Real-time Aircraft Telemetry using Wireless Sensor Network

Rodolfo Rodrigues de Sousa and Cintia Borges Margi

***Abstract*— This paper describes the design of a real time monitoring system based on wireless sensor networks aiming to measure accelerations, airspeed, spacial orientation and geographical position of a radio-controlled aircraft in order to allow their designers (university students) to measure how their planes performed. We use a Microsoft .NET Gadgeteer board connected to sensors, a SD card and XBee radio module, and a visualization software on ground to depict the airplane characteristics while on flight. After specification and implementation, individual tests were realized with sensors, as well as an in-flight test.**

***Keywords*— Telemetry, Aircraft, Wireless Sensor Networks**

I. Introduction

The design of an airplane is not simple. There are several books on developing and calculating large scale airplanes. However, design methods are not well established when it comes to smaller scales, as in the design of unmanned aircraft, like UAV's [1], radiocontrolled, for hobbists, of for specific competitions such as SAE-Aerodesign. In such scenarios, aircraft design tends to be either overly theoretical or experimental, and led by people who frequently are not keen on electronics. Moreover, in these cases, embedded electronics can be as expensive as the plane itself.

In order to aid designers to keep track and better analyze flight results, it is suggested to install an electronic sensoring system where the airplane designer and pilot will only worry about its proper installation, allowing them to analyze flight caracteristics on ground while the airplane is taking off, landing, or during its mission.

The contribution of this paper is to decrease the sensoring technology gap between jumbo and radio controlled aircraft through a flexible (in the sense that one can use any sensor needed) and easy-to-use (in the sense of simple installation, use and modification) wireless sensoring system.

In the following sections the specification of the system is detailed, as well as the description of tests and validations perfomed to ensure its funcionality.

II. Related Work

This work is primarily based on wireless sensor networks, WSNs. These can be seen as MANETs, multi-hop ad-hoc networks, featuring flexible architecture and wireless communication where elements connect directly to each other [2]. Many WSNs use colaborative paradigms, sending sensored data to a sink (a base station), where they are further processed by a corresponding application.

Integrated with aeronautics, these networks are commonly used as a mobile sink, in scenarios with remote sensors, specially where no other kind of common wireless communitacion (such as 802.11 or cellular), particularly useful for agricultural monitoring [3]. Other applications include monitoring conservation state of large scale aircraft [4], traffic and urban pollution [5]. Although proprietary solutions on telemetry for small airplanes exist, they are not flexible, thus an open application of WSNs specifically to keep track of the airplane itself is a field yet mostly unexplored.

III. Proposed System

The goal of the project was achieved with a set of sensors, mobile processing platforms, wireless communication and software. These are detailed below.

As the core system, a FEZ Spider .NET Gadgeteer board was used. It features an ARM7 72MHz 32bit processor, 16MB of RAM and 4.5MB of flash storage for programming. The platform allowed fast prototyping (through flat cable connectors for its sensor modules) and simplified coding (in C#, using .NET Micro Framework 4.1).

The following measurable information are relevant for a flight log and are taken as requirements:

- *Airspeed in the wings of the airplane*: all forces acting on the airplane are function of this value;
- *Airplane spacial orientation*: flight dynamics depend greatly on the plane's orientation. Specifically in the tests performed, useful for determining takeoff perfomance;
- *Geographical position*: besides being useful for keeping track of where the airplane flew (to calculate curve radius, for example), this is useful to avoid integration errors on sensor measurements.

The sensors used are listed in Table I.

A standard format for message was adopted for the network in order to allow the instalation of new sensors in the future (requiring more bandwidth). They are sent assynchronously through IEEE 802.15.4 protocol directly to the base station.

Data is sent from the sensor installed in the airplane to a basestation, with an XBee plugged to an USB port, in a serial port. A MATLAB® program was designed to address the real time visualization data, plotting graphs of estimated orientation angles. It was designed to be simple to to use, so the pilot and airplane designers can only worry about the proper installation of the system on the airplane, not its communication setup.

