# Intelligent Mobile Robot Motion Control in Unstructured Environments

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*Abstract: This paper presents the intelligent wheeled mobile robot motion control in unstructured environments. The fuzzy control of a wheeled mobile robot motion in unstructured environments with obstacles and slopes is proposed. Outputs of the fuzzy controller are the angular speed difference between the left and right wheels of the mobile robot and the mobile robot velocity. The simulation results show the effectiveness and the validity of the obstacle avoidance behavior in an unstructured environment and the velocity control of a wheeled mobile robot motion of the proposed fuzzy control strategy. Wireless sensor-based remote control of mobile robots motion in unstructured environments using the Sun SPOT technology is proposed. The proposed method has been implemented on the miniature mobile robot Khepera that is equipped with sensors. Finally, the effectiveness and efficiency of the proposed sensor-based remote control strategy are demonstrated by experimental studies and good experimental results.*

*Keywords: intelligent wheeled mobile robot; motion control; unknown and unstructured environments; obstacles and slopes; fuzzy control strategy; wireless sensor-based remote control; Sun SPOT technology; simulation results; experimental studies; mobile robot Khepera*

## 1 Introduction

In recent years, there has been a growing interest in mobile robot motion control. This paper presents intelligent mobile robot motion control in unstructured environments. The paper actually is a continuation of a conference paper [1]. The paper deals with the fuzzy velocity control of a mobile robot motion in an unstructured environment with slopes and obstacles and gives the wireless sensor-based remote control of mobile robots motion in an unstructured environment with obstacles using the Sun SPOT technology.

The wheeled mobile robot must be capable of sensing its environment. Conventionally, mobile robots are equipped by ultrasonic sensors and a stereo-vision system. It is supposed that the autonomous mobile robot has groups of ultrasonic sensors to detect obstacles in the front, to the right and to the left of the vehicle, that the model of the wheeled mobile robot has two driving wheels and that the angular velocities of the two wheels are independently controlled.

When the vehicle is moving towards the target and the sensors detect an obstacle or slope, an avoiding strategy is necessary. While the mobile robot is moving it is important to compromise between avoiding the obstacles and slopes and moving towards the target position. The fuzzy control of a wheeled mobile robot motion in unstructured environments with obstacles and slopes is proposed. Outputs of the fuzzy controller are the angular speed difference between the left and right wheels of the vehicle and the vehicle velocity. The simulation results show the effectiveness and the validity of the obstacle avoidance behavior in unstructured environments and the velocity control of a wheeled mobile robot motion of the proposed fuzzy control strategy. The wireless sensor-based remote control of mobile robots motion in unstructured environments using the Sun SPOT technology is proposed.

The proposed method has been implemented on the miniature mobile robot Khepera that is equipped with sensors and the free range Spot from the Sun Spot technology.

Finally, the effectiveness and efficiency of the proposed sensor-based remote control strategy are demonstrated by experimental studies and good experimental results of the obstacle avoidance behavior in unstructured environments.

The paper is organized as follows:

- Section 1: Introduction.
- In Section 2, the strategy of autonomous wheeled mobile robot motion control in unstructured environments is proposed.
- In Section 3, the simulation results are illustrated.
- In Section 4, the wireless robot-sensor networked systems are illustrated.
- In Section 5, the Sun-SPOT-based remote control of mobile robots is proposed.
- Conclusions are given in Section 6.

Currently much research in robotics deals with different problems of the motion of wheeled mobile robots and the motion control of wheeled mobile robots in unstructured environments. Fuzzy logic approaches to mobile robot navigation and obstacle avoidance have been investigated by several researchers. Many application works of fuzzy logic in the mobile robot field have given promising results.

[2] has presented a strategy for the autonomous navigation of field mobile robots on hazardous natural terrain using a fuzzy logic approach and a novel measure of terrain traversability. The navigation strategy is comprised of three simple,

independent behaviors: seek-goal, traverse-terrain, and avoid obstacles. This navigation strategy requires no a priori information about the environment.

