An Integrated GPS and DR Positioning System Designed for Archaeogeophysical Kinematical Surveys

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Abstract: Some preliminary tests of various types of inexpensive single frequency Global positioning system (GPS) receivers were performed in order to assess the utility of the technique to geophysical surveying conditions. A 30 cm basic kinematical accuracy of the fixes was sought. As the GPS positioning technology, using single frequency GPS receivers, is capable of achieving this accuracy only under favorable conditions, seldom encountered in fieldwork, we have developed a hybrid positioning system, comprising of a GPS receiver and (DR) MEMS accelerometers, which is capable of augmenting the GPR positioning data in kinematical operational mode. The described system is capable of reducing the GPS trajectory orientation errors, which usually amount to ± 1 °, by 60 %, thus assuring the required accuracy.

Keywords: hybrid positioning, GPS augmentation, inertial navigation, DR reckonning

Introduction

In this paper we consider a hybrid system for positioning in geophysical surveying at an archeological site. A typical application of the positioning system in an archeological prospecting setting is a combination of position data with ground penetrating radar, resistivity, conductivity and magnetic survey (BARRAT et al. 2000, DIMC et al. 2008a, MUŠI Č et al. 2007).

Under favorable conditions a 30 cm relative uncertainty of the kinematical positioning was achieved solely by the single frequency GPS. This is considered sufficient in the type of surveying named as stop&go (VAN SICKLE 2001), by which also attached inertial measurement unit (IMU) performance is enhanced. Also static vertical 30 cm relative uncertainty point positioning by the use of high quality single frequency GPS receivers is feasible after further data processing, but a quality GPS receiver is needed which delivers unprocessed data (BERAN et al. 2007).

Hybrid GPS system advantage

A GPS receiver performance is upgraded by another positioning unit, which exhibits an opposite time character of errors - nevertheless both sets of errors also origin from different sources. An IMU consists from a group of inertial instruments, linked together by a microcontroller which carries about the sensor calibration and compensation. The use of GPS/IMU is relevant (STRUS et. al. 2008) also for the geophysical work since quality of micro electromechanical systems (MEMS) as IMU sensors

become affordable. Errors get by tracking of kinematics below 6 m/s with
GPS solely are significantly lowered after introduction of the platform dynamics as get from IMU. For tactical systems with employed navigation grade IMUs the accuracies are improved to the 0.1 degree pointing accuracy while in the case of geophysical surveying 1 degree is sufficient. To get an orientation (attitude) of the platform with the geophysical sensors a standalone GPS solution is not practical since the heap of space with more, comparatively displaced, GPS antennas. Modern miniaturized solutions of chip - compasses base on magneto-resistive element and give an opportunity to get a resolution of 0.1 degree. Their accuracy largely depends on the presence of hard-iron influences on sensor biases, which due to some extension could be deduced by initial calibrations. Since the surveying areas usually do not excessively suffer from hard-iron anomalies it is normally sufficient for the attitude estimation to compare the orientation get from GPS receiver with the one from miniature magnetometer. In our setup we used an IMU in a 'strap-down navigation' platform, which is rigidly attached to the mobile body with geophysical instruments. The strap-down navigation platform comprises MEMS accelerometers and magnetometer. Mathematic procedures behind the positioning from sensors data rely mostly on transformations from the geodetic frames to the platform (mobile body) frame or vice versa and filtering data after they become comparable. Geodetic frames cover not only local but also global (world) geodetic frame on which the satellite navigation system is performed and is called WGS-84. A navigation solution formula gives the position, velocity and attitude out of the attitude data and accelerations from sensors and is computed on a personal computer. Our set of accelerometers is shown on Fig. 1.

