# Telecontrol of AutoMerlin Robot by Employing Fuzzy Logic

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***Abstract*—In this work the novel teleoperation of real mobile robot is presented. In order to cope with the issue of random time delay which makes system unstable, Fuzzy logic approach has been used to design a stable controller to teleoperate AutoMerlin mobile robot. The fuzzy controller has been designed in such a way that it takes two inputs to give one output. First input is generated by human operator from control station using master device like joystick. The second input to the controller is generated based on the obstacles in front of mobile robot. The onboard proximity sensors scan the environment and the algorithm deployed on the mobile robot as local intelligence determines the location of nearest obstacle and feeds its value to controller as second input. When controller gets both inputs then it calculates the appropriate speed for mobile robot. The fuzzy rules have been defined in such a way that they protect the robot from colliding with obstacles and random delay does not affect the performance and stability. The presented results exhibit the performance and stability of overall system in the presence of random time delay.**

***Index Terms*—telecontrol, ground robot, fuzzy logic, fuzzy sets model, teleoperation, time delay**

## I. Introduction

The main ambition of a teleoperation system is to manipulate two separate systems and to make the remote system track closely the local system. The teleoperation system is composed of a human operator, master device, local control station, communication channel and slave mobile robot. The master device is maneuvered by a human operator and a slave mobile robot is designed to follow the human operator's commands [1].

Teleoperation is primary choice to control mobile robots navigation in unknown, unstructured and dangerous environments. The presence of human operator in teleoperation is beneficial due to his/her sophisticated cognitive capabilities [2]. As compared to autonomous robots, teleoperated robots can utilize human wisdom to complete the desired navigation, manipulation or handling dangerous material task more accurately because human operator can take different decisions according to environment and situation demand. Another advantage of teleoperation is safety of human operator because the environment in which teleoperated mobile robot operate is often dangerous for human health. Therefore, teleoperated mobile robots are employed to perform different tasks by human operator from control station which is situated at a safe place from operation site. In present day world, they find their effectiveness in explosive disposal, landmines clearance, nuclear waste handling, planet exploration, complicated industrial constructions *et al* [3]-[5]. Teleoperation of mobile robot is also being employed in medical field for treatment of patients using the technique of tele-surgery. They are becoming the essential part of hospitals for performing a variety of tasks [6].

Teleoperated robots are being utilized in educational institutes for training and learning purposes. They are also being used in service industry for guiding humans in big malls and flying robots teleoperation is helping in monitoring large gathering of peoples by mounting video cameras on them. Teleoperation has become more and more affordable using Internet as communication medium because it is cheap and is easily available these days. It has fast transmission rate and therefore it is primary choice of researchers to utilize its availability and benefits to teleoperate robots. Therefore, nowadays Internet based teleoperation of mobile robots has opened new opportunities in long distance learning, resources sharing, and remote experimentation [7]-[9].

This paper is structured as follows. Section II is related work in the area of telecontrol using different approaches have been elaborated with a few examples from recent research. In Sections problem description has been elaborated, it is describing the working of control loop and challenges involved. Section IV deals with the Fuzzy control approach and its implementation in current scenario. Sections V shows the experimental results and their description and Section VI concludes the paper with a brief outline on future work.

## II. Related Work

The mobile robot teleoperation has been discussed with visuo-haptic interface [10]. The main focus was to drive the robot in unknown maze-like rectangular environment. However they did not consider time delay involved in telecontrol of mobile robot. As there is always some delay in teleoperation which makes the system unstable, this crucial problem has been left for future work. Mobile robots prototype has been developed for teleoperation using RF transceivers [11]. The main idea behind development of such prototype is surveillance. But it did not talk about stability, time delay and difficulties due to unstructured environment. In Ref.

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[12] sixteen ultrasonic sensors are attached around a mobile robot in a ring pattern to measure the distances to the obstacles and a collision vector is introduced. A virtual reflection force is generated to avoid the obstacles and then the reflection force is transferred to the operator who is holding the joystick which is used to control the mobile robot. Based on this reflection force, the operator can control the mobile robot more smoothly and safely. The incorporation of motor nonlinearities and human hand dynamics in order to convey the environmental information to the operator more realistically is left as a future work, which is necessary for the mobile robot to navigate in the environment with random obstacles on the irregular surface.

