Lucerne University of
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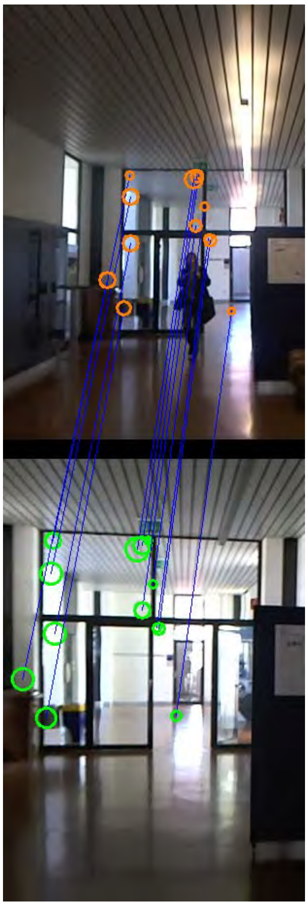
CC Innovation in Intelligent Multimedia Sensor Networks (IIMSN)

Marauder: Improvement of Inertial Sensor Based Indoor Navigation by Video Content Analysis

Due to the non-availability of GPS signals in buildings the area of indoor positioning and navigation is currently a very active field of research. Available systems can be distinguished into infrastructure based and autonomous approaches.



Infrastructure based navigation systems mostly rely on preinstalled access points[1] of known location that determine the position of a mobile device, e.g. carried by a person, based on Time-of-Flight technology and triangulation methods. While commercial solutions in this area already exist, they have the considerable disadvantages that their installation requires significant investments and that they are not suited for ad-hoc applications where no previous installation is possible.

Therefore a special focus is currently brought to the research of *autonomous* indoor positioning and navigation systems that do not rely on any preinstalled infrastructure. One of the most promising approaches there is the so-called inertial navigation [1], a method where a highly integrated sensor unit (IMU[2]) is used to track both the linear acceleration and the angular velocity in a reference coordinate frame attached to the moving system. Based on this data the linear acceleration of the moving system as measured in the inertial reference frame (coordinate system of the earth) is determined. Then, based on the kinematic equations and by making use of the initial location and velocity the current position is obtained through a double integration of the acceleration data.

However, the mathematical problem of double integration is intrinsically unstable and small errors in the measurement accumulate and lead eventually to a quadratic increase of the overall position error. While the application of the so-called Zero Velocity Update (ZUPT) algorithm[3] limits the accumulation of the *distance* error to a level acceptable for practical applications there is currently no possibility to correct for a possible *directional* error. However, only a few degrees of directional error may induce a large positional error over distances of

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[1] This expression should be considered in a wide sense, and cover standard WLAN technology as well as Ultra Wide Band (UWB) systems or Radio Frequency Identification Devices (RFID).

[2] IMU: Inertial Measurement Unit

[3] Therefore the IMU is attached to the foot of the person, whose trajectory should be measured and based on heuristic criteria the step pattern is recognized from the IMU data. Then, at each instant when the foot is remaining motionless in contact with the ground (of typically 0.1 – 0.3 s duration) the velocity of the track is set to zero (ZUPT)

Project
Marauder

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some hundred meters. Therefore different research projects have been launched in order to investigate the potential of the fusion of IMU based inertial navigation with other sensor techniques.

One promising approach was developed in a collaboration between the Technical University of Graz (TU Graz) and the Lucerne University of Applied Sciences & Arts (HSLU), where a novel approach has been developed based on the fusion of an IMU based system (called AIONAV[4]) with a video sensor [2][3]. The underlying idea is mainly motivated by the human perception: a human can “navigate” with closed eyes rather precisely over some ten meters using the vestibular system, i.e. the human “inertial sensor” situated in the middle ear. However, at longer distances the heading will diverge and has to be recalibrated using the human “vision sensor”.

Here a similar approach is used: MEMS based inertial sensors will provide information sufficiently precise to allow for dead reckoning at shorter time scales up to minutes. At longer times, when inertial based navigation tends to accumulate integration errors, video image fingerprinting techniques are used to recalibrate the system. The IMU sensor system is therefore extended by a small portable camera taking live pictures which are processed in real time. The principle system setup is shown in Figure 1.

