A Wearable Computing System for Dynamic Locating of Parking Spaces

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Abstract

This paper describes a dynamic locating system implemented in an autonomous wearable computing system for the automobile warehouse management application. Since the first prototype is developed as jacket [1], this prototype is miniaturized and therefore realized as holster which consists of several modules for identification, communication and localization. It is worn by employees during warehousing of automobiles. The modules collect data, which are used by the operating system to calculate the location of parking spaces dynamically.

Keywords: **automobile warehouse management, embedded system, global positioning, wearable computing system**

1. Introduction

Logistics in these days are permanently developing. One recent development is enhancement of automation and improvement of efficiency of dynamic warehousing. An automotive warehouse management system holds huge numbers of automobiles which have to be moved between parking spaces or terminal gates by staff. Because of the number of different parking spaces used as temporary storage, enhancing efficient and transparent warehousing requires that every car can be identified and localized at any time.

A solution inside the car is expensive and not accepted by the costumer. Automated collection of specific information related to a particular automobile can be realized with RFID (Radio Frequency Identification) labels. These are cheap, recyclable and easily adaptable for an automobile warehouse management system. Besides saving and comparing RFID-enabled automobile information, the new approach is to retrieve the position of every car at any parking space. This is done using this developed wearable computing system that allows receiving of RFID information, global positioning and wireless communication. This system is worn by the employee as a holster and is ready for use as a prototype. Figure 1 shows the second prototype of the wearable computing system, where a shoulder holster is used for integration.

Fig. 1 Holster as wearable computing system

2. The Wearable Computing System

For this reason, a wearable computing system has been developed, which is included to the holster shown in Fig. 1 and will be worn by the staff [2].

2.1 Hardware Overview

The wearable computing system is a combination of low-power and small-package modules, connected to and controlled by a an embedded microcontroller with its own operating system [3].

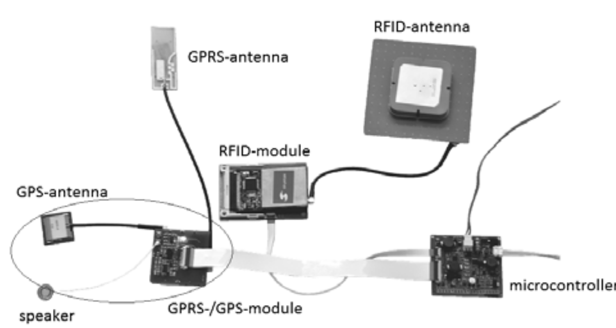

Fig. 2 Hardware configuration of the wearable computing system

As shown in Figure 2, the microcontroller controls all modules. The power management and the serial communication components are realized on an adaptor, which interacts with the microcontroller. The combined GPRS/GPS module [4] with high sensitivity provides a low-cost communication with server, where the internet is used as the platform. The GPS receiver allows positioning to a precision of 2.5 meters by using a Satellite-Based Augmentation System (SBAS) - in Europe the European Geostationary Navigation Overlay Service (EGNOS). Every wearable computing system that is online can exchange data with the server. In addition, a UHF-RFID module [5] has been connected just like the GPRS/GPS module to identify RFID labels inside the car. To save energy the microcontroller is able to toggle the power supply of the RFID. A loudspeaker is needed for feedback to recover vehicles using the wearable computing system.

2.2 Software Description

The software is preinstalled with the open-source operating system Linux. So the used software can be programmed in e.g. ANSI-C using a cross-compiler to allow operating the program with the ARM-architecture. With the implemented functions - written in ANSI-C - a dynamic allocation of parking places becomes possible. A background process receives GPS data and stores the information of this NMEA-Code in a shared memory area to make it accessible to other processes.

The global positioning data is received automatically after leaving an automobile using a proximity sensor on the back side of the holster (not shown in Fig. 2). This sensor detects whether the employee is sitting inside the car or not. Inside the car the RFID label is detected automatically. This information combined with global positioning data represents a parking space for the system. Every parking space is part of a matrix calculated by the operating system. This matrix is researched previously with MATLAB [6] and allows the program code to be easily ported to the microcontroller, because they share nearly the same language.