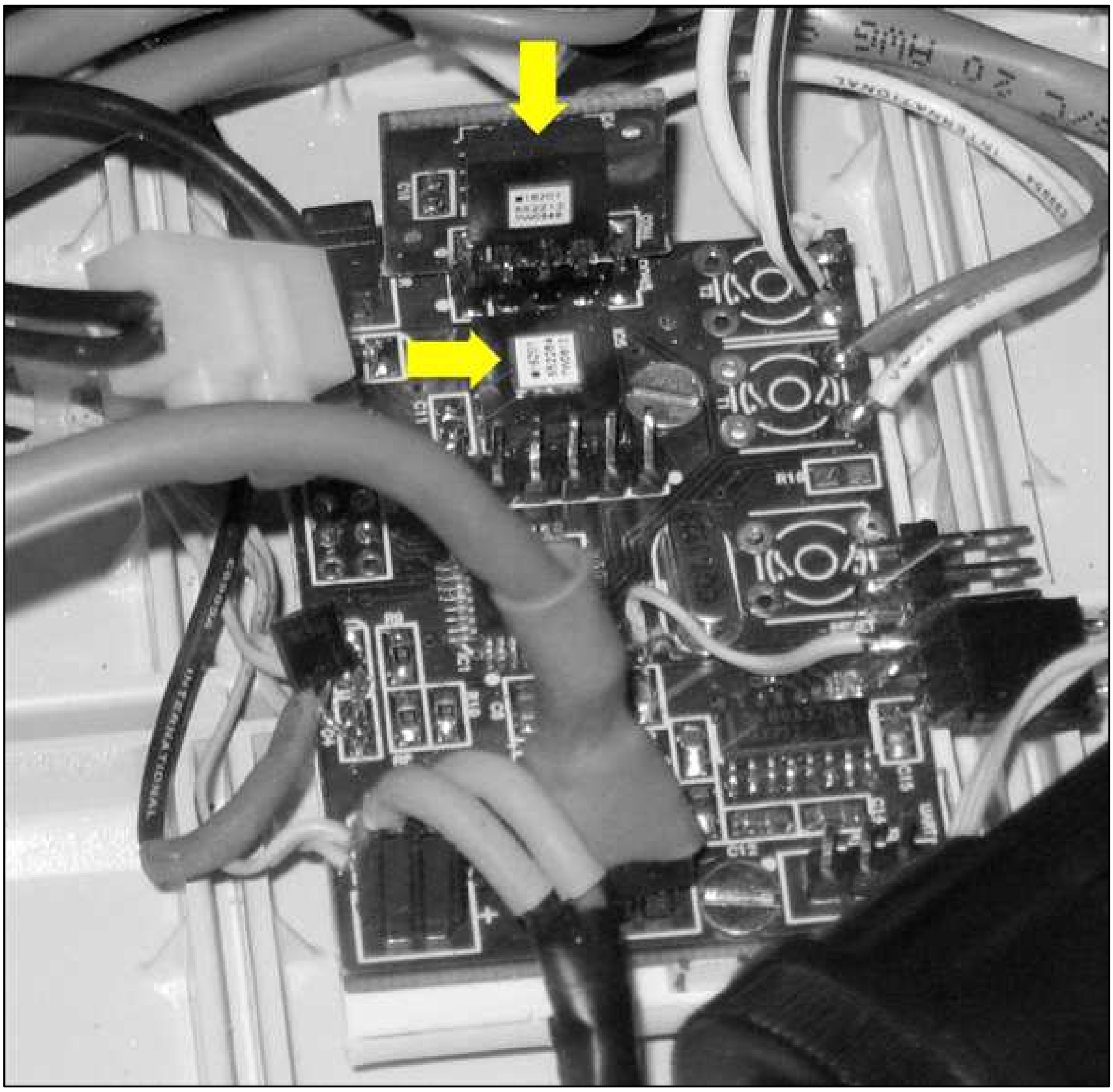

Fig. 1 - Testing single frequency GPS receiver with hybrid components mounted. Arrows point two perpendicularly mounted 2 axis chipaccelerometers (MEMS). IMU is paced by a microcontroller, a compass is placed on a separate position due to the hard-magnetic influences, not shown. (after DIMC et al. 2008b).

Platform attitude data are often derived from gyroscopes as angular rates (consult the processing data flow on Fig. 2), but they are also encompassed by magnetometers as standard navigation rotation angles (yaw, pitch, roll) with respect to the magnetic north. Mobile body attitude angle names origin from the aircraft navigation terminology and stand for the rotation about the vertical axis, the rotation about the wing axis and the rotation about the fuselage axis, respectively. The latter two in our setup are due to the focusing on two-dimensional solution mainly used in gravity acceleration compensation (g-compensation), since accelerometer itself does not differentiate between a dynamic and the gravitational accelerations. Combining the incommensurable time sampling rates as from the GPS receiver and other sensors might cause timing errors. A synchronization of positioning device outputs of the hybrid system involves a matching algorithm which takes typical delay times in consideration.

