Indoor Simultaneous Localization and Mapping for the Visually Impaired and Blind People

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Abstract **This paper presents a wearable guiding system for visually impaired and blind people in an unknown indoor environment. The objective of this system is to obtain a map and to track the position of the pedestrian during the exploration of the new environment. The user can interact with it to provide additional information. In order to build this system the well known Simultaneous Localization and Mapping (SLAM) from mobile robotics will be used. One of the most used solutions is the Extended Kalman Filter. The user will be equipped with a short range laser, an inertial measurement unit (IMU), a wearable computer for processing purpose and a bone head phon. This system does not intent to replace the use of the white cane. Its purpose is to gather contextual information and transmit it to the user for navigation.**

Keywords**—SLAM; Wearable computing; Visually Impaired and Blind People**

I. INTRODUCTION

In recent years there has been a major interest in the localization and guiding of people in indoor and outdoor environments. Different methods to accomplish this are available. The application of each can depend on the environment and on the precision of localization that is required. Such methods are for example GNSS, field strength measurements (WLAN, GSM, Bluetooth), PDR, etc. For a precise indoor localization GPS cannot be used due to attenuation and scattering of the signals [2]. Preferred methods for indoor localization are the use of pre-installed indoor communication infrastructures, laser, radar, sonar, camera, motion sensors, etc. Assuming that not all buildings have a pre-installed communication infrastructure, the field strength measurements methods also cannot be used. For a precise indoor independent localization, it is crucial to perform sensor fusion [2].

An interesting application scenario for precise pedestrian localizations is for the visually impaired and Blind people [1]. This group of pedestrians still relies and trusts the white cane to travel with a minimal use of technology.

Many projects aim to solve this problem in different forms. In this project the plan to integrate various techniques known for localization and to provide the user with a precise guiding system.

A major problem known in the visually impaired and blind community is the exploring of unknown environments. The aim is to solve this issue in an indoor environment. When a visually impaired person explores an environment, they usually need to be accompanied by a visual capable person to guide them around. In this process, the blind person searches for landmarks. These landmarks are used later on to recognize their position. It is a long period of adaptation until the person is able to move alone in this environment.

The proposed system will scan the environment that the blind person is exploring. With this a map will be constructed while simultaneously the persons position is tracked in this map. The person can interact with this system and provide additional landmark information. The recollected data will be useful for guiding this person throughout the explored environment.

The best way to provide orientation commands to the blind person is via audio. Since blind people rely on external audio information, the use of conventional head phones is not a appropriate solution because these cover the ears of the person. A solution for this are the bone phones that transmit audio information at back of the ear via the bone [6].

II. STATE OF THE ART AND EXPLORATION OF UNKNOWN INDOOR ENVIRONMENTS

For the millions of people around the world who have a visual impairment, technological and non-technological innovations have contributed fundamentally to the quality of life. Thanks to modern technology it is possible to browse the web, send and receive e-mails almost as easily as a sighted person do. This is enabled by two factors: computer hardware and software interfaces that try to present information through speech or with Braille, and the fact that many web pages and applications are designed with accessibility in mind.

When it comes to navigating in the physical world the scenario is complex; in fact navigating independently in unfamiliar environments is nearly impossible for someone who does not pick up much of the contextual information provided by the environment-information that is mostly visual. For instance, if a person found him/herself in a random building, a quick glance around the current location tells about the building. Things such as signs, furniture, corridors and staircases, and the view from windows can tell about what the purpose of the building is, and a location can be approximated from the outside view. Most of this information will be completely missed by someone who cannot pick it up with their eyes, and so a major challenge is to design a system that can transmit this information, or provide the knowledge in another way.

A blind person navigates in a highly structured manner using both physical and artificial landmarks. Examples of the former include walls, pavement edges, material changes and auditory information such as the beeps of a traffic light or how the sound reverberates in the location. Artificial landmarks are, for example, "third door on the left" when walking in a corridor. Since route familiarity is important, it is desirable to reuse as much of a route as possible, because straying from the path might mean a complete loss of the route. If this should happen, it is important to be able to retrace back to a known landmark in order to regain the sense of location and orientation. Routes that stay fairly static might often be preferred because of the lower risk of someday encountering a large obstacle forcing a different route.

