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# FUZZY LOGIC CONTROL SYSTEM TO THE MOBILE ROBOT MOTION THROUGH WEB

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***Abstract***. *This work describes the implementation of a controller based on Fuzzy logic for the speed control of the Nomad XR4000 mobile robot. The system has as inputs data from the sonar sensors of the robot and the 'to go' distance, and has as output the robot's speed, based on the input data. It is used five triangular fuzzy sets to each variable, twenty-five fuzzy rules and the centroid deffuzyfication method. This system was developed to actuate as a auxiliary intelligence in the teleoperation system developed to the mobile robot to cope with the unexpected delays from the Internet data communication. The final implementation was tested by the factorial design method,*

***Keywords***: *mobile robot, fuzzy control, teleoperation.*

## 1. INTRODUCTION

The existence of environmentally ill sites to humans, like nuclear power plants, brought the need to the development of remotely operated systems. The use of mobile robots to visualize and monitor dangerous places is growing due to the technological advances in computing and sensors, as in the work of Byrd (1996). In these days there are several academical researches in the field of the use of Internet as a communication vehicle to remote control of machines, like mobile robots in the work of Nehmzow (1996).

The subject of remote control through Internet has some possible pitfalls, including: time delay between client (teleoperator) and server (the robot); unexpected time delays (that are function of network traffic, network paths, and so on) and network freezing (that locks the control interface). These issues can be handled by several ways, including neural nets and fuzzy logic. The latter approach reveals to be simple and robust to be used in a mobile robot environment.

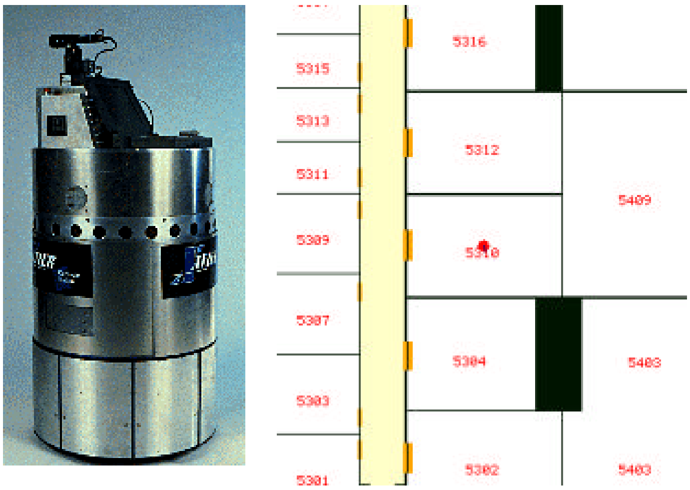


Figure 1. Xavier mobile robot and its localization map.

Many people are working in the Internet control of robots. The work of Mondana (1998) presents a small mobile robot, Khepera, that can be controlled by a remote user through Internet (see its homepage). Its interface uses Java applets, receiving images from the robot's environment. Another work, developed by Simmons (1998), is the Xavier robot (see fig. 1). Its teleoperation interface utilizes a simple WEB page, in which the user can command the robot by means of general tasks (organized in a list) and can see the result in images updated every 5-10 seconds.

This works deals with the development of an fuzzy controller to the Nomad XR4000 robot, controlled through Internet. Results are analyzed and future improvements to the system are defined.

## 2. FUZZY LOGIC AND MOBILE ROBOTS

The creation of fuzzy logic by Zadeh at 60's brought to the field of robotics a new tool to deal with uncertainties that this research field has to cope with. Nowadays the fuzzy logic is used in many fields in mobile robotics (see http://iridia0.ulb.ac.be/FLAR/wsc1/papers/index.html as an example), like:

- Autonomous navigation;
- Behavioural control;
- Speed control;
- Map creation in unknown environments;
- Tracking of natural features in robot's environment;
- Vision-based navigation;

The field of fuzzy logic and mobile robotics is still growing, as in the work of Saffiotti (1997) or Boudihir (1999), and many research results are presented in the main congresses over the world.

## 3. NOMAD XR4000 MOBILE ROBOT

The Nomad XR4000 robot is a fully integrated system designed to industrial or research purposes. It's features includes:

- Onboard dead reckoning system (odometry);
- Infrared sensors;
- Sonar sensors;
- Two PC Pentium computers;
- Framegrabber for vision tasks;
- Radio/ethernet card for wireless communication;

The system can be viewed in the fig. 2, where can be seen it's geometry and size.

