Sensor-Based Intelligent Mobile Robot Navigation in Unknown Environments

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Abstract *– This paper presents sensor-based intelligent mobile robot navigation in unknown environments. The paper deals with fuzzy control of autonomous mobile robot motion in an unknown environment with obstacles and gives a wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology. Simulation results show the effectiveness and the validity of the obstacle avoidance behavior in an unknown environment and velocity control of a wheeled mobile robot motion of the proposed fuzzy control strategy. The proposed remote method has been implemented on the autonomous mobile robot Khepera that is equipped with sensors and the free range Spot from the Sun Spot technology. Finally, the effectiveness and the efficiency of the proposed sensor-based remote control strategy are demonstrated by experimental studies and good experimental results of the obstacle avoidance behavior in unknown environments.*

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Keywords *– fuzzy control, mobile robot, navigation, wireless sensor network*

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1. INTRODUCTION (Style: Ariel Bold, 10pt)

Tab: 3mm Many researches in robotics are currently dealing with different problems of motion of autonomous wheeled mobile robots and motion control of autonomous wheeled mobile robots in unknown environments. In recent years, autonomous wheeled mobile robots have been required to navigate in more complex domains, where the environment is unknown.

This paper deals with fuzzy control of autonomous wheeled mobile robot motion in an unknown environment with obstacles and gives a wireless sensor-based remote control of autonomous wheeled mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology.

Paper [1] 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. 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.

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Fuzzy reactive control of a mobile robot incorporating a real/virtual target switching strategy has been made in [2].

Navigation control of the robot is realized through fuzzy coordination of all the rules. Sensed ranging and relative target position signals are input to the fuzzy controller.

Real-time fuzzy reactive control is investigated for automatic navigation of an intelligent mobile robot in unknown and changing environments. A 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 [3] presents a strategy for 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.

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The sensor-based navigation of a mobile robot in indoor environment is very well presented in [4].

The paper deals with the problem of navigation of a mobile robot either in an unknown indoor environment or in a partially known one. Fuzzy controllers are created for navigation of the real robot. Good results obtained illustrate the robustness of a fuzzy logic approach with regard to sensor imperfections.

Design, stability analysis and implementation of new intelligent fuzzy control systems for perception and navigation of nonholonomic autonomous mobile robots have been made in [5]. Reactive, planned and teleoperated techniques are considered.

Paper [6] proposed the use of a single side reflex for autonomous navigation of mobile robots in unknown environments. In this work, fuzzy logic based implementation of the single-sided reflex is considered. The use of perceptional symmetry allows perception–action mapping with reduced sensor space dimensions. Simulation and experimental results are presented to show the effectiveness of the proposed strategy in typical obstacle situations.

The model of an autonomous wheeled mobile robot has two driving wheels and the angular velocities of the two wheels are controlled independently.

Fuzzy control of an autonomous wheeled mobile robot motion in unknown environments with obstacles 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. Simulation results show the effectiveness and the validity of the obstacle avoidance behavior in an unknown environment and velocity control of a wheeled mobile robot motion of the proposed fuzzy control strategy.

Wireless sensor-based remote control of mobile robots motion in unknown environments using the Sun SPOT technology is proposed. The proposed method has been implemented on the miniature autonomous mobile robot Khepera that is equipped with sensors and the free range Spot from the Sun Spot technology.

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

The paper is organized as follows:

Section 1 gives Introduction. The model of the autonomous wheeled mobile robot is given in Section 2. Section 3 illustrates environment perception. In Section 4, a strategy of autonomous wheeled mobile robot motion control in unknown environments is proposed. Section 5 illustrates a wireless sensor network (WSN). In Section 6 Sun-SPOT-based remote control of wheeled mobile robots is proposed. Conclusions are given in Section 7.

