A Real-Time Position, Velocity, and Physiological Monitoring and Tracking Device for Equestrian Training

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BIOGRAPHIES

Kyle Green is a senior undergraduate student majoring in electrical and computer engineering at Miami University. He was the team leader of the autonomous lawn mower, Miami Red Blade III and has been involved in navigation related projects since his junior year. He is interested in pursuing a future career in navigation related fields.

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Dr. Jade Morton is an Associate Professor of electrical engineering at Miami University. Her research interests are digital signal processing, software GPS receivers, and ionosphere physics. She holds a PhD in EE from the Pennsylvania State University.

Dr. Mikel Miller is the Technical Director for the Advanced Guidance Division of AFRL at the Eglin AFB. His areas of research are GPS, GPS/INS and other multi-sensor fusion, autonomous vehicle navigation and control, and alternative navigation techniques. He holds a Ph.D. in EE from AFIT.

Dr. Jacob Campbell is an Electronics Engineer at the AFRL Reference Systems Branch at the Wright Patterson AFB. His research interests are laser-based terrain referenced navigation techniques, cold atom-based inertial systems, and other navigation techniques in GPS-denied environments. He received his Ph.D in EE from Ohio University.

ABSTRACT

This paper presents the design and implementation of a real-time tracking and monitoring device of the position, velocity, and physiological states of a horse for equestrian training purpose. The system consists of a mobile unit, a base station, and a wireless radio modem that allows a mobile unit and a base station to communicate over the industrial, scientific, and medical (ISM) radio band. The core of the mobile unit is a microprocessor which interfaces with a commercial GPS receiver module, a low-cost inertial measurement unit (IMU), and a horse heart rate sensor. The base station is a computer equipped with real-time data acquisition, processing, and analysis software. A Kalman filter is implemented to loosely couple the GPS and IMU measurements to capture the horse position and motion dynamics. Field test results will be presented in the paper.

1. INTRODUCTION

The equestrian sport is a worldwide multi-million dollar industry. Tremendous amounts of time, effort, and financial resources are devoted to the training of horses and riders. A real-time tracking and monitoring device that provides critical information about the horse and the rider can be an effective and efficient way to help the training process. This information may include the position, velocity, posture, and physiological states of the horse and rider. Current available systems are limited to provide only GPS position and velocity with low update rate (*1*Hz) and horse heart rate monitoring. Furthermore, the existing system data are post-processed for analysis [3].

This paper presents the design, implementation, and field testing results of a real-time tracking and monitoring device capable of measuring the horse position and velocity with a high update rate of *50*Hz and the horse heart rate. This increased position and velocity update rate provides trainers detailed motion dynamics of the horse. The real-time capability will enable trainers to provide riders immediate feedback and increase the effectiveness and efficiency of the training process. The system consists of a mobile unit, a base station, and a wireless radio modem that allows them to communicate over the industrial, scientific, and medical (ISM) radio band. The core of the mobile unit is a Motorola 68HC11e9 microprocessor which interfaces with a NovAtel Superstar II GPS receiver module, a Microstrain 3DM-GX1 inertial measurement unit (IMU), and a modified Polar Easy Rider horse heart rate sensor. The base station is a Dell laptop equipped with custom developed real-time data acquisition, processing, and analysis software. A Kalman filter is implemented to loosely couple the GPS and IMU measurements to capture the horse's position and motion dynamics. Communication between the mobile unit and the base station is achieved through a Maxstream radio modem. Figure 1 shows the conceptual system design.

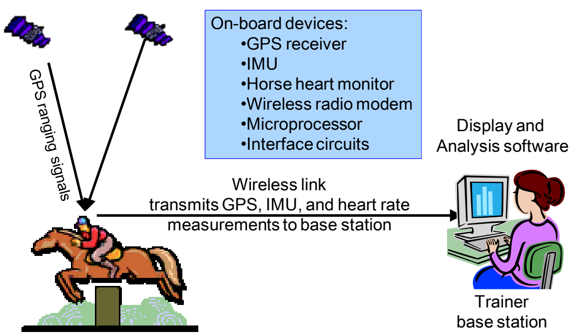

Fig. 1 Conceptual system design

A brief discussion of the system architecture and hardware and device interface design will be discussed in Section 2. Section 3 describes the Kalman filter implementation. Field test data and Kalman filter processing results are summarized in Section 4. Section 5 concludes the project and highlights potential future improvement of the system.

