A Laboratory Testbed for Self-Contained Navigation

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***Abstract*—Presented a customizable laboratory testbed for the sensor fusion of multiple Inertial Measurement Units (IMU) and SOund Navigation And Ranging sensors (SONAR), for self-contained navigation experiments. We described the architecture and communication interfaces for the simultaneous collection of data from two IMUs and two SONARs, however, parallel acquisition from a larger variety of sensors is also feasible. Representative human gait patterns are experimentally acquired to demonstrate the functionality of the testbed.**

I. Introduction

The use of low-cost inertial sensors for pedestrian positioning has been a subject of research over the last decade, [1], and, more recently, the research has expanded to include sensor fusion of large arrays for chip-scale personal navigation systems, particularly for scenarios when/where GPS signals are unusable. In such cases, the pedestrian trajectory is obtained through the integration of angular velocity and double integration of acceleration during the gait motion. This information is provided by the IMU which consists of multi-axis accelerometer and gyroscope sensors. Along with the integration of this information, algorithms based on so-called Zero velocity UPdaTe (ZUPT) have been used during stationary periods to correct accumulated errors of the positioning system. Other sensors, such as SONARs, have also been used for detecting the time epochs for which the updates can be applied. Among other sensors, magnetometer and barometer sensors are commonly used for pedestrian navigation, e.g. [2]. As more innovative sensors become available and are considered for utilization, the further challenges raise mainly in terms of system architecture. The key challenges of self-contained navigation based on sensor fusion include: 1) integration of multiple sensors with different communication protocols and interfaces, 2) simultaneous use of different formats of the information stream, and 3) logging of data for algorithm development.

Many architectures have been proposed to fuse multiple sensors for pedestrian navigation, for example, the use of a custom PCB with MCU including real-time display [3], and the use of FPGA with embedded computer electronics [4]. Although the existing methods are suitable for pedestrian navigation, they are not sufficiently flexible for exploring a multitude of sensor modalities, as this typically triggers a major modification to custom electronics, firmware, and software. With such variety of available COTS sensors today and a dynamic development of new sensors, a flexible testbed for pedestrian navigation would be beneficial. Such a platform is envisioned to streamline laboratory research, while minimizing complexity of hardware integration.

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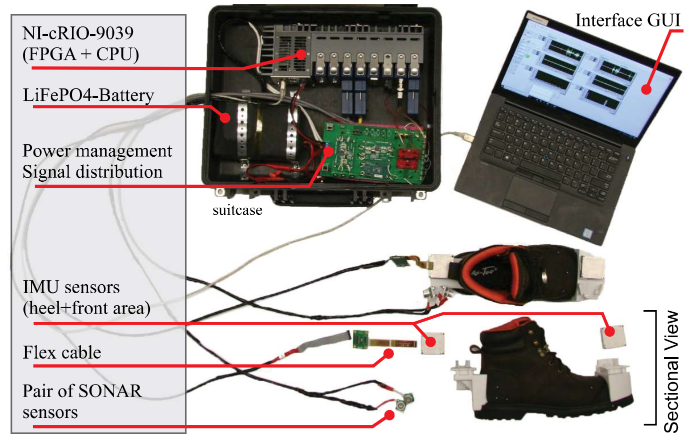

Fig. 1. A photograph of the proposed testbed: The suitcase contains cRIO controller, battery, PCB power flow, IMU and SONAR sensors, boot-mounted sensor fixtures, and a laptop for GUI, monitoring and data storage.

