Integral Positioning System for indoor applications

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Abstract— **A portable system for indoor navigation in unknown environment is presented. The approach is based on stereo vision aided inertial navigation and real time data fusion algorithms.**

Keywords — **image based navigation; inertial navigation; stereo camera; data fusion**

I. Introduction

For many applications in indoor environments an accurate and reliable estimation of position and orientation of the moving object is required. The single sensor systems like low cost inertial measurement unit (IMU) typically do not provide a stable navigation solution because of non estimated sensor errors. A multi-sensor approach for realisation of this task is needed. A stereo camera as aided sensor was preferred to obtain 3D information from the unknown environment which is used for self localization and ego motion estimation. Both, inertial and optical data are fused in real time within filter to provide an accurate navigation solution. The multi-sensor navigation system developed by DLR and called IPS (Integral Positioning System) is based on combination of stereo vision and inertial navigation.

II. Integral Positioning System (IPS)

A. Stereo Vision

The basic idea of stereo vision is to identify corresponding points in images of stereo camera pairs in two consecutive frames. Calculating 3D object points for the first stereo frame allows for reconstructing the relative orientation change of the second frame. The pinhole camera model was applied.

For image based pose estimation features in image space are detected and tracked over consecutive frames. Natural landmarks such as corners, isolated points or line endings are suited to be used for pose estimation. Several algorithms were implemented and evaluated. We decided for Harris corner detector [1] because of its isotropic properties and its computationally cheap calculation.

Assuming a sequence of synchronously acquired stereo images, we apply two different matching steps: intra-matching (features in the left image and in the right image at time $\mathbf{t_n}$) and inter-matching (left image at time $\mathbf{t_n}$ and left image at time $\mathbf{t_{n+1}}$, right image at time $\mathbf{t_n}$ and right image at time $\mathbf{t_{n+1}}$). Normalized cross correlation is applied as matching algorithm. Epipolar constraints allow a reduction of the size of the search window for intra-matching, the estimation of position and attitude change with the help of aiding sensor systems allow a prediction of the position of the search window for inter-matching. The result of an intra-frame matching is shown in Fig.1.

Figure 1. Stereo image with intra-frame matching

The relative change in pose from time $\mathbf{t_n}$ to time $\mathbf{t_{n+1}}$ is estimated by considering all 3D points which could be reconstructed after inter-matching successfully. The transformation of point cloud at $\mathbf{t_n}$ to point cloud at $\mathbf{t_{n+1}}$ is estimated minimizing the residual errors. A RANSAC approach stabilizes the solution.

B. Intertial navigation

An inertial measurement unit (IMU) consists of 3-axis gyroscopes and acceleration sensors. The strapdown mechanization [2] was implemented to integrate the IMU signals to a navigation solution.

The corresponding 22 element state vector includes 7 parameters (position, velocity, acceleration, acceleration bias, angular velocity and angular velocity bias) with three dimensions and the quaternion with four components.

$$x = [s^n \; v^n \; a^n \; a^n_{bais} \; \omega^n \; \omega^n_{bais} \; q^n_b]^T \qquad (1)$$

For state estimation several filters were analyzed. Classical Extended Kalman filter (EKF) and scaled unscented Kalman (sUKF) filter were implemented.

Besides from being computational more costly than the EKF the sUKF has many advantages. By being accurate to the third order with Gaussian inputs it produces more stable estimates of the true mean and covariance. Furthermore it behaves better in case of unknown initialization values and analytic derivations are not needed.

C. Data Fusion

Fig.2 shows the combination of inertial navigation (Kalman filter) and optical system (Tracker). Receiving IMU- or inclinometer measurements the full filter cycle is completed including a check for feasibility of the data. For incoming stereo images first the time-update is done. The a priori estimate enables the tracker to perform a very fast and reliable inter-frame matching.

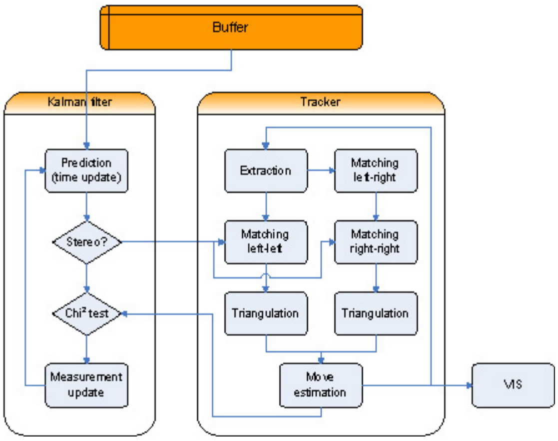

Figure 2. Data fusion

After triangulation within the tracker calculated movements provide incremental attitude- and position updates. These are used for the measurement updates within the Kalman filter [3].

D. IPS Sensor Head

The sensor head of IPS System is shown in Fig.3. The core components are a low cost MEMS-IMU, stereo camera and inclinometer. The used IMU shows noise terms of 0.035 deg/s and a bias stability of 7.4 deg/hr for the gyroscopes respectively 1.3mg / 70g for the acceleration sensors. The data rate is 410Hz. In the current setup the IMU is aided by a stereo camera system with 200 mm base that provides increments of attitude and position. The combination with 4.8 mm lenses gives good results for indoor environments. Additionally a 2-axis inclinometer with a noise of 0.027 deg is also included to support the state estimation if the system is not moving.

Figure 3. Sensor head of IPS System

III. RESULTS

To show the capability of the system an indoor environment of an office buiding was chosen providing triangulated markers at the beginning and at the end of trajectory, which were not used for navigation but only for validating the later result. The distance from a start mark to a second arbitrarily mark seen by the cameras had to be measured in real time without post processing the data.

A course off about 90 m length leading over two floors was selected. At the beginning of every run the system was not moved for about 45 seconds to initialize the Kalman filter. The sensor head was caried by a person.

With normal walking speed of about 1.5 m/s the destination mark was reached after 85-90 seconds with a final distance error of 20-50 cm for several runs. This difference is mainly caused by phases where no or little features could be seen resulting in no or low quality vision data and as a consequence an increased error grow from integrating the IMU measurements. Fig.4 shows the overlap of calculated 2D trajectory and the floor plan.

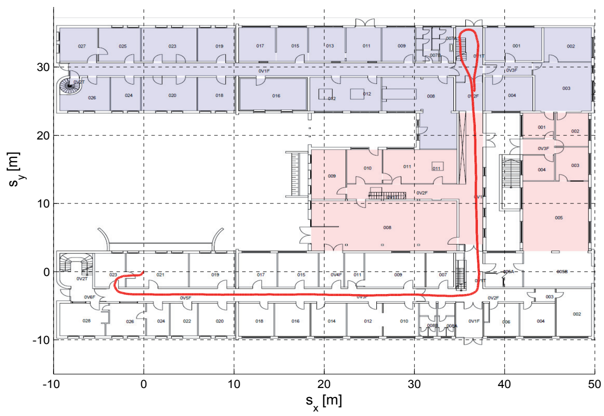

Figure 4. Overlap of 2D trajectory with building map

It is to stress that the experiment was not conducted in protected environment but during working hours with many people interfering the optical measurements. Due to the before mentioned build in safety mechanisms for matching, triangulating and move estimation the IPS system provides robust navigation solution.

IV. OUTLOOK

Integration of additional aiding sensor e.g. barometer into the IPS system and optimisation of computational costly image processing algorithms will be the next steps. This will improove the stability and real time properties of provided navigation solution. Future work will also adress outdoor applications by including GNSS measurements.

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