INDOOR NAVIGATION AND MODELING USING
PHOTOGRAPHED EVACUATION PLANS AND MEMS IMU

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ABSTRACT:

In this paper, we present an approach for the modeling of building interiors by a user who is equipped with a navigation system, which integrates MEMS IMU data processing with automatic interpretation of photos of evacuation plans. Such emergency plans for the evacuation of buildings are compulsory for public buildings in a number of countries. They consist of an approximate floor plan, the current position and escape routes. Additionally, semantic information like stairs, elevators or the level number may be found. If an image of such a floor plan is captured by a potential user, this information is made explicit again by a suitable raster-to-vector-conversion. The resulting approximate indoor building model can then refined by semi-automatic data collection. Similar to outdoor scenarios like OpenStreetMap, features of interest can be collected interactively while the user moves through the building. By these means the entrances of rooms, positions of windows, facilities etc can be integrated into the available indoor model. However, this presumes a suitable positional accuracy during indoor navigation. This is realized using inertial measurements from a low-cost MEMS IMU. Their evaluation by a ZUPT-(zero velocity update)-based algorithm is further supported by integrating information from the evacuation plan like the initial position of the user at the location of the plan. Furthermore, typical constraints for indoor environments like detected stairs or an assumed movement parallel to outer walls are applied to eliminate drift effects of the used low-cost sensor system. This provides a suitable accuracy to allow for an efficient map refinement.

1. INTRODUCTION

The success of Volunteered Geographic Information (VGI) in projects like OpenStreetMap is closely coupled to GPS as prevalent and inexpensive sensor system. In such scenarios, the volunteer frequently uses his GPS or GNSS tracks to georeference the potential objects of interest as captured during semi-automatic geo-data collection. While VGI has become very popular in outdoor areas, the lack of a suitable positioning sensor prevents corresponding developments in indoor environments. In order to enable data collection, the path of the respective volunteer is required at suitable accuracy while he moves through the building. For this purpose a wide range of experimental and commercial positioning systems are available. However, they either require infrastructure like WLAN-Networks or RFID beacons, or are based on high quality indoor models. Therefore, they do not allow for an inexpensive and generally available indoor navigation. This can be realized by low-cost inertial measurement systems based on MEMS IMUs. However, position determination by naïve integration of such inertial measurements suffers from unfavorable error characteristic with large drifts after short time periods. In order to improve the positional accuracy from such MEMS IMU measurements during pedestrian navigation, so-called ZUPTs

(zero velocity updates) can be used (Godha & Lachapelle 2008), thus, the foot-mounted MEMS is in principle used as a pedometer. As demonstrated in the section 2 of the paper, this considerably improves the quality of the measured user's trajectory. The accuracy of MEMS IMU indoor navigation is further improved by an alignment of the captured trajectories. This presumes that most parts of indoor routes will be parallel or perpendicular to the main direction of the respective building.

Since inertial navigation only provides relative coordinates, additional measurements to relate the generated trajectory to a reference coordinate system are required. For outdoor applications, this reference is usually provided by integration of GNSS positions. Since this is usually not available in indoor environments at suitable accuracies, we use an initial position of the user which can be derived from images of evacuation plans. Such plans are compulsory for public buildings in a number of countries. They consist of an approximate floor plan, and escape routes. Furthermore, they provide the current position of the user with respect to the plan, which can be used as starting point for inertial navigation (section 3). For scenarios, which imply an active participation of a potential user, we assume that he is willing to capture an image of such a floor plan by a mobile device like a cellular phone. As it will be demonstrated in section

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4, ground plan information can be made explicit again from such images by a suitable raster-to-vector-conversion. This information is then used to support and improve pedestrian navigation similar to map matching in outdoor environments. Furthermore, such a floor plan can provide semantic information like stairs, elevators or the level number. As discussed in section 4, an approximate indoor model of the respective building can be generated during further processing. This model can then potentially be refined based on the available tracks of the user.

2. INDOOR NAVIGATION USING MEMS IMU

In order to navigate in indoor environments as well as collect user tracks for their modeling, a sensor system independent from preinstalled infrastructures has to be used. In the last years, the application of MEMS IMUs as foot mounted sensors has proven to be usable for the solution of this challenge. Among others, (Foxlin 2005), (Godha & Lachapelle 2008) and (Feliz et al. 2009) describe the application of zero velocity updates to get the large drift errors of integrated inertial measurements under control. (Glanzer et al. 2009) present a further amelioration of the results by supporting the indoor navigation by building information like indoor ground plans.