The sensor-based navigation of a mobile robot in an indoor environment is very well presented in [3]. The paper deals with the problem of the navigation of a mobile robot either in an unknown indoor environment or in a partially-known one. Fuzzy controllers are created for the navigation of the real robot. The good results obtained illustrate the robustness of a fuzzy logic approach with regard to sensor imperfections.

The fuzzy reactive control of a mobile robot incorporating a real/virtual target-switching strategy has been made in [4]. Real-time fuzzy reactive control is investigated for automatic navigation of an intelligent mobile robot in unknown and changing environments. The reactive rule base governing the robot behavior is synthesized corresponding to the various situations defined by instant mobile robot motion, environment and target information.

Paper [5] presents a control method for the formation on nonholomic mobile robots. Robots track desired trajectories in the environment with static convex-shaped obstacles. The algorithm includes collision-avoidance between robots and obstacles.

# 2 Strategy of Autonomous Wheeled Mobile Robot Motion Control in Unstructured Environments

In this section fuzzy control is applied to the navigation of the autonomous mobile robot in unstructured environments with obstacles and slopes [1], [6], [7], [8], [9], [10], [11], [12]. It is supposed that: the autonomous mobile robot has two wheels driven independently and groups of ultrasonic sensors to detect obstacles in the front, to the right and to the left of the vehicle. When the vehicle is moving towards the target and the sensors detect an obstacle, an avoiding strategy is necessary. While the mobile robot is moving it is important to compromise between:

- avoiding the obstacles and
- moving towards the target position.

With obstacles present in the unknown environment, the mobile robot reacts based on both the sensed information of the obstacles and the relative position of the target [4]. In moving towards the target and avoiding obstacles, the mobile robot changes its:

- orientation and
- velocity.

When an obstacle in an unknown environment is very close, the mobile robot slows down and rapidly changes its orientation. The navigation strategy has to come as near to the target position as possible while avoiding collision with the obstacles in an unknown environment.

The intelligent mobile robot reactive behavior is formulated in fuzzy rules. Fuzzy-logic-based control is applied to realize a mobile robot motion in an unknown environment with obstacles.

Inputs to the fuzzy controller are:

- the obstacle distance p,
- the obstacle orientation $\theta_1$ (which is the angle between the robot moving direction and the line connecting the robot's center with the obstacle),
- the target distance l,
- the target orientation $\theta_2$ (which is the angle between the robot moving direction and the line connecting the robot's center with the target).

Outputs of the fuzzy controller are:

- the angular speed difference between the left and right wheels (wheel angular speed correction) of the vehicle: $\Delta\omega = \omega_r - \omega_l$ and
- the vehicle velocity.

The obstacle orientation $\theta_1$ and the target orientation $\theta_2$ are determined by the obstacle/target position and the robot position in a world coordinate system, respectively. The obstacle orientation $\theta_1$ and the target orientation $\theta_2$ are defined as positive when the obstacle/target is located to the right of the robot's direction of movement; otherwise, the obstacle orientation $\theta_1$ and the target orientation $\theta_2$ are negative [1].

The block diagram of the fuzzy inference system is presented in Fig. 1.

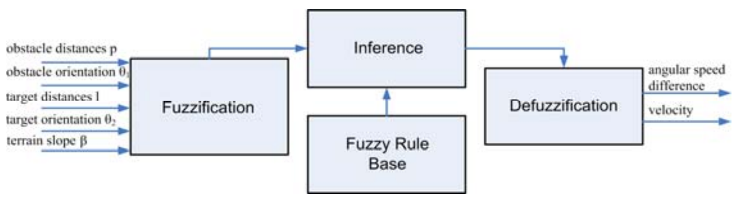


Figure 1
The block diagram of the fuzzy inference system

For the proposed fuzzy controller the input variables for the obstacle distance p are simply expressed using two linguistic labels - Gaussian membership functions - near and far (p Є [0, 3 m]). The input variables for the obstacle orientation $\theta_1$ are expressed using two linguistic labels - Gaussian membership functions - left and right ($\theta_1$Є[-π,π rad]).