Many researchers have used passivity control and scattering theory approach to design suitable controller for teleoperation of mobile robot [13], [14]. However, they have evaluated the system based on pretty simple tasks by ignoring the crucial problem of presence of time delay in teleoperation and further experimentation and evaluation of system in complex environments including the presence of communication delay in the data transmission is under planning [13]. Ref. [14] the work is based on simulation and it has not taken into account the unstructured environment which is always present around the slave robot. Therefore, it is hard to implement in real world. It is impossible to teleoperate the robot without having any knowledge about environment around the robot. Ref. [15] a design of the telecontrol electrical vehicle system is presented using wave variables. Contrary to real world random delay, in this simulation work time delay is assumed to be constant and environment is assumed to be passive. The human operator needs accurate perception of environment around the robot to teleoperate the robot efficiently. Otherwise, it would be tedious task for him to teleoperate the robot. Therefore, in order to dexterously teleoperate the robot we have presented a fuzzy logic controller for the navigation of robot in ill-structured environment by considering obstacles in the environment around the robot.

## III. Problem Description

The telecontrol setup is shown in Fig. 1. It consists of a joystick which is connected to a laptop. The laptop hoists the algorithm which translates the joystick movement into input velocity for robot. It also displays the visual feedback from the robot. This whole setup is regarded as control station. The human operator stays in control station and sets different commands for the robot navigation at remote location. The velocity command travels from control station to the robot through communication channel. The communication has been established using TCP/IP protocol. So at control station human operator acts like client and on the other end of communication channel there is a micro pc which controls the behavior of robot acts as server. When the velocity command reaches the server pc it sends it to the robot via serial port and receives visual and sensory feedback from robot.

The telecontrol suffers from time delay due to communication between control station and robot. This delay depends upon the distance between the control station and the mobile robot. It has fixed value like when the distance is fixed and there is dedicated medium of communication between the control station and the robot like planetary exploration or it has random value like communication through Internet. This delay is vital for teleoperation of mobile robot. This delay causes the system to become unstable. Another issue is correct presentation of environment to human operator so that he can take appropriate decisions. Among the sensors used for environment recognition, the camera is the most popular and powerful. However, there are several limitations if only camera is used in teleoperation of a mobile robot. For example, shadows and curved areas cannot be viewed using a narrow view angle camera, especially in an environment with bad illumination and several obstacles.

Therefore, in this work we have implemented the fuzzy logic to design a suitable controller which can work in ill-structured environment potentially dangerous to human health, in the presence of random communication delay. The design is based on two inputs. One input comes from the human operator and other from an algorithm developed and deployed on the robot, which takes the values of onboard proximity sensors and sort out the shortest one. This shortest distance value from robot to obstacle is fed as second input to fuzzy controller give appropriate output speed. The implication of fuzzy logic enables us to teleoperate the AutoMerlin robot in the presence of random time delay. The robot listens to human operator and follows him/her until there is no obstacle in front of him. But if it detects the obstacle then it calculates the speed based on the objects in front of it and slows down to zero speed if the robot reaches very near to object. Then robot can listen to operator for reverse movement only but ignores the commands for advancement. Additionally, the live video feed is made available to operator so that he can perceive the environment.

## IV. Intelligent Fuzzy Sets Model

The mostly used controller for the nonlinear system is the fuzzy controller. The fuzzy system is able to have robust control of the robot and it has low sensitivity to a variation of parameters or noise levels [16]. As it is known, the fuzzy logic is a powerful problem-solving methodology with a myriad of applications in embedded control and information processing. It could provide a remarkably simple way to draw definite conclusions from vague information. In fuzzy reasoning, the most important fuzzy implication inference rule is the Generalized Modus Ponens (GMP), which uses IF-THEN rules that implicitly represent a fuzzy relation. The fuzzy rules define the connection between input and output fuzzy (linguistic) variables. The fuzzy rule based system is composed of four main stages: Fuzzifier, Rule base, Inference engine, and Defuzzifier [17]-[19]. The fuzzification stage is defined as the process to convert the crisp value input $u_0$ to a fuzzy point A' which is defined in (1).

