Certain Aspects of Foot-Mounted Inertial-based Indoor Navigation Systems

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Abstract

Indoor Navigation Systems (INS) plays pivotal role in undergoing project ICRA (Intelligent Commander Remote Assitance) — designing decision support system for commanders during firefighting and rescue operations. Most promising approach for INS problem is utilization of foot mounted inertial sensors, whose reading are assessed to recover foot movement trajectory with very small error. Such setup can provide INS without any assumption of building infrastructure, gps/gsm/radio reception. Moreover, it is very cheap and fairly reliable.

Direct integration of sensor readings can introduce substantial errors. In order to overcome this drawback INSs are using the Kalman Filter (KF) along with so called Zero-velocity Update (ZUPT). The system is defined by equation:

$$\begin{bmatrix} x_k^- \\ v_k^- \end{bmatrix} = \begin{bmatrix} x_{k-1}^- + v_{k-1}^- dt \\ v_{k-1}^- + (q_k a_k q_{k-1} - g_0) dt_k \end{bmatrix}$$

A priori states (x_k^-, v_k^-, position and velocity) in the filter are computed using mechanization equations (basing on sensor readings) and a posteriori states are estimated with respect of stationary states of the foot. When the foot is not moving the first integral of acceleration should be 0, and most probably it is not. The error, which is observed in this way, is used later in the KF Update phase to correct position and orientation (Euler angles) of the foot.

In related work both orientation quaternion (q_k) and position of the foot is estimated by the KF. Our preliminary experiments suggest that performing orientation estimation separately (by the Madgwick algorithm, in our case) from Mechanization Equations, provides better results due to the independence of errors. Moreover, there exists some assumption about roll and pitch Euler angles during zero-velocity state of the foot that could be used explicitly.

Most crucial part of the work is to properly determine the nature of errors that influence overall system performance. Our preliminary experiments suggest that sources of errors falls into following categories:

- sensor readings — sensor resolution, range and bandwidth have substantial influence of the system;
- calibration errors — accelerometers and gyroscopes must be calibrated to be properly exploited (due to different current, place of mounting, mechanical shocks, temperature, scale and zero-level). Most of the errors comes from gyroscope bias that can randomly shift during operation;

- computation errors — integration introduces significant error;
- zero-velocity detection — recognition of update phase can be determined in various way.

All of those errors make overall performance of INS to degrade in propagative way. Therefore, it seems natural to develop a hybrid solution that performs sensor & information fusion of different kind and different source.

Our work will focus on following topics:

- extrinsic position fix — position of described system can be revised by some external system and infrastructure, e.g. GPS (if available, wifi, radio rssi/tof ranging, building information, etc.);
- automatic calibration — by using external information it is possible to correct gyroscope bias (especially combining this method with zero-velocity detection);
- portable motion capture device — there exist some approaches (e.g. 5DOF permanent magnetic system) that can be exploited here;
- double-foot inertial INS — the important aspect is how to address and fuse position from two foots.