Versatile Geo-referenced Maps for Indoor Navigation of Pedestrians

Michael Peter, Dieter Fritsch
Institute for Photogrammetry
University of Stuttgart
Stuttgart, Germany
Michael.Peter/Dieter.Fritsch
@ifp.uni-stuttgart.de

Bernhardt Schäfer, Alfred Kleusberg
Institute of Navigation
University of Stuttgart
Stuttgart, Germany
Schaefer/Kleusberg
@nav.uni-stuttgart.de

Jó Ágila Bitsch Link, Klaus Wehrle
Communication and Distributed Systems
RWTH Aachen University
Aachen Germany
Jo.Bitsch/Klaus.Wehrle
@rwth-aachen.de

***Abstract*—We propose a system enabling users to capture the data needed to construct maps of building interiors, complemented by a smartphone-based pedestrian navigation application utilizing these maps.**

For this purpose, the user captures photographs of evacuation plans which are processed by the system using a suitable image processing pipeline. As a result, a coarse floor map is available, consisting of polygonal room outlines and identified staircases, where possible. Furthermore, the system derives the user's initial position (which is marked in the plan) and orientation from the photographed plan.

The coarse model can be further refined by geometric or semantic data geo-referenced by a pedestrian positioning solution. In a prototype configuration, two foot-mounted IMUs are used to process position and orientation with an extended Kalman Filter, using the such derived positions of features as door openings, stairs and elevators. In our system, the user downloads these traces from a repository.

We make the final floor map available to the user. The coarse area-based model is transformed into walkable paths, annotated with additional semantic annotations, as available on the evacuation plan.

Following this, smartphone users can easily use these maps for indoor navigation using only locally available information, without the need for a the building owner to make the maps available to the general public.

Our proposed system therefore allows the easy creation and refinement of indoor maps directly applicable for navigation.

***Keywords*—foot-mounted IMU; indoor navigation; floor maps; map refinement**

I. Introduction

Pedestrian navigation in indoor environments has received increasing interest in recent years. However, in comparison to outdoor environments, indoor navigation is complicated by multiple factors: Firstly, location based services and applications in indoor environments demand for much higher accuracies than typical outdoor applications. Secondly, global positioning systems are unavailable or do not provide the necessary accuracy, which results in either the necessity for expensive infrastructure or the use of less accurate infrastructure independent positioning approaches. Furthermore, map matching as used to support outdoor positioning is hindered by the fact that pedestrian movement is generally less constraint than vehicle movement. Finally, the availability of indoor models is heavily dependent on the owner of the respective buildings.

Therefore, we propose a system for the reconstruction of indoor models from photographed evacuation plans. The generated maps can be further refined using data traces recorded with an IMU system. The result is directly usable for smartphone-based infrastructure-less positioning.

The paper consists of three parts: Section II describes the data collector's derivation of a coarse indoor model by analyzing the photographed evacuation plan. With initial values from this analysis, the MEMS IMU positioning is initialized. Additional measurements for the positioning are obtained from the map and activity analysis, which is outlined in section III. The end user scenario is presented in section IV, where a map is created on the fly using the evacuation plan and corrected using the high precision IMU data, which can be immediately used for pedestrian indoor navigation in a smartphone application.

Contributions

The main contributions of our work are:

- **Creating navigable maps from evacuation plans on the fly:** We derive a coarse indoor model by analysis of photographed evacuation plans and set initial values for MEMS IMU positioning.
- **IMU based map refinement:** We propose to further refine automatically the created indoor model. An experiment with two foot-mounted MEMS IMUs was conducted to improve the positioning accuracy and to investigate additional benefits from dual the IMU approach.
- **Infrastucture independent smartphone navigation:** The end user can directly use the refined maps for smartphone based indoor navigation at no additional overhead for the building owner.