2.1 Zero velocity updates

As stated before, system immanent large drift errors prevent from integrating the raw IMU measurements twice in order to get coordinate values. Thus, we refer to the work carried out by (Godha & Lachapelle 2008) and use a foot mounted XSens MTi-G MEMS IMU together with an algorithm based on zero velocity updates (ZUPTs). Following their approach, we use the IMU as a strapdown system by attaching it to the user's foot. Then, the two phases of the movement of a walking user's foot (swing and stance phase) like stated by (Chai 2010) may be found in the IMU measurements. After integrating the accelerometer measurements once, the resulting velocities are supposed to be zero during a detected stance phase. However, as these velocities differ from zero due to measurement errors, the difference may be used to eliminate the errors during the last two steps (as only one foot is equipped with a sensor). The resulting coordinates can then be computed by integration (Figure 1, left hand side).

2.2 Alignment using principal building directions

While ZUPTs significantly reduce the drift errors coming from the IMU measurements, this method is not applicable to completely eliminate them, especially in longer tracks. Thus, appropriate means for a correction of these errors have to be found. Here we use the fact, that most parts of indoor routes will be parallel or perpendicular to one of the principal directions of the building contour, as additional support information.
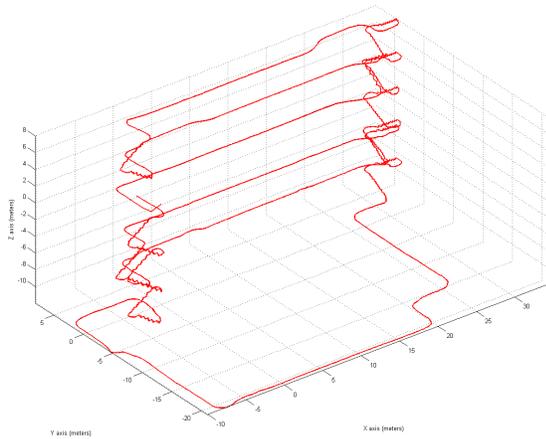
For many buildings, at least some information on the external building structure may be found, be it ground plan contours from surveying offices, OpenStreetMap or a complete 3D outer building shell. Using these building models, the principal direction of the building, in which the user is located, may be computed using e.g. the approach presented by (Duchêne et al. 2003). In order to align the IMU track to this principal direction, we use a basic detection strategy for straight lines in the IMU tracks. Therefore, the ratio $\Delta x/\Delta y$ for every double step is computed and compared to a threshold. If at least six consecutive steps are below the threshold, the respective steps are marked as straight line. The computed angular difference between the direction of this straight line and the principal building direction is then eliminated by a rotation around the z-axis (Figure 1, right hand side).
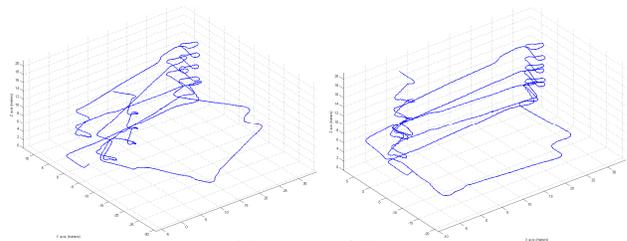
Figure 1. Left hand side: Indoor track using only ZUPTs; right hand side: alignment using principal building directions.

2.3 Height correction using stair detection

The aforementioned method is usable for a reduction of drift errors in the X and Y coordinates, however, remaining effects in the Z coordinates can be seen in Figure 1 (right hand side).As a first additional support information for the amelioration of IMU navigation results, we use the fact, that nearly all indoor movement will be in a strictly horizontal direction, with the exception of stairs and elevators. This means, by applying a reliable detection of these two features of an indoor environment, most errors concerning the Z axis can be eliminated. Currently, only stair detection is implemented, while the detection of elevators using the IMU measurements resides in the domain of future work.

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**Figure 2.** Indoor track using ZUPTs, alignment and height correction.

