Sensor Based Control of Autonomous Wheeled Mobile Robots

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Abstract — The paper deals with the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and gives the fuzzy velocity control of a mobile robot motion in an unknown environment with slopes and obstacles. The model of the vehicle has two driving wheels and 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 slopes, an avoiding strategy and velocity control are necessary. We proposed the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and a fuzzy reactive navigation strategy of collision-free motion and velocity control in an unknown environment with slopes and obstacles. 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 an unknown environment and velocity control of the proposed fuzzy control strategy. The proposed method have been implemented on the miniature mobile robot Khepera® that is equipped with sensors and the free range Spot.

Keywords – sensor-based, remote control, Sun SPOT technology, fuzzy reactive navigation strategy, collision-free motion, obstacle avoidance, mobile robot Khepera®

I. Introduction

The paper deals with the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and gives the fuzzy velocity control of a wheeled mobile robot motion in an unknown environment with slopes and obstacles. The autonomous mobile robots are very interesting subjects both in scientific research and practical applications. The wheeled mobile robot must be capable of sensing its environment. Conventionally, mobile robots are equipped by ultrasonic sensors and a stereo-vision system. The model of the vehicle has two driving wheels and the angular velocities of the two wheels are independently controlled. This model is the simplest and the most suitable for the small-sized and light, battery-driven autonomous vehicle. First, the modeling of the autonomous wheeled mobile robots is considered. Then the fuzzy control of a wheeled mobile robot motion in an unknown environment 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 an unknown environment and velocity control of a wheeled mobile robot motion of the proposed fuzzy control strategy.

Finally, the proposed method have been implemented on the miniature mobile robot Khepera® that is equipped with sensors and the free range Spot from the Sun Spot technology.

The paper is organized as follows:

- Section 1: Introduction.
- In Section 2 modeling of the autonomous wheeled mobile robots is illustrated.
- In Section 3 strategy of autonomous wheeled mobile robot motion in an unknown environment with obstacles and slopes is proposed.
- In Section 4 the simulation results are illustrated.
- In Section 5 Sun SPOT based remote control of mobile robots is proposed
- Conclusions are given in Section 6.

II. Modeling of the Autonomous Wheeled Mobile Robots

We consider a mechanical system with n generalized coordinate's q subject to m kinematics constraints. A large class of mechanical systems, such a wheeled vehicle and mobile robots involve kinematics constraints. In the literature these kinematics constraints can generally be classified as: nonholonomic or holonomic. A mobile robot involving two actuator wheels is considered as a system subject to nonholonomic constraints. Let's consider the kinematics model for an autonomous vehicle. The position of the mobile robot in the plane with obstacle and target position is shown in Fig. 1.

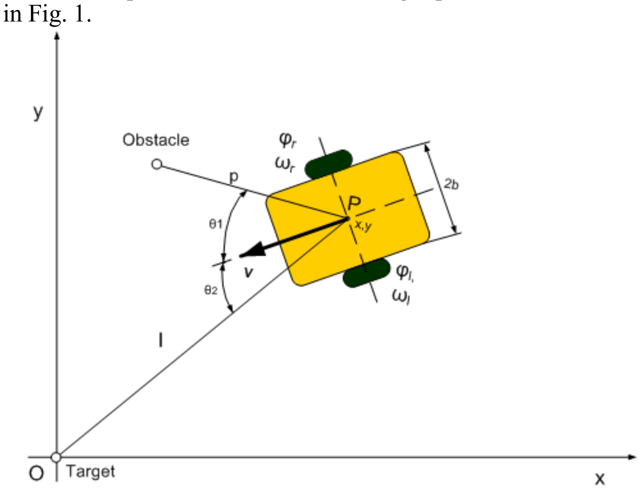

Figure 1. Position of mobile robot in plane

Where: p - the obstacle distances, θ_1 - the obstacle orientation, l - the target distances, θ_2 - the target orientation.