II. Hardware Architecture

For this study, a core platform by National Instruments was selected, which includes CompactRIO (cRIO-9039) with programmable FPGA Xilinx Kintex-7 and a real-time processor 1.91 GHz Intel quad-core CPU with 2GB DDR3 RAM. The platform provides easy integration with different sensors by selecting an appropriate chassis. In our case, we used the NI-9870 C Series module for UART serial interfaces and the NI-9401 and NI-9402 bidirectional digital I/O modules to achieve SPI and I2C communications, respectively. Fig. 1 illustrates a prototype for in-field experiments. A LiFePO4 rechargeable battery of $25.6V$ with a capacity of $10Ah$ was selected (CU-JAS217 Batteryspace), which was sufficient for 6 hours of in-field measurements. The system also contains a PCB for signal and power distribution, Fig. 1. The programming was done in the LabView Virtual Instrument (VI) environment, for both FPGA and CPU.

The algorithm for data acquisition was implemented on the FPGA-VI part of NI CompactRIO, while the algorithm for navigation was implemented on the real-time processor using VI. The FPGA part of the platform defined sensor-specific communication protocols, requested and acknowledged data, maintained time synchronization among attached sensors, and transmitted data to the real-time processor. The processor scaled the raw data to real values, applied the navigation algorithm, and down-sampled and sent the data through the network stream channel to the host processor-VI for visualization and data logging for subsequent post-processing.

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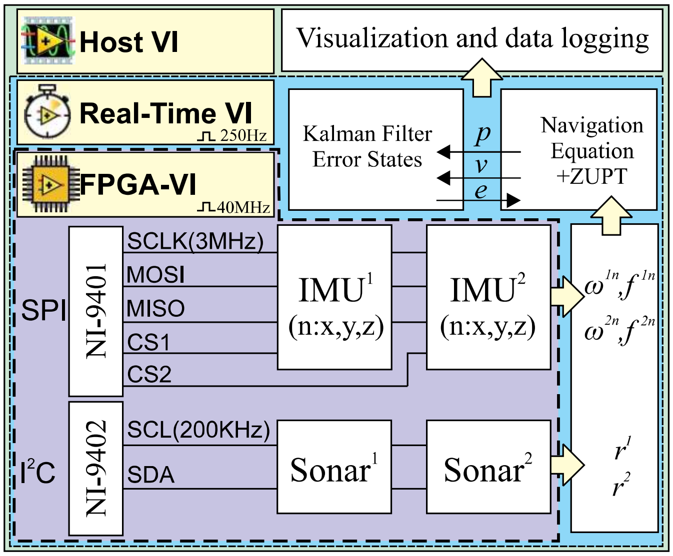

Fig. 2. The software architecture implemented on NI-cRIO9039 for multiple inertial and SONAR sensors solution. The hierarchy of VIs demonstrates the dataflow from the low-level communication protocol to the high level. IMUs and SONARs are served at 3MHz and 200KHz relative to the FPGA onboard clock rate of 40MHz.

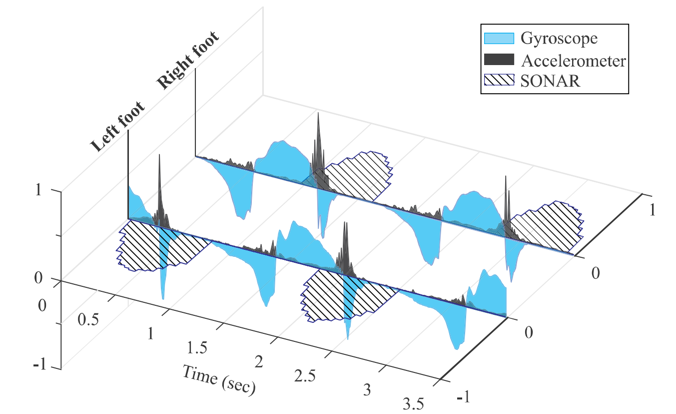

Fig. 3. Recorded data by the platform during a normal walking from both the left- and the right- foot mounted sensors. The units are $+8g$, $\pm 450^o/sec$ and $100cm$ for acceleration, angular velocity, and displacement reading, respectively. The $3.5sec$ corresponded to two full steps.

