

Using Photographed Evacuation Plans to Support MEMS IMU Navigation

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Abstract — In this paper, we present various procedures to support a ZUPT-based MEMS IMU navigation application by available external building models and photographs of evacuation plans. In detail, these are approaches for horizontal alignment of the track using the external building shell, for height correction by stair and elevator detection, for the extraction of the initial position and direction using the photographed plan and for the derivation of coarse indoor models from the plan.

Keywords—IMU; Navigation; Modeling; Evacuation Plan

I. INTRODUCTION

In the past years, an increasing scientific interest in indoor navigation has been observed. While in outdoor scenarios GPS exists as prevalent and sufficiently accurate source for position information, MEMS IMUs just started to emerge as corresponding positioning devices for building interiors. These IMUs are often used as foot-mounted systems and are combined with algorithms like ZUPT (zero velocity updates) [1]. However, they deliver only coordinates relative to a starting point and an initial direction. In most scenarios, this limitation is overcome by a GPS-guided user navigating to an entrance, followed by a handover to inertial navigation. Another disadvantage of this positioning approach, despite the need to use ZUPTs, is the existence of drift errors. In most scenarios these are resolved by map matching algorithms using given high

precision indoor models (e.g. [2]). However, while 3D city models provide the external contours of many buildings to end users, this is not available for high precision models of building interiors. Nevertheless, information on indoor environments is frequently accessible from evacuation plans, which are compulsory for public buildings in a number of countries (see figure 1). As it will be demonstrated within the paper, indoor navigation can be improved considerably, if map-like information from the interpretation of such an evacuation plan is integrated in the processing pipeline.

In this paper, we present various procedures to support foot mounted MEMS IMU navigation by a given external building shell and photographed evacuation plans. In section II, we describe a basic approach to align IMU tracks horizontally using both the principal directions of the outer building shell and the assumption that pedestrian movement in building interiors usually will be parallel to one of these directions. Secondly, height correction using stair and elevator detection is also demonstrated in this section. Section III is used to explain how a photographed evacuation plan may be employed to derive the initial position and direction for IMU navigation. In section IV, we show that these plans may furthermore be used to reconstruct coarse models of building interiors. These models then may serve as a basis for map matching or for the acquisition of more detailed models, e.g. using a modeling strategy similar to the one employed by OpenStreetMap.

II. INDOOR NAVIGATION USING MEMS IMU

A. Zero Velocity Updates

In our indoor navigation scenario, we use a foot mounted XSens MTi-G MEMS IMU as positioning sensor. To compensate the system immanent drift errors, we use the well-known zero velocity updates [1]. In short, the accelerometer measurements are integrated once and the resulting velocity values are supposed to be zero during a stance phase detected using the gyro measurements. However, due to measurement errors, these values differ from zero. The offset may be used to correct the errors which occurred since the last stance phase. The resulting coordinates of every second step (as only one foot is equipped with a sensor) may then be computed by a second integration.

B. Alignment Using Building Model

While ZUPTs significantly reduce the drift errors in comparison to naïve double integration, especially long tracks that are not supported by GPS measurements or other fixed points still suffer from drift effects.

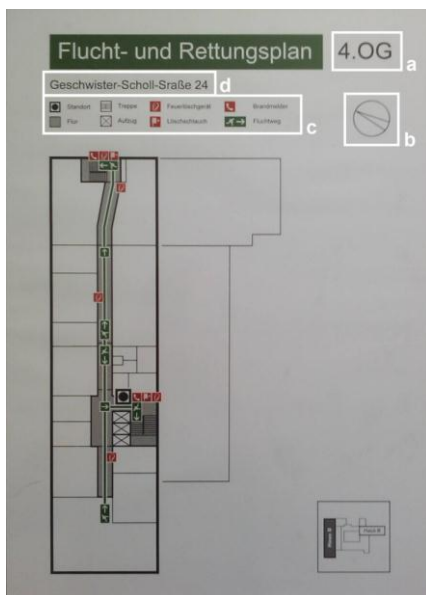


Figure 1. Evacuation plan photographed using a mobile phone camera (a: floor, b: north direction, c: legend, d: address)

