Towards a Sign-Based Indoor Navigation System for People with Visual Impairments

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ABSTRACT
Navigation is a challenging task for many travelers with visual impairments. While a variety of GPS-enabled tools can provide wayfinding assistance in outdoor settings, GPS provides no useful localization information indoors. A variety of indoor navigation tools are being developed, but most of them require potentially costly physical infrastructure to be installed and maintained, or else the creation of detailed visual models of the environment. We report development of a new smartphone-based navigation aid, which combines inertial sensing, computer vision and floor plan information to estimate the user's location with no additional physical infrastructure and requiring only the locations of signs relative to the floor plan. A formative study was conducted with three blind volunteer participants demonstrating the feasibility of the approach and highlighting the areas needing improvement.

Keywords
Navigation, wayfinding, blindness, low vision.

1. INTRODUCTION
Blind or visually impaired people face severe difficulties navigating indoors and in other GPS-denied environments, which creates barriers to independent travel needed for a variety of daily activities related to work, health care, leisure and education. Different approaches and sensors have been proposed to assist a visually impaired person to navigate in an unknown environment [1]. Headlock [2] uses Google Glass to help users with visual impairment to navigate in large open spaces. The user can lock onto a salient landmark in the space and the system will provide audio feedback to guide him/her towards the target. On the other hand [6] presents the Digital Sign System, a computer vision approach that uses infrared retroreflective markers and a hand-held camera with an infrared light that enhances the markers' detectability and can be used for both indoor exploration and navigation.

A key part of any navigation aid system is the estimation of the localization of the user. Smartphones provide a powerful sensor platform to perform such localization. Pedestrian Dead Reckoning approaches (PDR) [5, 9] use inertial sensors to estimate how the user moves. Other approaches make use of computer vision techniques to process the images acquired with a phone to estimate the position [8]. Bluetooth beacons are becoming very popular, but by themselves they don't provide directional information and have batteries that must be replaced periodically, which can represent a burden when including all the beacons in an entire building.

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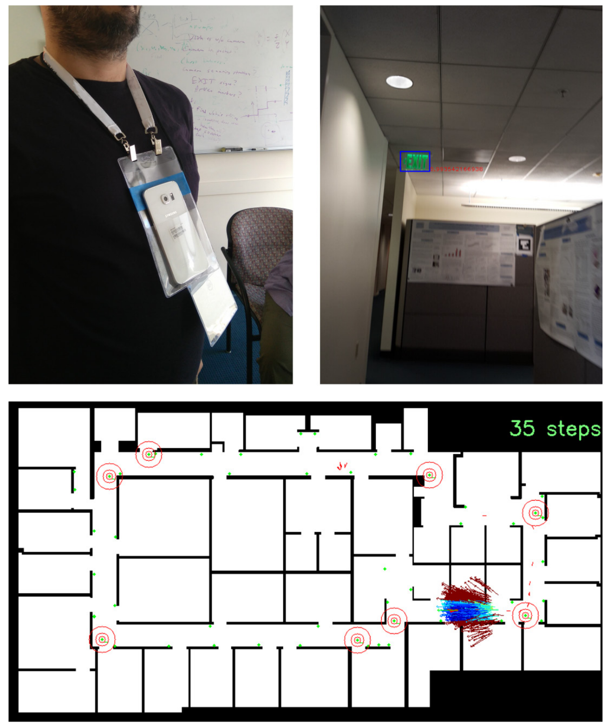

Figure 1 (a) User wearing the lanyard with the smartphone. (b) Camera image showing an Exit sign detection (blue rectangle). (c) Floor plan of the environment (39x21 m) with particles (short line segments) shown around the estimated user location. Red particles correspond to impossible positions while blue particles correspond to plausible position hypotheses (brighter blue means better particles). Exit signs are shown as green points inside two concentric red circles.

In this work (see Fig. 1) we estimate the user's location in an indoor environment using a minimum of infrastructure, namely a map annotated with a few features that can be detected and recognized using computer vision techniques. We restrict these features to be existing Exit signs and printed barcodes (ArUco markers [4]) that we post near existing signs. In the future we will rely solely on existing signage. We also rely on inertial odometry to estimate the user's movements.

2. APPROACH
Our approach is based on Particle Filtering, a method widely used for robot localization. This method allows different sources of information to be combined to estimate the user's position in the environment. In this work, we combine information from three

different sources: a map of the environment, an inertial odometry system and a computer vision algorithm for object detection.

We incorporate information about the environment in the form of a digitized floor map in which walls, corridors and rooms are labeled and the positions of some important signs (such as Exit signs and fiducial markers) are annotated. The inertial odometry system, based on the work described in [7], enables us to track the user's footsteps and their heading, while the computer vision module processes the acquired images (at a framerate of 2 FPS) and detects the annotated signage using the method in [3].

We use an off-the-shelf Android smartphone and we access its IMU (Inertial Measurement Unit) and the RGB camera. The current prototype transmits the sensor readings and camera images in real time from the phone (using a Wi-Fi connection) to a laptop, where the data is processed; in the future, the entire system will run on the smartphone alone.

Our system is able to track the position of the user while he/she is moving around the environment and communicates, via text-to-speech, a list of nearby rooms or marked points of interest when the user stands in one location for longer than 5 seconds.

3. FORMATIVE STUDY

We began a formative study of our prototype with three blind participants with no usable vision. Two participants were familiar with the environment, while the third had little prior knowledge of it. The users wore a lanyard that held the smartphone (without covering the camera lens) on their chest, leaving both hands free for other purposes, such as holding a white cane, while holding the camera stable in order to acquire good-quality images. Users were instructed to walk as usual through their environment, without aiming the camera in any particular fashion; however, they were told that additional visual information could be obtained whenever needed by standing still while slowly rotating their torso to pan the camera left and right. Note that the use of a white cane didn't cause any significant occlusions in the video captured by the camera, and we expect the same to be the case for guide dog use.

Currently, the weakest part of the system is the step detection algorithm which estimates when each step is taken by analyzing the accelerometer readings over time. This estimation process is noisy because: (a) each individual has a different style of walking; (b) gait characteristics change under different conditions, e.g., walking straight along a corridor vs. turning at a corridor junction; and (c) increased uncertainty about the path immediately ahead, causes the person to slow down his/her steps, which may lead to the steps being missed by the step counter (since the acceleration amplitude is attenuated under these conditions).

The detection of map features in the camera images improved the estimation of the user position. Even the detection of just standard Exit signs (when the detection of the markers was switched off) was enough to correctly track the user motion on the map. The ability to recognize more visual features in the future will lead to greater robustness of the localization algorithm.

The annotated floor map helped to remove invalid position estimations (to rule out hypothetical paths hitting or entering walls), allowed the system to calculate the visibility of features in the map from the current estimated position and to look for map features nearby when the user stopped.

4. CONCLUSION

This formative study has shown the feasibility of our approach and helped us to assess its weaknesses and to plan the next steps towards our objective. In the future we will study the inclusion of more sources of information such as beacons and more computer vision signage detection algorithms, eliminating the use of markers. An important goal is to transform the current prototype into a true navigation aid that provides turn-by-turn directions to a desired destination (instead of the current functionality which is limited to providing information about the user's current location). We also plan to test our system in different environments of bigger size and to assess the precision of the localization in a quantitative way. We will involve more potential end users to test navigation and localization performances and to determine the type of interface that will most benefit the users.

5. ACKNOWLEDGMENTS

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