Our approach for the detection of stairs currently works on the final coordinate values delivered by the ZUPT and integration step. Firstly, the initial value for the user's height is set to zero or – if known – to a value derived from the floor, in which the user is located. In the future, we aim at extracting this information from the photographed evacuation plans (see Figure 3, a). Every following height is then set to the same value until stairs are detected. The actual detection of stair steps is straightforward: all steps with height differences greater than 20cm are annotated as stair candidates, after the appearance of a minimum of three consecutive stair steps these are marked as detected stair steps. As we have equipped just one foot with a sensor unit, every stair step is then divided into two steps of the fixed height of 20cm, which is a common step height for public buildings following (E. Neufert et al. 2002). The resulting indoor track through our institute's building can be seen in Fugure 2.

In the future, we will investigate the possibility to detect elevators from the IMU measurements and automatically integrate them into the resulting indoor model. Other areas of interest are the modeling of indoor environments using only these user tracks and means to support the modeling process by combination with other sensors and user interaction.

3. EVACUATION PLANS FOR IMPROVED NAVIGATION

Using the described correction steps, the aforementioned positioning system for indoor environments delivers sufficient accuracy for coarse manual modeling of indoor facilities like corridors, rooms, room entrances and stairways. However, the chosen positioning approach is only capable of delivering coordinates relative to a known initial position. In many cases, this starting point may be the entrance into a building, to which the

user has been guided by GPS. However, GPS accuracies of 5-10 meters or worse in urban canyons do not promise to deliver an initial position with sufficient accuracy for the navigation in building interiors. In combination with a detailed semantic façade model like the ones delivered by (Becker & Haala 2009), however, the starting point – i.e. the building entrance – may be found with the accuracy of the façade model. In cases, where no such model is available or the user wishes to start navigating at a position different from the entrance, we propose the use of photographed evacuation plans to deduce the initial position.
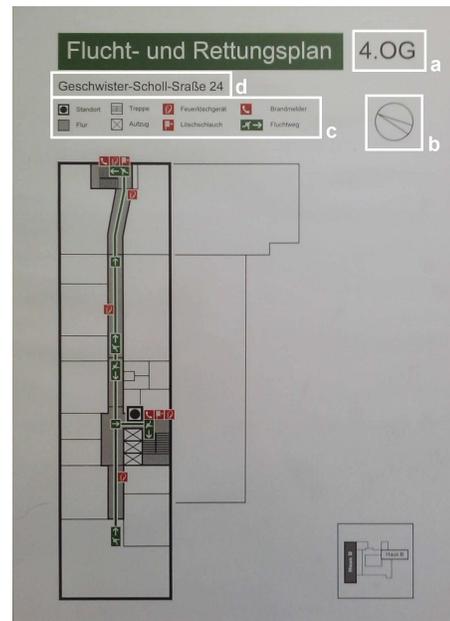

Figure 3. Evacuation plan of our institute, photographed using mobile phone camera (a: floor, b: north direction, c: legend, d: address).

Without question, the need for indoor positioning and navigation exists mostly in the domain of large public buildings like shopping centers and administrative office buildings. For such buildings, more or less detailed evacuation plans are compulsory in many countries. Besides from evacuation routes, these plans contain a great amount of information needed and usable for the modeling of building interiors like inner walls, stairs, elevators (see Figure 3) and some of them even doors and windows. However, for the presented indoor navigation approach using an IMU, the information about the user's position ("You are here") here is the most interesting.

Like in the case of the geometric correction step during IMU navigation, we assume the external building contour is available to the application. Furthermore, the user of the navigation system has taken a photo of the evacuation plan in front of him (e.g. with their mobile phone camera). As this photo was taken for the purpose of analyzing the evacuation plan, we may assume that a) the evacuation plan will be the biggest object shown in the photo, and

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b) the actual ground plan will be the biggest object in the evacuation plan. Thus, the image may be cropped accordingly.

While symbols vital for the task of evacuation (fire alarm boxes, fire extinguishers, hoses and evacuation routes) are mostly standardized (umwelt-online 2010), this is not applicable for the "you are here" symbol. Thus, in the current stage of our approach, this symbol has to be passed to the application. In the future, we aim at detecting the symbol used in the available plan's legend. This symbol and its coordinates in the image may then be found reliably using template matching techniques (see Figure 4).
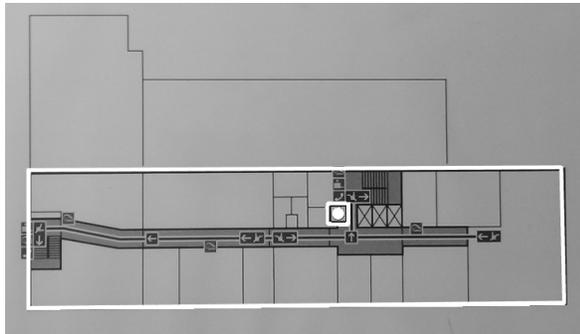
Figure 4. "You are here" information found using template matching; building contour extracted using Hough transform.