An effective coupling of the deduced reckoning data from IMU with the GPS data is then achieved by Kalman filtering.

Kalman filtering brings the relative positions, derived from IMU, which are additionally recursively filtered as a type of least squares adjustment approach, where the measurement vector and the corresponding noise vector are composed after the pre-processing. Knowing the exact noise distribution in idle and kinematical mode for each used sensor whose results should not expose any correlation it is possible to get reliable position estimations. However, through comparison with the reference positions filter parameters are tuned. Combinations of GPS and IMU for the real time processing vary from uncoupled operation where IMU results are used only at GPS outages to deep integration modes where both sensors mutually ‘exchange’ semi-results; sensors control each other’s bandwidth to get especially reliable final results.

The kinematics and the demands for the IMU of the dragged GPR shows similarities to the land-vehicle behavior (NIU et. al. 2007) while navigation solution of carried anomaly meters has much in common with the pedestrian behavior [CHO et. al. 2006]. The question of sensor redundancy occurs again: it is perhaps remarkable that if an additional sensor contributes very little to the navigation information it should be excluded, since the integration of more than two positioning systems into one usually does not result in any further improvement of accuracy. Again, with an exclusion of the gyroscope we assumed the reasonably clean hard-iron magnetic conditions and relying also on the attitude solution by GPS receiver which is a matter of reliability of results, not the accuracy per se. Since with the geophysical surveying the vertical axis of the IMU is by the nature of subsurface sensing parallel to the vertical axis of local geodetic frame it even reduces complexity of processing.

