Compact Wireless GPS/Inertial System

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Abstract— **This paper reports the state of works in the development of a wireless, low-cost, inertial-georeferencial system, designed to evaluate the obtainable performance in aerial photogrammetry direct georeferencing applications. It integrates an advanced tri-axial inertial sensor with a GPS and a wireless module. A low-cost camera has been also interfaced. The information management is carried out by two 8bit microcontrollers; synchronization, data handling and communication between them and the functional blocks is managed in order to optimize the data transmission throughput. In building the prototype, particular effort has been spent to minimize size and weight and to increase battery autonomy. A PC interface, allowing for parameters control and data logging, completes the system. The reported preliminary testing results point out the system potentialities and let to foresee a wide field of applications.**

***Keywords*— inertial sensors, navigation systems, GPS, direct georeferencing, MEMS**

I. Introduction

Today, in several application fields, it is more and more important to real-time monitor the axial accelerations, angular rates, position, attitude and speed of a moving body. The possibility to do this by means of a low-cost, compact, flexible, lightweight, highly integrated system is not present, to the best of our knowledge, in the market.

Aerial photogrammetry was the application that we started to consider at the beginning of the work. Other applications could be high-resolution navigation systems and body motion real-time analysis.

Data acquired from an inertial sensor, also called IMU (Inertial Measurement Unit), can be processed to track position, orientation and velocity of an object, relative to a known starting point: this navigation technique is called inertial navigation and is used in a wide range of applications [1-5].

There are two categories of IMU: *gimballed* systems, in which accelerometers and gyroscopes are mechanically isolated from any external rotational motion, and *strapdown* systems, where sensors are rigidly attached to the vehicle. The first systems are more accurate but mechanically complex and of large size and, hence, high-cost; the latter, instead, are small, lightweight and potentially low-cost, even if require a more complex elaboration. As the cost of computation has decreased, strapdown systems, like ours, have become the dominant type of INS (Inertial Navigation System).

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II. System Architecture

The system (Fig. 1) is based on an advanced MEMS inertial sensor that includes a tri-axial accelerometer and a tri-axial gyroscope; it also integrates a GPS module and a wireless ZigBee™ transceiver.

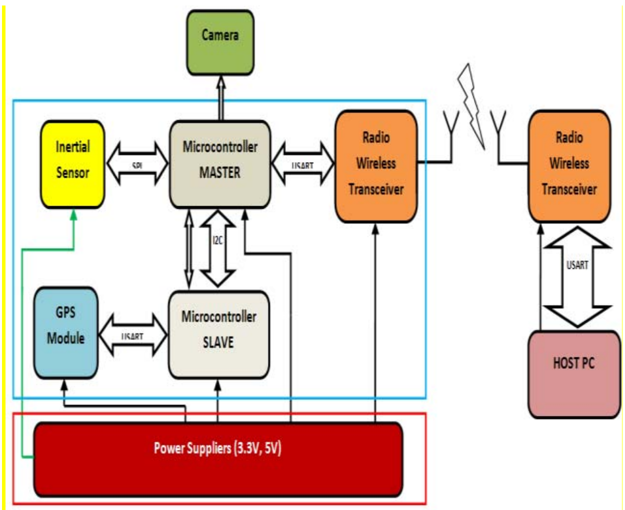

Fig. 1 Complete system block diagram.

It is structured in a pile of 3 printed circuit boards (Fig. 2), one of them being the development kit board of the inertial sensor, and the other two being the power and the main boards. The management of data coming from different sensors has been optimized, through a packets organization, in order to obtain the maximum performance from the available data link. As a complement to the sensors system, a software remote Graphical User Interface (GUI) has been developed in order to monitor system operations, setting inertial sensor parameters, displaying variables evolution, tracking trajectories, logging data and shooting photos.

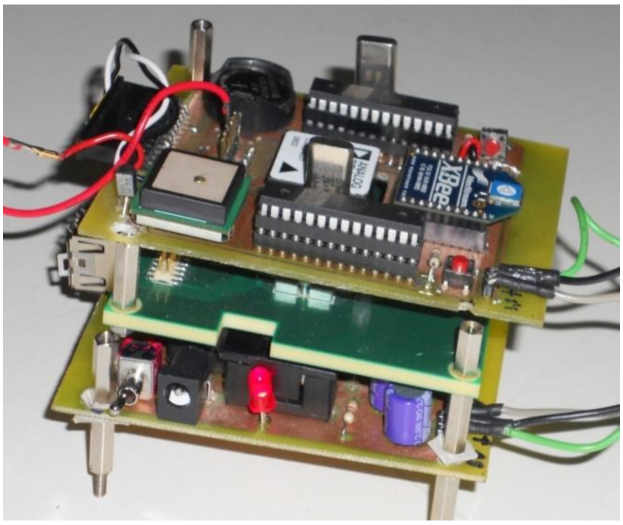

Fig. 2 System prototype.