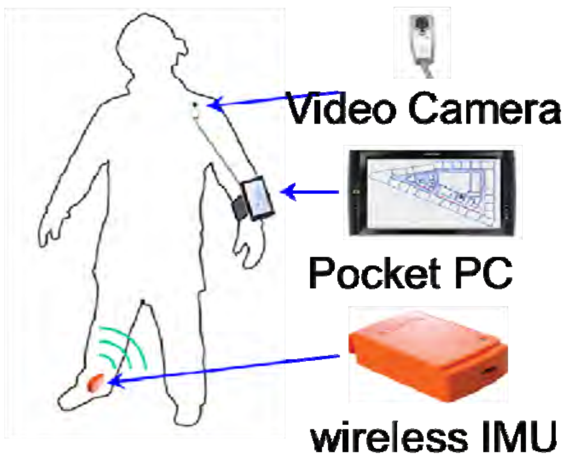

Fig.1: Principle system setup – AIONAV + Camera.

This described approach is realized as follows: during an initia-lization step images of the facility are taken in advance along certain paths (Figure 2, red) and are stored in a data-base on the system together with the positions and optical axes (blue dots and arrows, respectively), from where these images were taken. These positions and direction are obtained from the running AIONAV system, which is corrected periodically via a simple calibration process in which the user manu-ally marks strategic positions (marked with a light blue star in Fig. 2) by setting the actual position on the map via the gra-phical user interface. This correction is necessary because the raw IMU data tends to be subjected to the cited directional drift.

[4] Autonomous Indoor and Outdoor NAVigation, developed by TU Graz.

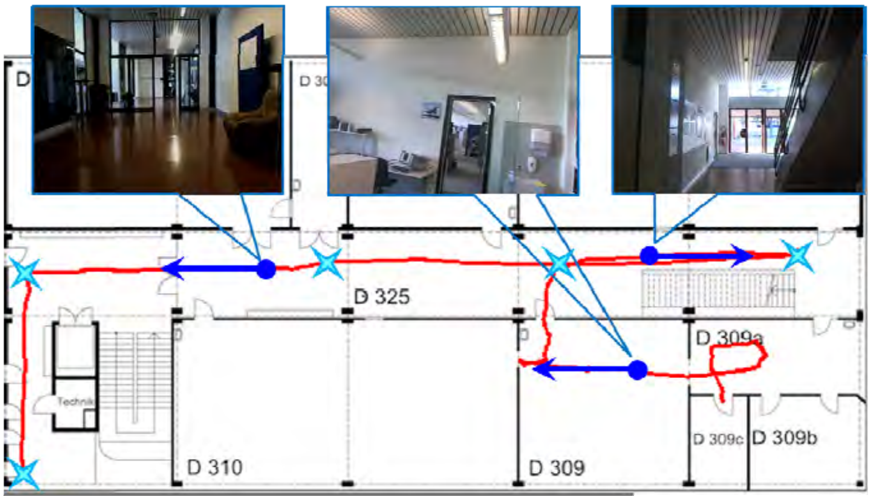

Fig.2: Initialization procedure for the sensor fusion approach.

When operating in navigation mode the live images from the video camera are correlated in real time to the images in the database. Therefore a hierarchy of criteria is applied in order to reduce the probability of false matches to a minimum.
In a first step only those images from the data base are considered that are within a given search range of the current position and where the optical axis is compatible with the current orientation. Then, in a second step SURF features matching between the live (bottom) and the selected database (top) images is applied (Figure 3, left). Only those database images where a minimum number of matching features is obtained are considered for the next, third step. Therefore weak perspective conditions are applied, i.e. we assume that a significant fraction of the SURF feature points lie in a single plane. The validity of this approach, which cannot be proven a priori, will be justified a posteriori through the test results. Under this assumption the homography matrix, which represents the transformation between the two planes (or images) can be extracted by standard techniques from the set of corresponding SURF feature points based on a random sampling (RANSAC) approach.

Fig.3: Feature matching between live and database images.

Finally, based on the homography transformation the database image is “warped” onto the reference frame of the live image. This is shown by the green overlay (database image) onto the live image in Figure 3 (right). Then, based heuristic closeness criteria, the best matching database image is determined.