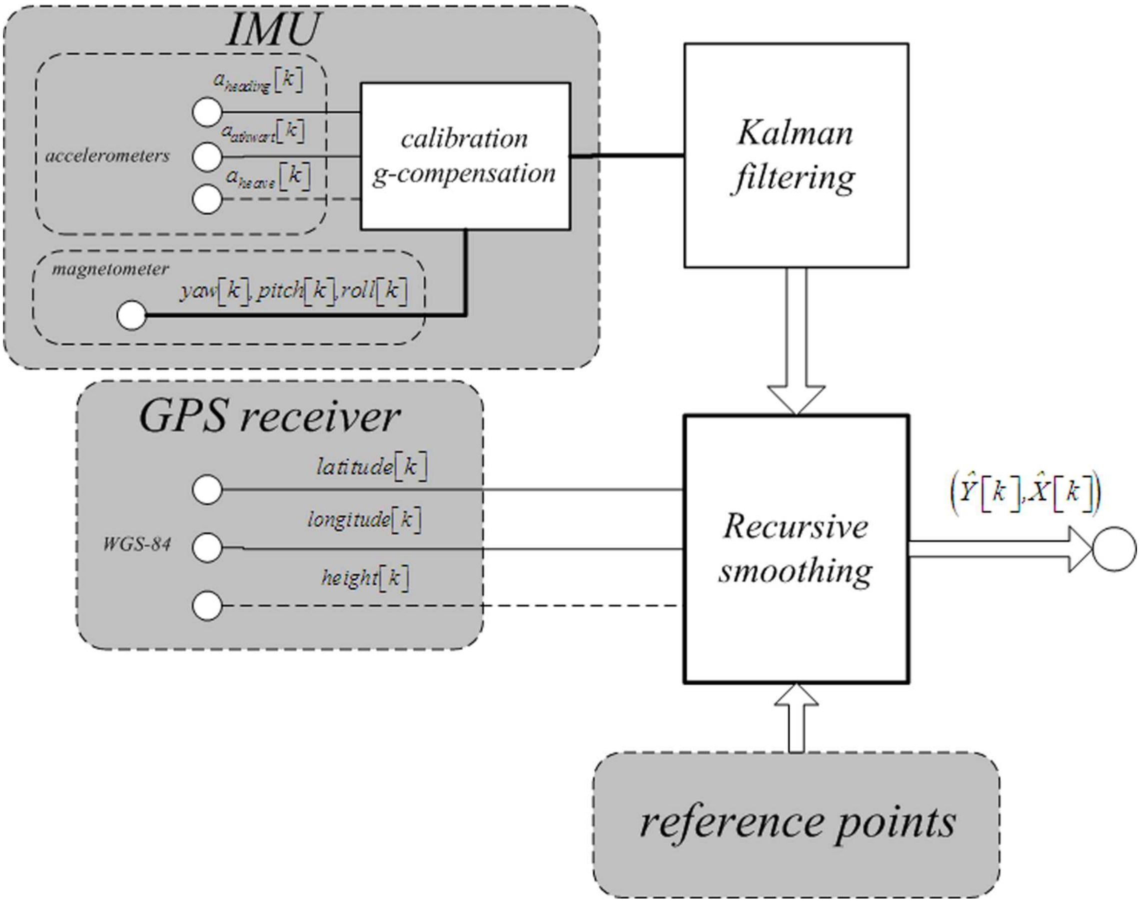

Fig. 2 - Data flow basics of the recursive filtering post processing on IMU and GPS data, collected simultaneously at 5 Hz rate.Transformation from the global to local frame is skipped. Estimated positions (Y,X) in a local geodetic frame are get after comparison of GPS/IMU and fixed reference point.

The sample averaging technique basically uses the stability of the IMU to average the GPS especially at the work with ground penetrating radar. On the other hand for positioning of the carried anomaly meters the augmentation task requires even higher data rates and lacks from accuracy since the average length of anomaly meter operator's steps are used for processing. The pedestrian kinematical single frequency GPS positioning augmented by IMU does not meet the desired accuracy levels in various GPS signaling conditions such as signal multipath or due to the sudden one GPS satellite signal diminish.

Preliminary results

An important practical distinction favors test sites from real life archeological sites in that at the later favorable conditions are seldom encountered. In our positioning are concerned primarily on horizontal positioning. Capability checks of accelerometers on a smooth surface at a relatively short distance shows narrow distribution of angle error (consult Fig. 3) the resulted average trajectory lengths are significantly too short in the case of using only the MEMS sensors. To a certain degree this can be compensated for by frequent referral to the established reference points in the field and (or) corrected by the calibrated deduced reckoning acceleration data.

The basic determination of the actual trajectory taken by the surveyor in the filed proceeds by measuring the starting and end points of segments of the trajectory taken. Starting from a known position, the pseudo position of the end point of each approximately 10 -15 m long segment is first determined from the GPS data, and then corrected by the DR attitude data. This position is then taken as the starting point of the next segment and its endpoint determined in the same manner. From the known position of the starting and end points of a segment, the actual position of a point on a segment can then be determined by the standard interpolation of its pseudo position. The segmentation of the trajectory thus takes advantage of the relatively accurate absolute distance data offered by the GPS part of the hybrid system, and then relatively accurate attitude data of the DR subsystem, whose limited range is not exceeded by the segment length.

