

# Context Dependent Heading Fixing Approaches in IMU-based Pedestrian Navigation

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**Abstract** – With the emergence of micro-electromechanical systems smaller and cheaper inertial measurement units became available. These constitute the basis for affordable dead reckoning applications but exhibit characteristics leading to errors in the long term. Especially the error of the gyroscopes lead to heading drift resulting in enlarging positioning error with the distance walked. This paper outlines several approaches to improve and maintain the heading for pedestrian dead reckoning using sensor fusion, context specific information and justifiable human interaction.

## BIOGRAPHIES

Martin Krammer is a teaching / research assistant and PhD student at the Institute for Building Informatics at Graz University of Technology, Austria. His studies concern several topics in the area of indoor positioning with software applications. Starting from inertial sensor data processing with Kalman filters and sensor fusion techniques to improve position accuracy his works have advanced to the design and implementation of location based mobile information systems for professional and consumer services.

Thomas Bernoulli is a research assistant and PhD student at the Institute for Building Informatics at Graz University of Technology, Austria. His research deals with the design and implementation of large, modular and flexible software frameworks demonstrated by the development of a location based service framework currently in use as a base for several different professional and consumer applications as well as research.

Sergej Muhič is a teaching / research assistant and PhD student at the Institute for Building Informatics at Graz University of Technology, Austria. His research deals with the generation of building information models. He tries to automatically extract information from CAD building plan drawings to get data for a building model used in different applications later in the lifecycle of a building like indoor navigation.

Ulrich Walder is professor and head of the Institute for Building Informatics at Graz University of

Technology, Austria. His research targets the development of a novel computer aided disaster management system combining interdisciplinary knowledge of facility management, civil engineering, navigation and software development.

## I. INTRODUCTION

Localization and navigation using inertial measurement unit (IMU) sensors has been used for decades, first starting in the aeronautics. The key characteristics of an IMU based positioning system are highly accurate short-term positioning but sensor errors which lead to an accumulation of position errors without further stabilization.

Moving IMUs measure accelerations which are integrated to travelled distances. To allow an observation of random three-dimensional movements, the time sampled accelerations have to be aligned to a common coordinate frame. The alignment procedure is based on the propagation of the sensor's rotation matrix from angular velocities synchronously measured by gyroscopes incorporated within IMUs. Not depending on any preinstalled infrastructure, IMUs built the base of a completely autonomous dead reckoning positioning system. But following that relative principle, a definition of initial conditions has to be performed somehow else.

With the emergence of micro-electromechanical systems (MEMS) smaller and cheaper inertial sensors reached a stage where they have become interesting for pedestrian positioning too. Because of their natural flexibility and differing duties, pedestrians are able to or have to walk around in diverse surroundings – basically everywhere from urban areas to rough nature. This would also require a highly flexible pedestrian positioning system working equally well under all circumstances, being light (portability) and economically reasonable.

MEMS IMU based systems fulfill that requirement, but certain characteristics of such gyroscopes lead to an unacceptable amount of errors in the position calculation; mainly referred to as *heading drift*. So, to be considered as suitable by pedestrians, a sufficiently

accurate IMU-based positioning system has to take drift properties of gyroscopes into account.

This paper outlines several approaches to gather, improve and maintain a correct heading for pedestrian dead reckoning applications by using sensor fusion, context specific possibilities and justifiable human interaction.

## II. HEADING IMPROVEMENT USING MAGNETOMETER DATA

For the improvement of drift behaviour modern IMU use magnetometer data already within the firmware to stabilize the gyroscopes. However this happens under the condition that the earth's magnetic field is to some extent constant. When using IMUs for positioning and navigation in indoor environments this case is rare (Fig. 1). Buildings with metal facades or with electromagnetic interference sources like power lines, machines or metal installations, can disturb the northward adjustment sensitively.

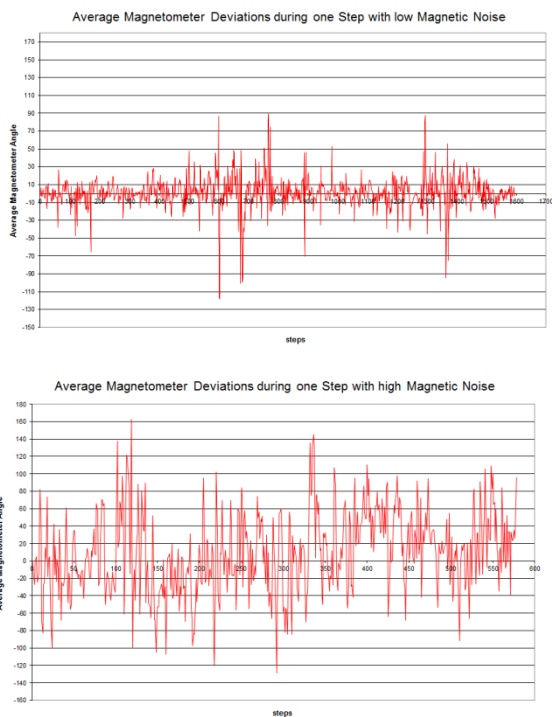


Figure 1: Indoor navigation track with original sensor Kalman Filter and enhanced Kalman Filter

Therefore even using high quality sensors it can be favorable to use the raw data of the sensor only and to implement the strap down algorithm and the Kalman Filter oneself. The stabilization of the gyroscopes can take place then punctually and leads to substantially better results, than the use of the already filtered data of the IMU (Fig. 2a, 2b).