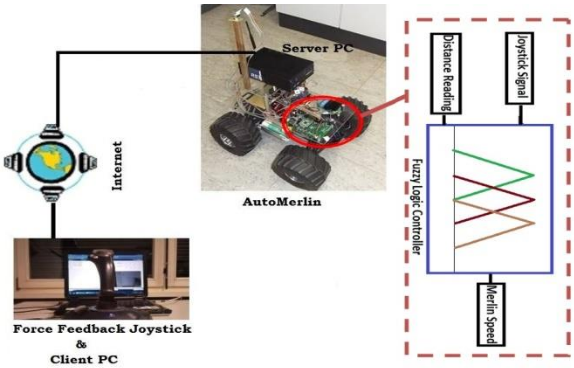


Figure 1. Telecontrol loop along with control station and robot.

$$\mu_{A'}(u) = \begin{cases} 1, & if\ u = u_o \\ 0, & otherwise \end{cases} \quad (1)$$

In the rule-base system for more than one rule, the fuzzy rules that describe the fuzzy system are given as the following:

**$r_1$: IF** Joystick is High Negative **AND** Obstacle Distance is Close **THEN** Speed is Low Negative

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**$r_k$: IF** Joystick is Low Positive **AND** Obstacle Distance is Far **THEN** Speed is Low Positive

......................

**$r_n$: IF** Joystick is High positive **AND** Obstacle Distance is Very Far **THEN** Speed is High Positive

Therefore, the translation of this rule base into a fuzzy relation is done by constructing the fuzzy relation $R_n$ for each rule $r_k$; and then combines these relations into single fuzzy relation R as described in (2). This process for combining the fuzzy rules into a fuzzy relation is called aggregation. This aggregation relies on the type of the relation used to represent the rule in the rule base system. In case of Mamdani approach $R_k$ is represented by using conjunction operator; then the aggregation is done by using disjunction operator [20].

$$R = \bigcup_k R_k \quad (2)$$

When the rule is represented by Mamdani (conjunction relation) and since our case has two antecedents (The Joystick signal and Distance from sonar sensors) then, the Mamdani inference is obtained in (3).

$$\mu_{c^*}(w) = \bigvee_u \bigvee_v \begin{bmatrix} (\mu_A(u) \wedge \mu_{A'}(u))\ldots \\ \wedge (\mu_B(v) \wedge \mu_{B'}(v))\ldots \\ \wedge \mu_C(w) \end{bmatrix} \forall w \in W \quad (3)$$

In the Defuzzification stage that converts the fuzzy set obtained from inference mechanism process into crisp value by Center of Gravity as described in (4).

$$w^* = \frac{\sum_i \mu_{c^*}(w_i) w_i}{\sum_i \mu_{c^*}(w_i)} \quad (4)$$

The intelligent fuzzy sets model is divided into two main parts. First, there are three sonar sensors (S1, S2, S3) mounted in front of the robot to detect obstacles in the environment. Based on the probability and the angle between the sensors which is here $\phi = 20°$, the algorithm will find the shortest distance between the robot and any obstacle based on these three readings as it is shown in Fig. 2. Here we have assumed that the view angle of the sonar sensor is 24.5°. So there is no confliction between the sensor readings. Accordingly, there are three probabilities for the sensors: S1 is the shortest, S3 is the shortest or S2 is the shortest. Second, fuzzy control was designed in order to control the speed of the robot and deals with random delays due to communication through shared medium like Internet. The controller is based on two input variables and one output. The first input is the joystick command that comes from the user with five membership functions and the linguistic variables are (high negative HN, low negative LN, zero Z, low positive LP, and high positive HP) as it is illustrated in Fig. 3. The second input comes from algorithm. It has 5 triangular membership functions and 5 linguistic variables (very close VC, close C, medium M, far F and very far VF) as it is shown in Fig. 4. The controller has one output that is the speed of the robot with five triangular membership functions (negative high NH, negative low NL, Zero Z, positive low PL, and positive high PH) as shown in Fig. 5. The generalized modus ponens and T-norms have been used to design the fuzzy rules base with 25 rules in terms of relationship between inputs and output as it is illustrated in Table I.