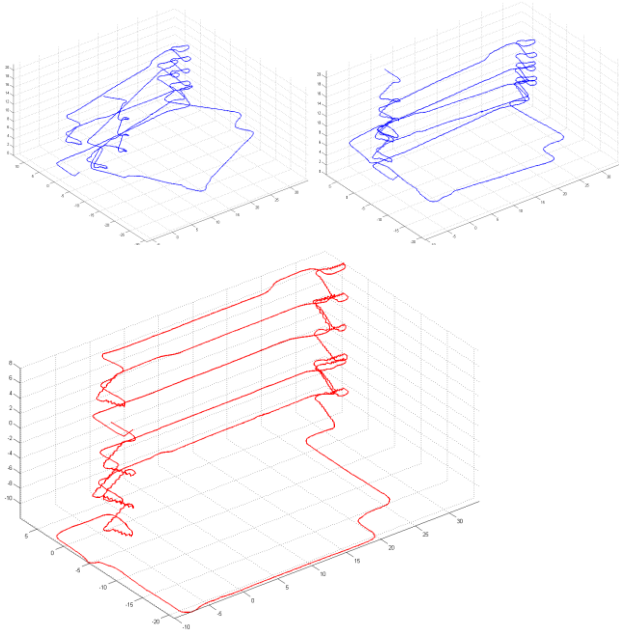


Figure 2. Indoor track using ZUPTs (top left); supported by principal building direction alignment (top right); supported by alignment and stair detection (middle)

If precise indoor models are available to the application, these effects may be reduced by map matching. However, in our scenario only the outer building contour (either from a 3D city model or OpenStreetMap) is usable. In addition, we observed that – due to hallways or similar structures – most indoor architecture constrains the user to move approximately parallel to one of the building’s principal directions. Thus, our approach consists of the extraction of the principal directions of the available external building model (using e.g. [3]) and the detection of straight lines in the IMU track. Movement along a straight line is detected if more than five consecutive steps have a small directional difference from each other. The angular difference between the direction of this line and the nearest principal building direction is then compensated by a rotation around the z-axis.

C. Height Correction

The aforementioned approach corrects the horizontal components of the user’s position, but it is not applicable to reduce vertical drift effects. In indoor environments, however, vertical movement will usually be limited to the use of stairs or elevators. Thus, we propose approaches for the detection of these features from the IMU measurements. Starting from an initial height (which can be zero or a known floor level), every following height is set to the same value until the appearance of stairs or the usage of an elevator is detected.

Our basic stair detection approach uses the final coordinate values delivered by ZUPT correction and double integration. All steps with height differences greater than 0.2m are labeled as stair candidates and the appearance of a minimum of three consecutive stair candidates causes them to be marked as stair steps. The resulting height change per double step (as only one foot is equipped with a sensor) is set to 0.34m, which represents a common step height for public buildings [4]. Alternatively, the predominant mean stair height may be

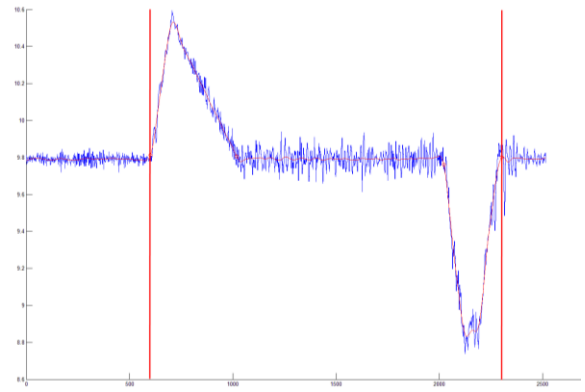


Figure 3. Typical accelerometer measurements during elevator movement (here from 1st to 7th floor)

computed and used instead. The result of building model alignment and height correction by stair detection is depicted in figure 2.

Elevator detection is carried out by detecting the different phases which occur during the movement of an elevator (see figure 3). These are a) acceleration phase, b) phase of constant acceleration and c) brake phase. However, only the start time of a) and the end time of c) are needed. If no other movement occurs at the same time, their detection is straightforward: the start times of both phases are marked by a significant difference of the acceleration vector’s norm from $g = 9.81 \text{ m/s}^2$, while their end times are marked by returning to this value. As a result, the height difference may be computed by double integration. Although this approach also suffers from drift errors, the accuracy of the resulting height difference is sufficient to determine the floor the user is located in.

III. INITIAL VALUES FROM EVACUATION PLAN

As stated before, the navigation approach using ZUPT supported MEMS IMUs only delivers coordinates relative to a known initial position and initial direction. In a continuous navigation scenario, approximate values may be determined using GPS and a precise façade model [5]. When entering a building, the initial position is defined by the center of the entrance and the initial direction will be perpendicular to the wall. However, in order to determine those values when starting to navigate in the building, we propose the analysis of photographed evacuation plans like the one depicted in figure 1 together with a given outer building shell.