For the proposed fuzzy controller, the input variables for the terrain slope $\beta$ is simply expressed using three linguistic labels - Gaussian membership functions – sloped left, flat and sloped right ($\beta$ Є [-3.14, 3.14 rad]), $\beta$ is the average slope value. The input variables for the target distance l are simply expressed using two linguistic labels - Gaussian membership functions - near and far (l Є [0, 3 m]). The input variables for the target orientation $\theta_2$ are simply expressed using three linguistic labels - Gaussian membership functions - left, targetdirection and right ($\theta_2$ Є [-3.14, 3.14 rad]).

The fuzzy sets for the output variables of the wheel angular speed correction $\Delta\omega = \omega_r - \omega_l$ (*turn-right, zero* and *turn-left*) of the mobile robot are shown in Fig. 2.

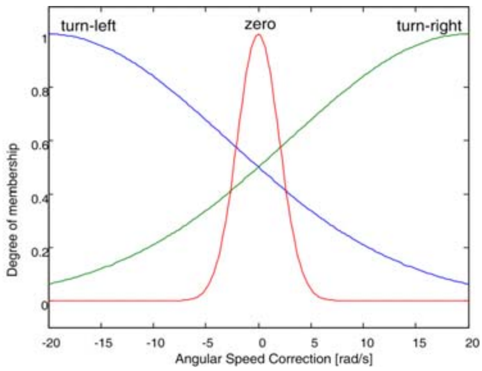


Figure 2

Membership functions of the angular speed difference $\Delta\omega$

The output variables are normalized between: $\Delta\omega$ Є [-20, 20 rad/s]. The other output variable of the fuzzy controller is vehicle velocity. The output variables are normalized between: Velocity Є [-10, 20 m/s]. The fuzzy sets for the output variables - Velocity (low and high) are shown in Fig. 3.

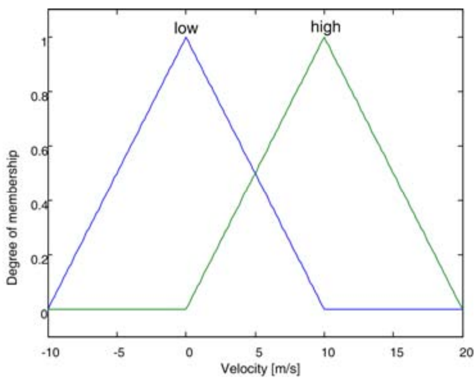


Figure 3

Membership functions of the velocity of the mobile robot

The rule-base for mobile robot fuzzy control are:

R1: If $\theta_2$ is right and $\beta$ is sloped left then $\Delta\omega$ is turn-right

R2: If $\theta_2$ is left and $\beta$ is sloped right then $\Delta\omega$ is turn-left

R3: If p is near and l is far and $\theta_1$ is left and $\beta$ is sloped left then $\Delta\omega$ is turn-right

R4: If p is near and l is far and $\theta_1$ is right and $\beta$ is sloped right then $\Delta\omega$ is turn-left

R5: If $\theta_2$ is target direction and $\beta$ is flat then $\Delta\omega$ is zero

R6: If p is far and $\theta_2$ is target direction and $\beta$ is flat then $\Delta\omega$ is zero

R7: If p is near and l is far then velocity is low

R8: If p is far and l is far then velocity is high

R9: If p is far and l is near then velocity is low.

In the present implementation of the fuzzy controller the Center of Area method of defuzzification is used.

# 3 Simulation Results

Simulation experiments are commonly used for the initial system analysis and control design while the experimental scalable testbed system must be used in the final phase of system evaluation and control verification. The obtained results and control architecture can afterwards be adapted to the different application of mobile robots. Based on this, the important task in system development is the accurate and valuable modeling of the observed system.

In this instance, the author applied the proposed fuzzy controller to the mobile robot moving in an unstructured environment with obstacles [14]. A simulation example of a wheeled mobile robot is presented in Fig. 4. The corresponding fuzzy control is implemented to perform tasks of obstacle and collision avoidance. The results of the simulation are shown in Fig. 4. regarding the goal seeking and the obstacle avoidance mobile robot paths.