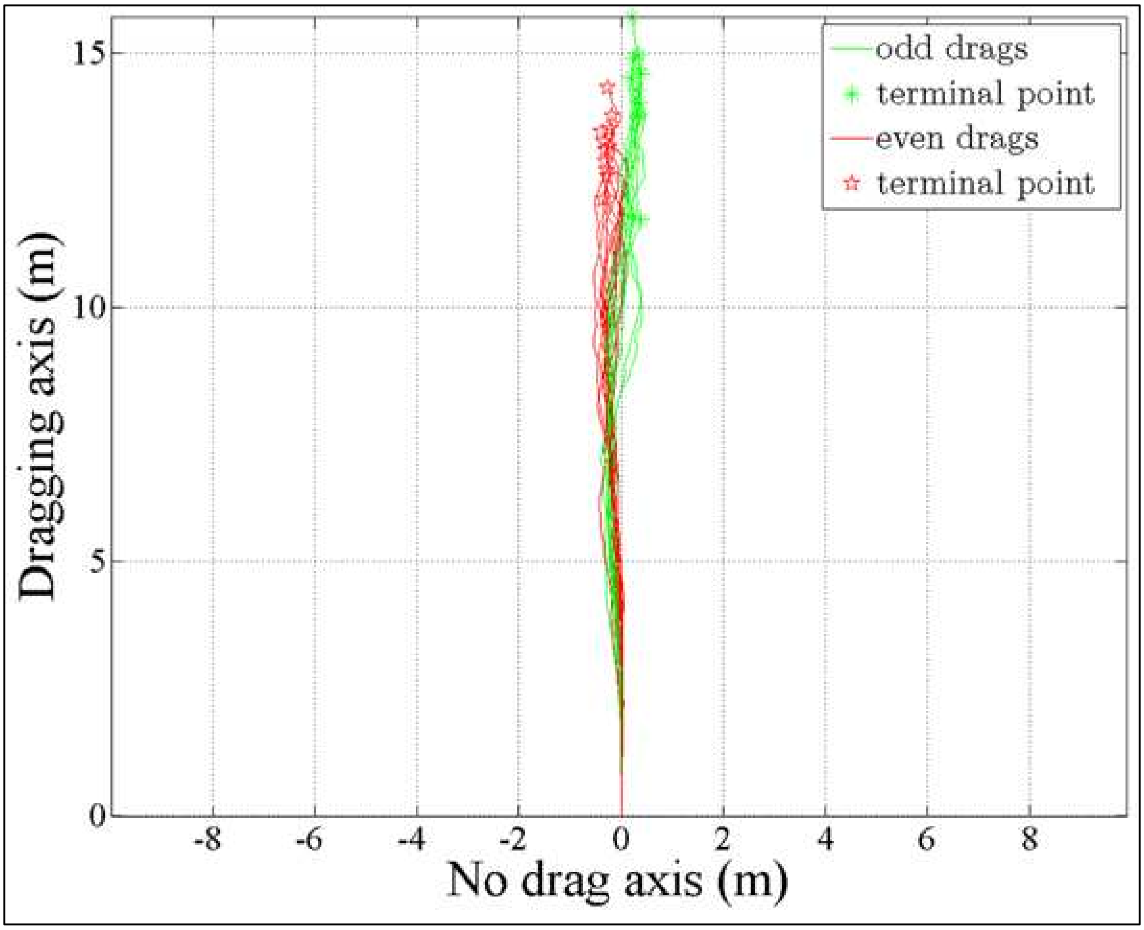

Fig. 3 - IMU only on smooth surface: processed accelerations shows desired orientation, but poor trajectory length results comparing to the 15,0 m line. A sledge was dragged along the same line in both directions for 20 times thus drags are labeled as odd and even.

A more profound augmentation method of GPS data was selected which consumes the type of data from commercial GPS receivers and reflects the usual straightness of the drag trajectory. Augmentation of GPS receiver data with inertial navigation system (IMU) data was performed as a recursive smoothing, which is a common post processing procedure. The post processing is oriented on events of sudden GPS position changes also named as ‘staggering’ (GAFFNEY et. al. 2008), which normally reflects the changes of GPS satellite signals availability in commercial GPS receivers (see Fig. 4). From the geophysical collecting data by GPS alone perspective it is also important that GPS tracking of low speed mobile body inserts the start delays with observed averages of 2 s (DIMC et al. 2008a). The influences of consequent positioning errors are also improved by the adaptive filtering for the first meters after the drag commence and is also more reliable by the use of hybrid system. Also IMU noise is smoothed digitally by standard genuine processing approach by instant navigation data comparison. So the algorithm filters the outages out if they are sensed by one sensor only. The described system is capable of reducing the GPS trajectory orientation errors, which usually amount to ± 1 °, by 60 %, thus assuring the required accuracy.