A. Initial Position

The position of the user while he photographs the plan is marked in the plan by a symbol which can be found using template matching. In the current state of our implementation the template has to be passed to the application, however, an analysis of the plan’s legend may be used in the future. Furthermore, the ground plan’s outer contour is extracted from the image using a Hough transformation or contour finding approaches in OpenCV [6][7]. Using the image coordinates of the derived corner points and their corresponding vertices in the external building model, the transformation between both systems is computed. Once this transformation is known, it may be used to transform the initial position to world coordinates or to display the IMU track in the image (by applying the inverse transformation). In the future, we plan to derive the

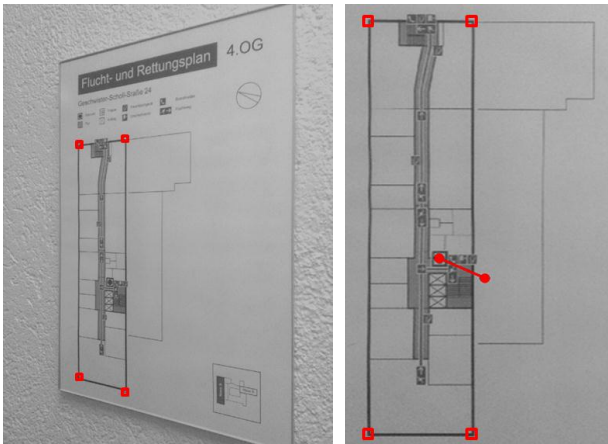


Figure 4. Initial position and direction derived from plan

unknown z-coordinate from the floor number depicted in the plan (see figure 1a).

B. Initial Direction

In order to compute the initial direction, i.e. the angle between the user's line of sight and the evacuation plan, we use the approach presented in [8]. Using the ground plan's corners in the image and the assumption, that they form a rectangle, the camera's pose during image acquisition may be reconstructed (see figure 4). Here, we use the observation (derived from the plans we used in our tests), that the plan is oriented according to the direction of view of the user in front of it. This means, in a rectified image, the user's line of sight is the vector $[0;1]$ when standing in front of the plan. While this is useful for an intuitive readability of the plan, we cannot always assume this as given.

IV. 3D MODEL GENERATION FROM EVACUATION PLAN

In addition to the aforementioned approaches that employ the evacuation plan for the extraction of initial values for navigation, we present the steps needed to reconstruct a coarse indoor model from the plan. Apart from being used to support indoor navigation using map matching techniques similar to the one presented in [9], this model may then be used as a base for further detailed modeling.

A. Preprocessing

In order to prepare the photo of the evacuation plan, some preprocessing steps have to be carried out.

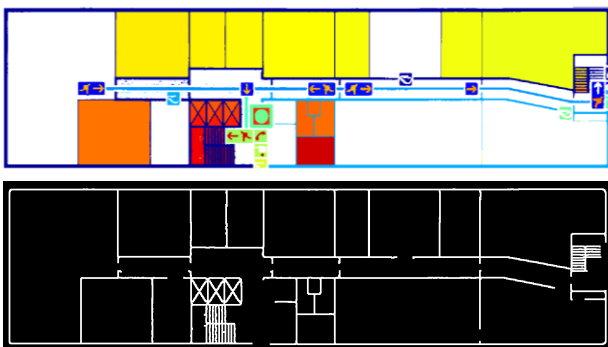


Figure 5. Identified regions (top); skeleton derived from evacuation plan, usable as "map of walkable areas" (lower)

Firstly, the perspective transformation and ground plan's contour computed in section III may be used to rectify the image and crop it to the borders of the plan.

The second preprocessing step is the binarization of the image. Here, we use the fact, that these plans are designed for good legibility, resulting mostly in a white background and good contrast. Therefore, only brightness differences that originated from lighting or reflections have to be removed. This is done by using a morphological opening with a big structuring element on the image and subtracting the result from the original image. The resulting image may then be binarized using a single threshold.

B. Symbol Detection

The detection of the evacuation symbols in the plan is very important for the following reasons:

- The evacuation information should be provided in the final model,
- a special treatment for the parts occluded by the symbols has to be carried out and
- symbols contain valuable information like the direction of staircases (evacuation routes seldom direct people to the roof).

Our symbol detection approach at first uses the aspect ratio of regions in the image, detected by a connected components analysis [6] (see figure 5). By these means the candidates for symbol regions are identified. Secondly, the symbol templates (extracted from the legend or taken from standardization documents) are scaled according to the mean size of the symbol regions. Finally, the symbols are detected using cross correlation, while analyzing only the candidate regions. In order to delete also the lines representing the evacuation routes, these are identified as the regions between two arrow symbols, using the arrow directions to restrict the search regions.