II. Analysis of Photographed Evacuation Plans

The general feasibility of indoor modeling from photographed evacuation plans in a single well-known layout has already been shown in [1]. Here, we will present the main idea

978-1-4673-1954-6/12$31.00

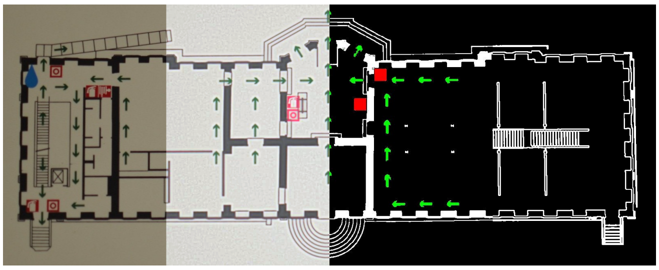

Fig. 1. From left to right: original image; enhanced image; wall structures (white) and symbol areas (colored); symbol-bridging edges

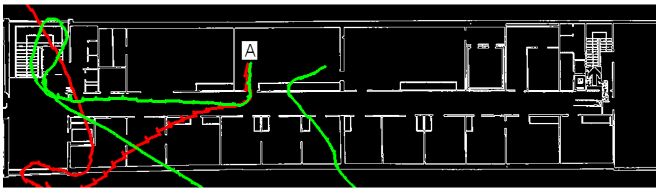

Fig. 2. Trajectories (right = red, left = green) of two foot-mounted IMUs only using ZUPTs. Initial heading and position from from the emergency map.

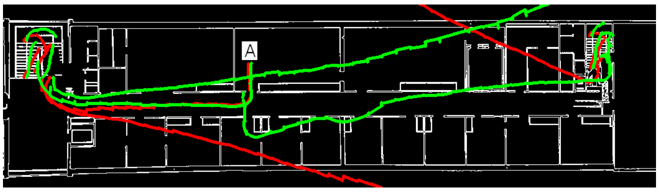

Fig. 3. Trajectories of two foot-mounted IMUs. Coordinates extracted from the emergency map (begin and end of the stairs) are used to update the EKF.

of the approach and improvements enabling its generalization to arbitrary plans.

A. Reconstruction of Coarse Indoor Models

In the first step, we enhance the input image correcting the color balance and brightness differences (see figure 1, second from left).

Secondly, the image is divided into foreground and background using adaptive thresholding with a big block size. The resulting binary image contains both the sought-after ground plan and evacuation symbols which have to be identified and removed. Even though most currently available plans do not follow the ISO standard [2] completely, colors are generally used to distinguish symbols from other plan elements. We use this fact and the Color Structure Code [3] combined with thresholds for the colors to be expected to identify symbol areas (see figure 1, third from left). If the symbols contained in the plan are known, a further classification using template matching may be carried out (see [1]).

For the reconstruction of the wall structures, edges are derived from the resulting cleaned binary image by simplifying the extracted contours (figure 1, rightmost). These edges can be used to extrapolate the underlying shape whenever a symbol area is hit.

In order to derive the transformation parameters from image coordinates to real world coordinates, the outer boundary of all edges will then be matched to an available model of the building's outer shell (e.g. from OpenStreetMap). As both shapes may differ to a great extent and the reconstructed indoor model may be incomplete, this results in a matching problem between two possibly incomplete shapes with unknown scaling, orientation and level of detail. To tackle the differing level of detail, we carry out a 2D version of the ground plan preserving generalization approach presented by [4]. Then, the ratio between the previous and next edges' lengths and the angle between both edges are computed for every node in both models. By comparing these features, match candidates can be found and the transformation parameters with the maximum resulting contour overlap (according to [4]) and the minimum shape change are selected.

During the following reconstruction of the facets of the 2D model, apart from rooms also stairs may be detected by their aspect ratio and the length of their shortest edge. The repeated occurrence of neighboring stairs will, in turn, lead to the identification of staircases. The number of detected stairs together with a common stair height results in an approximate room height which can be used to extrude the edges of the 2D model to walls in the final 3D model and explicitly reconstruct the stairs.

