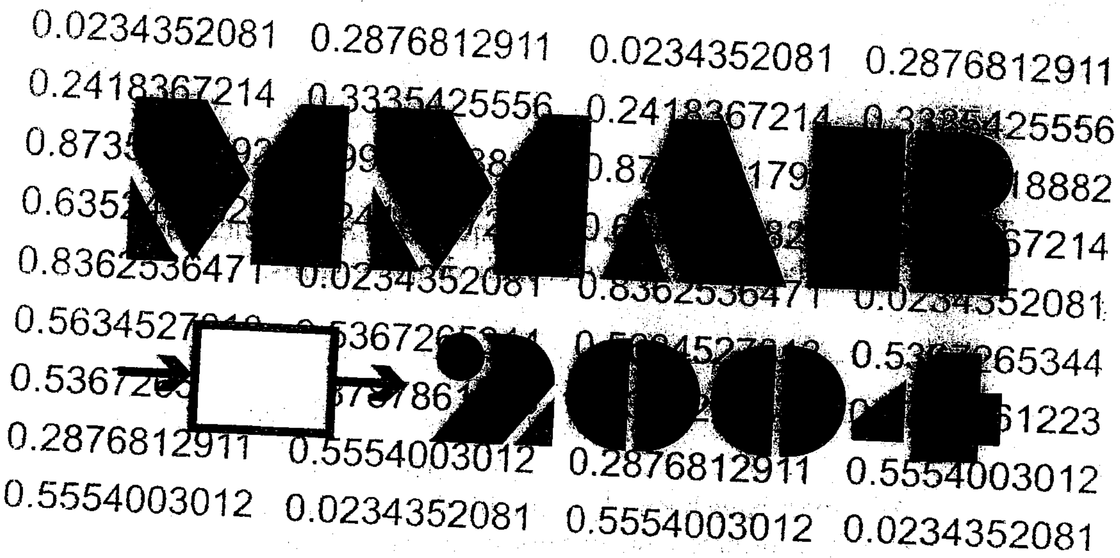

Proceedings
of the 10th IEEE International Conference on

Methods and Models in Automation and Robotics

30 August – 2 September 2004
Międzyzdroje, Poland

EDITORS
S. Domek, R. Kaszyński

Control Theory
Control Engineering
Modeling and Simulation

IEEE
IEEE Robotics & Automation Society
IEEE Control Systems Society

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MMAR 10th IEEE International Conference on **Methods and Models in Automation and Robotics**
2004 30 August - 2 September 2004, Międzyzdroje, Poland

ROBUST NAVIGATION INDOOR USING WIFI LOCALIZATION

M. OCAÑA, L.M. BERGASA, M.A. SOTELO

Departamento de Electrónica. Universidad de Alcalá.
28805 Alcalá de Henares, Madrid, SPAIN
{mocana,bergasa,sotelo}@depeca.uah.es

Abstract. In this paper we present a robust navigation system for indoor environment using data fusion of WiFi signal strength, dead reckoning and ultrasound range. We analyse the main causes of the WiFi signal strength variation using real data from our WiFi infrastructure and we demonstrate that this information can be employed for global robot localization. We use a probabilistic approach for global localization using WiFi and dead reckoning readings fused into a Particle Filter. This information is input in some local navigation tasks, based on ultrasound range measurements, in order to obtain a global navigation system. Some experimental results on a simulated mode are shown. Finally, the conclusions and future works are presented.

Key Words. WiFi localization, particle filter, fusion sensor, indoor navigation

1. INTRODUCTION

The boom in wireless networks over the last few years has given rise to a large number of available mobile tools and their emerging applications are becoming more and more sophisticated by year. Wireless networks have become a critical component of the networking infrastructure and are available in most corporate environments (universities, airports, train stations, tribunals, hospitals, etc) and in many commercial buildings (cafes, restaurants, cinemas, shopping centres, etc). Then, new homes are slowly starting to add WiFi services in order to enable mobility to perform many routine tasks, in the known as intelligent houses. There are even emerging some projects about WiFi enabled cities as Paris, Barcelona, etc.

The recent interest in location sensing for network applications and the growing demand for the deployment of such systems has brought network researchers up against a fundamental and well-known problem in the field of the robotics as is the localization. Determining the pose (position and orientation) of a robot from physical sensors is not a trivial problem and is often referred to as "the most important problem to providing a mobile robot with autonomous capabilities" [1]. Several systems for localization have been proposed and successfully deployed for an indoor environment. Examples include infrared-based systems [2], various computer vision systems [3], ultrasonic sensors and actuator systems [4], physical contact based actuator systems [5] and radio frequency (RF) based systems [6].

