System based on inertial sensors for behavioral monitoring of wildlife

R.Tapiador-Morales, A.Rios-Navarro, A.Jimenez-Fernandez, J.Dominguez-Morales, A.Linares-Barranco
Robotic and Technology of Computers Lab, University of Seville
Seville, SPAIN
ricardo@atc.us.es

Abstract—**Sensors Network is an integration of multiples sensors in a system to collect information about different environment variables. Monitoring systems allow us to determine the current state, to know its behavior and sometimes to predict what it is going to happen. This work presents a monitoring system for semi-wild animals that get their actions using an IMU (inertial measure unit) and a sensor fusion algorithm. Based on an ARM-CortexM4 microcontroller this system sends data using ZigBee technology of different sensor axis in two different operations modes: RAW (logging all information into a SD card) or RT (real-time operation). The sensor fusion algorithm improves both the precision and noise interferences.**

Keywords—IMU; Sensor Fusion; Zigbee; ARM-CortexM4

I. Introduction

Nowadays wild animals behavior monitoring is a hard technological commitment. There are several commercial artifacts that are able to track animals through GPS and some of them include inertial sensors to track activity thresholds. Usually these existing systems send data from sensors (speed or temperature) to computerized systems that process the information in order to extract conclusions around those parameters under study, like sociability, resting periods, feeding, copulation, etc. MINERVA is an excellence project from Andalusia Council which main aim is to develop an embedded system with energy harvesting techniques that will be able to digest the inertial sensor information combined with other sensors (temperature, hearth rhythm,) in order to classify the animal behavior in real time. The project has also the aim to develop an infrastructure for collecting this information and make it accessible through internet. The animal behavior knowledge requires a continuous observation (today by a person), what increases the cost considerably. There are systems that replace a person by a camera and computerized techniques to recognize patterns [1]. This allows anyone to know the animal activity without the need of a person, but it assumes a continuous power consumption and a discontinuous animal activity monitoring since cameras must be static while animals are in freedom.

In these years wearables technology has grown so much in part because of the advance in MEMs (Microelectromechanical Systems) integration technology. These systems are characterized by little size and low energy consumption. The wearable technology allows today to keep people up to date about different interesting daily variables like number of steps walked for a day or sleeping hours. This technology is commonly used in human health care [2].

Applying the same concept of wearable technology of human's health it is possible to design an intelligent artifact that allows people from Doñana National Park [3] to get as much information as possible about wildlife and semi-wildlife animals behavior.

To create a low energy sensor network able to transmit data from these intelligent sensors that are composed of sensors and a post-processing layer able to classify sensors information into behavior patterns, special care must be taken in transmitting the information. XBee transceivers family allows configuring a low energy mode establishing an efficient network [4]. Most of networks for animals monitoring are based on GPS, which is not low energy [5] [6], so high capacity batteries are needed and this increases collar's weight. By reducing the GPS data reading period and by processing sensor data locally it is possible to reduce transmission data bandwidth considerably and, therefore, the power consumption.

Nowadays, most of the systems based on inertial sensors for pattern recognizing use accelerometers [7] [8], which get important information but results could be better if others devices are used for complementing the information, like gyroscopes and magnetometers.

In this paper, we present a system that combines these three devices to offer more detailed information about the animal behavior by using a sensor fusion algorithm. This allows fusing data from each device reducing the possible noise or alterations while reading the device. Without using fusion algorithm, applying some kind of filter (low pass), it is possible to reduce the noise due to the animal movement, but it cannot filter the noise coming from magnetic alteration for example. The idea here is to reduce as much as possible the noise coming from sensors, so it is possible to apply a training system to automatically perform pattern recognition [9]. Particularly, we present the results of applying a fusion algorithm to an IMU reducing the noise produced from many factors so it can resist animal activity giving us good approximation of IMU orientation. The information is sent using XBee with 60mW and 2.4GHz following the 802.15.4 standard.

The paper is structured as follows: section II presents the most important system components. Then, section III presents the sensor fusion algorithm. Finally, section IV presents the results.

II. Hardware Components

An IMU is in charge of collecting data from the environment. When this data is threated, it is sent using a XBee module allowing a user to visualize that information on a PC.

A. *Inertial Measure Unit*

An inertial measure unit (IMU) includes three sensors: accelerometer, magnetometer and gyroscope. In this work, we are using the MinIMU-9V2 IMU. Each sensor has a resolution of 12 bit and it communicates using an I2C port. The gyroscope has a scale from 250 to 2000 dps (degrees per seconds).The accelerometer has a scale from 2G to 16G, where G is the acceleration that gravity would give to an object in ideal conditions, and the magnetometer has a scale from 1.3 to 8.1 gauss.