B. Initial Values for MEMS IMU Positioning

Apart from the possibility to reconstruct a coarse indoor model, photographed evacuation plans may furthermore be used to derive the initial values needed for the foot-mounted MEMS IMU positioning approach. These initial values are the position of the user photographing the plan and his orientation.

The initial position is marked in the evacuation plan by a symbol which may be detected by template matching (if the symbol is known) or by its uniqueness (concerning color, shape or size) among the other symbols. These image coordinates can then be transformed to world coordinates using the transformation parameters found as stated in section II-A.

The initial orientation is a combination of the viewing direction inside the plan and the angle between the user's line of sight and the evacuation plan. As stated in [2], the plan should be oriented according to the direction of view of the user in front of it, resulting in the "up" direction in image coordinates. To compute the angle between the user's line of sight and the evacuation plan, we use the approach presented by Zhang & He [5].

III. Positioning and Orientation with Two Foot-Mounted IMUs

In the prototype configuration, two foot-mounted IMUs are used to obtain positions and orientation individually for both feet using a strapdown calculation and a 15 element error state EKF. In contrast to [6], [7], no magnetometer sensors are used additionally. The initial positions and the heading from section II-B are used together with roll and pitch values from a static alignment [8] for the initialization of the strapdown calculation.

With activity recognition algorithms, the stance phases and the type of locomotion (e. g. walking, running, upstairs and downstairs) are detectable using the inertial observations. Stance phases are used to feed the EKF with zero velocity updates (ZUPTs) [6], [7]. With only the (pseudo)measurements of the velocity, the complete error state vector is not observable, therefore additional measurements are needed: Some features from the model reconstructed before (section II-A) can be used as coordinate updates (CUPTs), e.g. elevators, beginning and ending of stairs, because they can also be identified by the activity recognition.

Due to gyroscope errors and the absence of a (magnetometer) heading measurement, the trajectories are without a stable heading, still they offer stride lengths which are accurate to a few centimeters [9]. A heading measurement can be formed using the stride length differences from the right and the left trajectory [10]. Also the geometric constrains of the footfalls from both feet can be implemented and used.

An experiment was performed using two IMUs, one at each foot, walking a short path at an university building. The starting position was equal to the ending and was manually marked at the map with 'A', see figures 2 and 3.

The result of the strapdown calculation with EKF can be extended by various additions, as the results will show one of them exemplary. The trajectories are placed on the afore mentioned map with an initial position and heading, performing a two-dimensional similarity transformation, but without any additional heading measurement, (see figure 2). As expected, the trajectories' heading accuracy worsens very fastly.

Figure 3 shows the trajectories using initial heading and position from the emergency plan and positions of the beginning and ending of the stairs. The coordinates are derived by a simulated feature extraction of the map. The corresponding stance phases are extracted from the initial raw data using the activity recognition. Now this information is used as a measurement input for the EKF for the epochs of the stance phases. The trajectories fit better and the heading accuracy of the right IMU (red trajectory) has improved significantly. After some position and heading updates at the left stair, both trajectories suffer from the inaccurate heading again, which will be enhanced by the implementation of the geometric constrains of the footfalls.

IV. Using Maps for Smartphone Navigation

As we showed in our previous work [12], smartphones are well equipped to serve as navigational aids to users not only in outside environments, but also inside buildings. However, the general availability of indoor maps is still problematic: Many building owners do not want to make exact building plans available to the general public, but only to authorized people or visitors. In addition, they may not have or want to spend the resources to create or provide electronic versions of the building maps.