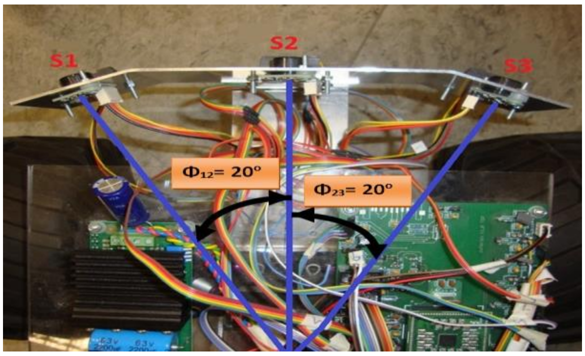


Figure 2. Sonar sensors mounted in front of the robot.

TABLE I. FUZZY RULES BASE FOR SPEED CONTROLLER

| **Sonar Readings** | **Joystick Command** | | | | |
|---|---|---|---|---|---|
| | ***HN*** | ***LN*** | ***Z*** | ***LP*** | ***HP*** |
| ***VC*** | NL | NL | Z | Z | Z |
| ***C*** | NL | NL | Z | Z | Z |
| ***M*** | NL | NL | Z | PL | PL |
| ***F*** | NL | NL | Z | PL | PL |
| ***VF*** | NL | NL | Z | PL | PH |

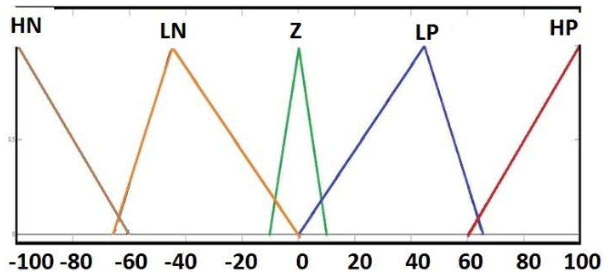


Figure 3. Fuzzy membership functions for input1.

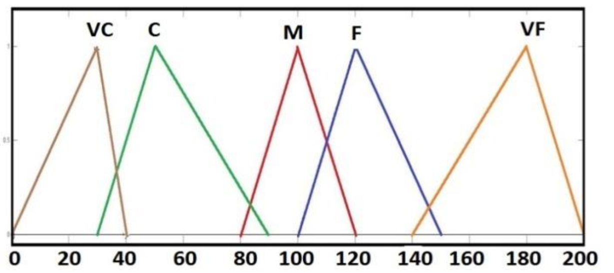


Figure 4. Fuzzy membership functions for input2.

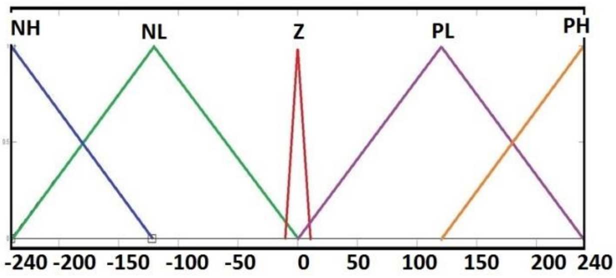


Figure 5. Fuzzy membership functions for output.

Fig. 6 demonstrate the fuzzy surface generated by two inputs and one output. The surface shows the output speed based on input from joystick and sonar reading.

## V. Experimental Results

Several experiments were carried out to analyze the behaviors of the controller. The robot was tested in indoor environment and results have been plotted to show the performance during the experiments. Fig. 7, Fig. 8, and Fig. 9, are illustrating the values of sensors readings. Fig. 10, is showing fuzzy speed controller output speed. Blue line plot is representing the sensor S1, red line plot shows sensor S2, dark green plot shows sensor S3 and light green plot is showing the output speed. When there is no obstacle then the sensors are showing the maximum distance i.e. 200cm. In this case the robot is following the human operator and the variation in speed is being brought by the operator command according to the fuzzy rules defined in the Table I Operator is driving the robot in forward or backward directions but when the objects are being detected by the sensors in the near vicinity of robot then the speed is reduced as shown by light green plot in Fig. 10, and the robot stops when it goes very close to obstacle as shown in light green plot after 120 samples.

Fig. 11 shows the performance of controller, the robot moves according to the commands from the human operator but once it detects the obstacle it reduces its speed regardless the value of input from human operator, and then stops when it goes very close to the obstacle and only follow the human operator command in backward direction and ignore the command for forward motion.