The inertial-based frame (Oxy) is fixed in the plane of motion and the moving frame is attached to the mobile robot. In this paper we will assume that the mobile robots are rigid cart equipped, with non-deformable conventional wheels, and they are moving on a non-deformable horizontal plane. The center of the driving wheels is regarded as the gravity center.

During the motion: the contact between the wheel and the horizontal plane is reduced to a single point, the wheels are fixed, the plane of each wheel remains vertical, the wheel rotates about its horizontal axle and the orientation of the horizontal axle with respect to the cart can be fixed. The center of the fixed wheel is a fixed point of the cart and b is the distance of the center of the wheel from P.

The contact between the wheel of the mobile robots and the 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. For low rolling velocities this is a reasonable wheel moving model.

The rotation angle of the wheel about its horizontal axle is denoted by $\varphi(t)$ and the radius of the wheel by R. Hence, the position of the wheel is characterized by two constants:

b and R

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.

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

$$q = [x,\ y,\ \theta,\ \varphi_r,\ \varphi_l]^T \qquad (1)$$

Where: x and y are the two coordinates of the origin P of the moving frame (the geometric center of the mobile robot), θ is the orientation angle of the mobile robot (of the moving frame). The vehicle velocity v can be found in (2):

$$v = R(\omega_r + \omega_l)/2 \qquad (2)$$

where:

$$\omega_r = \frac{d\varphi_r}{dt} \text{ – angular velocity of the right wheel,}$$

$$\omega_l = \frac{d\varphi_l}{dt} \text{ – angular velocity of the left wheel,}$$

The position and the orientation of the mobile vehicle are determined by a set of differential equations (3-5) in the following form:

$$\dot{x} = (R\cos\theta\,(\omega_r + \omega_l))/2 \qquad (3)$$

$$\dot{y} = (R\sin\theta\,(\omega_r + \omega_l))/2 \qquad (4)$$

$$\dot{\theta} = R\,(\omega_r - \omega_l)/2b \qquad (5)$$

Finally, the kinematics model of the vehicle velocity v and the angular velocity $\dot{\theta}$ of the mobile robot can be represented by the matrix as follows:

$$\begin{bmatrix} v \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} R/2 & R/2 \\ R/2b & -R/2b \end{bmatrix} \begin{bmatrix} \omega_r \\ \omega_l \end{bmatrix} \qquad (6)$$

III. Strategy of Autonomous Wheeled Mobile Robot Motion in an Unknown Environment with Obstacles and Slopes

Currently many researches in robotics are dealing with different problems of motion of wheeled mobile robots. Let us consider the autonomous motion of wheeled mobile robots in an unknown environment. The mobile robot must be capable of sensing its environment. Conventionally, mobile robots are equipped by ultrasonic sensors and a stereo-vision system. The role of cameras is to identify the relative position and direction of motion of biped robot in unknown environment. The accurate distance of the obstacle can be obtained from the ultrasonic sensors. In moving towards the target and avoiding obstacles, the mobile robot changes its orientation and velocity. We proposed a fuzzy reactive navigation strategy of collision-free motion and velocity control of mobile robots in an unknown environment with obstacles and slopes. In this section fuzzy control is applied to the navigation of the autonomous mobile robot in an unknown environment with obstacles and slopes [1], [2], [3]. We 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 the obstacle in an unknown environment is very close, the mobile robot slows down and rapidly changes its orientation. The navigation strategy is 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 distances p, the obstacle orientation θ_1 (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 θ_2 (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: $\Delta\omega = \omega_r - \omega_l$ and

- the vehicle velocity.

The obstacle orientation θ_1 and the target orientation θ_2 are determined by the obstacle/target position and the robot position in a world coordinate system, respectively. The obstacle orientation θ_1 and the target orientation θ_2 are defined as positive when the obstacle/target is located to the right of the robot moving direction; otherwise, the obstacle orientation θ_1 and the target orientation θ_2 are negative [1].