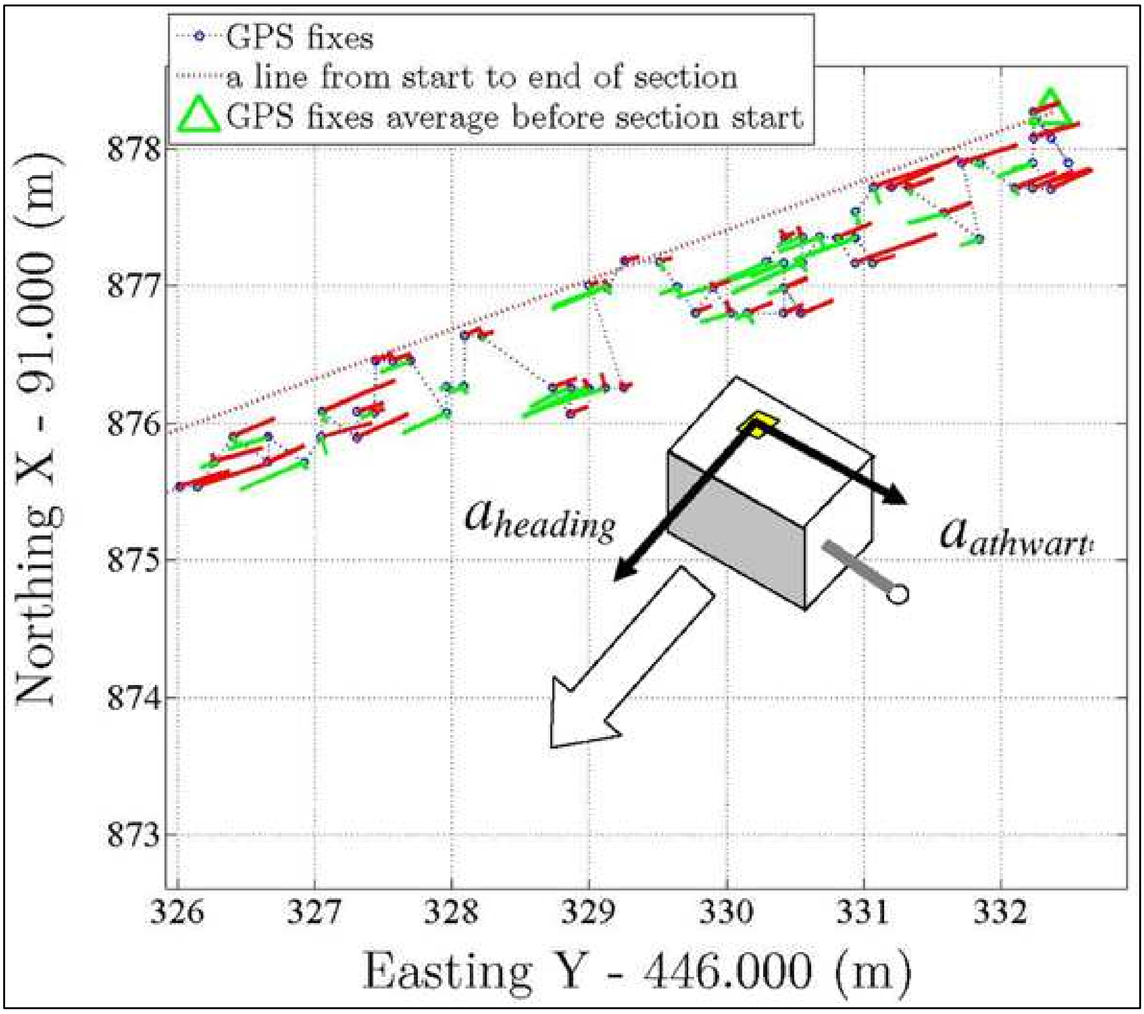

Fig. 4 - GPS/IMU view: compass oriented lines at each fix represent heading and athwart accelerations combined by simultaneous GPS fixes. Staggering of GPS fixes occurs however athwart accelerations are negligible which justifies smoothing. Color of scaled acceleration lines represents their sign: green for +, red for –

Conclusions

Special cases when due to avoiding obstacles real considerable excursions from the straight trajectory are made are still under examination, especially due to the filtering of vibrations on various sites. Also on-terrain real time trajectory processing is scheduled after enough augmentation parameters from various conditions are collected. In the forthcoming years before introduction of Galileo global navigation system a described augmentation hybrid GPS/IMU system meets the requirements for kinematical positioning, whereas reliable static positioning of one point per survey area still remains a geodetic work.

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