Figure 2. Nomad XR4000 Mobile Robot.

## 4. FUZZY CONTROLLER SPECIFICATION

The fuzzy system was developed with the use of the *Xfuzzy* software, from the Microelectronic Institute of Sevilha (2000).

The system is based on two input variables (sonar sensor data and commanded distance) as has as output the best speed for the robot. The fuzzy rules are defined as simple sentences like 'If sensor is near and distance is near then speed is slow'. In the following section the system will be detailed, based in the book of Shaw (1999).

### 4.1. Fuzzy Operators

The system uses the common Zadeh's operators for the union and intersection: max and min operators.

### 4.2. Fuzzy Variables

There are two input variables: sonar sensor data and the commanded distance (from user's control). There is one output variable: the speed for the robot.

The input fuzzy variables were defined in five triangular fuzzy sets each. It was used a few superposition to optimize the output smoothness. The sonar sensor data is entered in the range 0-8000 mm. The distance data is defined in the range 0-5000 mm. The speed output was defined in five trapezoidal fuzzy sets, and his data is in the range 0-1500 mm/s. In spite of the robot's full speed is 2500 mm/s the system limits the top speed to about 1500 mm/s, to increase the security.

The figures 3 to 5 show the defined fuzzy sets for the input and output variables.

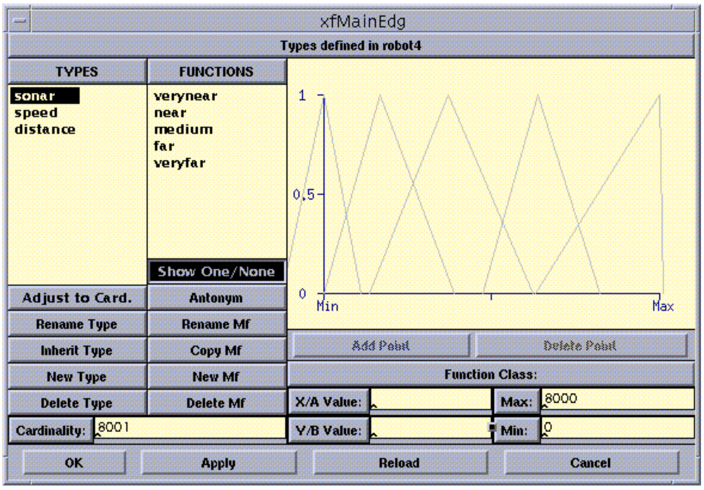


Figure 3. Sonar sensor data fuzzy sets.

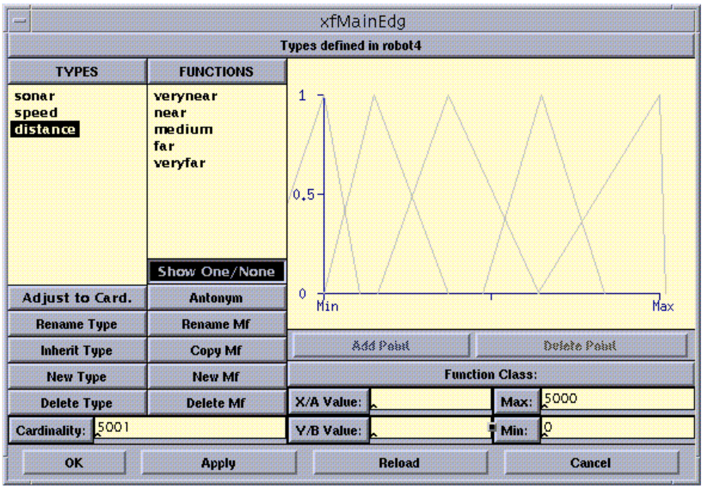


Figure 4. Distance data fuzzy sets.