2. MODEL OF THE AUTONOMOUS WHEELED MOBILE ROBOT (Style: Ariel Bold, 10pt)

In this paper, the model of the autonomous wheeled mobile robot has two driving wheels (which are attached to both sides of the vehicle) and the angular velocities:

$$\sim_l, \sim_r \tag{1}$$

of the two wheels are controlled independently (Fig. 1).

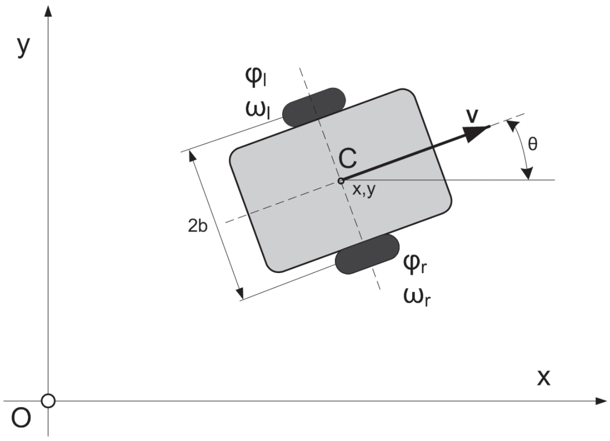

Fig. 1. Model of a differentially driven autonomous wheeled mobile robot in the two-dimensional work space (Style: Ariel Regular, 10pt)

The contact between the wheel of autonomous mobile robots and a non-deformable horizontal plane supposes both the conditions of pure rolling and non-slipping during the motion. This means that the velocity of the contact point between each wheel and the horizontal plane is equal to zero.

The rotation angle of the wheel about its horizontal axle and the radius of the wheel are denoted by $\varphi(t)$ and R, respectively.

Hence, the position of the wheel is characterized by 2 constants:

2b – the distance between wheels,

R wheel radius,

and its motion by a time-varying angle:

$\varphi_r(t)$ – the rotation angle of the right wheel, and

$\varphi_l(t)$ – the rotation angle of the left wheel.

Configuration of the mobile robot can be described by five generalized coordinates such as:

$$q = [x, \ y, \ \theta, \ \phi_r, \ \phi_l]^T \tag{2}$$

where:

x and y are the two coordinates of the center of mass C – robot position (the geometric center of the autonomous wheeled mobile robot), θ is the orientation angle of the autonomous wheeled mobile robot (robot orientation).

A kinematic model of the velocity v and the angular velocity $\dot{\theta}$ of the mobile robot are given by the equation:

$$\begin{bmatrix} v \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} R/2 & R/2 \\ R/2b & -R/2b \end{bmatrix} \begin{bmatrix} \omega_r \\ \omega_l \end{bmatrix} \quad (3)$$

3. ENVIRONMENT PERCEPTION

The autonomous wheeled mobile robot must be capable of sensing its environment. Every autonomous wheeled mobile robot needs some sensing devices first to get perception of its environment and then to move in this environment [5]. It is really important to have fast distance measurement from the mobile robot to the surrounding obstacles [14].

Conventionally, autonomous wheeled mobile robots are equipped with ultrasonic sensors. It is supposed that the autonomous wheeled mobile robot has groups of ultrasonic sensors to detect obstacles in the front, to the right and to the left of the mobile robot. An imprecise perception of ultrasonic sensors is a result of the fact that these sensors provide a relatively accurate measurement of the distance to an object, but poor information about its exact location due to angular resolution. Another source of uncertainty is a consequence of specular reflection and well-known problems such as cross-talking and noise. Several procedures have been developed to overcome the disadvantages of ultrasonic sensors [5].

4. STRATEGY OF AUTONOMOUS WHEELED MOBILE ROBOT MOTION CONTROL IN UNKNOWN ENVIRONMENTS

When the autonomous wheeled mobile robot moves towards the target and the sensors detect an obstacle, an avoiding strategy is necessary. While the autonomous wheeled 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 autonomous wheeled mobile robot reacts based on both the sensed information of the obstacles and the relative position of the target [2].