C. Skeletonization and Vectorization

Using the binary image cleaned of symbol regions, the skeleton can be derived using the approach presented in [10] (see figure 5). Together with the known transformation from image to world coordinates, the resulting image may support the navigation as a "map of walkable areas".

However, to derive a correct boundary representation model, a specialized vectorization step has to be carried out. It consists of tracing the skeleton between the branch points and constructing the according edges. While this approach delivers good results for most parts of the skeleton, it fails in parts formerly occluded by symbols or areas where information is lost during the binarization step.

Former symbol areas are filled by extrapolating the adjacent edges and computing their end points by intersecting the extrapolated edges. Moreover, if the occluding symbol was an evacuation route, the newly created edge is additionally annotated as door (see figure 6). In the case of dangling edges not ending near a symbol area, errors caused by binarization are assumed and the final edge direction is extracted from the original gray value image.

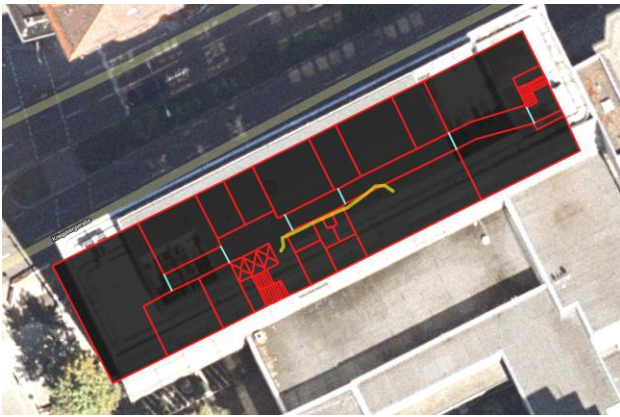


Figure 6. Automatically derived 2D indoor model, visualized in Google Maps (red: walls, cyan: doors); IMU track (yellow)

D. Final 2D and 3D Models

The edges extracted from the plan in the aforementioned way are then used to reconstruct the facets of the 2D model, which represent hallways, rooms and stairs (see figure 6). This reconstruction is followed by an adjustment using rectangularity and parallelism constraints.

After the transformation to world coordinates (using the parameters derived in III.A), we compared the final model edges to a paper plan in scale 1:100 in order to get a first estimation of the accuracy. This revealed length differences of below 0.1m per edge which may partly be caused by the low measurement accuracy in the paper plan. However, in the future we will extend the accuracy analysis to a comparison to automatically derived models using the approach described in [11].

In order to reconstruct a full 3D model from the 2D ground plan derived with the aforementioned approach, we employ the observation that the number of stairs is truthfully represented – at least in our plans. Thus, we firstly identify stairs by analyzing the aspect ratio and the shortest edge of all rooms. Secondly, adjacent stairs are merged to staircases, which are completed by stair steps formerly occluded by an evacuation route symbol. As stated before, this symbol also delivers the direction of the partially occluded staircase. Even without explicitly reconstructing the stairs in 3D, this knowledge may be used to support the stair detection step during navigation. Furthermore, the stairs can be reconstructed in 3D using the same standard stair height as in section II.C. Finally, the floor height can be computed and used to extrude the widened walls.

V. CONCLUSIONS AND FUTURE WORK

While a 3D model of the building interior was generated successfully, the implemented automatic image interpretation is still highly dependent on the visual appearance of the captured evacuation plan. Similar problems have also been reported during the use of architectural drawings for the reconstruction and 3D modeling of building interiors [12]. Even though a number of researchers and CAD developers aim at the automatic conversion of 2D drawings into 3D models, the lack of generality still remains the most important shortcoming. This problem is facilitated for evacuation plans since they do not contain too much and too complex information.

However, future work to allow an interpretation on a more abstract and thus general level is still required. In this context, we plan to use the presently unused information in the photographed plans. As an example, the analysis of the legend (figure 1c) could deliver the templates needed for the symbol detection. Furthermore, the address (figure 1d) may be used to automatically link to the external building model in a GIS.

Furthermore, we will use the IMU tracks to add details like doors to the coarse model reconstructed from the evacuation plan. This could be done by analyzing the angle under which the IMU track penetrates a modeled wall. In principle, our system also allows for indoor data collection by combining the low-cost sensor navigation with manual modeling similar to the process realized within OpenStreetMap. There, volunteers use their GPS or GNSS tracks to georeference the potential objects of interest as captured during semi-automatic geo-data collection and refine given maps. Similarly, MEMS IMU tracks can be used for indoor environments since coarse map like information is extracted from photographed evacuation plans. This map can then be used as a framework to further integrate semantic information like room number, position of stairs or elevators, which again is highly beneficial during navigation and route planning in indoor environments.

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