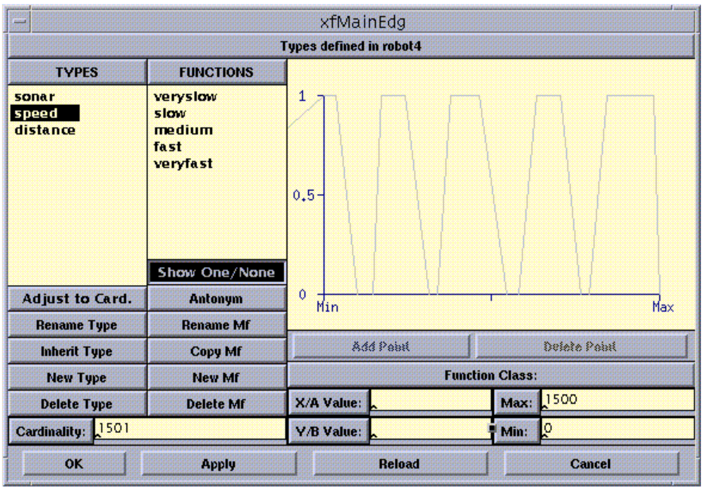


Figure 5. Speed output fuzzy sets.

### 4.3. Fuzzy Rules

The fuzzy rules are based in the common sense, as the following sentence:

*If the sensor is far and distance is far then the speed is fast.*

The defining sentences tries to optimize the travel time and the security for the robot, giving more importance to the latter. The table 1 resumes the fuzzy rules.

The data got from the sonar sensors applies only to the control speed, not for the obstacle avoidance. The collision monitoring is mainly realised by the infrared sensor, that monitors at any time the received signal from the near obstacles. If a very near object is detected by the IR sensor the robot is instructed to stop, whatever is the sonar reading. This approach reveals very robust, since the robot, by means of sonar data, slows itself smoothly and finally stops if the obstacle remains in its proximity. The security distance, verified by the IR sensor, is about 0.5m for usual objects in the lab (the distance is measured by the IR level received, and this data changes for different types of materials). The sonar measurement distances are in the range from 0.3m up to 8m.

Table 1. Fuzzy rules used in the system.

| **Sonar data / Distance** | **Very near** | **Near** | **Medium** | **Far** | **Very far** |
|---|---|---|---|---|---|
| **Very near** | Very slow | Very slow | Very slow | Very slow | Very slow |
| **Near** | Very slow | Slow | Slow | Slow | Slow |
| **Medium** | Very slow | Slow | Medium | Medium | Medium |
| **Far** | Very slow | Slow | Medium | Fast | Fast |
| **Very far** | Very slow | Slow | Medium | Fast | Very fast |

Figure 6 shows the fuzzy rules implementation in the *Xfuzzy* software.

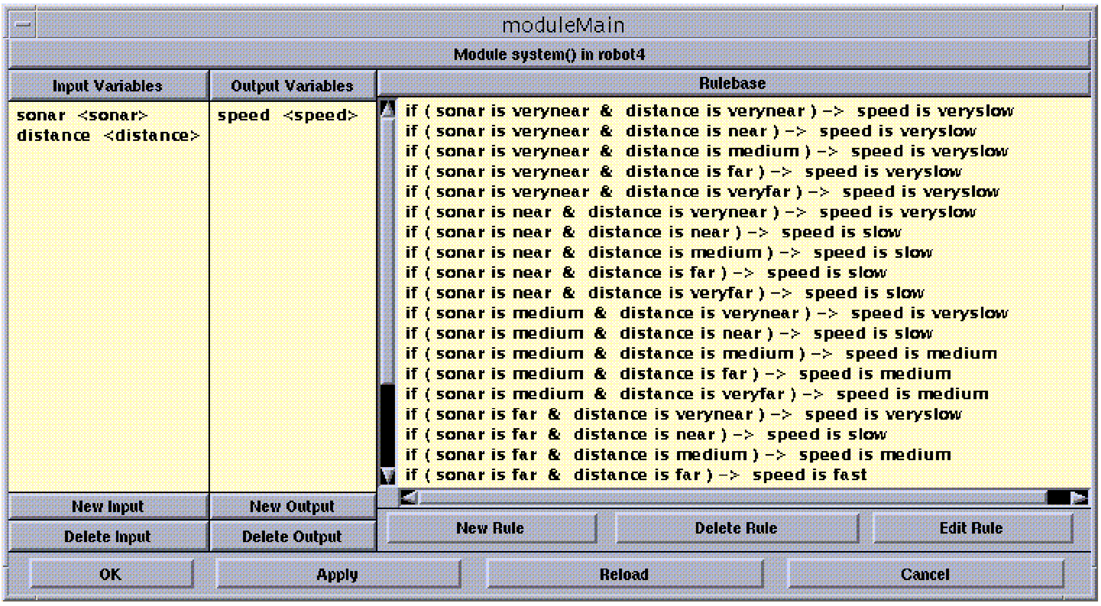


Figure 6. Fuzzy rules in the Xfuzzy environment.

