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Smart phone based indoor navigation for guidance in public transport facilities

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Abstract: A system for indoor navigation in public transport transfer buildings was designed and implemented as an element of a dynamic seamless mobility planning and travel guidance application for public transit networks of urban and metropolitan areas. The main components of the smartphone based system use data from WiFi, GPS, Bluetooth, camera and pressure sensor as well as inertial measurement units for Pedestrian Dead Reckoning and multi-level navigation in arbitrary building structures. Map data of multi-level buildings is collected from OpenStreetMap data being enhanced by geo-referenced escape/rescue floor maps displayed on the mobile device. Navigational aids collected from sensors provide en-route orientation and position updates. The indoor route over multiple levels, elevators, stairs and escalators is calculated by a combination of route search and grid based pathfinder algorithm. Changes of floor levels are detected by relative barometric pressure measurements.

Keywords: Transport telematics, Pedestrian navigation, Indoor positioning, Public transport, Bluetooth, Pedestrian dead reckoning

1. INTRODUCTION AND PROBLEM STATEMENT

Indoor navigation is a key element of multi-modal door to door journeys especially during transfer events between public transport vehicles at complex station buildings. Indoor positioning and navigation services are realized by various components of an Android smartphone application to build up a dynamic seamless mobility planning and travel guidance system for large public transportation networks of metropolitan areas. See Figure **??** for a typical use case.

The objective is to accomplish a multi-modal door-to-door journey planner and navigation application using real time data for seamless mobility. Thereby, indoor navigation provides important information on location of the user during transfer from public transport route segment to his next public transport (mass transit) opportunity.

The purpose is to provide orientation guidance to passengers unfamiliar with localities during transfer between public transport services. Further it is intended to help commuter trip planning and to improve reckoning of transfer times. Public transit transfer facilities are multiple level building structures including pathways, floors and platforms connected by stairways, escalators and elevators. Therefore, indoor routing includes grid based navigation on floors of each individual level as well as network graph based navigation between all reachable levels and floors of the transfer facility.

2. APPROACH

As a central component of the indoor navigation system (see Figure **??**) *Pedestrian dead reckoning (PDR)* is implemented using smartphone sensors accelerometer, gyroscope and magnetometer for step and heading detection. Navigational aids include GPS, WiFi, Bluetooth and camera and feed the location (LOC) component. Building layout data and floor maps are collected from *OpenStreetMap* **?** and are projected to conformal Web Mercator coordinate system (EPSG:3857) **?** to compose the line layer.

For any given building, a topological 2.5D floor network is constructed. The nodes of this network represent contiguous areas of a building level, denoted as a floor. The edges of this network represent floor transfer opportunities such as elevators, escalators and stairs. The term 2.5D refers to the fact that for positioning in the x-y plane a continuous value domain is used, whereas for the z-axis only discrete values, i.e. integer level numbers are allowed. The component denoted as pathfinder conducts a *Breadth-first path search* between origin and destination coordinates to analyze reachability and to obtain a list of transfer points between levels of the building. A method to test if a position found is located indoor or outdoor is implemented based on map information to provide information on potential deviations of the user from calculated paths.

Given the transfer points within the building, for each floor on which a pedestrian can move, a grid based network is generated. The preferred shape of the grid element is a hexagon. This hexagon grid is similar to those as used in models for *Simultaneous Localisation and Mapping (SLAM)*, see Robertson (2003) **?**. It is temporarily constructed to observe inner and outer walls, obstacles and other constraints for each floor level between transfer points. For navigation on the floors an A* algorithm is applied with modified *Manhattan* distance heuristic that

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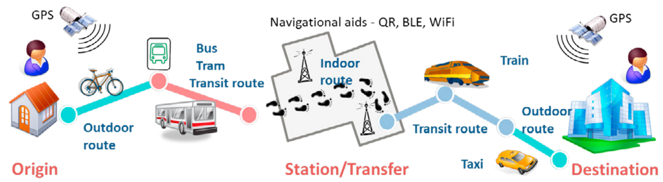


Fig. 1. Indoor navigation is a key element of public transport of the multi-modal door to door journey especially during transfer of trains at complex station buildings.