To address these limitations our approach is to make the creation of navigable maps as fast and easy as possible, while

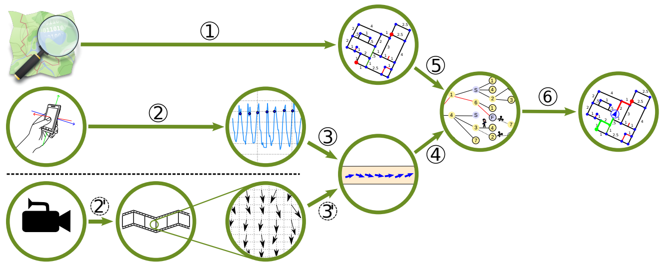

Fig. 4. Flow of information during navigation using FootPath [11]. (1) The application obtains map material, e.g., from the photograph of an evacuation plan. (2) Using the inbuilt accelerometer, a mobile phone detects steps. (3) The detected steps are combined with heading information using the inbuilt magnetometer. Alternatively, (2') the smartphone camera records and compresses a video of the floor. Our system reads out the motion vectors. (3') The detected motion vectors are transformed into virtual steps together with heading information from the magnetometer. (4) The detected steps are mapped onto a map. (5) The base map provides the available orientations and candidate paths. (6) The user gets feedback about the current most probable position, based on the detected scores.

at the same time not interfering with the rights of the building owners.

We envision the process in the following way:

1) A user enters a building and takes a picture of an evacuation plan. Either using on-board resources or using a webservice, the photograph is transformed into a basic coarse grained map.
2) Our system downloads high accuracy tracks, recorded previously inside the building using an IMU system. This data is used to correct inaccuracies and incomplete parts in the evacuation plan based map creation.
3) We immediately make the derived map available to the user for navigation.

Keep in mind, that we do not need to share the created map with other users or the general public. Through this mechanism, we do not infringe on the buildings owners rights, while at the same time providing the user with a better indoor navigation experience.

The navigation process follows our previous work on FootPath [11], [12] as shown in Figure 4. After obtaining map material either from a public source or via a photographed evacuation plan, we present the user with a selection of destinations, to which she can navigate. The smartphone then detects the steps of the user using the inbuilt sensors. If this is not possible, we use the rear-facing camera instead to measure the optical flow and derive pseudo-steps. On the basis of this speed and heading detection, we map the resulting steps onto the available map. As we show in [11], this system is accurate enough to provide the user with accurate turn by turn navigation instructions.

V. Discussion

In this work, we addressed the problem of missing indoor maps and how to solve it, especially when the building owner is not willing to release building plans to the general public. However, there are also other possibilities, especially in the context of public buildings or hospitals:

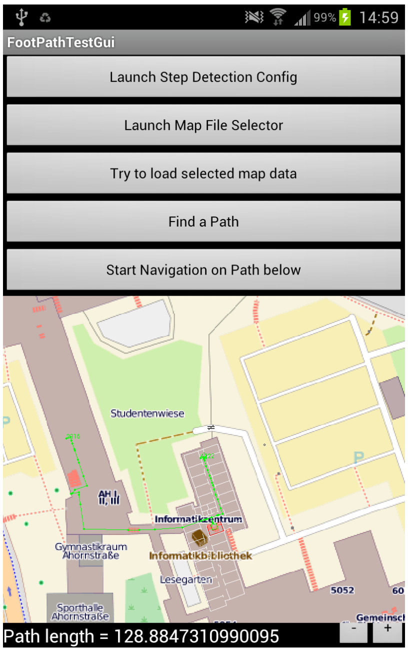

Fig. 5. Screenshot during navigation of our FootPath application.

- Specially prepared Wifi-Access Points at the building entrance. These access points might have a specific SSID, identifying them as a local indoor map provider.
- QR-Codes or RFID Tags with links to a usable building plan, which are locally accessible. As these might include passphrases, only people actually visiting the building have access to building plan.
- RFID Tags, that contain the complete map necessary to find a specific location from the current location. At an information poster, there might be tags embedded in behind the name, including the complete path information to a destination.

But all this possibilities are limited by the usage of additional infrastructure, which is not available everywhere. Using data which is already available and visible for the user has a clear advantage. When the map is available on the mobile device, the next question to solve is the pedestrian navigation. With the dual IMU approach, we try to use as much information as possible from the human walking pattern. Using FootPath, we can then make use of this information for efficient smartphone-based indoor navigation. We expect the different approaches to complement each other well.