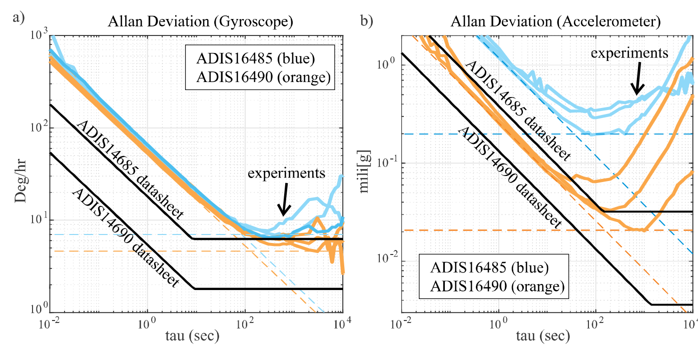

Fig. 4. The noise characteristics of the system from 12-hrs data were estimated and compared to the sensor performance reported in datasheets, (a) gyroscope, and (b) accelerometer. The recording was done while IMUs were mounted on the shoe fixtures at laboratory room temperature.

III. Experimental Results

Two tactical grade, six degrees of freedom MEMS IMUs (Analog Devices ADIS16485) and two SONARs (Devantech SRF08) were selected to demonstrate functionality of this platform. Fig. 2 shows the implemented software architecture. For a higher data rate, the SPI communication scheme was used for multiple IMUs in parallel and I2C communication was used for SONAR sensors. The fused data was transferred to the workstation for processing with 16-bit resolution for IMUs and 3-4cm resolution for SONARs. For the architecture considered in this study, the sampling limit due to VI's dataflow execution time was at 100Hz and 20Hz, when utilizing simultaniosly two IMUs and two SONARs, respectively. The sampling number increased to 200Hz and 25Hz when utilizing only a single IMU and a single SONAR.

With this platform, a human gait cycle was experimentally extracted with sensors attached to the heel area of the shoe. Details of the foot motion data collected throughout the walking phase are shown in Fig. 3. The reported signals are: 1) magnitude of the acceleration vectors where the maximum indicates an initial contact of heel with ground, 2) pitch-axis rotation of the IMU, and 3) inter-foot distance where the information is only valid when the SONAR pairs are facing each other (TX and RX). It is important to emphasize that the SONAR information was used to identify stationary periods of the walking phase. The integration of SONAR sensors using directional ranging resulted in lower navigation errors; the detailed analysis and algorithms are reported in [5].

We report noise characteristics of IMUs integrated in the system, with ADAV illustrated in Fig. 4. The difference between the datasheet and experimental noise values is attributed to the noise contribution from the PCB, cables and interconnects used for implementation of the system.

IV. Conclusion

We presented a laboratory testbed for integration and processing of data from multiple foot-mounted inertial and foot-to-foot ranging sensors. The platform is designed to study self-contained pedestrian navigation. The presented architecture intends to provide a flexible solution that can be adopted for investigation of INS with aiding functionality. We discussed the use of this testbed and illustrated the noise and sampling limitation of this architecture.

References

[1] E. Foxlin, "Pedestrian tracking with shoe-mounted inertial sensors," *IEEE Computer Graphics and Applications*, vol. 25, no. 6, pp. 38–46, 2005.

[2] M. Romanovas *et al.*, "A study on indoor pedestrian localization algorithms with foot-mounted sensors," *IPIN, Sydney, NSW, Australia*, pp. 1–10, Nov 2012.

[3] J.-O. Nilsson *et al.*, "Foot-mounted inertial navigation made easy," *IPIN, Busan, South Korea*, pp. 24–29, Oct 2014.

[4] M. Laverne *et al.*, "Experimental validation of foot to foot range measurements in pedestrian tracking," *Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation*, pp. 1386–1393, 2011.

[5] Y. Wang *et al.*, "Directional ranging for enhanced performance of aided pedestrian inertial navigation," *IEEE INERTIAL, Naples, FL, USA*, Apr 2019.