3. Theory of Dynamic Allocation

3.1 Reference Data Collection

The dynamic allocation of parking spaces depends on reference global positioning data. The existence of this data is essential for each global localization system, e.g. the use of digital maps in navigation systems. The wearable computing system makes use of an additional touch-screen interface, which is placed in the underarm of the holster (not shown in Fig. 1), that enables it to acquire reference GPS data of parking areas. Through an instruction-lead system in the form of moving to a selected corner point of the parking area, confirmation via the touch screen display, measurement of the actual position, the required data can be gathered. This method is required just once for each parking area and does need only three positions (data points). Although reference points provided by the land registry office are advantageous for its higher accuracy, this method offers a rapid and locally independent approach. Using these reference points leads to an abstracted matrix of parking places (Fig. 3).

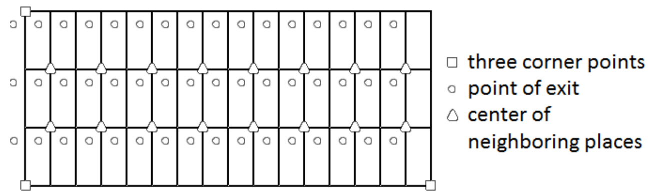

Fig. 3 Abstracted matrix of parking area

Its structure can be modified and has following exemplary appearance: an identification code e.g. generated from a time code and an RFID reader, information of occupancy plus the latitude and longitude of the position measured after leaving the vehicle.

3.2 Measurement, Calculation and Assignment

Assuming the given matrix uses Cartesian coordinates and the bottom left corner is equal to the point of origin, a transformation of each measured GPS location from the GPRMC (Global Positioning recommended minimum sentence C) standard to a relative position within the matrix has to be performed.

Table 1: Used variables with their corresponding units

Symbol	***Description***	***Unit***
a_i	Latitude of position i	Decimal degree rad.
b_i	Longitude of position i	Decimal degree rad.
r_e	Equator radius	km
r_p	Polar radius	km
r_{lat}	Radius depending on geodetic latitude	km
$d_{i,j}$	Distance between position i and j	m
φ	Geodetic latitude	Decimal degree rad.
x, y, x', y'	Relative positions	m
α, ω	Angle	Decimal degree rad.

Determining the relative position has been achieved by using the concept of orthodromes. The distance between two arbitrary measured positions is calculated in meters by using the following formula for small GPS distances [7].

$$d_{1,2} = \cos^{-1}\left(\sin a_1 \cdot \sin a_2 + \cos a_1 \cdot \cos a_2 \cdot \cos(b_2 - b_1)\right) \cdot r_{lat} \qquad (1)$$

Therein r_{lat} equals the radius depending on the geodetic latitude and can be calculated with

$$r_{lat} = \sqrt{\frac{\left(r_e^{\,2} \cdot \cos(\varphi)\right)^2 + \left(r_P^{\,2} \cdot \sin(\varphi)\right)^2}{\left(r_e \cdot \cos(\varphi)\right)^2 + \left(r_P \cdot \sin(\varphi)\right)^2}} \qquad (2)$$

In Equation 2, φ stands for the latitude in radian measure, r_e for the equatorial and r_P for the polar radius in kilometers [8]. The GPRMC sentence includes positioning data in decimal minutes for latitude and longitude which have to be converted into decimal degrees and finally into metric coordinates x and y.

According to the definition of the point of origin the calculated relative position is submitted with coordinate transformation. The needed rotation is accomplished using Equation 3.

$$[x', y'] = \begin{pmatrix} \cos\omega & \sin\omega \\ -\sin\omega & \cos\omega \end{pmatrix} \cdot \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \cdot \begin{bmatrix} x \\ y \end{bmatrix} \qquad (3)$$

The pair of coordinates x and y equals to the position before the transformation and the pair x' and y' after it [9]. The angle ω corresponds to the rotation of the parking area relative to the Earth's grid (Eq. 4).

$$\omega = \arctan\left(\frac{d_{2,3}}{d_{1,3}}\right) \qquad (4)$$

The angle α corresponds to the rotation of a parking place in relation to the parking area (Eq. 5).

$$\alpha = \cos^{-1}\left(\frac{d_{0,2}^{\,2} - d_{0,1}^{\,2} - d_{1,2}}{-2 \cdot d_{0,1} \cdot d_{1,2}}\right) \qquad (5)$$

Equations 4 and 5 enable calculation of both angles. These calculations are performed once during the reference data collection for the parking area (Section 3.1). Because every piece of GPS measurement data has to be transformed using Equation 3, it is vital to ensure high accuracy of the reference data.