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

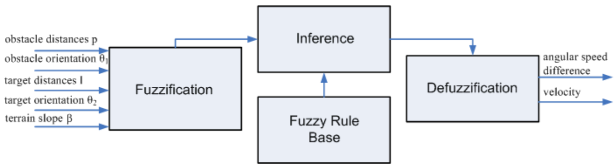

Figure 2. The block diagram of the fuzzy inference system

For the proposed fuzzy controller the input variables for the obstacle distances p are simply expressed using two linguistic labels *near* and *far* (p ϵ [0, 3 m]). Fig. 3 shows the suitable Gaussian membership functions.

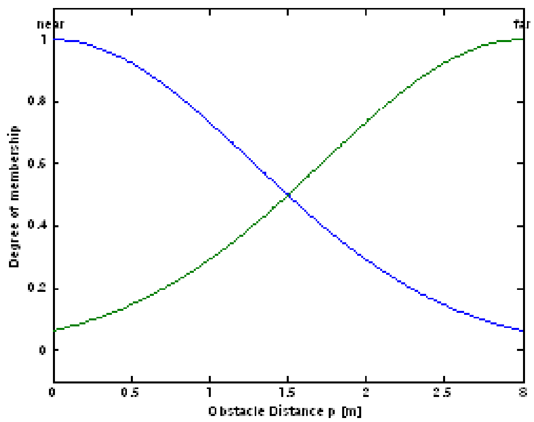

Figure 3. Membership functions of obstacle distances p

The input variables for the obstacle orientation θ_1 are expressed using two linguistic labels *left* and *right* (θ_1ϵ[-π,π rad]). Fig. 4 shows the suitable Gaussian membership functions.

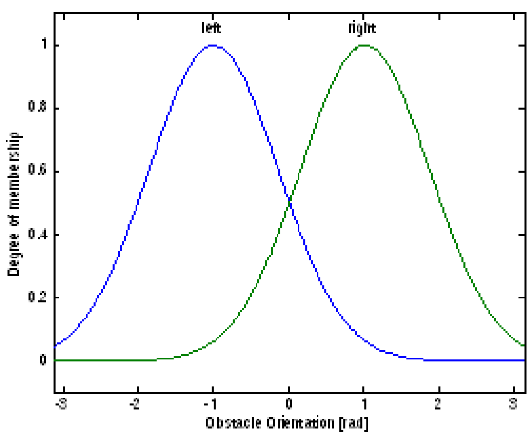

Figure 4. Membership functions of obstacle orientation θ_1

For the proposed fuzzy controller the input variables for the terrain slope β is simply expressed using three linguistic labels: *slopedleft, flat* and *slopedright* (β Є [-3.14, 3.14 rad]). Fig. 5 shows the suitable Gaussian membership functions (β is the average slope value).

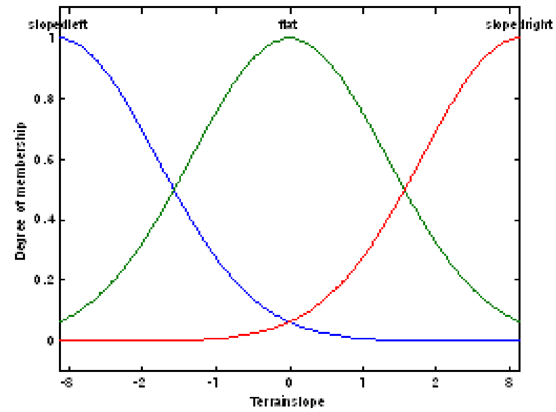

Figure 5. Membership functions of terrain slope β

The input variables for the target distances l are expressed using two linguistic labels near and far (l Є [0, 3 m]). Fig. 6 shows the suitable Gaussian membership functions.

