Interactive Indoor Localization on Helmet

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Abstract. We present a human-sensor interaction approach for indoor navigation, where we incorporate inertial motion unit sensors, human knowledge and human-computer interaction into the navigation process. The algorithm uses semantic representations of navigational constraints such as walls, stairs, and elevators, to correct the trajectory. The objective is to reduce the IMU drifting errors. The navigation prototype is implemented on a helmet with a holographic screen that can mix the actual visible image with mapping and visualization information, voice command and tactile interface. The helmet is to assist first responders in emergency environments of fire, flood, shooting, cyberattack, and medical distress, where GSP, cellular and regular WiFi is not available. The results show that the interactive navigation reduces drifting errors and it is an affordable alternative to existing technologies such as ultrasound, RFID, UWB radios, WiFi signatures, and camera-based SLAM (simultaneous localization and mapping) algorithms where matching features are not sufficient, especially in a dark or smoking environment.

Keywords: helmet, augmented reality, indoor navigation, first response, HADR

1 Introduction

Indoor or subterrain navigation is critical to search and rescue teams where GPS, cellular signals, and radio signals are not available. Existing technologies incline to infrastructural related landmarks such as ultrasound, RFID, UWB radios, and WiFi signatures, or ego-motion-based methods such as inertial motion sensors and camera-based SLAM (simultaneous localization and mapping) algorithms. Unfortunately, those approaches have their weaknesses. For example, infrastructural devices can change over-time and they could be beyond affordable. Inertial sensor-based navigation have accumulative “drifting errors” over time. SLAM algorithms usually need clear images to extract matching features that are not always available, especially in a dark or smoke filled environment. Here, we present a human-sensor interaction approach to solve the indoor navigation problem, where we incorporate human knowledge and human-computer interaction into the navigation process. The algorithm uses semantic representations of navigational constraints such as walls, stairs, and elevators, to correct the trajectory. The objective is to reduce the IMU drifting errors.

The navigation system is implemented on a hyper-reality helmet display, which is to superimpose the on-demand information to the objects in an actual scene image so that the user can see more in-depth information beyond reality. In contrast to many prevailing augmented reality technologies, our approach focuses on enhancing reality with minimal graphical and textual highlighting without obscuring the user’s view. The hyper-reality helmet contains a holographic screen that can mix the actual visible image with mapping and visualization information, and voice command.

2 Related Studies

The prevailing indoor navigation methods include digital beacons such as ultrasound [1], LoRa [2], and WiFi [3]. Installing and calibrating beacons in a building are expensive and there are wall-attenuation problems [4]. There are growing technologies of infrastructure-free localization by mobile beacons [5] or collaborative positioning [6]. Simultaneous Localization and Mapping (SLAM) algorithm [7] has been popular for 3D modeling from motion, tracking and mapping at the same time. Visual SLAM is computationally expensive and it often fails in poor lighting, smoky, or feature-less environments such as a painted white wall. LiDAR-based SLAM can work in dark by tracking the 3D point clouds but is very expensive [8]. Thermal IR cameras can also be used for SLAM but its images are rather low-resolution and is expensive as well [9].

Reality is interaction. In nature, insects navigate with very limited computational power but efficient sensory fusion and interaction with their environment, based on smell intensity, lighting, sound, magnetic field, and simply tactile sensing [10]. Blind people use wall-following and landmark-checking, as well as a cane to navigate. These novel concepts might pave the way for affordable and practical indoor localization, for example, the mobile device for helping a visually impaired user to navigate indoors [11], and the one-dimensional LiDAR and IMU sensor for first-person view imaging [12].

3 Helmet System Architecture

The hyper-reality helmet sensory system contains a 1-D Lidar for distance measurement up to 40 m, thermal camera, a 10 DOF IMU sensor, including 3 axis gyro, 3 axis accelerometer, 3 axis compass, and altimeter. The hyper-reality helmet system also includes a microprocessor and a projection heads-up display. The sensors are placed on the front section of the fireman’s helmet as shown in Figure 1.