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TABLE I
SENSOR LIST: SPECIFICATIONS

Sensor	Objective	Model used
3-axis Accelerometer	Orientation	FreeScale MMA7455L, $\pm$8g, 64LSBs/g.
3-axis Gyroscope	Orientation	InvenSense ITG-3200, $\pm$2000 °/s, 14.375 LSB/(°/s)
Compass / Magnetometer	Orientation and Position	Honeywell HMC5883 $\pm$8 gauss, 10mG resolution
GPS	Position	GPS Model
Barometer	Air Density	HopeRF HP03M Piezo resistive
Pitot tube	Airspeed	80S [VectusImportatum] low pressure sensor

System characterization tests were run to assure measured data accuracy and communication ranges.

Pitot tube validation: It is used to measure inderectly the flow speed (here, airspeed) through the difference of two pressures inputs. A differencial pressure sensor was used to implement the pitot tube, with an analog voltage output of up to 5V. To map these voltage values (V) to its pressure counterparts (Pa), a test was made where a small pressure was applied to both the sensor and a standard manometer (Type 4 manometer, Airflow Developments Ltd.). The curve $\Delta P[Pa] = (58.00 \pm 0.31)[Pa/V] * V_{measured}[V] + (152.14 \pm 0.98)[Pa]$ was obtained from the experiment, allowing the right interpretation of data.

Communication range test: Wireless transmission is the most battery-intensive part of a sensor node in a WSN, thus a range test was run to make sure a) the airplane remains in communication range during, at least, the takeoff (considered a critical part of a flight); while b) not consuming the whole battery before landing. Using XCTU (a configuration software for XBees modules, by Digi) for a range test with 5 different power levels for the wireless communication, the range was measured. The experiment has shown that range would not be a problem during the takeoff using the communication module tested (modelo XB24-ASI-001, antena RPSMA 2dBi, 2.4GHz). However even on the highest power level, the airplane would be out of communication range in part of its flight. This led to the storage of all sent data in a SD card inside the airplane (to ensure no data is lost). Despite that, using other XBee modules (simply changing the hardware module, no software changes are needed) with larger transmssion power would be the solution for whole-flight tracking.

Static orientation tests: A static test was made to test accelerometer-compass integration for orientation tracking. These are enough to determine the three angles (yaw, pitch and roll) relevant for the airplane. Gyroscope was not used in this part of the project because in stable flight conditions (when the airplane is cruising), acceleration due to movement is small (the movement is almost uniform) so it can be approximated to a static scenario. The test intended to compare this project's measurements with the angle-measuring system *FlexMeter* [6]. Comparison was made fixing both systems together and moving them both, so that measurement should be the same on both systems. Each measurement was repeated five times and an average difference was calculated. Differences were not considered significant, as they were at most 6 degrees for yaw and at most 4 degrees for pitch and roll (average difference: 2.3 degrees).

IV. PROTOTYPES

The prototype was implemented first on early development, using an accelerometer, gyroscope and an SD card for data logging, only. The measured data is shown in figure IV. With a moving average filter, though, the effects of undesired noise due to the airplane engine vibrarion were reduced, allowing the visulization of the speed increase during takeoff through integration. However, a more accurate analysis of the data captured is left for future projects, and a more proper physical installation was proposed for the second prototype (trying to reduce vibration).

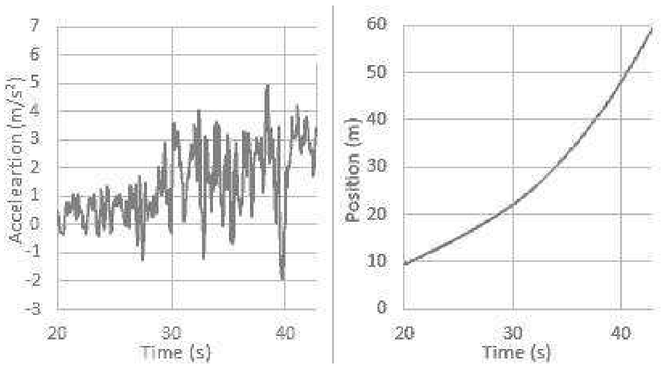

Fig. 1. Dados adquiridos e calculados (aceleração e posição longitudinais ao longo da pista)

The second prototype, which aims to implement the system as a whole, was tested in laboratory, allowing tuning of the interval between measurements and proper integration with the MATLAB® software.

V. CONCLUSIONS

We succesfully described the design of a real time monitoring system based to monitor in real time a radio controlled aircraft. After specification and implementation, experiments were realized, validating sensor readings. As future work, it would be recommennded to study data filtering in order to extract more information and further use acquired readings.

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