Presentation of a magneto-inertial positioning system: navigating through magnetic disturbances

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***Abstract*—We present a prototype of a magneto-inertial positioning system. Attitude estimates are obtained by classical use of inertial MEMS sensors (accelerometers and gyrometers), whereas the velocity (in the frame of the system) is given by an innovative use of an array of spatially distributed magnetometers. This velocity is computed and integrated in real time in the building reference frame, thanks to initial position and heading. This provides a solution for relative navigation problems of practical interest indoors. During the demonstration session, several walks (typically 40-200m long) in the building corridors and halls will demonstrate the capabilities of the system, and the computed current position will be displayed on screen in real time.**

I. Introduction

In the last few years, indoor positioning has given rise to much research. Numerous of the considered techniques require an infrastructure to work. Yet, in some applications, cost and time constraints may become stringent, and discard those solution, as in those case, waiting for the required infrastructure to be deployed is unconceivable (e.g. firemen exploring a building). Other ways to get a position information have thus to be explored. Inertial systems [1], with the spread of relatively cheap MEMS sensors, have provided a ground basis for many of the candidate systems. Nevertheless, their huge drifts prevent them to be used alone without care. Many systems have been proposed which use those Inertial Measurement Units (IMU) in conjunction with Zero-Velocity Updates (ZUPTs) techniques [2] to lower the drifts. The IMU is most often attached to the foot, the body part that stops moving each time it touches the ground. Unfortunately, the use of electronic equipment on the foot has to be avoided in some applications, for instance for safety reasons (soldiers, firemen...) The presented system follows another approach. While still relying strongly on the inertial sensors, it complements them with a set of spatially distributed magnetometers to directly estimate the velocity in the sensors frame. This magneto-inertial approach [3] preserves the main pros of purely inertial technology: no infrastructure is required and no signal has to be emitted.

II. Principle

The large disturbances of the magnetic field observed in buildings (typically yielding 30° of heading error) may lead to significant misinterpretations. Yet, those disturbances are not simple random noise as they are structured by physics equations. They are due to all the metals used in building (reinforced concrete, door frames...), by the strong electric currents nearby. Therefore information lies in those disturbances.

Let us consider only time-invariant disturbances in the inertial frame, $\Re_i$ (taken as the frame attached to the building), and a rigid body moving in the building (a body frame $\Re_b$ is attached to this rigid body).

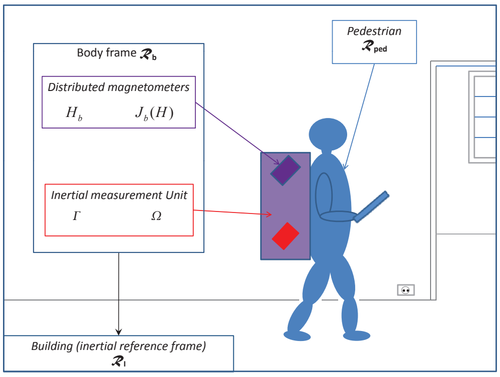

Fig. 1. Diagram representing the system worn by a pedestrian in a building. The inertial unit provides measurement of the acceleration Γ and of the rate of turn Ω. The measurements of the set of magnetometers are derived to obtain the magnetic field H_b and the Jacobian of this field $J_b(H)$.

Denoting the following quantities in the body frame

- H_b the magnetic field,
- v_b the velocity,
- $J_b(H)$ the 3x3 Jacobian matrix of the magnetic field (i.e. the term (i, j) is the gradient of the i^{th} component of the field along the j^{th} space coordinate: $\frac{\partial H_i}{\partial x_j}$)
- Ω the rate of turn of the moving body with respect to the reference frame,

then, the dynamic of the sensed magnetic field in the body frame is

$$\dot{H}_b = -\Omega \times H_b + J_b(H) v_b \quad (1)$$

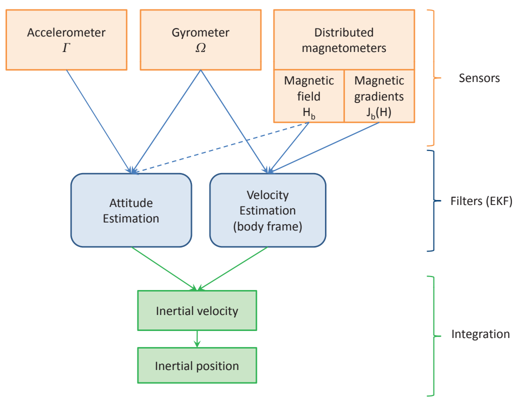

Fig. 2. Principle of the position estimation process.