In moving towards the target and avoiding obstacles, the autonomous wheeled mobile robot changes its orientation and velocity.

When the obstacle in an unknown environment is very close, the autonomous wheeled 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.

Fuzzy-logic-based control is applied to navigation of the autonomous wheeled mobile robot in unknown environments with obstacles [7], [8], [9].

The intelligent mobile robot reactive behavior is formulated by means of fuzzy rules. Inputs to the fuzzy controller are:

- the obstacle distances p,

- the obstacle orientation θ1 (which is the angle between the robot moving direction and the line connecting the robot center with the obstacle),

- the target distances l,

- the target orientation θ2 (which is the angle between the robot moving direction and the line connecting the robot 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: Δω= ωr - ωl , and

- the vehicle velocity V.

The obstacle orientation θ1 and the target orientation θ2 are determined by the obstacle/target position and the robot position in a world coordinate system, respectively.

The obstacle orientation θ1 and the target orientation θ2 are defined as positive when the obstacle/target is located to the right of the robot moving direction; otherwise, the obstacle orientation θ1 and the target orientation θ2 are negative.

The block diagram of the fuzzy inference system is presented in Fig. 2.

For the proposed fuzzy controller the input variables for the obstacle distances p are simply expressed using

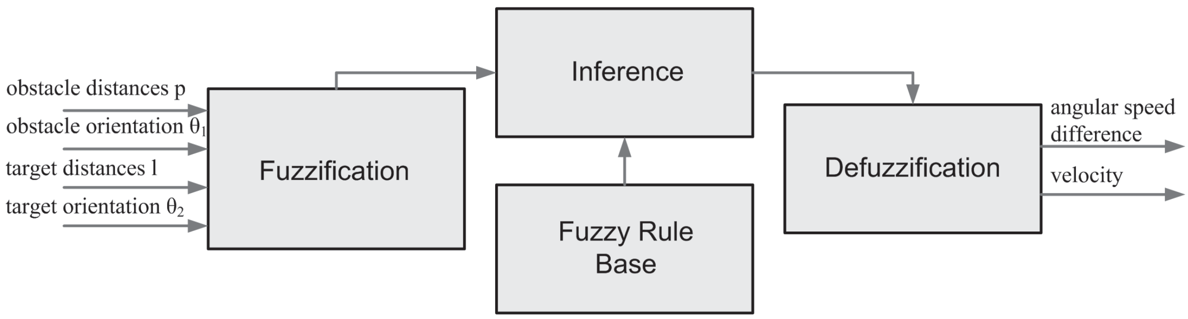

Fig. 2. The block diagram of the fuzzy inference system

two linguistic labels - Gaussian membership functions near and far (p ∈ [0, 3 m]).

The input variables for the obstacle orientation θ1 are expressed using two linguistic labels - Gaussian membership functions left and right (θ1 ∈ [-π, π rad]).

The input variables for the target distances l are simply expressed using two linguistic labels - Gaussian membership functions near and far (l ∈ [0, 3 m]). The input variables for the target orientation θ2 are simply expressed using three linguistic labels - Gaussian membership functions left, target direction and right (θ2 ∈ [-3.14, 3.14 rad]).

Fuzzy sets for the output variables the wheel angular speed correction Δω= ωr - ωl (turn-right, zero and turn-left) of the autonomous wheeled mobile robot are shown in Fig. 3.

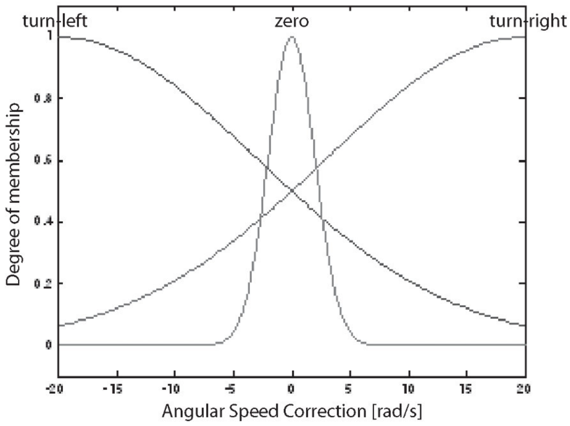

Fig. 3. Membership functions of the angular speed difference Δω

The output variables are normalized between: Δω ∈ [-20, 20 rad/s].