These sensors have a great accuracy and for this work we have used a configuration of 2000dps for the gyroscope, 2G for accelerometer and 1.8gauss for magnetometer. The reasons for these configuration is because the gyroscope is a fast sensor so to get the best information it is necessary to put the maximum scale, however the accelerometer and magnetometer are slow sensors if we compare with the gyroscope. The selection for the accelerometer configuration is because in general an animal cannot raise more than 2G of acceleration. Finally, the magnetometer is a device that does not add much information to the sensor fusion algorithm, but to avoid getting alteration for this sensor we use the lowest possible scale.

B. *Zigbee*

ZigBee is a set of specifications of protocols oriented to WPAN (wireless personal area network), which is based on 802.15.4 [10], a standard whose aim is to give a low rate network for low capacity batteries.

This technology has two characteristic that make it adequate for our project: the low energy consumption and mesh network topology. The aim is to make a network of motes, where one mote will represent an animal and there will be some other motes working as nodes recollecting information from animal-motes.

In this paper ZigBee communication is used as point to point because it is the first prototype ready to test over one animal. It works such as a serial COM port transmitting all the information from a microcontroller to a computer and receiving configuration orders, i.e. calibration.

C. *System architecture*

Our proposed system is composed of an ARM-CortexM4 microcontroller powered with an external battery. The microcontroller is connected to an IMU via I2C. And it communicates through a ZigBee module.

The microcontroller initializes each device and it configures them when it starts running. The main task is to process all data from gyroscope, accelerometer and magnetometer, using a sensory fusion algorithm.

The system is initially connected to a PC and it will be logging all the information in a SD card (Logging mode) when we want to extract the data from it, an order from the PC is needed to make the microcontroller to send the log file and, then, an acknowledgement signal.

The information is stored in CSV format, characterized by columns and rows. Each row represents a type of data from sensors and each column the value of that field in this sample.

When the file is correctly sent the microcontroller sends the information in real time but is not logging (Real time mode), it is possible to change the operation mode by sending appropriate commands. Currently there are three possible actions: (1) force a calibration of the IMU, (2) configure sensors and (3) get the log file. These three actions are done remotely allowing anyone to get measurements from the system from a distance.

Fig. 1 shows a diagram of the system that describes the communications and the different functions that each module can do.

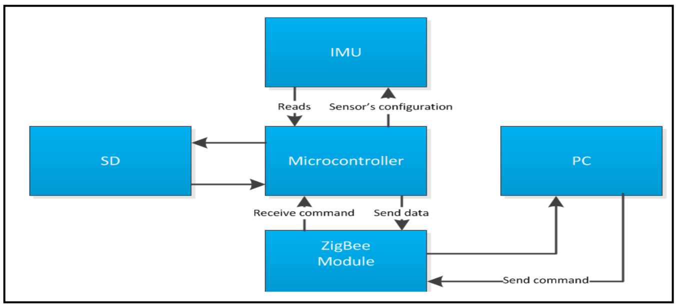

Fig. 1. System's architecture and commands.

III. Sensory Fusion

The principal problem to solve in this project is how to combine the data from sensors to filter the noise and get useful information. The useful information we refers are pitch, roll and yaw, angles of rotation in each axis of 3D dimension.

A. *Pitch,roll and Yaw.*

Pitch represents y-axis rotation, roll represents x-axis rotation and yaw the variation from z-axis. An accelerometer is a sensor where the linear acceleration is based on the gravity. Pitch and roll calculation is possible to obtain by applying formulas based on accelerometer [11] but if the accelerometer is precise a small variation can change the values of pitch and roll. In the other hand, it is difficult to calculate yaw without combining tilt compensation from magnetometer and the change variation from gyroscope.

Because of these reasons, it is necessary to use a Fusion algorithm that reduces the noise from devices and joins all data.

B. *Fusion algorithm*

Currently, Kalman filter [12] has become the principal orientation algorithm, in part, because of its effectiveness and accuracy. However, it has a big disadvantage, the complex implementation. In the face of making a faster prototype we have implemented the FreeImu algorithm [13], alternatively to Kalman filter, which gives and easier solution to fusion data.