A. *Power Board*

Two rechargeable NiMh AA-type batteries are used to supply the system. High efficiency switching circuits (MAX756) are used to provide both 5V and 3.3V voltage, guaranteeing up to 400mA load current each and an efficiency of about 85% with an input voltage level over 2.2V. The battery pack has a nominal capacity of 2650mAh that is a nominal input energy of about 6.36Wh. The continuous operation required load power has been measured to be about 625mW, thus allowing a system autonomy (experimentally verified) of about 9 hours.

B. *Main Board*

The Main Board hosts two Atmel ATMega8 microcontrollers (defined, in the following, only as Master and Slave), a Fastrax UP500 GPS module, a Maxstream XBee transceiver and interfaces the development board of an ADIS16350 inertial sensor from Analog Devices. It provides the trigger signal for shooting photos by means of a digital camera. Main features of these devices are:

1) *ADIS16350*: is a highly integrated solution, providing calibrated, digital inertial sensing. It is constituted by one tri-axial accelerometer, one tri-axial gyroscope and one tri-axial thermometer for thermal compensation. It transfers inertial data with 14 bit resolution (in the measurement ranges +/-10g, +/- 300°/s), to the output registers, accessible via a 2MHz SPI interface, at a maximum sample rate of 819.2Hz (350Hz bandwidth). The inertial sensors are precision aligned across axes, and are calibrated for offset and sensitivity. The module requires 165mW @ 5V.
2) *UP500*: is a low-power (90mW @ 3V) GPS receiver module with embedded antenna and fix rate up to 5Hz. Communication is based on NMEA protocols, via RS232 link up to 115.2kbps. It supports WAAS/EGNOS correction to improve position resolution up to about 2m.
3) *XBee*: is a low-power (165mW @ 3.3V) 2.4GHz transceiver which implements ZigBee™ protocol and has a transmission range of about 80m. Transmission and reception buffers allow efficient data stream packetization, also required to reach the rated communication speed because every data exchange requires the presence of an about 20 bytes long header. It is interfaced through RS232 protocol up to 115.2kbps.

The Master is connected to ADIS16350 through the SPI interface, to XBee through the USART, to the Slave microcontroller through the TWI interface and to the camera by means of one I/O pin. The Slave is connected only to the UP500 by means of USART interface and to the Master as said before. An additional signal, implemented through I/O pins link, allows the Slave to advise the Master that a new GPS answer is ready.

C. *Camera*

We used a low-cost 12,1 Mpixels Canon SX200IS camera, with 5 to 60mm lens focus, 12X optical zoom and a shutter speed from 1s to 1/3200s. The firmware has been updated with an unofficial version in order to acquire full control of the camera functions. In particular, we exploited the possibility to remotely shoot photos applying a 3V pulse to the USB port and to store photos in uncompressed format (RAW) instead of JPEG, as required for photogrammetry applications. For georeferencing each picture, a progressive number, corresponding to the file number on the memory card, is recorded on the inertial data frame.

III. System Operation and Data Protocol

Every system operation is started by host pc by means of a remote GUI, as will be explained in Section IV. There are three kinds of command packets that can be sent to the system:

1) operation request (GPS/INS data readout, photo shooting, offset readout);
2) configuration setting;
3) configuration readout.

The system requirement was to transmit synchronized data from inertial sensor, operating at 100Hz, and GPS module operating at 5Hz. This kind of sample rate is important to get a good position resolution in trajectory tracking calculations. Hence the data stream has to contain 20 inertial frames plus one GPS frame every 200ms.

The inertial data frame is 20 bytes long and contains the following fields: supply voltage, x/y/z temperatures, x/y/z angular rates, x/y/z linear accelerations. The sensor has to be read by the Master every 10ms and this is guaranteed by a dedicated timer.

The most important problem is constituted by the verboseness of GPS data: in fact, NMEA sentences contain hundreds of bytes. So we have to select only the necessary information, otherwise we will not be able to reach the specified data rate.

Because we aren't interested in all GPS information, at the start up the Slave initializes the GPS to send only three sentences:

- GGA: Global Positioning System Fix Data;
- GSA: GPS DOP and active satellites;
- VTG: Track Made Good and Ground Speed.

Moreover, the Slave creams off the received sentences and stores in RAM only the information to display, as specified in Section IV, i.e. a total of 72 bytes.

Even if reduced in this way, the time required to send such information is still too high (about 6.25ms) in order not to compromise the regularity of the inertial sensor reading.

So we decided to divide the GPS answer in 8 packets of 9 bytes and to send, every 20 ms, two inertial frames plus a GPS packet. So, in 200ms, we send 8 frames of 51 bytes (frame number, 2 inertial frames, 1 GPS packet, photo number) and last 2 frames of 42 bytes (frame number, 2 inertial frames, photo number).

Data acquired from PC are reconstructed, displayed and stored in a text file for further elaboration; GPS data are also processed at run-time to display the trajectory. The frame number is used to identify each frame within a second (50 frames/s) and is used for:

- reconstruction of GPS information;
- identification of any frame lost in reception.

Finally, the Photo number allows for the association of picture files in the SD card with time, position and attitude of the camera.