VI. Conclusions and Outlook

We presented a work-in-progress system for deriving and using geo-referenced maps for indoor navigation of pedestrians. The extracted features of photographed evacuation maps are used for indoor navigation with foot-mounted IMUs. On the other hand, the trajectories are used to specify walkable areas in the maps. Finally, geo-referenced maps for indoor navigation can be created with the shared IMU trajectories via a smartphone application.

The algorithms of the dual IMU trajectory calculation should also be implemented for online calculation on a mobile platform. With possible positions updates from the map extraction and activity recognition, a backward filtering of the trajectories could improve their accuracies.

Acknowledgment

This research was funded in part by the Federal State of Baden-Württemberg, Germany and the DFG Cluster of Excellence on Ultra-high Speed Information and Communication (UMIC), German Research Foundation grant DFG EXC 89.

References

[1] M. Peter, N. Haala, and D. Fritsch, "Using photographed evacuation plans to support MEMS IMU navigation," in *Proceedings of the 2011 International Conference on Indoor Positioning and Indoor Navigation (IPIN2011)*, Guimarães, Portugal, 2011.

[2] "ISO 23601: Safety identification - escape and evacuation plan signs," 2009. [Online]. Available: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=41685

[3] L. Priese and P. Sturm, "Introduction to the color structure code and its implementation," 2003. [Online]. Available: http://www.uni-koblenz.de/~lb/lb_downloads/download/csc.pdf

[4] M. Kada, M. Peter, and Y. Filippovska, "3D building generalization under ground plan preserving quality constraints," in *Proceedings of the 6th International Symposium on Spatial Data Quality*, St. John's, Canada, 2009.

[5] Z. Zhang and L.-W. He, "Whiteboard scanning and image enhancement," *Digital Signal Processing*, vol. 17, no. 2, pp. 414–432, Mar. 2007.

[6] E. Foxlin, "Pedestrian tracking with shoe-mounted inertial sensors," *Computer Graphics and Applications, IEEE*, vol. 25, no. 6, pp. 38–46, 2005.

[7] A. R. Jiménez, F. Seco, J. C. Prieto, and J. Guevara, "Indoor Pedestrian Navigation using an INS/EKF framework for Yaw Drift Reduction and a Foot-mounted IMU," in *WPNC 2010: 7th Workshop on Positioning, Navigation and Communication 2010*, 2010.

[8] P. Aggarwal, Z. Syed, A. Noureldin, and N. El-Sheimy, *MEMS-based integrated navigation*, ser. GNSS technology and applications series, P. Aggarwal, Ed. Boston: Artech House, 2010.

[9] B. Schäfer, F. Wild-Pfeiffer, W. Xue, C. Becker, and U. Lindemann, "Applications of body-mounted MEMS inertial sensors," in *International Union of Geodesy and Geophysics (IUGG) General Assembly 2011 - Earth on the Edge: Science for a Sustainable Plane, 28 June - 7 July 2011*, Melbourne, Australia, 2011, Presentation only.

[10] B. Schäfer, "Determination of heading information from gait cycle pattern using stride length estimation with reduced IMUs on right and left foot," in *Proceedings of the 2011 International Conference on Indoor Positioning and Indoor Navigation (IPIN2011)*, Guimarães, Portugal, 2011.

[11] J. A. Bitsch Link, F. Gerdsmeier, P. Smith, and K. Wehrle, "Indoor Navigation on Wheels (and on Foot) using Smartphones," 2012, under review.

[12] J. A. Bitsch Link, P. Smith, N. Viol, and K. Wehrle, "FootPath: Accurate Map-based Indoor Navigation Using Smartphones," in *Proceedings of the 2011 International Conference on Indoor Positioning and Indoor Navigation (IPIN2011)*, Guimarães, Portugal, 2011.