Figure 2a: Indoor navigation track with original sensor Kalman Filter

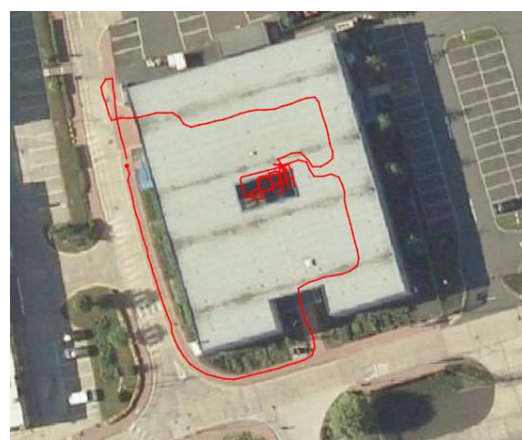


Figure 2b: Indoor navigation track with original sensor enhanced Kalman Filter

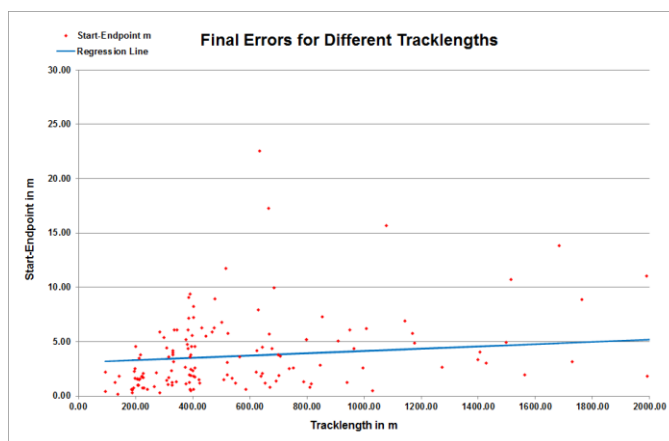


Figure 3: Accuracy of 150 tracks in different environments

Together with further techniques (context-adaptive ZUPT (Zero Velocity Update) recognition [1], continuous error correction of the steps, due to the ZUPT corrections of the speed [2]), result very high accuracies in most different environments. This is

especially indispensable, when no other information for position correction is available (e.g. WiFi, RFID, image pattern recognition or building interaction). Fig. 3 shows the results of 150 measurements in very different building types, reached with the raw data by Xsens MTx and MTw sensors and an own extended Kalman Filter. As error measure serves the deviation of the starting point from the terminal, whereby the difference between correct and actual position on the whole track was never bigger.

### III. HEADING IMPROVEMENT USING GPS DATA

Autonomous Indoor positioning and navigation systems should be able to be used outdoor or in mixed environments as well, e.g. by fire fighters, soldiers, Special Forces or police forces which operate in urban areas. In this case GPS data can be helpful to reposition and realign the track of the IMU. Because normally the basic quality of an IMU track is much higher than GNSS positions in areas with weak signals and multipath effects, it is a challenge to fusion positions from both sources. There are two possibilities to do so. Either the GPS positions are directly taken into account into the Kalman filter or by performing a statistical quality analysis of the two trajectories.

In the first case it is better to implement a second Kalman Filter on the level of single steps, than to introduce the GPS data directly into the Kalman Filter at the level of each IMU measurement. The reason is that GPS positions of commercially available GPS receivers are not gained at the same sample rate than the IMU. Therefore it is very difficult to adapt the filter parameters in a way that a real improvement of the results can be observed.

#### Methods used

- IMU - GPS fusion with Kalman filter on step level
- Track analysis and comparison
  - Affinity of curvatures for several steps
  - Position priority = IMU
  - Heading priority = GPS

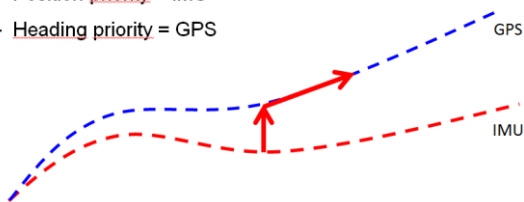


Figure 4: Two methods to improve IMU data by GPS input

Since the IMU track characteristics are very good in distance, but very vulnerable in heading, GPS data are mainly used to improve the direction of a path. An elegant method is to compare the trajectories of the IMU and the GPS tracks by evaluating the quality of the two. In fact the two tracks normally differ in position

but have very similar characteristics of the curvature. If the two curves are assumed to be affine the characteristic of the GPS path can be superimposed to the one of the IMU (Fig. 4). In any case the IMU is the leading system.