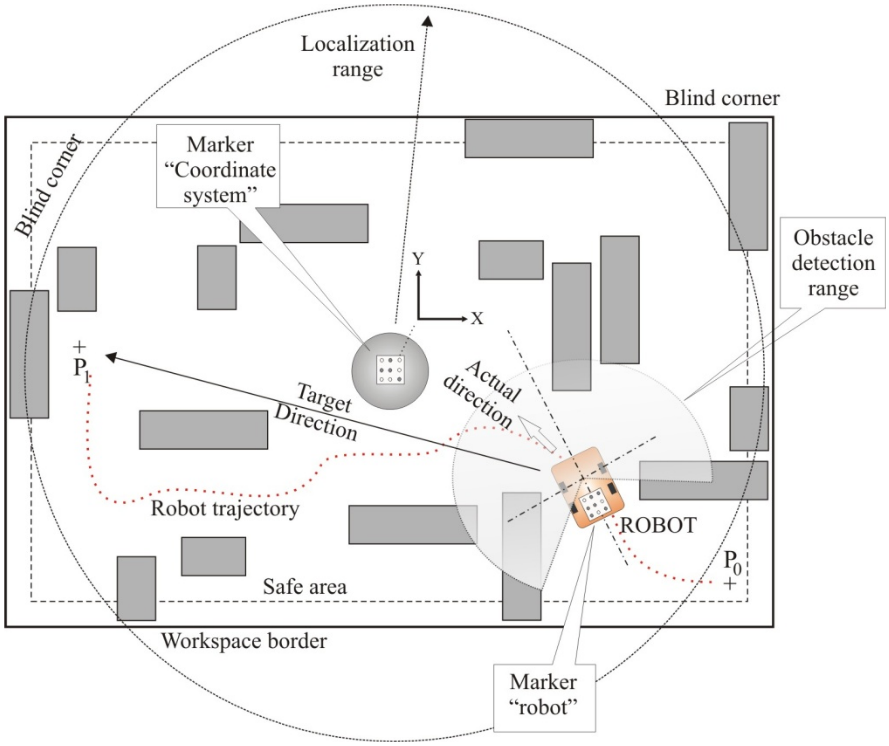


Figure 4
Example of an obstacle avoidance scenario, obstacle avoidance trajectory of mobile robot

# 4 Wireless Robot-Sensor Networked Systems

Wireless Robot-Sensor Networked systems refer to multiple robots operating together in coordination or cooperatively with sensors, embedded computers, and human users [13], [14]. Cooperation entails more than one entity working toward a common goal while coordination implies a relationship between entities that ensures efficiency or harmony.

Communication between entities is fundamental to both cooperation and coordination and hence the central role of the networked system. Embedded computers and sensors are now ubiquitous in homes and factories, and increasingly wireless ad-hoc networks or plug-and-play wired networks are becoming commonplace.

Robots are functioning in environments while performing tasks that require them to coordinate with other robots, cooperate with humans, and act on information derived from multiple sensors. In many cases, these human users, the robots and sensors are not collocated, and the coordination and communication happens through a network. Networked robots allow multiple robots and auxiliary entities to perform tasks that are well beyond the abilities of a single robot [13], [14].

Robots can automatically couple to perform locomotion and manipulation tasks that either a single robot cannot perform or that would require a special-purpose larger robot to perform. They can also coordinate to perform search and reconnaissance tasks exploiting the efficiency that is inherent in parallelism. Further they can perform independent tasks that need to be coordinated.

Another advantage of networked robots is improved efficiency. Tasks like searching or mapping, in principle, are performed faster with an increase in the number of robots. A speed-up in manufacturing operations can be achieved by deploying multiple robots performing operations in parallel, but in a coordinated fashion.

Perhaps the greatest advantage of using the network to connect robots is the ability to connect and harness physically-removed assets. Mobile robots can react to information sensed by other mobile robots in the next room. Human users can use machines that are remotely located via the network.

The ability to network robots also enables fault-tolerance in design. If robots can in fact dynamically reconfigure themselves using the network, they are more tolerant to robot failures. Finally, networked robots have the potential to provide great synergy by bringing together components with complementary benefits and making the whole greater than the sum of the parts [13], [14].