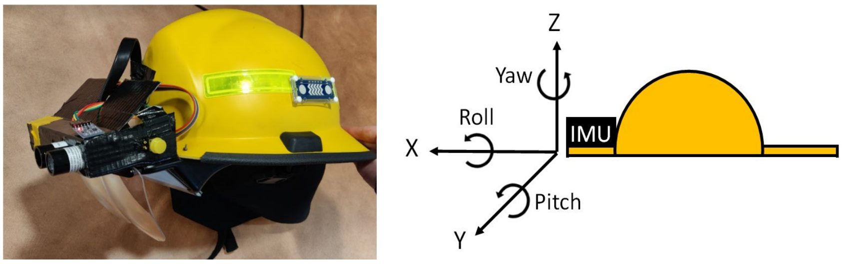

Fig. 1. Hyper-reality helmet (left) and coordinate system (right)

The hyper reality software is currently divided in multiple packages for the individual aspects of the helmet. The indoor navigation functionality is implemented in Python and the pseudo code for the system is as follows:

```
Initialization of sensors
Setup HUD
Set starting position on map
Main loop
        Read in raw acceleration data and filter
        Call sensor fusion library for orientation
        Landmark checking
        If (step detected == true)
                Calculate new user position
                Wall following and collision detection
                Update user position on HUD
```

4 Map Generation

For the navigation we need a geocode-annotated map, which gives us the floor plan with the walkable paths and all landmarks. To achieve this, an Android app was developed. In this app a scanned floor plan is overlayed with the matching building footprint from Google Maps. Walkable paths are added as polygons and landmarks such stairs, doors, elevators, corners can be GPS tagged with an icon, as shown in Fig. 2. The map can then be exported for use in a mobile navigation app, or to the hyper-reality helmet navigation system.

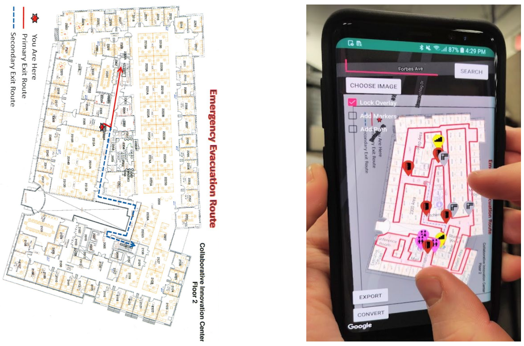

Fig. 2. The floor plan (left) and the floor plan overlaid on top of Google Maps building (right)

5 Inertial Sensory Fusion for Estimating Steps and Orientation

The current implementation of the indoor navigation uses the described IMU sensor from section 3.1 to detect steps and the users heading. The project aim was to develop a simple and lightweight solution, which can be run on a microcontroller or single board computer system. For that reason the step detection shouldn't depend on additional sensors on typical position for a pedometer (such as the foot, arm, hip), but should rather be positioned on the helmet with the other sensors. At this position it’s challenging to detect steps and in our current prototype it’s possible to detect steps for a normal walking scenario. For the coordinate system defined in Figure 3.1 the acceleration measurements of the IMU can be used to evaluate if a step event occurs. For this, the acceleration of the x- and y-axis are used and the horizontal acceleration vector amplitude

$$a = \sqrt{a_x^2 + a_y^2} \tag{1}$$

can be calculated. The amplitude a is filtered by a moving average filter, which is implemented for a sequence a_i for $i \in [0, N]$ as it is convolved with a list b_i of the same length. This list contains the weights $\frac{1}{N}$ and second half of the resulting vector

$$\widehat{a} = a_i * b_i \tag{2}$$

of the convolution is the filtered amplitude sequence $\overline{a}$. A step event occured when $\overline{a}$ contains zero crossings in the acceleration, so two crossings equal one taken step. The size of the step is currently a fixed value and can be adjusted for the user of the helmet.

The detection of the heading of the user gets calculated over a sensor fusion approach within the RTIMULib library in [13]. This library uses the acceleration, gyroscope and magnetic field sensor measurements to calculate the absolute orientation of the IMU sensor. From this orientation the yaw φ of the helmet can be used as the heading for the next step

$$x_{i+1} = x_i + \Delta x \cdot \cos \varphi \tag{3}$$

$$y_{i+1} = y_i - \Delta y \cdot \sin \varphi \tag{4}$$

over the position of the last step (x_i, y_i) and the length of the step in the corresponding axis as Δx and Δy.

6 Wall-Following Algorithm

In the navigation system we assume that the user only walks along the predefined paths. Due to the IMU drift error, the estimated position may drift from the actual path, e.g. pass through the wall in the hallway. Therefore, we need to detect the collision between the user location and the boundary of the path, e.g. a wall.