2. SYSTEM ARCHITECTURE AND HARDWARE INTERFACE

Fig. 2 depicts the high level architecture of the system. The GPS receiver outputs position, velocity, at a 1Hz rate via TTL serial to the Motorola 68HC11. The IMU captures the mobile unit 3D acceleration and attitude information with an update rate of 50Hz and communicates with the 68HC11 via a serial interface. The Polar Easy Rider is a handheld wrist watch type display device with an embedded heart rate sensor. We were able to find the output of the embedded heart rate sensor from a commercial off-the-shelf Easy Rider and the signal is tapped and sent over to the 68HC11. Custom software was written to perform multiplexing and time tagging of the GPS, IMU, and heart rate signals for the microprocessor. The multiplexed data is broadcasted via the Maxstream modem to the base station.

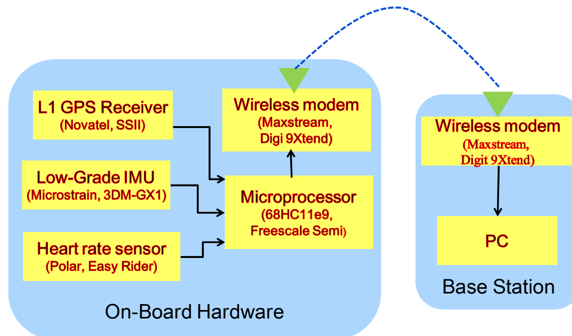

Fig. 2 System architecture

More detailed hardware interface is shown in Fig. 3.

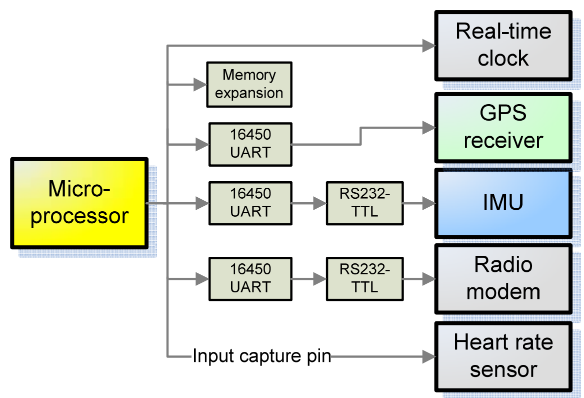

Fig. 3 Hardware interface

3. DATA PROCESSING SOFTWARE

A GPS receiver can provide a user with position and velocity information within an absolute error envelope. It suffers from two major drawbacks. First, a GPS receiver requires four or more satellites to be in direct line of sight to produce position and velocity measurements. Second, typical GPS receivers, especially low-cost GPS receivers, have limited data update rates. These drawbacks imply that GPS outputs may not be available in both regular and irregular manners and the low update rate also limits the observability of horse motion dynamics. An IMU sensor can generate a platform attitude and acceleration with a high update rate. Its accumulative bias, however, may lead to an unbounded long-term measurement error. A low-cost IMU such as the one used in this project, has such a high error drift rate that it renders the data useless in matter of less than a minutes. An integrated GPS/IMU system takes advantages of the two complementary sensor measurement error characteristics and generates reliable platform navigation solutions under a wide range of circumstances and over extended time periods.

Traditional GPS/IMU integration is accomplished through Kalman filtering [2][4]. There have been numerous theoretical studies, simulations, as well as real system implementation of the Kalman filter-based integration solutions [5]. A Kalman filter combines a pre-defined dynamic system model, statistical representations of the system noise and sensor errors, and some initial conditions or measurements of the system to generate system output state predictions. Typical system error states for a mobile platform include three position errors, three velocity errors, and three attitude errors. In this project, we model the horse training site as a flat two dimensional field and use only 4 states (2 positions and 2 velocities) to represent the system. Fig.4 shows the high level block diagram of a Kalman filter-based loosely integrated GPS/IMU system.

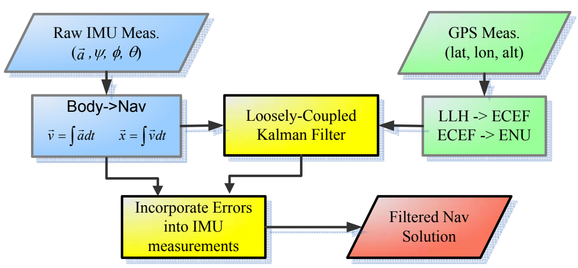

Fig.4 Block diagram of a Kalman filter-based loosely integrated GPS/IMU system

The raw acceleration and attitude measurements from an IMU are first transformed from the platform body frame to navigation frame. The acceleration measurements are then integrated to form velocity measurements and the velocity measurements are further integrated to generate position measurements. GPS latitude, longitude, and altitude (LLA) measurements are first converted to the Earth-center Earth-fixed (ECEF) coordinates and then to the local east-north (ENU) tangential coordinates. The IMU velocity and position measurements as well as the GPS ENU coordinates are inputs to the Kalman filter. The difference between the Kalman filter estimation and the IMU measurements of the platform position and velocity are the final filtered navigation solution of the platform.