IV. Remote GUI

The Remote GUI, developed in C language by means of LabWindows© development environment, allows the user to manage the system. As we can see in Fig. 3 we have three graphical panels, one at the top and two at the bottom of figure, to display respectively GPS trajectory, angular velocity and linear acceleration.

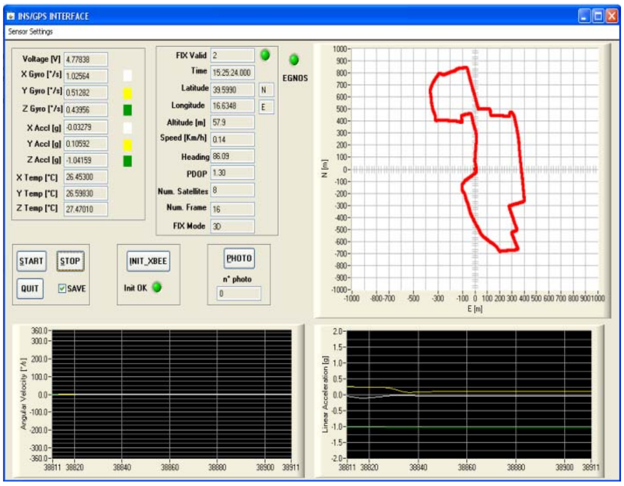

Fig. 3 Remote GUI.

In the top-left there are variable boxes in which both inertial sensor parameters and GPS parameters are displayed; in particular there are: supply voltage, x-y-z linear accelerations, angular velocities and temperatures, for inertial sensor; time, latitude, longitude, altitude above mean sea level, height of geoid above WGS84 ellipsoid, speed, heading and PDOP for GPS module. Data stream can be logged on a text file for post-processing purposes. In the top of window there is a menu in which user can access inertial sensor setting mode and manually change gyroscope dynamics, number of tapes of Bartlett FIR digital filter, sample rate, accelerometer ad gyroscope offset or use automatic procedures of axial alignment, offset compensation, calibration, etc., as specified by the manufacturer.

V. System Testing

In order to verify proper operation of accelerometers and gyroscopes, two types of tests have been conducted: first, the system was placed on a strobe speed-controlled turntable with velocity of 33 rpm and 45 rpm, to evaluate biases and the correct angular velocity measured by gyroscopes; then, it was placed on a radio-controlled toy car (Fig. 4) to test the performance of the whole system.

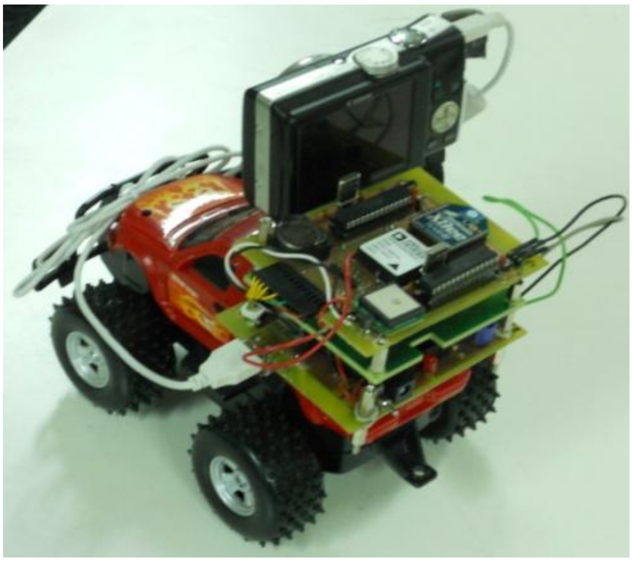

Fig. 4 The prototype mounted on a toy car for testing.

Moreover, the system was installed on a car in order to verify GPS module operation and the algorithm of reconstruction of trajectory with GPS data, along a closed path. Results have been compared with those of a professional differential GPS system operating as a reference, showing an average error of less than 5m.

Main features of first prototype are reported in the following table.

TABLE I
Main Technical Features

Dimensions : **83x76x55 mm**
Weight : **210 g (450g with camera)**
Inertial frame transmission rate : **100 Hz**
GPS frame transmission rate : **5 Hz**
Position resolution with EGNOS: **<5m (experimental)**
Maximum transmission range : **80 m (outdoor)**
Dynamic range accelerometers.: **±10 g**
Sensitivity accelerometers: **2.522 mg**
Dynamic range gyros: **±300 °/s, ±150 °/s, ±75 °/s**
Sensitivity gyros: **0.07326 °/s, 0.03663 °/s, 0.01832 °/s**
Nominal input voltage: **2.4V**
Nominal input energy: **6.36Wh**
Max power consumption : **625 mW**
Max battery autonomy : **9 h (working continuosly)**

VI. Conclusions

We have presented a low-cost wireless GPS/inertial system designed to maintain a high degree of flexibility even respecting the constraints to have low weight, high compactness, long autonomy and full remote control of its parameters. Next development step is to re-design the board architecture in order to minimize the weight and size, adopting SMD technology and the update of the inertial sensor with a new one including a tri-axial magnetometer. Work is in progress to implement real-time Kalman filtering and trajectory integration using *data fusion* techniques.

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