Many mobile robot platforms use wireless networking to communicate with off-line computing recourses, human-machine interfaces or others robots. Since the advent of inexpensive wireless networking, many mobile robots have been equipped with 802.11b wireless Ethernet. In many applications, a sensor from which position can be inferred directly without the computational overhead of image processing or the material expense of a laser is of great use. Many robotics applications would benefit from being able to use wireless Ethernet for both sensing position and communication without to add new sensors in the environment.

WiFi location determination systems use the popular 802.11b network infrastructure to determine the user location without using any extra hardware. This makes these systems attractive in indoor environments where traditional techniques, such as Global Positioning System (GPS) [7] fail. In order to estimate the user location, wireless Ethernet devices measure signal strength of received packets. This signal strength is a function of the distance and obstacles between wireless nodes and the robot. Moreover, the system needs one or more reference

WiFi infrastructure in order to test the feasibility and reliability of wireless positioning.

In [10] authors identify three main causes for the variation of the signal strength in an indoor environment:

1. *Temporal variations*: variations standing at a fixed position at a long time.
2. *Large-scale variations*: the signal strength varies over a long distance due to attenuation.
3. *Small-scale variations*: these variations happen when the user moves over a small distance and it is due to the wavelength of the signal (at 2,4GHz the wavelength is 12.5cm, then, this effect will appear for distances less than 12.5 cm).

In order to test temporal variation effect in our system a stationary measurement experiment was achieved. We have collected samples along a complete day (Friday to Saturday) from two access points (AP1 and AP2) and for a fix position of the robot near the AP1. The sampling rate was 1 s. Figure 2 shows the results of the experiment.

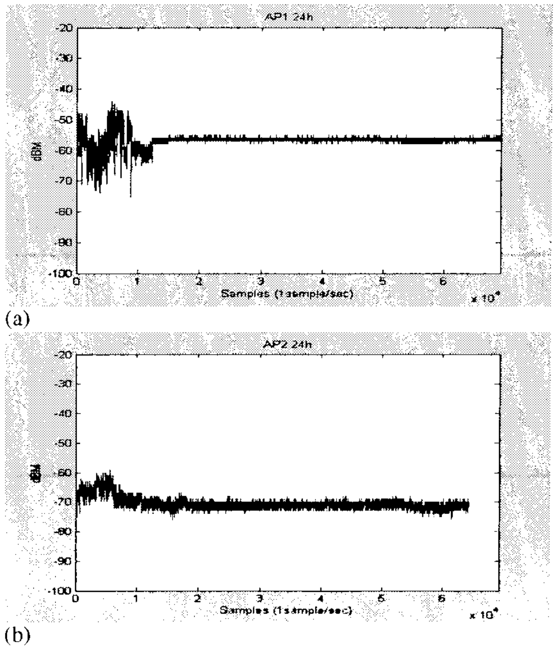

Fig. 2. Temporal variation (a) 24hs measurement from AP1. (b) 24hs measurement from AP2.

It can be seen that the signal strength from the AP1 (mean=-56.8dBm, σ=4.5dBm) is larger than from AP2 (mean=-70dBm, σ=3.7dBm). The reason is because the AP1 is farer away than the AP2 from the robot and then because the AP2 signal has to cross two walls with the corresponding attenuation. Other conclusion is that the standard deviation of AP1 signal is bigger than the AP2 one. The reason is because the effect of the secondary paths from the AP2 is lesser that the AP1 one. Then, almost all the signal received from AP2 is due to the direct path, while that the received signal from AP1 has high multi-path fading influence.

On the other hand, the signal strength is quite stable and consistent without people working (from 1.5 10^4 to 6.9 10^4 samples) and get worse during the rest time. Signal strength measures are highly affected by some environment elements such as the movement of people, the computer noise and the influence of other radio signals (Bluetooth mouse and keyboard links, etc). This influence provokes changes in the measures between 5 to 15 dBm. We must remark that the conditions of this experiment was very extreme because at working time a lot of people was moving around the robot and almost all the PCs have Bluetooth links.

For testing large-scale variations, signal strength from AP1 and AP2 has been collected with the robot moving across the three corridors. We took the radio map locations on the corridors on a grid placed 80 cm apart and taking 300 samples for each position. Results are shown in figure 3. As we can see the variation of the average signal strength over a distance of 18 meters is about 20 dBm. Moreover, there isn't a linear variation of the signal with the distance due to the multi path effect. This in the reason because it is very difficult to built a propagation model for indoors environments.