The other output variable of the fuzzy controller is vehicle velocity V. The output variables are normalized between: Velocity ∈ [-10, 20 m/s]. Fuzzy sets for the output variables – Velocity (low and high) are shown in Fig. 4.

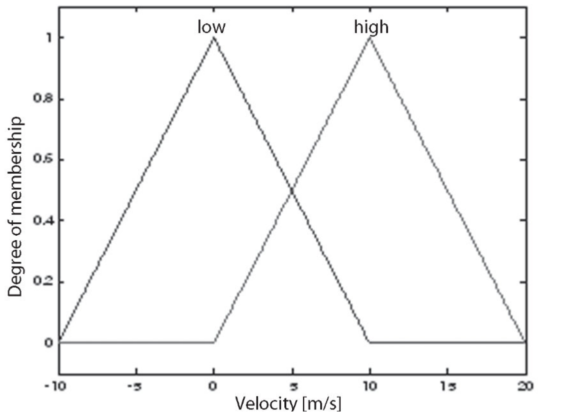

Fig. 4. Membership functions of velocity of the autonomous mobile robot

The rule-base for mobile robot fuzzy control is:

- If θ2 is right, then Δω is turn-right;
- If θ2 is left, then Δω is turn-left;
- If p is near and l is far and θ1 is left, then Δω is turn-right;
- If p is near and l is far and θ1 is right, then Δω is turn-left;
- If θ2 is target direction, then Δω is zero;
- If p is far and θ2 is target direction, then Δω is zero;
- If p is near and l is far, then velocity is low;
- If p is far and l is far, then velocity is high;
- 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.

Control surface of the proposed fuzzy controller as a function of the inputs (target orientation and obstacle distances) is shown in Figure 5.

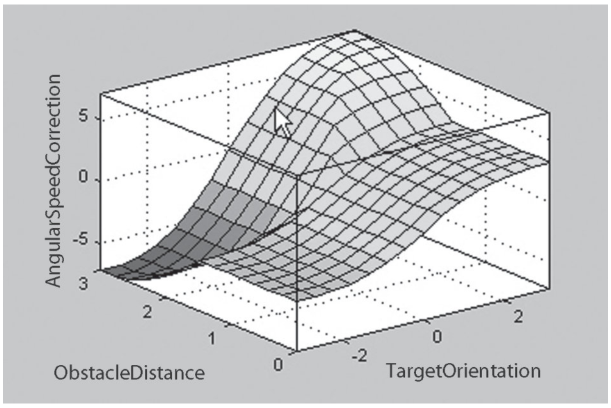

Fig. 5. Control surface of the fuzzy controller

Simulation experiments are commonly used for the initial system analysis and control design while the experimental scalable tested system has to be used in the final phase of system evaluation and control verification.

The obtained results and control architecture can be adapted afterwards to a different application of autonomous wheeled mobile robots. Based on this, an important task in system development is accurate and valuable modeling of the observed system.

Now, the author applied the proposed fuzzy controller to the autonomous wheeled mobile robot moving in an unstructured environment with obstacles [10]. A simulation example of an autonomous wheeled mobile robot is presented in Fig. 6. Corresponding fuzzy control is implemented to perform tasks of obstacle and collision avoidance.

The results of the simulation regarding goal seeking and the obstacle avoidance mobile robot paths are shown in Fig. 6.