### 4.4. Deffuzyfication Method

To simplify and optimize the processing speed of the controller it was used the centroid deffuzyfication method. This deffuzyfication method is well suited to systems using the Zadeh's operators.

## 5. RESULTS

This section analyses the surface response of the fuzzy controller and the factorial design tests realized with the system to check its performance.

### 5.1. Surface Response of Controller

The fig. 7, obtained with the GNUPlot software, shows the surface response obtained with the fuzzy controller. The xy plane refers to the input variables, and the z axis refers to the output speed variable.

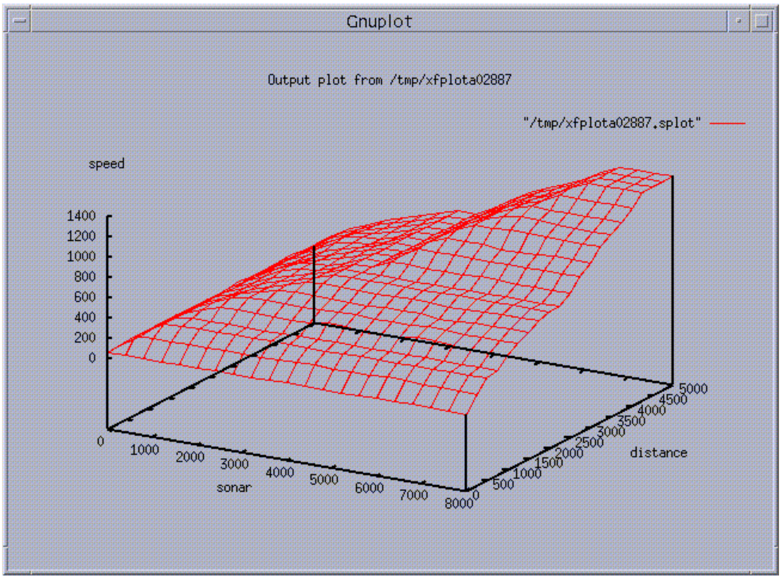


Figure 7. Surface response.

As can be expected from the defined rules, the system has a careful behavior next to obstacles as well as when the distance to go is small. The upper right section of the graph shows that the controller sets maximum speed only for great distances and sonar readings. The surface is almost smooth, showing that its response is very continuous and without high slopes.

### 5.2. Factorial Design Tests

In order to study and reveal possible improvements in the fuzzy controller the system was verified through the factorial design method. It was analyzed the influence of three variables: state of sensors (on/off), type of environment (open/close) and actuator acceleration (slow/fast). These test were ran twice, to compare the two runs to verify any variation in data response. The results obtained were put in table 2 for better understanding:

Table 2: Results from the factorial design analysis.

| Experiment | Runs | Distance | Sensor | Acceleration | Variation? | Oscillation? |
|---|---|---|---|---|---|---|
| 1 | 1,13 | - | - | - | No | Small |
| 2 | 2,6 | - | - | + | No | Big |
| 3 | 4,12 | - | + | - | Yes | Big |
| 4 | 10,11 | - | + | + | Yes | Big |
| 5 | 5,8 | + | - | - | No | Big |
| 6 | 15,16 | + | - | + | No | Big |
| 7 | 7,9 | + | + | - | Yes | Big |
| 8 | 3,14 | + | + | + | Yes | Big |

As can be seen, the main factor affecting the system's performance is the state of sensors. When the sensors were on the system presented a bigger speed variance, revealing that the controller was trying to set a new speed value to a new and different sensor data. Since the sensor data vary, the speed calculated by the fuzzy controller vary accordingly.

The figures 8 and 9 show the speed output from the controller for two analyzed cases: with and without sensors. It's clear that when the sensors are on the speed varies more often.