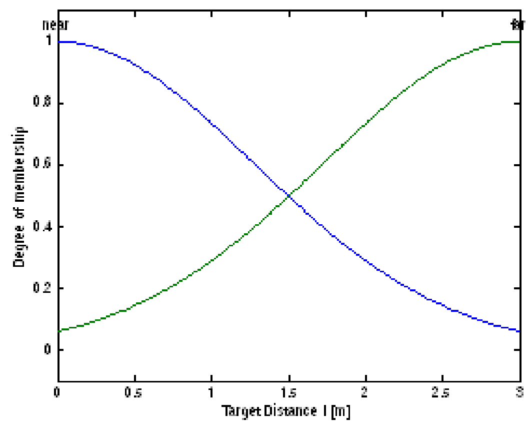

Figure 6. Membership functions of target distances l

The input variables for the target orientation θ2 are simply expressed using three linguistic labels left, targetdirection and right (θ2 Є [-3.14, 3.14 rad]), (Fig. 7).

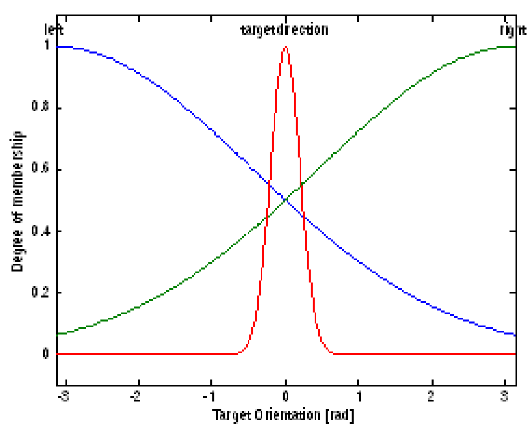

Figure 7. Membership functions of target orientation θ_2

The fuzzy sets for the output variables 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. 8.

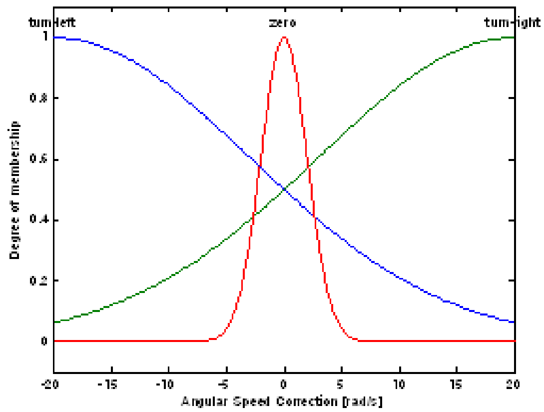

Figure 8. Membership functions of the angular speed difference $\Delta\omega$

The output variables are normalized between: $\Delta\omega \in [-20, 20$ rad/s]. The other output variable of the fuzzy controller is the vehicle velocity. The output variables are normalized between: Velocity $\in [-10, 20$ m/s]. The fuzzy sets for the output variables - Velocity (low and high) are shown in Fig. 9.

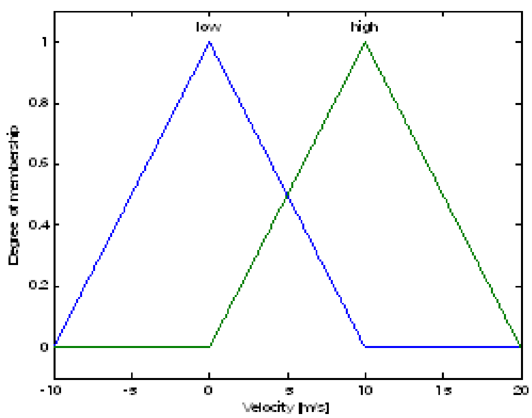

Figure 9. Membership functions of the velocity of the mobile robot

The rule-base for mobile robot fuzzy control are:

R1: If θ_2 is right and β is slopedleft then $\Delta\omega$ is turn-right
R2: If θ_2 is left and β is slopedright then $\Delta\omega$ is turn-left
R3: If p is near and l is far and θ_1 is left and β is slopedleft then $\Delta\omega$ is turn-right
R4: If p is near and l is far and θ_1 is right and β is slopedright then $\Delta\omega$ is turn-left
R5: If θ_2 is targetdirection and β is flat then $\Delta\omega$ is zero
R6: If p is far and θ_2 is targetdirection and β 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. Control surface of the proposed fuzzy controller as a function of the inputs is shown in Fig. 10.