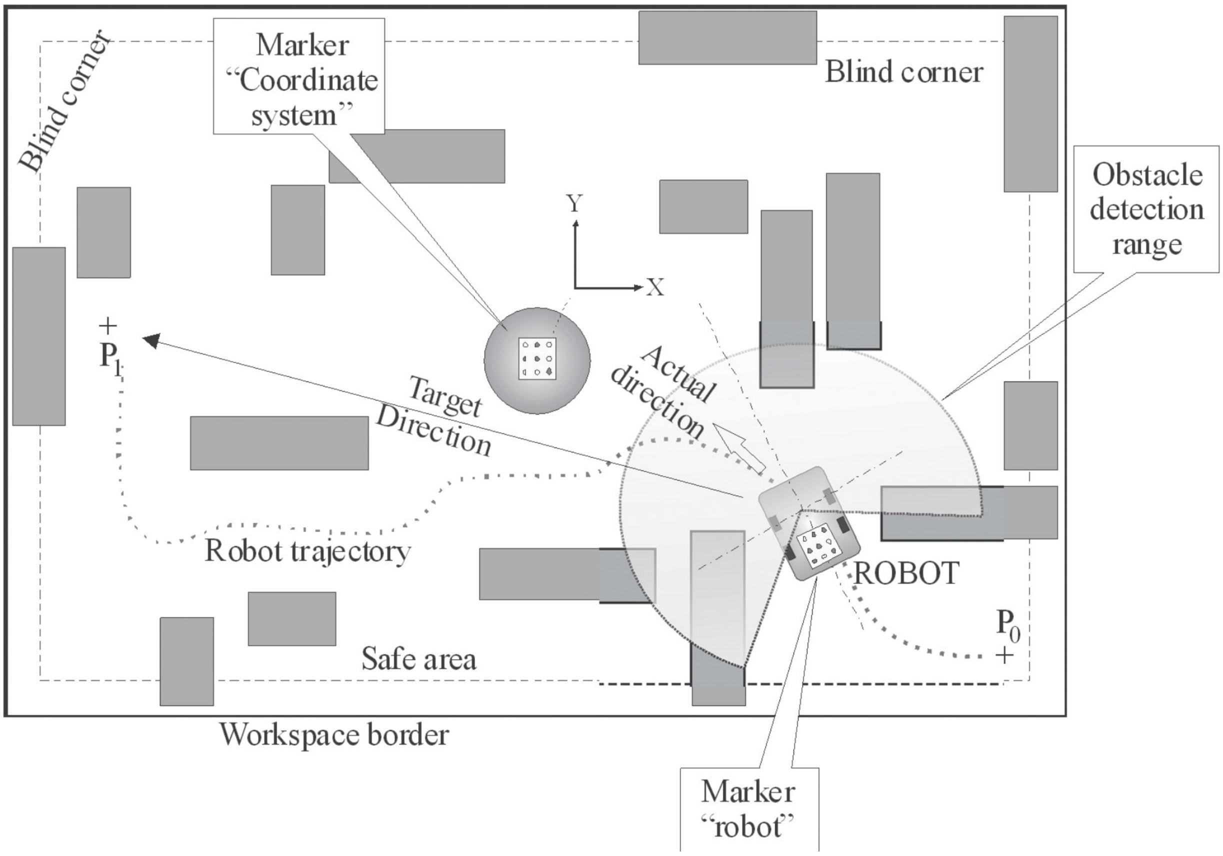

Fig. 6. Obstacle avoidance trajectory of a mobile robot

5. WIRELESS ROBOT-SENSOR NETWORK

A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations [19], [20], [21]. The development of wireless sensor networks was originally motivated by military applications such as battlefield surveillance. However, wireless sensor networks are now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, and traffic control.

In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. The size of a single sensor node can vary from shoebox-sized nodes down to devices the size of a grain of dust. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and bandwidth.