Fig. 12 and Fig. 13 shows the teleoperation using wireless network in the RST Institute. The robot is calculating the output speed based on the environment.

## VI. Conclusion and Future Work

In this paper, we have presented fuzzy control technique to cope with the issue of delay time from the Internet communication for ground robot teleoperation. The experimental results showed that the controller achieved the requirements of the project and it ensured the stability and reliability to accomplish the actual exploration missions. In addition, the results showed excellent experimental performance of the ground robot navigation. For the future work, we would like to inculcate servo control to steer the robot in desired left or right direction. Vision based navigation is also under planning, which will be used for tracking and detection purposes.

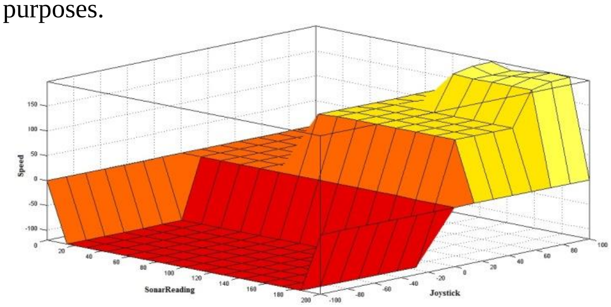


Figure 6. Fuzzy surface.

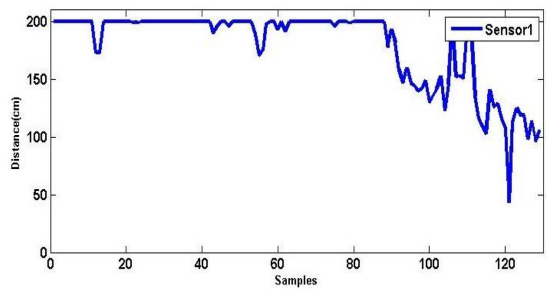


Figure 7. Readings of sensor 1.

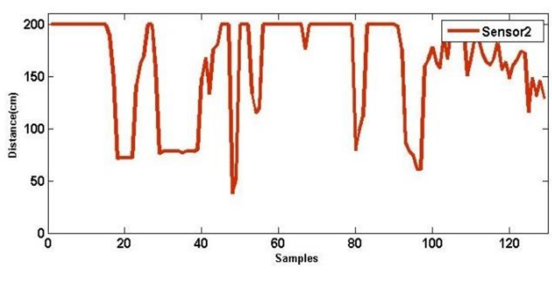


Figure 8. Readings of sensor 2.

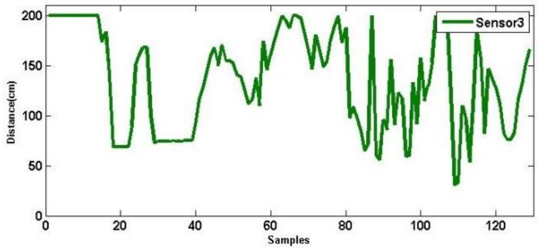


Figure 9. Readings of sensor 3.

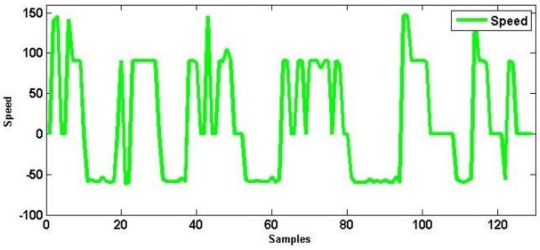


Figure 10. Output speed.

Figure 11. Robot detecting human obstacle and reducing speed.

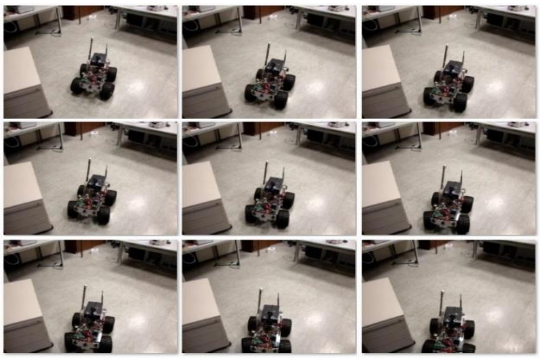

Figure 12. Robot navigation in lab.

Figure 13. Robot navigating in indoor environment.

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