INSERT # 2 – PROPOSAL
“AN INDOOR LOCALIZATION AID FOR THE VISUALLY IMPAIRED”

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1. CATEGORY JUSTIFICATION

Category 1: I am an Assistant Professor in the CSE Department. I intend to use this
funding to support a new research effort to leverage knowledge from the field of robotics
to introduce robust localization algorithms for a portable device, a travel-aid, for the
visually impaired.

2. ABSTRACT

This proposal addresses the problem of indoor navigation for the visually-impaired. Although there are numerous GPS-based devices that a person can use for outdoor navigation, way-finding inside a building is still a challenging problem for people with
limited vision. As the population of seniors is rising, the number of people who will soon
need a navigation aid for indoors is expected to increase accordingly. In this work, we
have implemented a first prototype of a portable device (sensor and processing payload
attached to a white-cane) that can be used for indoor navigation of people with low
vision. The focus of the proposed work is on the design of new, robust algorithms for
estimating the position of a person inside a building and providing directions between
locations.

3. PRESENT STATUS OF KNOWLEDGE

This work focuses on designing robust estimation algorithms for tracking the position of
a visually-impaired person inside a building. In order to achieve that, there is a number of
challenging issues that need to be addressed. Firstly, any assistive device needs to be
small, light-weight, and consume minimal power in order to be portable and operational
for long periods of time. Furthermore, since there is no continuous contact to the ground
(as is the case for the wheels of a mobile robot), the sensor payload on this device should
be such that it can track the motion of the person and provide reliable information for
his/her surroundings while freely moves in a 3-dimensional space (we consider a device
attached on a white-cane). Finally, the positioning tracking algorithms should be adaptive
so as to allow for variable operation, depending on the type of information available for a
building (existence of a map, previously visited building, or completely unknown area).

Recent work has focused on developing hazard detection aids for the visually impaired
[1]. These employ sensors for obstacle avoidance such as laser pointers [2] and sonars on
a wheelchair [3], on a robot connected at the tip of a white cane [4], [5], or as part of a
travel aid [6], [7]. Cameras have also been suggested [8], [9] for object description (in
terms of color and/or size) in addition to obstacle detection. While these devices augment
the cognitive abilities of a blind person and reduce the probability of an accident due to an undetected obstacle, they cannot be explicitly used as a way-finding aid without the development of appropriate algorithms for localization and mapping. Furthermore, they do not address new challenges in localization and mapping for human body-mounted or hand-held sensor systems. For example, given a reaching range (height and angle) via swinging the white cane, how can one accurately estimate the position and orientation of a person despite the variations in height, arm length, and swinging motion across humans?

Significant research work [10], [11], [12], [13], [14], [15] has concentrated on navigation for mobile robots, however, there are only few attempts to apply this knowledge to assist visually impaired people in their everyday navigation tasks. Most of these efforts have focused primarily on outdoor navigation and are based on GPS (e.g., [16], [17], [18], [7]) which cannot be used inside a building. An approach to indoor way-finding for the visually impaired is presented in [19], [20], [21]. In this case, an autonomous robot attached at the end of a leash, as a substitute for a guide dog, localizes using information from a network of Radio Frequency Identification (RFID) tags. One of main limitations of this approach is that mobility is restricted to areas that a mobile robot can reach. This rules-out areas where stairs or steps are part of the spatial layout and tight spaces such as inside an office or crowded rooms. Additionally, the weight and volume of the robot, negatively affects its portability and compactness. Furthermore, it requires instrumentation of buildings with RFID which is costly and time consuming, which is also the case for similar ultrasound [7] and Infra Red (IR) [22] based systems. In contrast, we are interested in designing human body-mounted or hand-held (e.g., white cane-based) sensor systems to aid visually impaired people for indoor navigation. This is more challenging due to the variations in body geometry (e.g., height and stride) and motion patterns across different people.