A collision occurs whenever the next step would be outside of a walkable path and the line of the step intersects with the path boundary polygons. For that reason it’s possible to check for collisions after each calculated step. When the collision is detected, the algorithm corrects the trajectory and updates the user’s position along the border of the path, as illustrated in Fig. 3.

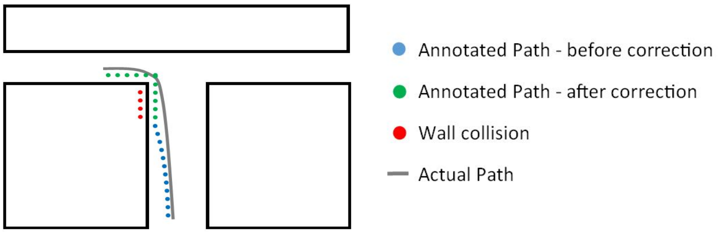

Fig. 3. Wall following method and its pseudo code

The pseudo code of wall-following algorithm is below:

```
Store coordinates of wall polygons
Calculate distance between user point and wall polygons
Find the closest wall
If (users next step crosses wall polygon)
       Collision occurs
       Next step follows wall angle
```

7 Landmark Checking

This is a manual approach to correct drifting when the user approaches a landmark. Using the annotated map with landmarks shown as icons or letters e.g. Stairs = "S", when the user position is tracked to be within 5m of the icon it will begin to blink. After receiving this notification on the HUD, the user can confirm when they reach this landmark using a push button on the helmet and their position will be updated to this landmark.

8 Indoor Navigation Experiments

Preliminary experiments have been conducted at an office building on the first floor including hallways, elevators and stairs. After aligning the scanned floor plan with Google Maps, we obtained the geocode coordinates of the floor plan. We then annotated landmarks on the floor plan with elevators, stairs, and doors. Fig. 4 shows the result of a test in the building. It shows that the wall-following algorithm indeed corrected the IMU drifting errors and put the trajectories back to the path. The landmark checking successfully updated the user position when in the vicinity of a landmark and helped further reduce the drifting errors.

We also found the collision detection algorithm may get stuck at a certain point when the walking angle is perpendicular to the wall which needs to be improved upon. Our initial experiments prove that this simple and affordable approach is feasible in a realistic building environment and have a reasonable accuracy within 1m to 1.5m, which is acceptable to many humanitarian rescue and recovery tasks.

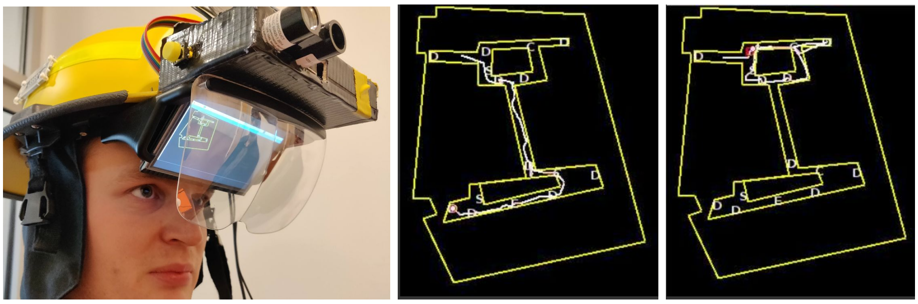

Fig.4. Indoor navigation experiment at the office building. Map on the HUD (left), tracking a long path through the building (middle) and tracking a loop (right)

8 Conclusions

In this paper we presented an indoor localization and navigation method for use by first responders. Our initial work shows that the navigation information can be displayed in simple and intuitive format to the user. The system can track the users position using step detection, wall following, and landmark checking to an accuracy of 1m to 1.5m, without the use of expensive beacons. This technology could be applied to indoor navigation in large building facilities such as malls, airports, subways, museums, schools, office buildings, and factories for tour guidance, and emergency services.

9 Future Work

Further work is required to enhance the functionality of the indoor localization of the hyper-reality helmet. Initial calibration of the users step size using the Lidar distance measurement will improve the accuracy for a new user. In addition we must accurately detect other types of movements and their step size, such as crawling and shuffle walking, commonly used by firefighters. Using GPS to set the user starting point on the map would be useful in addition to setting it manually if GPS is not available. The altimeter on the IMU and stair landmark checking will be used for transition between building floors.

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