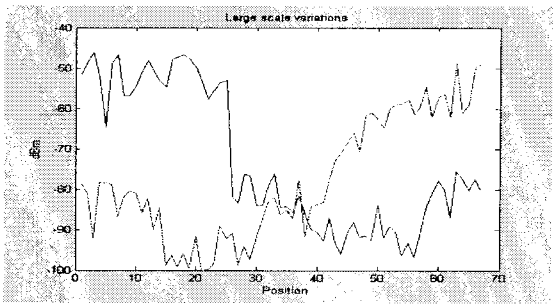

Fig. 3. Large-scale variation

For demonstrating small-scale variations we have achieved several measures from the AP1 in different points separated a short distance (<12,5cm) and we have represented a histogram for each case. Figure 4 shows the small-scale effect tested in three different positions: reference (figure 4(a)), position separated from the reference 1/4λ (figure 4(b)) and position separated from the reference 1/2λ (c) (figure 4(c)). As we can see, a variation up to 3 dBm is measured in a distance small than 10 cm with different profiles for the histograms.

We have also analysed the effect of the robot orientation in our environment. We have taken several signal strength measures and we have obtained its histograms in orthogonal orientations to observe that it is possible to obtain the orientation and not only the position of the robot. Figure 5 shows the results of this test for a reference position with an dimensions of the particles are updated based on a zero-mean Gaussian model. The value of each dimension of the particle is averaged across all particles and the resulting numbers are used as the best estimate. Some restrictions are imposed on the estimates in order to restrict from passing thought walls. In this moment we can start a new iteration of the algorithm taking a new observation and following the explained steps. Fusion between dead reckoning and wireless sensors will be used for the next observations. After now, the number of samples from each APs will be decremented until 30 samples for improving time process and because now we have a previous estimation of the robot position.

Once the robot position is estimated, it moves and movement model of the robot, based on dead reckoning data, are fused with the WiFi localization data into the particle filter, in order to obtain the new estimated position. Position obtained from the WiFi sensor is updated each time that the robot travels 80 cm (cell size). Under this distance only dead reckoning data is used in the observations. In this way, we eliminate the small-scale variation of the WiFi measures and we can obtain a tracking algorithm in real time for a robot maximum speed of 10 cm/s. We couldn't forget that time needed for a WiFi reading is 8 s. By using the fusion strategy, the particle filter, that is run each 100 ms, takes continuous observation from the robot position and improve its convergence because it is run a higher number of times than by using only WiFi measures. When the WiFi measures are updates, these are compared with the dead reckoning ones, if they are similar it means that the robot is good localized and then dead reckoning data are reset removing the odometry errors. If they are very different (more than 40cm) the robot is lost, then, it stops and the particle filter is started again taking a more accurate WiFi reading of 300 samples from each APs. With this algorithm we obtain an error underneath 40cm, as you can see in the results section.

5. ROBOT NAVIGATION

Robot navigation is mainly based in local navigation in corridors. This last is carried out based on ultrasound range measurements. Global location of the robot is run in parallel with the navigation tasks as we have explained in the previous point. Initial position of the robot is calculated using the global localization algorithm. Then, it obtains the beginning and final points of the corridors for the local navigation task.

The main goal of the local navigation task is to autonomously navigate a robot in a corridor, whatever the state of its doors and the position of persons walking around it. Basically, the specification of the local navigation task is provided as follows: at first, the robot find the beginning point of a corridor from the global localization system and gets the appropriate orientation in parallel with respect to the corridor walls. After that, a model of the corridor is estimated based on ultrasound range measurements. The robot's local position (lateral and orientation error with regard to the centre of the corridor) is measured based on the model of the corridor. Then, a lateral controller leads the robot to the centre of the corridor while navigating. When the robot is at the final point of the corridor, obtained by the global location system, it starts a turning maneuver until reaching a beginning point of a new corridor.

6. EXPERIMENTAL RESULTS

In this section, we present the experimental results of our robot navigation system in a simulated mode. In this mode, the robot moves in the environment and the WiFi readings were collected to a file during the moving. Next, in the simulation mode we use a model for the movements of the robot and other movement model based on dead reckoning sensor for movement estimation of the robot. The WiFi readings are obtained from the file previously recorded.

The environment of simulation is shown in figure 2. The figure shows three corridors (corridor 3 and 4 and main corridor of the environment) and it shows the particles of the filter in blue. In this experiment we have used 200 particles. A red circle indicates the robot estimation and a green asterisk represent the real position of the robot. Figure 6(a) shows the first iteration of the filter and figure 6(b) shows the real and estimated path during simulation phase.

Figure 7 shows the localization error obtained in the simulation test using data fusion of dead reckoning and WiFi localization during the navigation through corridor 3 and 4. In red colour we show the error using only WiFi readings and in blue colour the error using sensor fusion.

As you see in figure 7, the error using only WiFi reading oscillates because this readings are updated each 80 cm, remaining the last position until a new update. The error using fusion sensors is lower than 40cm in all the experiment.

7. CONCLUSIONS AND FUTURE WORKS

In this paper, we have presented a robust navigation system for indoor environment using data fusion of WiFi localization, dead reckoning and ultrasound range sensors. We have analysed the main causes for the variation of the WiFi signal strength and we have demonstrate that this information fused with dead reckoning data can be used in order to obtain a robust