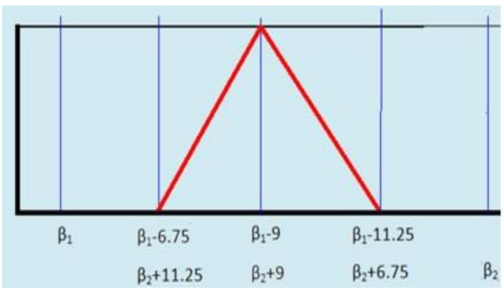

Figure 7. Fuzzy membership functions for β, case R2.

The value of **β**, can be obtained by three possibilities for the readings: **R1** is the shortest, **R3** is the shortest and **R2** is the shortest (**R1=R3**). The membership functions for the three possibilities based on view angle are shown in Fig. 5, Fig. 6, and Fig. 7. Now the value **β** in case **R1** is the shortest is membership function shown in Fig. 5, and it has trapezoidal shape with 4 values {0, 6.75, 9, 11.25}. Thus, **SD= {[80+1, μ=1]* cos (0), [80+1, μ=1]* cos(6.75)}, [80+1, μ=1]* cos(9)}, [80+1, μ=1]* cos(11.25)}** and by using (3) we obtain that **SD= min(81, 80.439, 80.003, 79.44)= 79.44 cm**

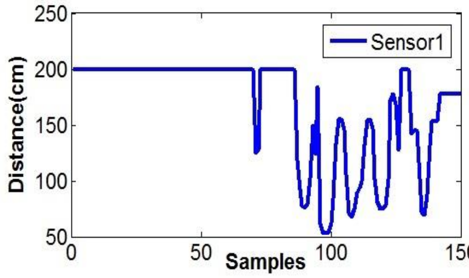

Figure 8. Sonar sensors S1 plot.

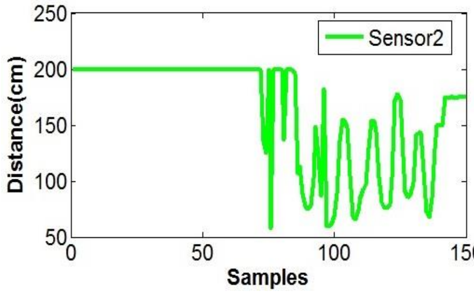

Figure 9. Sonar sensors S2 plot.

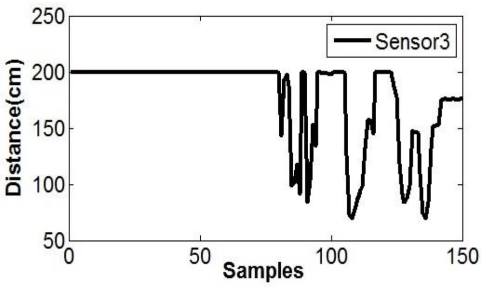

Figure 10. Sonar sensors S3 plot.

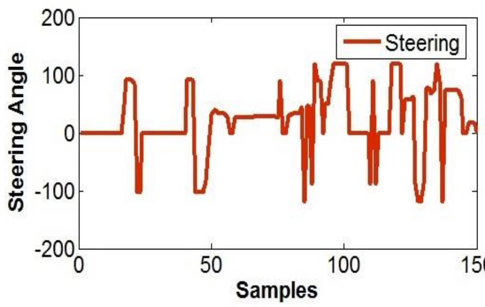

Figure 11. Steering value plot.

IV. Experimental Results

Fig. 8, Fig. 9, Fig. 10, and Fig. 11 show the three sensor readings and the steering value of robot. The robot is following human operator when there is no obstacle. When any of the sensors detect any object within a range of 1m, FIN algorithm comes into play to avoid it and steer the robot in appropriate direction. The robot would turn in rightward direction when the value of steering is positive and leftward direction when the value is negative e.g. at sample 100 sensor1 and sensor2 mounted at left and middle of robot respectively, detect some object therefore the robot is turning rightward indicated by positive value in steering plot.

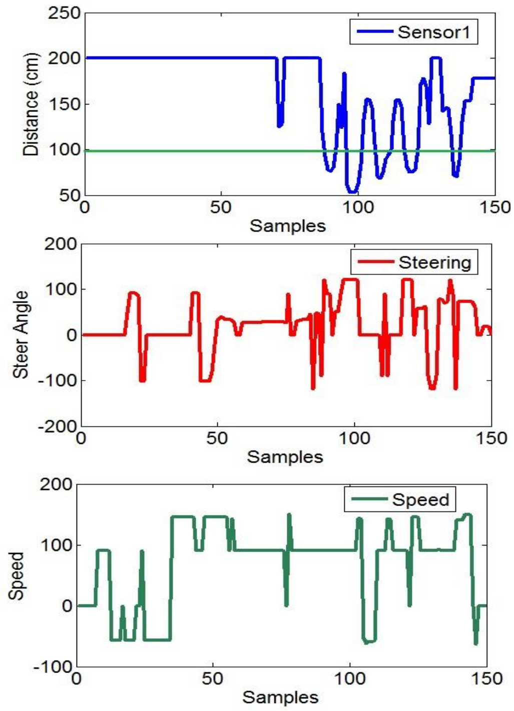

Figure 12. Sensor1 reading, steering angle and output speed.

Fig. 12 explains the working of algorithm. The sensor1 is reading maximum distance in the beginning so the robot is following the human operator. When obstacle is detected i.e. the reading of sensor is below **100cm** then either the operator can move robot backward or the FIN Algorithm starts functioning and reduces the speed to constant and steer the robot in suitable direction. In this scenario the obstacle is on the left side of robot and therefore steering action is positive i.e. in rightward direction and positive speed for forward movement is constant.

Fig. 13 and Fig. 14 demonstrate the performance of algorithm to avoid obstacles present in the environment in the form of sequences images in two test runs. The robot moves across the RST lab without colliding the other robots and objects.

V. Conclusion

FIN Algorithm has been designed to work along with speed controller in teleoperation to safely navigate and avoid collisions with obstacles in indoor environment during teleoperation. The FIN algorithm has ability to deal with the drawbacks in the ultrasonic sensors and has the ability to reduce these drawbacks. The addition of the algorithm is helpful for human operator in assisting him to teleoperate the robot with time delay without colliding with different objects presents in the environment. The performance has been tested number of times and presented in the result and sequential images. The presented results clearly exhibit the effectiveness of algorithm.

Figure 13. Sequential images for test run1

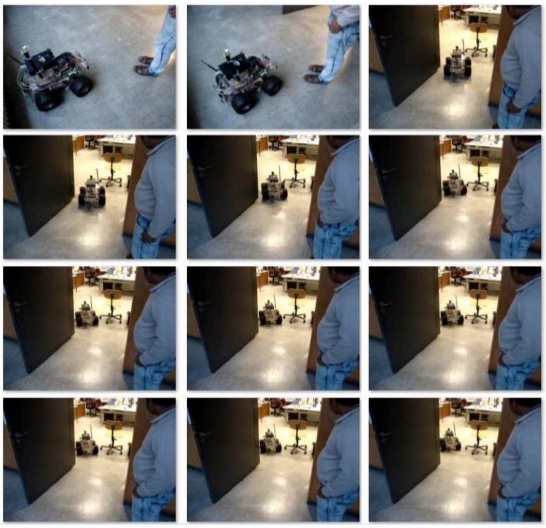

Figure 14. Sequential images for test run2

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