Wireless Robot-Sensor Networked systems (WR-SN) refer to multiple robots operating together in coordination or cooperatively with sensors, embedded computers, and human users [10]. 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 requiring them to coordinate with other robots, cooperate with humans, and act on information derived from multiple sensors. In many cases, these human users, 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 [10]. Robots can automatically couple to perform locomotion and manipulation tasks that either a single robot cannot perform, or would require a larger special-purpose robot to perform. They can also coordinate to perform search and reconnaissance tasks exploiting the efficiency 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 are, in principle, 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 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 [10].

6. SUN SPOT BASED REMOTE CONTROL OF WHEELED MOBILE ROBOTS

In this paper Sun SPOTs (Small Programmable Object Technology) have been used to create remote control over a Khepera ® mobile robot [11].

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 [10], [11], [12], [13], [14], [15], [16], [17] is presented in Fig. 7.

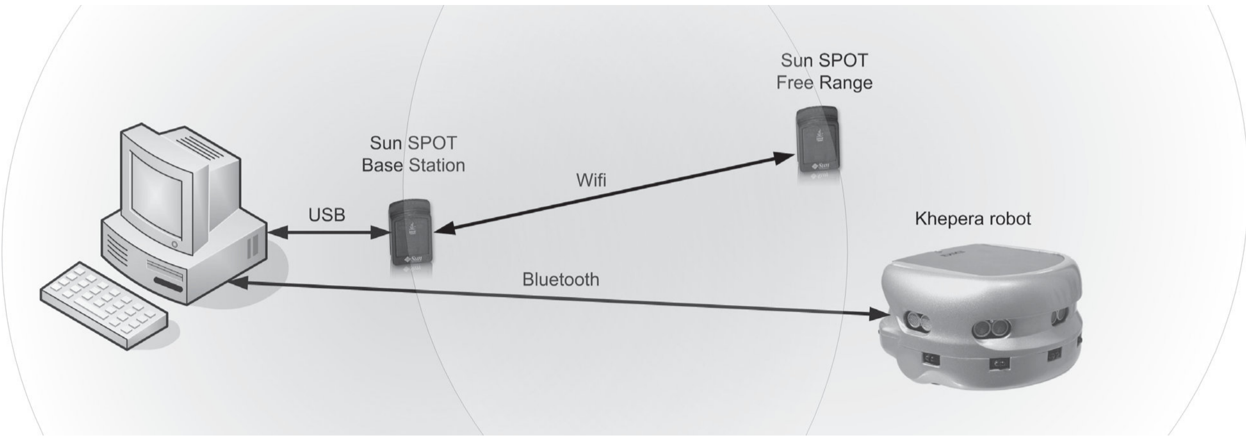

Fig. 7. Remote control system

For this task 2 SunSPOTs 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" serving as an IEEE 802.15.4 wireless network node. SunSPOT's wireless protocol is a Zigbee-based protocol [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24]. The SunSPOT base station has been used to read the data from the free range SPOT and send its contents to the PC.

The PC with a Bluetooth connection sends the control signal to the mobile robot Khepera®. The miniature mobile robot Khepera® is equipped with 9 infrared ND, 5 ultrasonic sensors and an integrated Bluetooth communication module. In the Robotics Laboratory , Department of Informatics, University of Szeged, it is possible to use the sensor-based remote control system [18]. The user can start a control experiment of mobile robots in the Sun SPOT environment (Fig. 8), [11].

Fig. 8. Remote control system

7. CONCLUSION

The paper proposed wireless sensor-based remote control of mobile robots motion in unknown environments with obstacles using the Sun SPOT technology and a fuzzy reactive navigation strategy of collision-free motion and velocity control in unknown environments with obstacles. The proposed method has been implemented on the autonomous mobile robot Khepera ® that is equipped with: 9 infrared ND, 5 ultrasonic sensors and an integrated Bluetooth communication module. Wireless robot-sensor networked systems are illustrated.

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

Corresponding fuzzy control is implemented to perform tasks of obstacle and collision avoidance.

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

ACKNOWLEDGEMENT

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