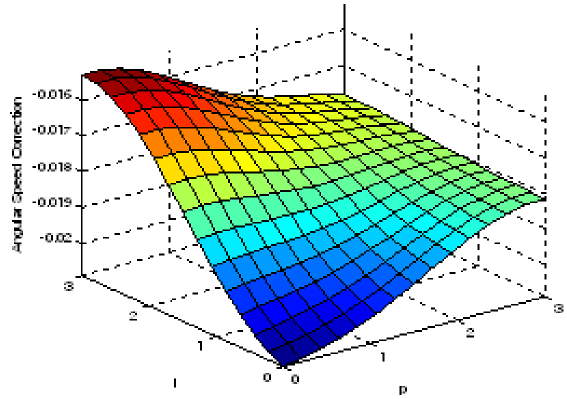

Figure 10. Control surface of fuzzy controller

IV. SIMULATION RESULT

Now, we applied the proposed fuzzy controller to the mobile robot moving in an unknown environment with obstacle. The results of the simulation are shown in Fig. 11-15. Fig. 11, Fig. 12 shows the x and y coordinates. Fig. 13 shows the vehicle velocity. Fig. 14 shows the wheel angular speed correction.

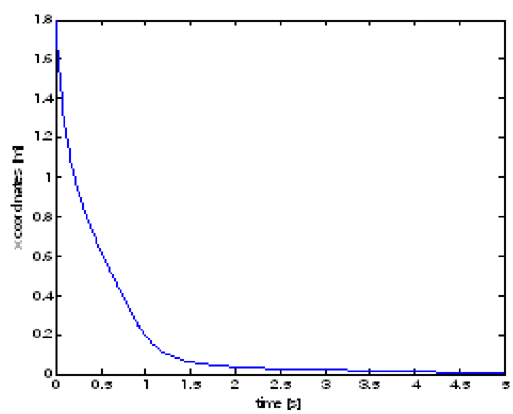

Figure 11. x coordinates

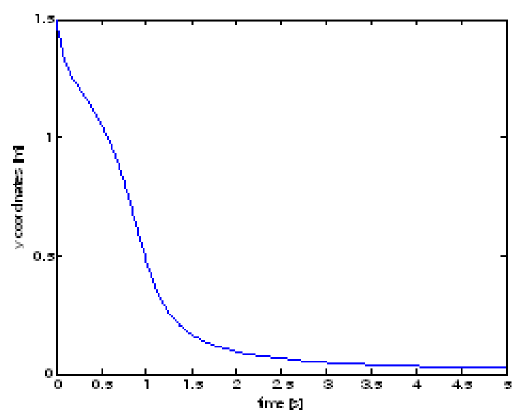

Figure 12. y coordinates

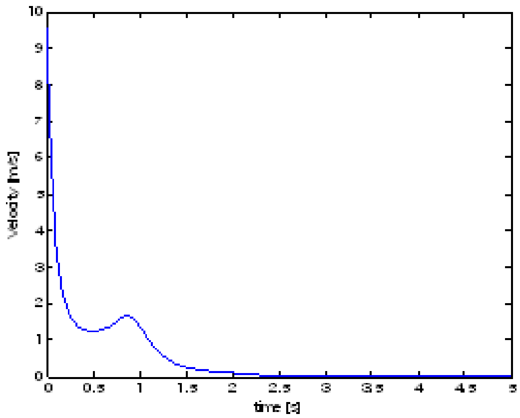

Figure 13. Vehicle velocity

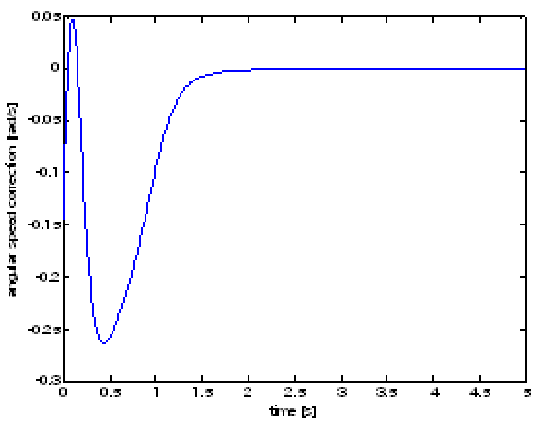

Figure 14. Wheel angular speed correction

Fig. 15 shows the goal seeking and the obstacle avoidance mobile robot paths of the right

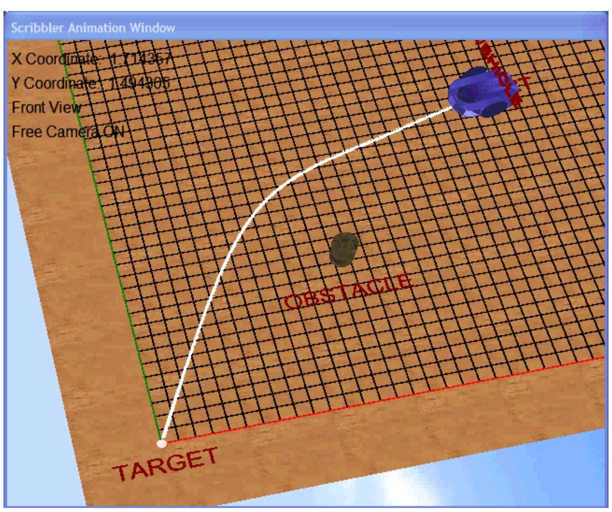

Figure 15. Obstacle avoidance trajectory of mobile robot

V. SUN SPOT BASED REMOTE CONTROL OF MOBILE ROBOTS

In this paper we have used:

SunSPOT-s

(Small Programmable Object Technology) to achieve remote control over a Kephera mobile robot. For this task we have used 2 SunSPOT-s from the development kit.

Sun SPOT's wireless protocol is ZigBee, standard: IEEE 802.15.4.

Sun SPOTS are small, battery operated wireles sensors. It contains:

32-bit ARM920T CPU,

512KB RAM, with