In this work, we propose to address the research challenges in designing algorithms for estimating the position and heading of a visually impaired person. To this end, we have equipped a white cane (Figs.1, 2) with a small-size sensor package equivalent, in terms of functionality, to that necessary for supporting indoor navigation of a mobile robot. These sensors include an Inertial Measurement Unit (IMU) and a laser scanner. Additionally, a wireless pedometer (Fig. 3) is attached on the shoe of the user.

The main attractive features of our proposed system for indoor navigation are: (i) no building instrumentation is required, (ii) the prototype device is of small weight and volume which facilitates portability.

4. PLAN OF WORK

4.1 Dead reckoning and heading estimation
A basic mechanism that organisms use for way-finding is dead reckoning [23]. This requires distance and heading to be estimated by integrating small changes in position and orientation (e.g., by counting steps, and inferring rotations from the motion of the body). We propose to use a pedometer to measure the distance traveled by a user. This
sensor can be approximately calibrated (off-line) for a specific individual and provide a means for estimating the location of a person with respect to a starting point (i.e., the entrance of a building). One of the main challenges when using such device is the inadequate level of accuracy due to the variations in stride-length across humans as well as variations in stride for a person over time. We propose to address this issue by providing online pedometer calibration capabilities. These will use exteroceptive information from a laser scanner for detecting changes in the step size and adjusting distance-traveled estimation accordingly. We expect that online calibration will significantly increase the accuracy of this process.

However, the main source of error in dead reckoning is the uncertainty in the estimate of orientation. Even small errors in the heading direction result in large errors in the position estimates. Species that rely primarily on dead reckoning for their navigation needs often use visual information (e.g., polarization of the sun light [24], direction towards stars or objects in the horizon) to correct for errors in their heading direction [25]. Humans have used similar type of directional information as well as technical means (e.g., a compass) to navigate over long distances. Inside a building, the disturbances of the earth's magnetic field caused by metallic objects renders a compass unreliable for navigation. Also, visual feedback cannot be assumed even for a person with mild visual impairment. Instead, we propose to use the structure of the building for inferring heading information. Most walls inside a building are long planar surfaces perpendicular or parallel to each other. Detecting the direction of a wall using the laser scanner will be used as a form of structural compass for providing absolute heading information. While this procedure is straightforward when the motion of the scanner is constrained in 2D, it becomes quite challenging when the laser sensor is attached on a white cane freely moving in 3D. In order to address this problem, we propose to employ attitude information inferred by inclinometers so as to account for the out-of-plane motion of the laser scanner. This will require accurate estimation of the gravitational acceleration among disturbances caused by the motion of the user.

4.2 Map-based localization
Although a precise estimate of heading direction can significantly improve dead reckoning accuracy, errors in the measurements recorded by a pedometer will eventually cause the person to be lost. Other means are necessary to provide periodic corrections to the position estimates. Henceforth, we consider the case of an individual navigating inside a building whose layout is represented by metric and semantic maps. A metric map records (i) the location, in allocentric coordinates, of salient features such as doors, walls, corner edges etc, and (ii) a spatial description of free-space (e.g., corridors, junctions, lobby areas etc). A semantic description refers to the names of locations of interest such as offices, restrooms, fire exits, and other facilities within a particular building. Salient features such as corridors and intersections will be used to inform people of their location and direction within the building while their metric relation will be processed to provide corrections to position estimates.

Landmark-based localization has been extensively studied in the robotics literature [14] and a number of successful systems exist [26]. However, robots are equipped with wheel encoders that provide accurate measurements of linear and rotational velocity. In
contrast human-body mounted pedometer devices merely count steps and thus can be very imprecise due to the variations in human strides. Loss of accuracy may increase errors in position estimation and cause a visually impaired person to become lost. This issue requires special attention when designing an estimator. Our focus will be to ensure robustness in the presence of variations in human stride and provide mechanisms for reacquiring position when tracking fails [27].