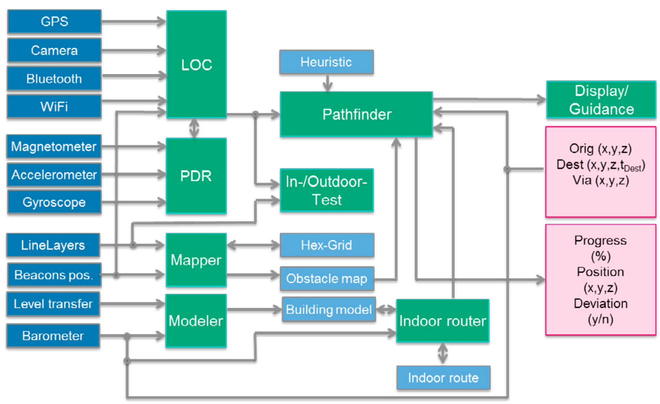


Fig. 2. Sensors and functional components of the indoor navigation system.

takes the hexagonal grid as input. En-route directions are passed to the user by dynamic display updates of position and path to destination as well as by voice guidance.

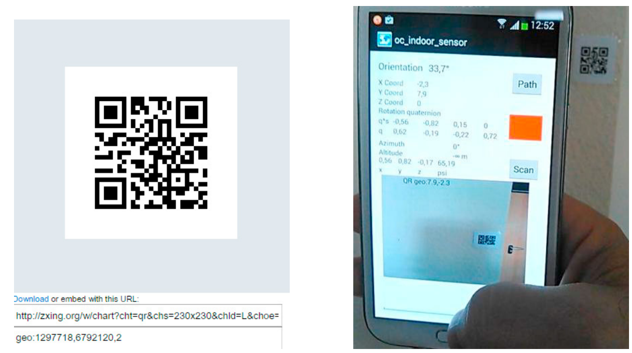
As an interface to other services it is defined to exchange messages with content on starting position, target position and en-route way points (via) in three dimensional coordinates as input parameters for the indoor navigation system. During active navigation messages are passed to calling services providing information on position in x,y,z coordinates, progress of entire route throughout the building, and possible deviations from the route. In the following sections the components introduced above are discussed in further detail.

3. INDOOR NAVIGATIONAL AIDS

3.1 QR-Codes

The widespread use and prevalence of QR-codes for quick response and coding of machine readable data and their transfer into mobile units suggest their application for the provision of additional navigational aids in an appropriate way. A formatted QR-Code is specified including a free text starting with the keyword geo:, followed by comma separated x-,y-, and z-coordinates, as shown in Figure ??.

The camera sensor of the smart mobile phone is used for semi-automatic acquisition and decoding of tag locations. The process of QR-code scan designed to be handled by the user requires a minimum of interaction. It is also possible to decode coordinates of destinations within the building to be scanned from a general orientation map.



(a) (b)

Fig. 3. QR-Code generation (a) and usage (b) for 2.5D coded coordinates of code locations as supplementary navigational aids.

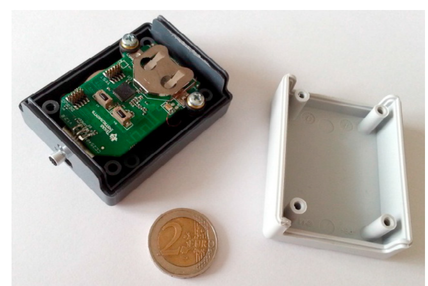


Fig. 4. Bluetooth low energy beacon deployed for indoor cell positioning mounted in a rigid case of 6 cm x 4 cm x 2 cm.

3.2 Bluetooth cell positioning

The concept of Bluetooth Low Energy (BLE) cell positioning involves distributed beacons placed at indoor positions of main pedestrian route choice locations. BLE beacons such as shown in Figure ?? are used as navigational aids to support the pedestrian dead reckoning algorithm processed on the mobile phone. Installation positions of BLE beacons are planned according to geometric conditions of the building. Recommendations for beacon placement include locations at entry doors as well as stairs, escalators, elevators, and additional orientation points within larger pedestrian walkable areas where main pedestrian flows cross each other. All attributes of distributed beacons are made available to the indoor navigation system prior to its usage. With an interval of one second, BLE beacons send periodical broadcast signals that are uniquely identified by their network (MAC) address. On the receiver side the received signal strength, RSSI is evaluated. RSSI values of greater than -65 dBm indicate a beacon-receiver distance of less than 1 m which is assessed as sufficient accuracy to adopt the beacon location as a position fix. The total set of installed indoor beacon parameters are registered at initial state and, by this way. made available to cell positioning algorithm as navigational aids for positioning updates. Parameters of the beacon are its position in 2.5D coordinates, whereas x- and y-coordinates represent its location in EPSG:3857 (Web Mercator Projection) and z-coordinate denotes the building floor level in discrete values.