In case a reliable match between the live and a preregistered image is found the current position estimation from the inertial navigation is checked for consistency with the position of the database image and the IMU position is corrected should a significant discrepancy be detected. In Figure 4 an example for such a correction is shown. In the upper figure the original IMU based path is shown (dotted red curve) in comparison to the real path (blue line). In the lower part of Figure 4 the image path after correction with the video image correlation technique is shown.

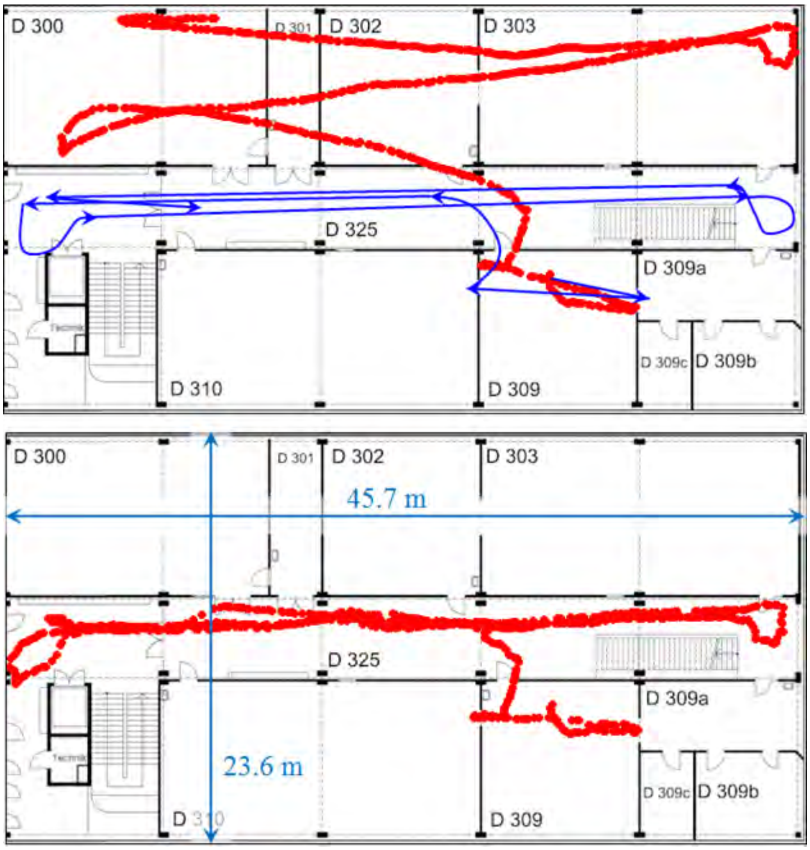

Fig.4: (top) IMU based navigation with heading deviation induced by a parasitic magnetic field (top). The same data corrected with the heading information obtained from the image correlation technique (bottom). The real path (for both cases) is shown as blue arrows (top)

As can be seen from the figure the directional drift of the bare IMU system could be corrected by use of the image fingerprint-ting technique. The important point to notice here is that the image fingerprinting approach works equally well for all times in contrast to the bare IMU data, where the precision decreases with time due to the directional (and eventually distance) error accumulation. Finally the sensor fusion approach has the considerably advantage that the initial position and (especially) heading can be found automatically, while these have to be set manually for a bare IMU system. This manual initialization represents a delicate step for a bare IMU system because a directional error of only 3 degrees will lead to 5 meters of error after a distance of 100 meters.

Currently different possible applications for the AIONAV + Camera technology are evaluated among which there are the tracking of first responders in case of emergencies and guidance of visually impaired persons.

[1] U. Walder, T. Bernoulli, "Context-Adaptive Algorithms to Improve Indoor Positioning with Inertial Sensors", Proceedings of the 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN), Mautz, R., Kunz, M. and Ingensand, H. (eds.), IEEE Xplore, page 968-973.

[2] T. Bernoulli, U. Dersch, M. Krammer, U. Walder & K. Zahn, "Improvement of Inertial Sensor Based Indoor Navigation by Video Content Analysis", accepted for *2011 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, Guimares, Portugal, Oct. 2011.

[3] T. Bernoulli, U. Dersch, M. Krammer, U. Walder & K. Zahn, "Positioning and Tracking of Deployment Forces Combining an Autonomous Multi-Sensor System with Video Content Analysis", Proceedings of the International Conference on *Future Security 2011*, Berlin, Sep. 2011.