4. FIELD TEST RESULTS

Field test is carried out in a *40*mx*60*m open field outside Oxford, OH (Fig. 5). We selected an older horse (Chloe) with mild temperament in order to have more controlled experiment. Fig. 6 shows the hardware box, heart rate sensor, and GPS antenna placement.

Fig. 5 Field test site

Fig. 6 Hardware placement

Three field tests were performed. In the first test, Chloe walked along a north-south oriented fence line for about 2 minutes. Fig. 7 shows Chloe's position in the ENU coordinates. There are three curves in each plot representing GPS and IMU measurements and Kalman filter outputs respectively. It is obvious from Fig. 7 that the IMU position measurement's drift error increases to beyond 10 m in about 30 seconds of experiment while the low update rate GPS position measurement error remains to less than 2m. The Kalman filter output was bounded by the GPS error with update rate matching that of the IMU.

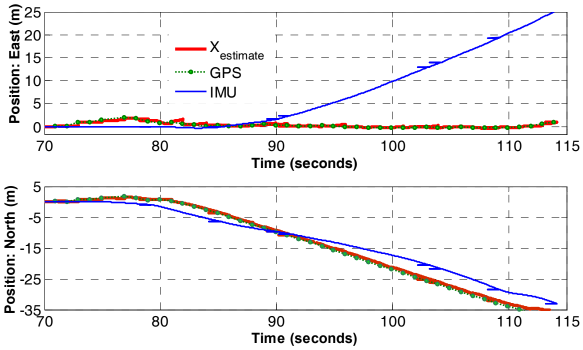

Fig. 7 Test scenario 1 position results

The more interesting results are related to the velocities. Fig. 8 shows the east and north direction velocity measurements from GPS, IMU, and Kalman filter output for the test scenario 1. Notice that the IMU has an eastward drift in velocity measurement and this drift is corrected at the Kalman filter output (recall that the horse is walking south along a fence in this test scenario). Additionally, the IMU velocity measurements show high frequency fluctuations which are characteristics of the horse motion dynamics. The Kalman filter output captures these dynamics.

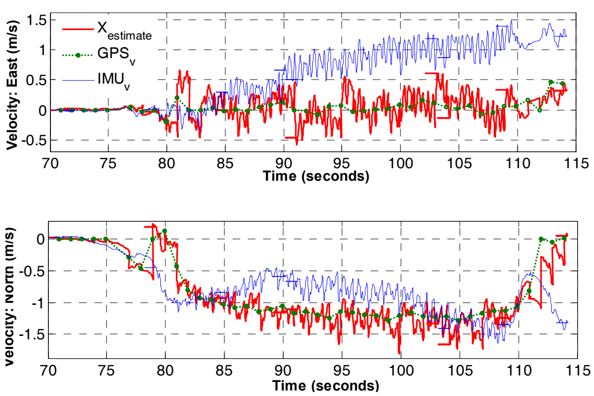

Fig. 8. Test scenario 1 velocity results

In the second test scenario, Chloe walked a rectangular path following a south-east-north-west pattern for over two and half minutes. Fig. 9 and 10 plot the positions and velocities for this scenario respectively. In the third test scenario, Chloe was allowed to walk randomly for about 1.5 minutes. Fig. 11 and 12 plot the corresponding results. From these plots we can clearly see the fast growing drift error associated with the IMU measurements in both position and velocity. The horse motion induced velocity fluctuations are clearly present in all test scenarios. These results demonstrate that the simple 4-state Kalman filter is effective in capturing the horse body motion.