4 Mb Flash memory.

Wireless networking is based on ChipCon CC2420 following the 802.15.4 standard with integrated antenna and operates in the 2.4GHz to 2.4835GHz ISM unlicensed bands.

The SPOT has flexible power management and can draw from rechargeable battery, USB host or be externally powered. The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules.

We used the SunSPOT base station to read a file from the controlling computer and send its contents to the second free range SPOT.

The second SunSPOT when receiving the data in turn opens up its outputs depending on what it received. These outputs control the speed of the wheels individually.

The Hardware basically centers around Sun SPOTs

The Sun SPOT base station will send data to Sun SPOT on mobile robot which will drive the controller to DC. The microcontroller will drive the Motors which will run the Khepera mobile robot. The Sun SPOT connection strategy is presented in Fig. 16.

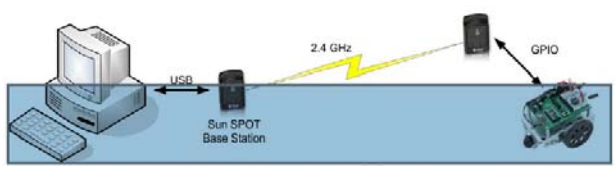

Figure 16. The Sun SPOT connection strategy

The Sun SPOT is designed to be a flexible development platform, capable of hosting widely differing application modules.

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The second SunSPOT when receiving the data in turn opens up its outputs depending on what it received.