Figure 4 depicts the quantities needed for the calculation of the abstracted matrix.

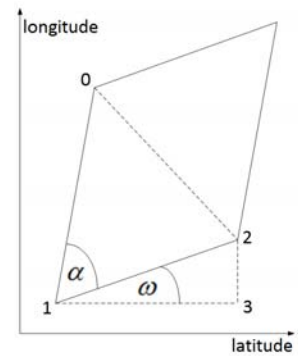

Fig. 4 Method to generate an abstracted GPS matrix

4. Simulation and Measurement Results

Different approaches have been researched to accomplish parking space locating. For instance, one method assumes that the parking area lies directly to the right of the field in which the measured GPS point is located. Figure 5 gives an example of a faulty result. On the right-hand side the algorithm assigns the incorrect space (black) instead of the correct (gray) parking space.

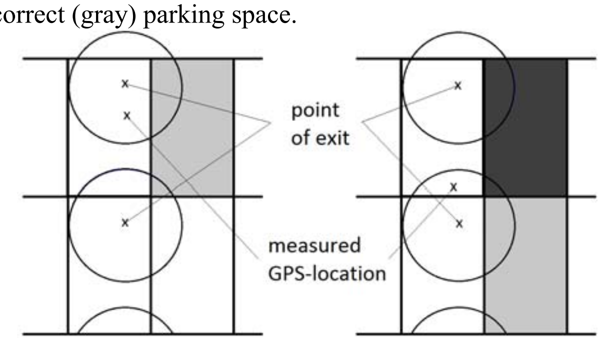

Fig. 5 Allocation of parking spaces

The chosen approach utilizes the measurement of distances between measured GPS data and (calculated) reference points in ascending order to assign parking places to collected GPS positions. Depending on the proximity of the GPS point to a corner of a parking space, a different set of adjacent parking spaces was taken into consideration. This paradigm is shown in Figure 6.

Fig. 6 Paradigm of considered fields depending on GPS measurement

Simulated distributions of global positioning data around an exit point, generated through pseudo-random values, are shown in Figure 7. The assignment of each of these 1000 randomly generated positions to a parking space is correct if the accuracy is equal to or less than the half-width of a parking space. The percentage of correct assignments decreases with decreasing accuracy of GPS data.

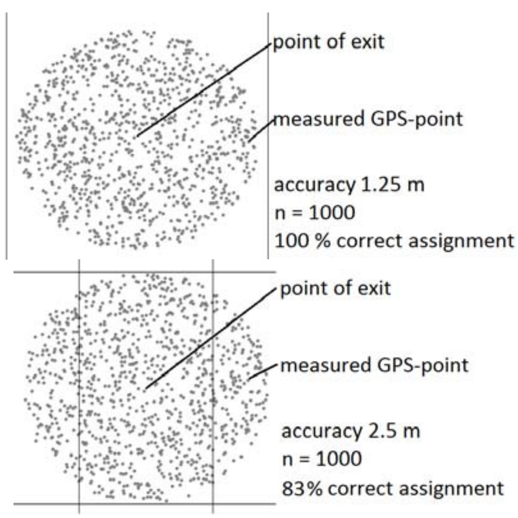

Fig. 7 Distribution of randomly measured GPS-positions with an accuracy lower than a half parking space width (upper figure) and 2.5 meters (lower figure)

As shown in Figure 7, the probability of a correct assignment of a measured GPS position with an accuracy of 2.5 meters to a parking space is below 100% and therefore not useful for the automobile warehouse management system.

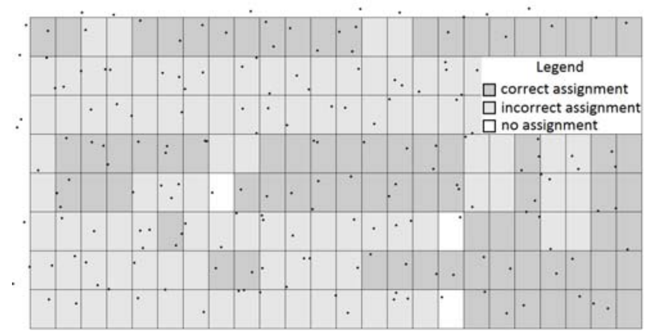

Fig. 8. Assignment of parking spaces using the warehousing system.