# 5 Sun SPOT-based Remote Control of Wheeled Mobile Robots

In this paper Sun SPOT-s (Small Programmable Object Technology) have been used to creat remote control over a Khepera® mobile robot [15], [16], [17], [18].

A Sun SPOT is a small electronic device made by Sun Microsystems. The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules. The Sun SPOT connection strategy [19], [20], [21], [22], [23], [24], [25], is presented in Fig. 5.

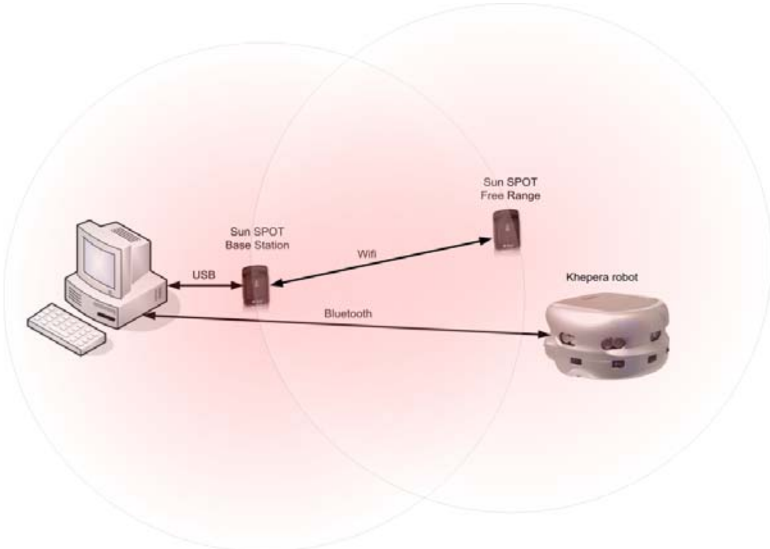


Figure 5
Remote control system

For this task 2 SunSPOT-s have been used from the development kit (Sun Microsystems, Inc. 2007). Sun SPOTs are programmed in a Java programming language, with the Java VM run on the hardware itself. It has quite a powerful main processor running the Java VM "Squawk" and which serves as an IEEE 802.15.4 wireless network node. The Sun SPOT's wireless protocol is Zigbee-based protocol [26], [27], [28], [29], [30], [31], [32], [33].

The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules. The Sun SPOT base station is used to read the data from the free range SPOT and send its contents to the PC. The PC sends via Bluetooth the control signal to the mobile robot Kephera. The miniature mobile robot Khepera® is equipped with 9 infrared sensors, 5 ultrasonic sensors and an integrated Bluetooth communication module (Fig. 6).

Figure 6
Khepera mobile robot

In the Robotics Laboratory, Department of Informatics, University of Szeged it is possible to use the sensor-based remote control system [21]. The user can start control experiment of mobile robots in Sun SPOT environment (Fig. 7), [22], [23].

Figure 7
Remote control experiment

## Conclusions

The paper deals with the fuzzy control of mobile robot motion in an unstructured environment with slopes and obstacles. Further, it presents the wireless sensor-based remote control of mobile robots motion in an unstructured environment with obstacles using the Sun SPOT technology. When the vehicle moves towards the target and the sensors detect an obstacle, an avoiding strategy and velocity control are necessary. With obstacles present in the unstructured environment, the mobile robot reacts based on both the sensed information of the obstacles and the relative position of the target.

The paper proposed the wireless sensor-based remote control of mobile robots motion in unstructured environments with obstacles and a fuzzy reactive navigation strategy of collision-free motion and velocity control in unstructured environments with slopes and obstacles.

The proposed method has been implemented on the miniature mobile robot Khepera® equipped with sensors. The wireless robot-sensor networked systems are illustrated.

The simulation results show the effectiveness and the validity of the obstacle avoidance behavior in unstructured environments and the velocity control of a wheeled mobile robot motion of the proposed fuzzy control strategy.

Finally, the effectiveness and efficiency of the proposed sensor-based remote control strategy are demonstrated by experimental studies and good experimental results.

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