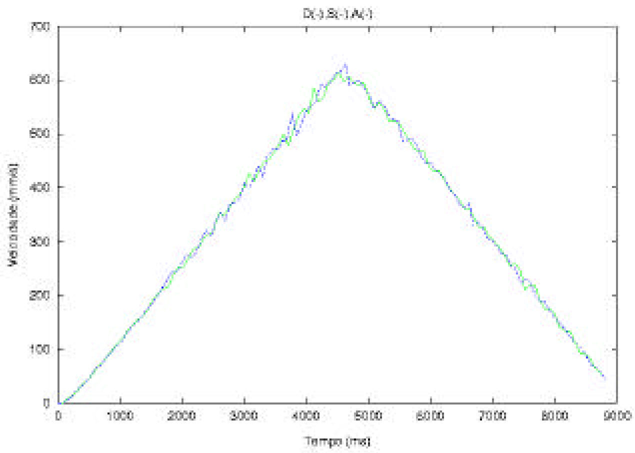


Figure 8. System response without sensors.

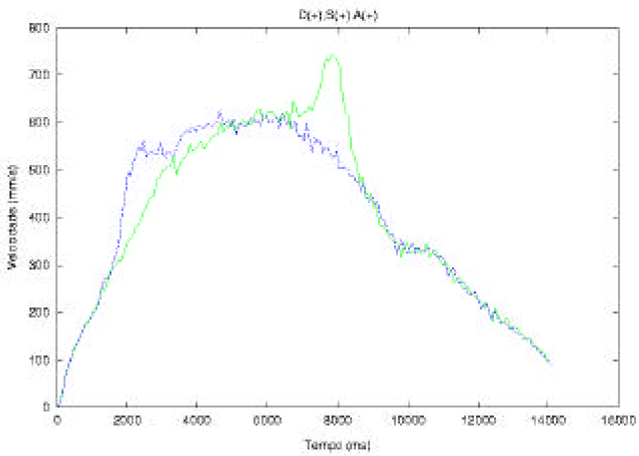


Figure 9. System response with sensors.

In the discussion section will be analyzed the consequences from these results.

## 6. DISCUSSION

Was noted from the factorial design analysis that the sensors can cause to the fuzzy controller a lot of problems, particularly in the repeatability of the results. Figure 10 shows the data over time for three of the robot's sensors. In the green line can be noted that there is a lot of noise, in the red one the noise is fewer and in the blue one there is not a perceptible noise. This problem occurs due to the unexpected sound wave reflections in the environment. In the green line sensor there was a lot of reflections, since it was pointing to a far object, but in the blue line sensor there was not reflections, since it was pointing to a near wall.

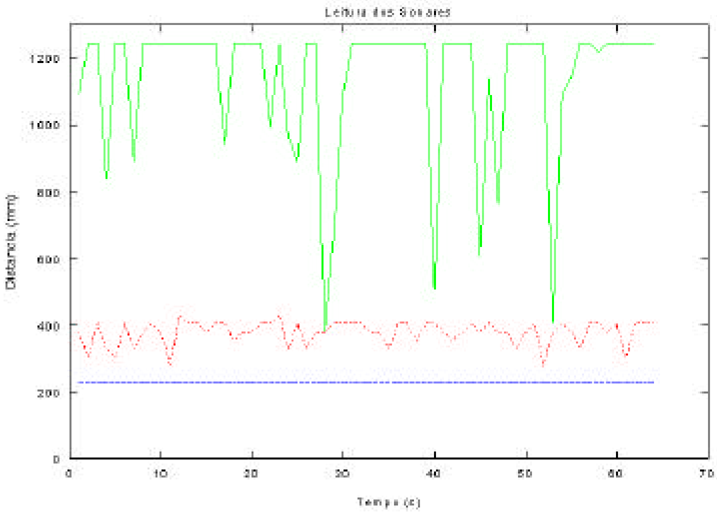


Figure 10. Data from three different sensors in the robot.

This problem can be minimized by the use of a filtering techniques, like Fuzzy filtering, Neural Net filtering or even Kalman filtering, that is well suited to systems where stochastic data is present.

## 7. CONCLUSION

The Fuzzy control in the mobile robotics can be expanded to a very large fields, like speed control, trajectory control, obstacle avoidance and so on. In this work a speed fuzzy controller was developed to act as an internal intelligence in the telerobotic application. The system shows very robust and useful to act as a security guardian to the teleoperation control. At this moment there was not reported any collisions of the robot and its environment, revealing that the problems with the sensorial data is of a less importance. The use of a Kalman filter in the sensorial data might improve the system's performance, since this methodology is very suitable to cope with statistical and stochastic sensor data.

## 8. ACKNOWLEDGMENTS

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