These outputs control the speed of the wheels individually. The Hardware basically centers around Sun SPOTs and DC Motors. The Sun SPOT base station will send data to Sun SPOT on mobile robot which will drive the Basic Stamp controller to DC IO pins. The microcontroller will drive the Motors which will run the Khepera mobile robot.

Figure 17. Control of Khepera mobile robot motion in Sun Spot environment

The user can start control experiment of mobile robots in Sun SPOT environment (Fig. 17). Sun SPOTs are programmed in a Java programming language, with the Java VM run on the hardware itself [12]. Because of its Java implementation, programming the Sun SPOT is easy. The Software consists of two parts: first from the program used on the base station and from the program implemented on the free range SPOT [13].

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Acknowledgments

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VI. CONCLUSIONS

The paper deals with the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and gives the fuzzy velocity control of a mobile robot motion in an unknown environment with slopes and obstacles. The model of the vehicle has two driving wheels and 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 slopes, an avoiding strategy and velocity control are necessary. We proposed the wireless sensor-based remote control of mobile robots motion in an unknown environment with obstacles using the Sun SPOT technology and a fuzzy reactive navigation strategy of collision-free motion and velocity control in an unknown environment with slopes and obstacles. 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 an unknown environment and velocity control of the proposed fuzzy control strategy. The proposed method have been implemented on the miniature mobile robot Khepera® that is equipped with sensors and the free range Spot.

VII. REFERENCES

[1]Matijevics István, Simon János, „ Comparison of various wireless sensor networks and their implementation", *Proceedings of the Conference SIP 2009*, pp 1-3, Pécs, Hungary, 2009

[2] Fabio Carusi, Marco Casini, Domenico Prattichizzo, Antonio Vicino. "Distance Learning in Robotics and Automation by Remote Control of Lego Mobile Robots", *Proceedings of the 2004 IEEE, International Conference on Robotics & Automation* New Orleans, LA, pp. 1820-1825, USA, 2004.

[3] Gyula Mester, „Distance Learning in Robotics", *Proceedings of the Third International Conference on Informatics, Educational Technology and New Media in Education*, pp. 249-245, Sombor, SCG, 2006.

[4] W.L. Xu, S.K. Tso, Y.H. Fung, "Fuzzy reactive control of a mobile robot incorporating a real/virtual target switching strategy", *Robotics and Autonomous Systems*, Vol. 23, pp. 171-186, 1998.

[5] Ranajit Chatterjee, Fumitoshi Matsuno, "Use of single side reflex for autonomous navigation of mobile robots in unknown environments", *Robotics and Autonomous Systems*, Vol. 35, pp. 77–96, 2001.

[6] Jian Wanga, Xiangyang Zhub, Masahiro Oyac, Chun-Yi Sud, "Robust motion tracking control of partially nonholonomic mechanical systems", *Robotics and Autonomous Systems*, Vol. 35, pp. 332–341, 2006.

[7] Gyula Mester, "Improving the Mobile Robot Control in Unknown Environments", *Proceedings of the YuINFO 2007*, pp. 1-4, Kopaonik, Serbia, 2007.

[8]Gyula Mester, "Intelligent Mobile Robot Control in Unknown Environments", *Intelligent Engineering Systems and Computational Cybernetics, Springer*, pp. 15-26, 2009.

[8] Gyula Mester, "Modeling the Control Strategies of Wheeled Mobile Robots", *Proceedings of the Kandó Konferencia 2006*, pp. 1-4, Budapest, Hungary, 2006.

[9] Gyula Mester, „Intelligent Mobile Robot Controller Design", *Proceedings of the Intelligent Engineering Systems, INES 2006,* pp. 282-286, London, United Kingdom, 2006.

[10] Sun™ Small Programmable Object Technology (Sun SPOT) *Owner's Manual Release 3.0*, Sun Microsystems, Inc. 2007

[11] Bojan Kuljic, János Simon, Tibor Szakáll, "Pathfinding Based on Edge Detection and Infrared Distance Measuring Sensor