We propose to employ a Kalman filter-based estimation framework to fuse measurements from the pedometer with data from the laser scanner and/or the camera. Measurements of distance traveled will be integrated in real time to compute the position and heading of a user. Information from the laser scanner and camera will be used to (i) correct the heading estimates, (ii) calibrate the pedometer, and (iii) detect and identify structural features. Prior knowledge of the position of landmarks in the map will be used to update position estimates. Once heading and position are determined, spatial database operations will be used to determine a user's situation with respect to the intended route (e.g., on or off course, distance to the next waypoint) and nearby hazards. This information will then be passed to the voice interface component, which will generate an appropriate sequence of directions. Preliminary results are shown in Fig. 4.

4.3 Simultaneous localization and mapping
While maps are available for many public buildings, for many others no map exists or available maps are out of date. Furthermore, most CAD drawings do not contain the location of large obstacles such as desks, closets, and vending machines, which a visually impaired person must be aware of. Therefore a navigation aid must be able to adaptively create, maintain, and update a map of an area of interest. This is known as the Simultaneous Localization and Mapping (SLAM) problem. In case of map-based localization, the estimated quantity is a vector containing the Cartesian \((x, y, \phi)\) coordinates for the position and orientation of the person. In SLAM, the state vector is augmented in real-time to contain the locations of previously unmapped objects (landmarks) that are being detected as the person navigates within an unknown or partially-known area. Accurately mapping the surroundings along the path traversed can significantly increase the accuracy of the position estimates when each of these areas is re-visited (e.g., when closing a loop around a corridor, or, tracing back a path along the same corridor).

The main challenge associated with this task is reliably detecting and identifying unmapped landmarks. Certain types of features such as edges of large objects can be robustly detected by processing distance measurements from the laser scanner [28] mounted on a white cane or human body. Other landmarks require visual identification. This process is quite challenging to automate, since the appearance of a feature changes with distance and viewing angle because of variations in geometry and motion of human. Recently, the Scale Invariant Feature Transformation (SIFT) has been shown to work for object identification even when the new image has undergone considerable rotations and changes in scale [29]. We propose to employ this vision-based algorithm, for detecting, registering, and identifying objects and locations along the path of a visually impaired person. The position of these unmapped features will be estimated, at first sight, by the Kalman filter and later on upon redetection, it will be processed for providing position
corrections. The detected objects are important navigational resources, and thus
information about them will be communicated to the users. Not only will this help them
travel more safely (by avoiding obstacles), but these features will serve as landmarks that
users can learn. This will aid learning routes and layout and increase their confidence
that they are on the right track.

5. BUDGET JUSTIFICATION

I need to fund one graduate research assistant for one year to work on this project. The
main responsibility of this graduate student will be to implement the derived position
estimation algorithms and test them in simulation and experimentally using the white-
cane prototype. The validation of these algorithms will require extensive testing over a
large set of conditions (operating within different types of environments with little or no
prior knowledge of the spatial layout).

6. NEED JUSTIFICATION

This is a relatively new research direction for me. I have worked for over 10 years on the
navigation of mobile robots, but this is the first time that I am analyzing and examining
how these algorithms can be modified and augmented so as to become appropriate for
localizing humans inside a building. Although, I have external funding for robotics-
related research work, I cannot use any of these resources for the purposes of this new
research effort.

My remaining startup funds from the Computer Science and Engineering department and
the Institute of Technology include support for two graduate research assistants. The
main task of these students is the hardware development for the ground and aerial
vehicles under development for the experimental testing of autonomous navigation
algorithms. Robotic hardware and sensor devices require hundreds of man-hours to set up
and maintain due to their complexity and failure-prone nature. Therefore, I cannot use
any of these resources for the purposes of this task.

However, I should mention that the CSE dept. and IT have been very generous with my
startup laboratory equipment fund (robots, sensors, and electronics) and it is because of
this equipment’s time-sharing between robots and the white-cane, that I was able to build
the first prototype for this assistive device.

I intend to submit proposals to NSF and NIH to request additional funding for this project
and budget for hardware purchases that will be exclusively used for this task. The scope
of this proposed research is such that I expect it will attract the interest of program
managers and proposal reviewers especially considering its humanitarian nature.

7. WORD COUNT