Unless the visually impaired person walks with someone else, there are two widely employed solutions to make navigating easier: the white cane and the guide dog. They both provide basic assistance in avoiding obstacles and detecting stairs, though the guide dog can learn routes and help much more than the cane when something has changed along the route. The cane on the other hand is very simple and is intuitive to use because it behaves like an extended arm. Because of this, it is easy to trust completely in the information the cane provides.

Aside from the white cane or the guide dog, some navigation systems (known as electronic travel aids, ETA's) specifically designed for the visually impaired are available [5]. These range from simple sound-emitting beacons that can be positioned in strategic places around the environment, to smartphone GPS. This can be useful at a high level but it has some major disadvantages. Firstly it is based on static maps and therefore cannot provide dynamic information on-the-fly, and secondly it does not work indoors. The GPS devices that are tailored for the visually impaired, like the usually have some extra features like easy tagging of locations, route logging and retracing functionality, and a "where am I?" feature which tries to describe the current location in terms of tagged locations around it [4].

III. SIMULTANEOUS LOCALIZATION AND MAPPING

Simultaneous Localization and Mapping (SLAM) is a well-known problem in mobile robotics. This is the process in which a mobile robot can build a map o the environment and at the same time compute its location[8].

The essential SLAM problem can be explained with the following diagram.

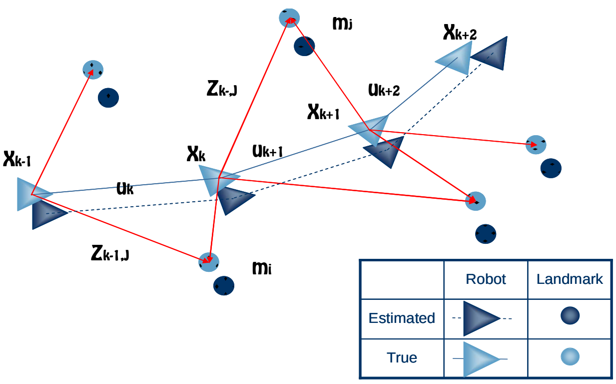

Figure 1. SLAM

The diagram in Fig.1 shows a mobile robot that moves through an unknown environment. This robot is equipped with sensors that provide observations to different landmarks and its odometry. The observation to landmarks can be obtained with a laser scanner [11] that provides distance and angle obtained from different positions. Landmarks are features in an environment that can be used as reference and for the registration of multiple scans when combining different measurements from diverse positions. For example, in an indoor environment, landmarks could be lines, walls, corners, edges or more specific obstacles [8]. So basically the

SLAM problem is to obtain an estimation of the position based on different types of observations.

Fig 1. At a time instant k, the following quantities are defined:

x_k: The state vector describing the location and orientation of the vehicle.

u_k: The control vector, applied at time k-1 to drive the vehicle to a state x_k at time k.

m_k: A vector describing the location of the i^{th} landmark whose true location is assumed time invariant.

z_{ik}: An observation taken from the vehicle of the location of the i^{th} landmark at time k.

In addition, the following sets are defined:

$X_{0:k} = \{x_0,\ x_1, .., x_k\} = \{X_{0:k-1}, x_k\}$: the history of vehicle locations.

$U_{0:k} = \{u_0,\ u_1, .., u_k\} = \{U_{0:k-1}, u_k\}$: the history of control inputs.

$m = \{m_1,\ m_2, .., m_n\}$ (3): the set of landmarks.

$Z_{0:k} = \{z_1,\ z_2, .., z_k\} = \{Z_{0:k-1}, z_k\}$: the set of all landmark observations.

To compute this problem, it is possible to do so in the probabilistic form, and its probabilistic distribution is shown in (1).

$$P(x_k, m | Z_{0:k}, U_{0:k}, x_0) \quad (1)$$

Observation model: $P(z_k, m | Z_{0:k}, U_{0:k}, x_0)$ (2)

Motion model: $P(x_k | x_{k-1}, u_k)$ (3)

Many approaches have been proposed for solving this particular problem. The most popular algorithms to solve the problem are based on the Extended Kalman Filter and the Rao-Blackwellized Particle Filters [8, 10].