During the storage process every car is parked consecutively and the GPS measurement data is received after the attendant leaves the vehicle. Filling of the parking area with vehicles is done by parking in lines column by column beginning each line at the top row and ending it at the bottom row of the parking area. In Figure 8 a typical storage process of the automobile warehouse management is simulated. The abstracted parking area, containing 24x8 parking spaces, was generated using original GPS data. The white-colored boxes correspond to parking spaces which have not been assigned to measured GPS positions. Correctly assigned parking spaces are represented by the dark-grey colored boxes, whereas incorrect assignments are depicted by light-grey colored boxes.

The simulation shows that solely using the described method leads to errors during a typical storage process, which are caused by the inaccuracy of the GPS receiver. Correctly assigning parking spaces, however, is absolutely necessary for the storage management system, because otherwise the vehicles are either untraceable or at least need an increased effort to retrieve them. According to this simulation example, a correct assignment level of only 35% has been reached.

Two methods were taken into account to improve the correct assignment of parking places. First of all, assignments based on multiple measurements at the same position were simulated.

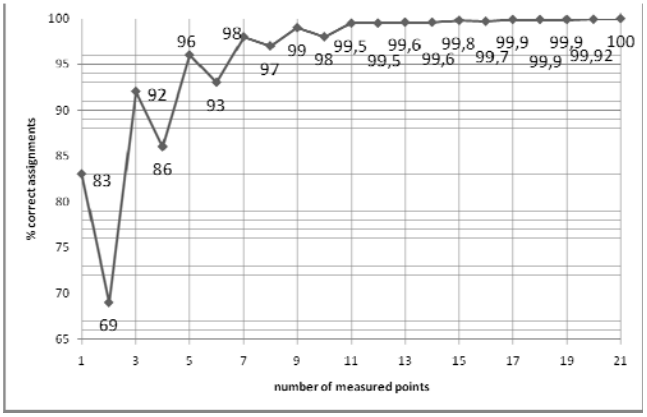

Fig. 9 Percentage of correct assignments of a parking place using a different number of measuring points in 1000 runs

As can be seen in Figure 9, the percentage of correct assignments of a singly measured GPS data point to a parking space equals 83%. The correlation between increasing the number of measurements and the increase in the percentage of correct assignments is non-linear. With an odd number of measured points the amount of correct assignment increases.

Table 2: Improving assignments by using additive measurement points

Number of measured points per location	*Probability of the correct assignment of one parking space [%]*	*Percentage of correctly assigned parking spaces in a parking area [%]*
1	83	35
3	92	77
5	96	86
7	98	95
21	100	100

Table 2 shows the correct assignments applied to the parking area shown in Figure 8. As can be seen, the percentage of correct assignments decreases if more parking spaces are considered. More than twenty measurement points are necessary to guarantee a correct assignment of 100 % for every parking space and therefore for a parking area. In due consideration of the update rate of the GPS receiver of one second, this method is not practicable.

The second approach to improve correct assignments of parking spaces under consideration is using the warehousing sequence of the storage process. Every vehicle is parked consecutively and therefore the previously assigned parking spaces can be used to help determine the current parking space. If for instance one of the possible parking spaces calculated by the algorithm has an occupied parking space above it (compare paradigm in Fig. 6) in the same column, the assignment is more probable.

Table 3: Correctly assigned parking spaces using the warehousing system with consideration of the warehousing sequence.

Accuracy [m]	*Without considering the warehousing sequence [%]*	*With considering the warehousing sequence [%]*
2.5	35	100
3	26	96
3.5	20	76

For example, assuming the possible parking space is at the top of a column the preceding parking space is at the bottom of the last column. As shown in Table 4, the amount of correct assignments could be improved significantly so that the assignment is correct to 100 % with the given positioning accuracy of the receiver.

5. Conclusions

This research shows the implementation of a method of dynamic allocation for an automobile warehouse management system using a standard GPS receiver in combination with a microcontroller as part of a wearable computing system. This method utilizes acquired GPS data to generate an abstracted matrix of a parking area to assign vehicles to parking spaces in order to improve their traceability. Because the accuracy of the GPS receiver alone is not sufficient to guarantee correct assignments, the storage process has been used to meet these requirements.

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