IMU track



GPS track



GPS + IMU fusion

Figure 5: Results of IMU and GPS superposition with affine curvature method

Today's technology of GPS receivers (high sensitivity GPS) allows to use them in difficult scenarios, where signals are weak and scattered. This allows to further focus to scenarios where reception is not optimal as it is often the case in urban areas.

The approach to be used in those scenarios is based on the fact a sequence of GPS measurements are not independent but can be treated as time series. Taking the chronological correlation into account a modified stochastic model of the filter it is possible to further improve detection of filter errors as they occur due to multipath signal propagation. This approach can be adapted to be used in the above described algorithm to further improve the detection of correlations.

#### IV. HEADING IMPROVEMENT USING BUILDING MODEL

In several scenarios GPS is not an option to improve the heading as it cannot be received. One of these are indoor positioning scenarios. But being indoors offers a new source of information to be used to improve not only the heading but the position in general: The model of the building in which the user is using the system. The building model can be used to perform map matching.

There are different potential sources of building models. If pedestrian positioning systems are used indoors their output is generally displayed to users on some kind of map. In most cases this is a floor plan of the building. Instead of only providing a bitmap of a floor plan the operator could provide a building model. These models often already exist as today's buildings are generally managed by some kind of computer aided facility management software (CAFM). Even if they do not really provide a 3D model of the building it can easily be enriched to provide enough information for building model based map matching, as those algorithms do not need a fully fledged 3D model of the building. The software AIONAV software used provides import options for such data and allows adding needed elements to the model if they are not provided by the CAFM system.

Map matching of positioning data is not a new field of research. GPS data has been matched to traffic routes for many years now. But they cannot be used unchanged to match pedestrian indoor tracks to building models. The reason is the underlying data model. Traffic routes are generally modelled as geometrical graphs called navigation networks. They model the small areas (routes) to which the positions have to be matched. The much bigger part of the plane is covered by areas positions are not allowed to be located in (the houses and fields between the routes).

Map matching using building models for pedestrian navigation face the opposite situation: The positions are allowed to be located nearly everywhere except a small percentage of the whole area (walls, inaccessible areas). Therefore such algorithms must take other characteristics into account which leads to several

heuristics; some of them can be used to correct heading errors.

##### A. Heuristic I: Humans do not cross walls

The most obvious one is easily formulated: Tracks are not allowed to cross walls. In case a track crosses a wall it must be corrected. As stated in the introduction most positioning errors are due to heading errors. Thus it can be assumed the observed error is caused by a wrong heading error in the past of the track (Fig. 6).

The difficult part is to figure out at which point this happened as there are generally no track characteristics correlated with a heading error. A good start is to select the position where the angle the track has to be rotated around is minimal. Variations of this strategy might also reconsider already performed corrections to optimize the track globally.

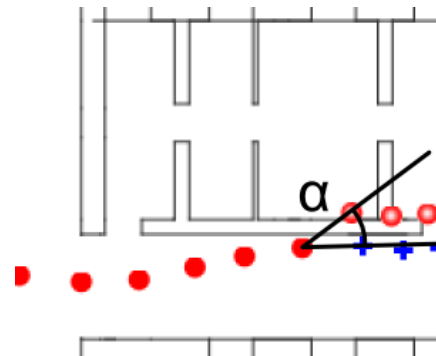


Figure 6: A descriptive example of a track with heading error (red) is corrected by an angle  $\alpha$ .

##### B. Heuristic II: Humans do not fly

Another heuristics can be found if the third dimension is taken into account. Generally the altitude values of the positioning system very reliable as barometer as well as accelerometer data is used to compute it. Therefore in case the z-value of the positions changes but the coordinate in the plane (x,y) does not match a building characteristic the user could use to change its altitude the current position is wrong has to be corrected. Such building characteristics are stairs, elevators or anything else a user can use to change its altitude.

The rational why the position is not corrected using translation vector is the same as in the previous heuristic: Heading errors are generally the cause for positioning errors. The strategies to be used to find the best rotation centre and angle are the same as stated in the above described heuristic.

## V. CONCLUSION

In this paper different methods to improve IMU based positioning by reducing and correcting heading errors are presented. The first approach using magnetometer data can be applied to any scenario, as it is always present. The other two approaches have some requirements that are not fulfilled in any situation: Either GPS (or other GNSS) signals must be receivable or a sufficiently detailed building model must be available. In either case it is possible to further reduce positioning errors due to heading errors, and the combination of the different approaches is favourable and future developments of all approaches will further increase positioning accuracy.

## ACKNOWLEDGMENT

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