The vehicle motion can be described in the following for by using the Extended Kalman Filter for Slam(EKF-SLAM)

$$P(x_k | x_{k-1}, u_k) \Leftrightarrow x_k = f(x_{k-1}, u_k) + w_k \quad (4)$$

where $f(\circ)$ models vehicle kinematics and w_k are additives, zero mean uncorrelated Gaussian motion disturbances.

In the same manner the vehicle observation model can be described as follows.

$$P(z_k | x_k, m) \Leftrightarrow z(k) = h(x_k, m) + v_k \quad (5)$$

where $h(\circ)$ describes the geometry of observation and v_k are additive, zero mean uncorrelated Gaussian observation errors.

The mapping can be accomplished by using a grid mapping method. It basically works by dividing the environment into small grids and deciding whether that grid is occupied or not by scanning the environment. If a grid is occupied, then the system assumes that there is a solid object there; so it is drawn in the map.

IV. Pedestrian Dead Reckoning (PDR)

PDR is a form of positioning based on a known staring point. After having this initial location the pedestrian is tracked with every move he does. This way it is possible to estimate the new position at any time. One form of tracking the movement of a pedestrian is by using an inertial measurement unit (IMU), which usually contain accelerometers, gyroscopes and magnetometers. This can be placed on different parts of the pedestrians body to recognize movements. The most precise way to obtain step length and direction from the pedestrian is done by a foot mounted IMU. Step length can be calculated by using the acceleration vectors obtained by the IMU [2]. Direction or orientation on the other hand can be obtained by fusing gyroscope and magnetometers data. In this last case the magnetometers data is not always consistent with the true orientation [3].

V. WEARABLE SLAM SYSTEM

It is intend to use the SLAM problem from mobile robots for pedestrians (visually impaired and blind). In this case the problem has to be addressed in a different manner, due to the different movement conditions. Pedestrians have a much more complex odometry than mobile robots. They differ in the type of movements and degrees of freedom. The laser scanner position with mobile robots is stable compared to the surface[11]. This cannot be guaranteed for human beings. Furthermore, the human body is specific to each person, as is motion. Thus, the challenge is to extract the odometry for each pedestrian and to obtain stable laser scanner data.

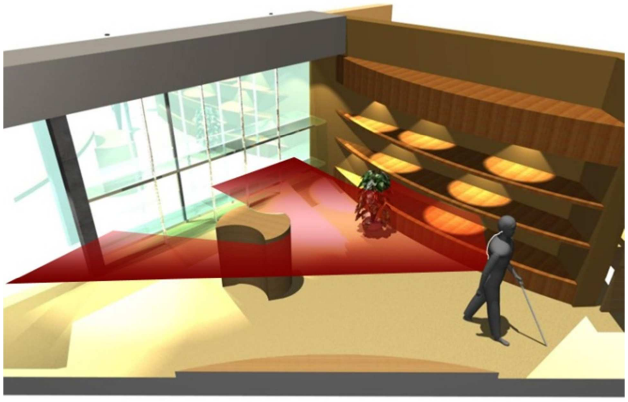

Figure 2. Blind Pedestrian wearing the SLAM system

To extract precise pedestrian odometry, step length and orientation, a foot mounted PDR will be used. The pedestrian is exploring an unknown environment, so there won't be a fixed starting point.

For land marks observations the pedestrian will be equipped with a short range laser scanner in the low back area. The decision to place it in this body regions is due to, its stability and to avoid interference from the hand by using the white cane. To obtain horizontal laser scans, the raw data requires processing with the IMU data and projection onto the horizontal plane.

With the recollected data from the sensors it is possible, by using the Extended Kalman Filter, to achieve a precise localization. Simultaneously with the scanner reading a map of the environment will be construct by using the above mentioned grid mapping.

The pedestrian can also interact with the system, by adding important landmarks or preferred locations in the environment, mean while he is exploring it.

Once the user has a map and his position is been tracked in the before unknown environment. The visually impaired person is able to navigate through it, by receiving commands via audio from the system.

Data processing will be accomplished with wearable computing devices, so there will be total independence of any main computer or network.

CONCLUSION AND FUTURE WORK

In this paper we presented an integrated framework of how a precise guiding system can be build, by using a pedestrian tracking method and SLAM for mobile robots. For visually impaired and blind people this would be a great improvement for the navigation and exploring of new environments.

This system is currently been tested with recollected data, and field test will be done with visually impaired and blind people.

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