In order to derive the user's position in world coordinates, the transformation between image coordinate system and world coordinate system has to be found. This is achieved by an identification of the building boundary in the image and matching it to the available building contour.

For the search for the building boundary in the image, we firstly erode the image to delete features like inner walls, which are superfluous in this step. Secondly, the edge image is computed using the Canny operator, before we apply the Hough transformation to derive the main lines from the image. From these main lines, we can compute the corner points of the building boundary (see Figure 4). Alternatively, a contour finding algorithm may be used, which also leads to the desired result. Using the image coordinates and the known external building contour, the parameters of the projective transformation from image to world coordinates can be derived.

By applying this transformation to the computed image coordinates of the "you are here" symbol, the world coordinates of the user may be computed and used as initial position for the IMU navigation (Figure 5). However, this approach only provides the X and Y components of the user's position, in order to find the Z component we aim at using the floor information in the future (see Figure 3, a).

Figure 5. Manually reconstructed indoor model using evacuation plan in Google Earth; IMU track using ZUPTs, alignment and height correction.

Furthermore, we started to develop an approach to automatically derive coarse indoor models from the photographed evacuation plan, which will be described in the next section. Using these coarse models as input for map matching techniques like described in (Glanzer et al. 2009), we aim at computing the missing initial orientation of the user's track and support the navigation process.

4. MODEL GENERATION AND REFINEMENT

The aforementioned approaches already enable a potential user of an IMU navigation system to manually model indoor environments in an OpenStreetMap like process (OpenStreetMap Wiki 2010). However, we see several ways to assist them in doing this. Firstly, in addition to the initial position, a coarse indoor model may be derived from the evacuation plan. This may also be used as further support information for the indoor navigation and therefore the track collection (Glanzer et al. 2009). Secondly, starting from this coarse model, the collected tracks can be used to further enhance this model by modeling missing features like doors automatically.

(Yin et al. 2009) give an exhaustive overview over different existing approaches for the reconstruction and 3D modeling of building interiors from architectural drawings. Using scanned high-resolution images of such drawings, (Ah-Soon & Tombre 1997) and (Dosch et al. 2000) describe a complete approach to use them for the derivation of correct 3D models. However, to our knowledge, there are no references describing the use of these approaches together with low-resolution images disturbed by specific symbols like in the case of evacuation plans.

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Therefore, we aim at extracting as much information as possible from the given evacuation plan. While it contains also semantic and possibly topologic information, we have started by developing a first approach to make the geometric information explicit again.

As a first step, the knowledge of the building boundary and the corners in image coordinates from the initial position detection step (section 3) allows us to remove perspective distortions and crop the image. In order to convert the raster image to vector data and finally a 3D model, it then has to be binarized. Here, we may exploit the fact, that evacuation plans are optimized to be legible also in emergency situations. Therefore, they should not contain more than the most necessary information (ground plan, symbols), which in addition will be clearly distinguishable from a white background. Thus, apart from reflections and brightness differences, the binarization may be carried out by simply comparing all pixels to a single threshold.

The resulting binary image may then be segmented into distinct regions using a boundary tracing algorithm. By detecting inner and outer regions, all regions with closed boundaries will be detected with the need for a further identification step in order to distinguish rooms from e.g. single stairs. However, Figure 6 clearly shows the need for an identification of the symbols contained in the image in order to complete the occluded parts of walls and stairs and produce closed boundaries.
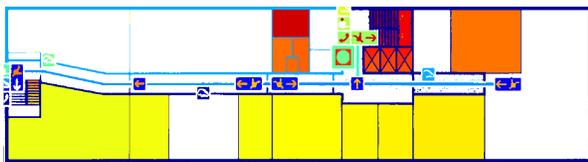

Figure 6. Identified boundaries and regions (without identification of symbols).

Furthermore, the symbols contained in the evacuation plan have to be identified due to two additional reasons: Firstly, the evacuation information should be available also in the resulting 3D model. Secondly, the information contained in the symbols may comprehend other information important for the reconstruction of the 3D model, e.g. the direction of an evacuation route comprehends the information of the downward direction of a staircase.