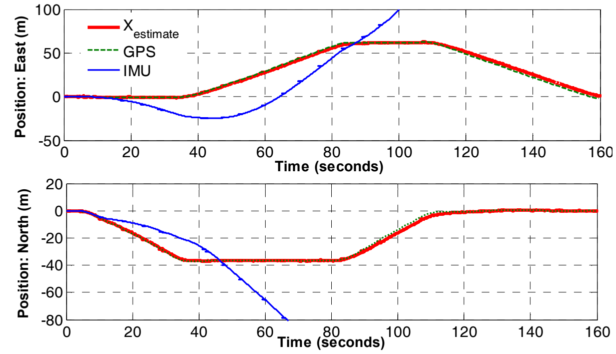

Fig. 9. Test scenario 2 position results

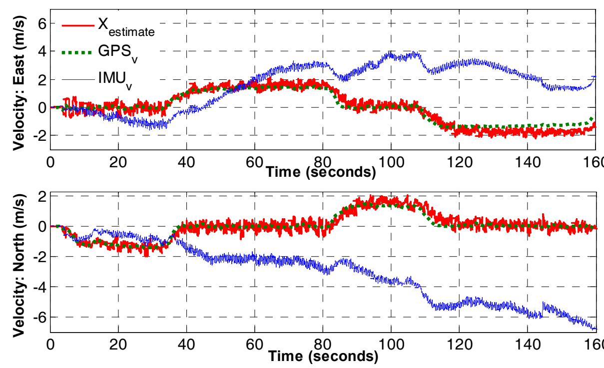

Fig. 10. Test scenario 2 velocity results

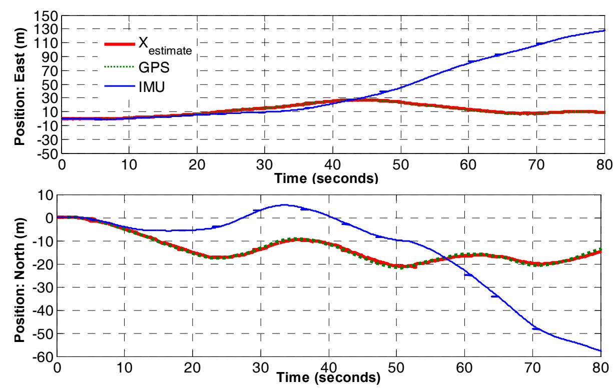

Fig. 11. Test scenario 3 position results

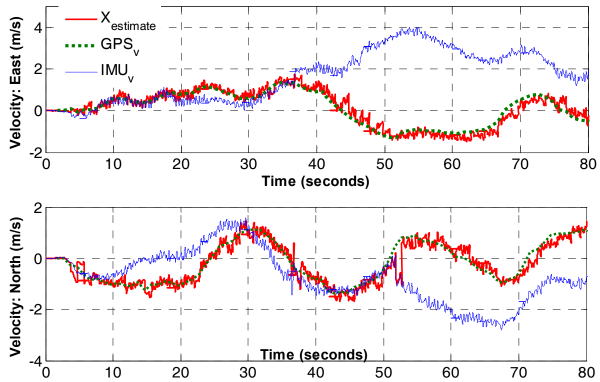

Fig. 12. Test scenario 3 velocity results

We were unable to capture reasonable horse heart rate data. This is because the heart sensor was attached to the inside of the saddle. During the experiment, the saddle became loose and the sensor was not making good contact with the horse. Previous experiments with the heart sensor did demonstrate that it functions well if the saddle was mounted appropriately. More experiments are being planned to collect the heart rate data along with the navigation data.

5. CONCLUSIONS AND FUTURE WORK

We designed and implemented a prototype real-time horse position, velocity, and physiological tracking and monitoring system. Three low-cost off-the-shelf sensors are used in this system: a GPS receiver, an IMU, and a horse heart rate sensor. These sensors are interfaced with a microprocessor and their measurements are transmitted via a radio modem to a base station. At the base station, a 4-state Kalman filter is implemented to fuse the IMU and GPS measurements to provide high update rate measurements of the horse position and velocity. Our field test results show that the system can accurately capture the horse motion dynamics.

Future improvement can be made in several areas. First, if the horse training site is on hilly areas, a 9-state Kalman filter needs to be developed to process the raw GPS and IMU measurement data. Second, although the integrated GPS and IMU were able to provide excellent horse body motion dynamics through the velocity measurements, it may be beneficial to have a more sophisticated system that can capture the posture of the horse. Such techniques do exists. For example, low cost, small source-less sensors have been used to track human limb segment motion [1]. We can apply these sensors to a horse limb segments and track the posture of the horse during the training course. Third, a critical element in equestrian sport is the rider's physiological condition and posture. Additional sensors can be added to provide information about the rider's state. And finally, analysis software that relates the horse and rider's physiological condition and posture to their performances can be developed to provide automated training tools.

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- Ms. Colleen Nagy of Miami University helped to arrange for field tests with Miami University's Equestrian team.

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