A set of spatially distributed magnetometers delivers two measurements. First, this set gives the value of the magnetic field in the body frame H_b by a direct reading. Secondly, by making use of the data provided by all sensors of the set, the Jacobian of the magnetic field in the body frame $J_b(H)$ can be estimated by a finite difference scheme. Finally, a

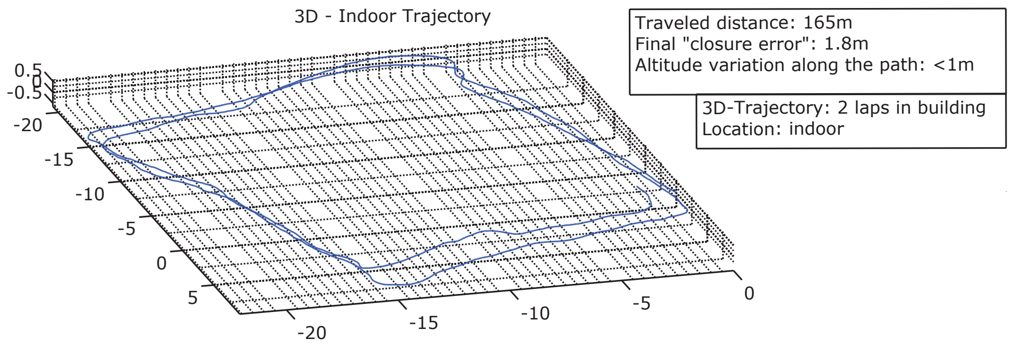

Fig. 3. 3D-Reconstructed trajectory of two laps in corridors.

gyroscope provides a measure of the rate of turn Ω of the moving body with respect to the reference frame $\Re_i$. The only true unknown in Equation (1) is thus v_b, the velocity in the body frame, which is precisely the quantity one desires to estimate to determine the motion.

Provided a starting point and an initial attitude are known, the velocity in the body frame and the attitude classically derived from the inertial sensors can then be integrated to obtain a position in the inertial building frame. Figure (2) pictures the successive steps in the position reconstruction.

III. Real-time Implementation: the presented prototype

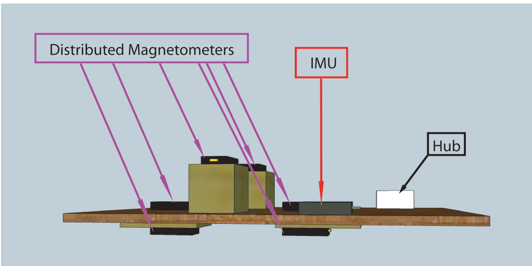

Fig. 4. Diagram representing the various sensors of the magneto-inertial system.

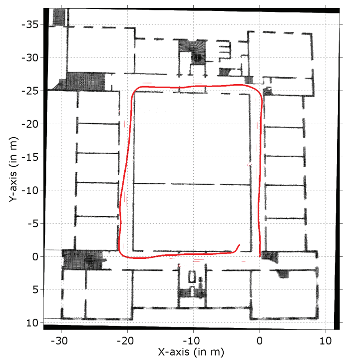

Fig. 5. 3D-Reconstructed trajectory projected on the map.

A complete real-time system implementing the principle shortly described above is presented during the demonstration session. It is made of

- a sensor board pictured on Figure (4) with 6 magnetometers (HMR2300 from Honeywell^{TM}) and one IMU (3DMG-X1 from Microstrain^{TM});
- an acquisition case (based on a microcontroller MPC555 from Motorola^{TM}) gathering and timestamping all raw data from the sensors and holding their batteries;
- a computation board (based on a pico-ITX running a customized Linux) performing the computation in real-time (EKF);
- a backpack carrying the above mentioned elements.

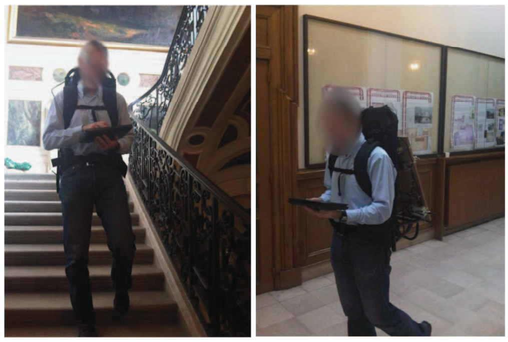

Fig. 6. System on trial.

This prototype, which has an autonomy of about 1 hour, delivers a real-time position estimate. This position and the whole reconstructed trajectory can be seen in real-time on an additional small laptop (see Figure (6)).

IV. Some results

The system is pictured during a trial on Figure (6). Figure (5) presents an example of results projected on a 2D-map of the building. One lap in a loop-shaped corridor is performed. Figure (3) shows 3D-results for a trajectory consisting in 2 laps in a similar environment. The error observed on the position is typically around 4-6% of the travelled distance.

V. Demonstration session

During the demonstration session, the system will be presented in more details. Several short trajectories (a couple of minutes each) will be conducted in the corridors and halls of the building to demonstrate the capabilities of the system at the light of real-time trajectory reconstruction.

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