Similar to the presented identification of the "you are here" symbol, the emergency symbols may be found using template matching. In addition to the legend which is usable as a source for the needed templates, these symbols are mostly standardized (umwelt-online 2010). Thus, high quality templates taken from standardization documents are available (which may differ slightly from the ones used in the evacuation plan). However, both template sources demand for a scale invariant template matching approach, as the size of the templates differs too much from the size of the symbols in the actual plan. Taking the rotated

evacuation route pictograms into account, the approach to choose additionally has to be rotation invariant. This leads to the approach presented by (de Araujo & Kim 2007), which we plan to use in the future. Meanwhile, we implemented a basic approach for symbol detection, based on the properties of the identified regions. After selecting all regions with an appropriate aspect ratio as candidate regions, the templates are scaled accordingly and the actual template matching is carried out by cross correlation. Instead of true rotation invariance, the rotated evacuation route symbols are provided to the application. The results of this step can be seen in Figure 7.
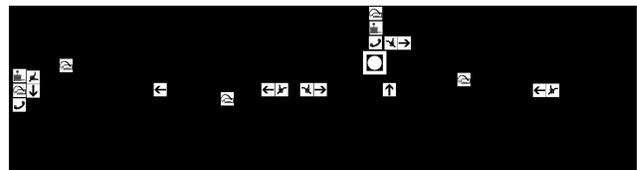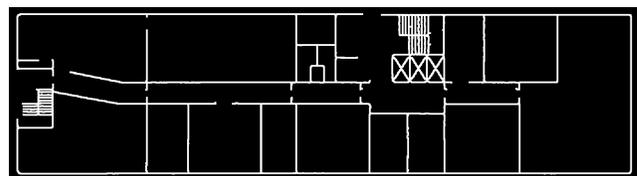

Figure 7. Detected symbols.

Furthermore, the identified evacuation route symbols deliver valuable information for the search of the respective lines. The search area for these lines is strongly constrained by the following facts: they will be located a) between two evacuation route symbols and b) in the direction shown by at least one of the evacuation route symbols.

After storing the locations and types of the detected symbols and lines for further use, their corresponding regions may be deleted. The remaining boundaries then should represent only the needed ground plan of the building interior. As a preprocessing step to the final vectorization, the skeleton of these boundary pixels is computed (see Figure 8) and the end points and branch points have to be identified.

Starting from the branch points, the vectorization is carried out by tracing the boundaries in the skeleton image. During this step, the identified symbol regions, marked mostly by end points, are bridged by extrapolating in the direction which predominated in the previous skeleton points. During vectorization, branch points represent directional changes, a fact which may be exploited in order to distinguish and model different walls. An alternative approach would be the identification of straight lines using e.g. RANSAC and a modeling step based on half space modeling similar to (Kada 2007) and (Budroni & Böhm 2009).

Figure 8. Skeleton of the boundaries after symbol detection and removal.

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After the vectorization, the identified closed boundaries have to be classified as the features they represent. This step bases on the scale derived from the transformation between image and world coordinates. Using this information, the found boundaries may be scaled to real world dimensions and their properties like width and area may be computed. These properties then are usable to distinguish e.g. between rooms (using e.g. a minimum area threshold) and stairs (using a maximum width threshold, repetition).

The final 3D model is then reconstructed by widening the constructed walls and by extruding them along the z axis. For a coarse approximation of the height needed for this extrusion step, the amount of identified stairs and a standard stair height may be used (see also section 2.3).

In the future, the presented approach to model building interiors from photographed rescue plans will be further improved. Here we aim at automatically deriving additional information like elevators, the address and floor information. This information may be extracted using OCR, be it by identifying the symbol used for elevators in the plan at hand or by digitizing the header of the plan's legend. The address information then may allow for an automated search for the needed building boundary in a geographic information system.

For the refinement of this coarse model using tracks collected with the help of IMUs we plan to start by automatically modeling room entrances. This may be done by looking at intersection points between the IMU track and walls in the indoor model. Furthermore, the IMU tracks may serve as information for a verification of the coarse models.

5. CONCLUSIONS

In this paper, we presented two basic approaches for indoor navigation as well as the modeling of building interiors.

We showed two sources of support information to improve the navigation in indoor environments using MEMS IMUs. These are height correction using stair detection and alignment using principal building directions.

Furthermore, we described approaches to derive the user's position and a coarse indoor model from a photographed evacuation plan. While many of the described steps are still work in progress and may be subject to change, we are confident in the ideas we described.

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