This algorithm is based on a quaternion representation. A quaternion is a complex number that represents the object orientation by four fields. The algorithm updates the quaternion per iteration. It compares the change of these fields with their values in the state before. One step of the algorithm is applying the gradient descent algorithm to integrate magnetometer and accelerometer reading when the fusion is done. Another step also adds gyroscope data for drift estimation.

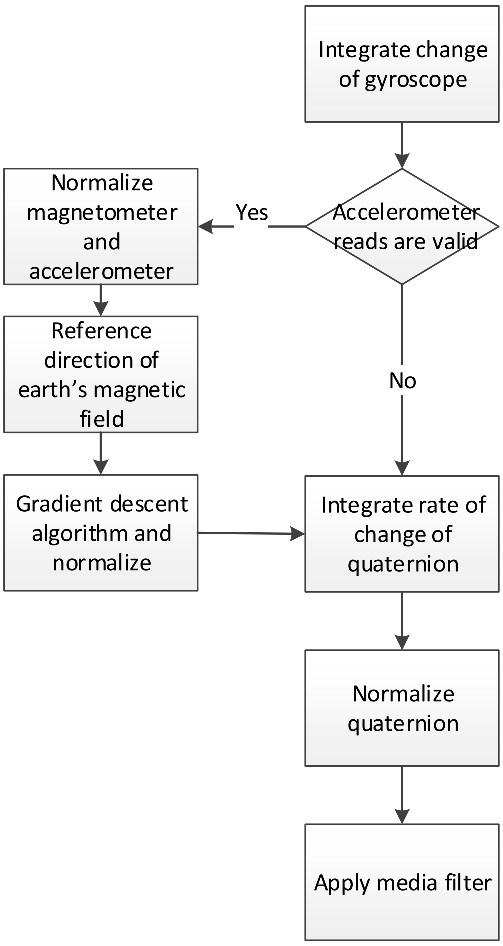

Fig. 2. Fusion algorithm block diagram

Fig. 2 shows how the algorithm starts integrating gyroscope changes. Then, if accelerometer data are valid, a normalization of the magnetometer and accelerometer data is performed. Next step is to reference magnetic direction of earth to avoid possible distortions in magnetometer data due to external alterations (i.e. a closer magnet). Following, the algorithm fuses accelerometer and magnetometer data using gradient descent algorithm and it normalizes the result. Finally, the algorithm integrates these data into the quaternion as an integration of changes, what reduces errors when accelerometer data is wrong. Last step is to normalize and then, to reduce the possible noise, to apply a smooth filter.

This algorithm depends on two essential factors: the sampling frequency and the gain. The first one is the rate of change in the quaternion's fields. This is important because an exact sampling time in the algorithm makes the filter more precise by reducing errors. To get the sample time, after configuring the IMU, with one available timer of the microcontroller we measured time between samples getting a frequency about 392.5Hz.

The second factor (gain) controls the effect of the filter over samples. A high value minimizes the error of integrated gyroscope drift. However, a small value avoids introducing unnecessary noise in a step of the algorithm. Our algorithm uses a gain value between 6-6.5.

In this paper we have added an improvement to the fusion algorithm. The FreeImu algorithm filters noise and normalizes sensors data, but measured results have still noise because of the IMU high sensitivity which gets some peak in the graphics to get a better representation. We have included the last step, with the average filter over each field of the quaternion.

Equation (1) shows an average filter that has an alpha factor, which gives us a weight to the current sample respect to the previous one. In this case our alpha factor has a value of 0.65 giving more weight to the present sample.

$$B = \alpha * s + (1 - \alpha) * sb \quad (1)$$

Where B is the result of applying the filter, s is the actual sample, *sb* the sample before actual value and α is the alpha factor.

The proposed system has been probed on a semi-wild horse in Doñana National Park. Prior to these tests, the first test of the system was moving the IMU in all axes in the lab. We compared the results applying FreeIMU versus the result of calculating pitch and roll without Fusion algorithm.

IV. RESULTS

Fig. 3 shows an example for pitch measurements. The black line represents the pitch and roll calculated without algorithm while the blue-green line represents the result from the algorithm and how both change with the time.

As it can be seen on the image the blue line has a slower rise/decrease than the black line, what means that the blue one is giving more information from one state to other, this can help when applying a training system to recognize patterns.

The principal difference between lines is that the black one has great oscillations against vibration. It represents animal's behavior and implies a continuous movement and with a high speed if we compare this with a person. Therefore, it is necessary to filter abrupt movements. In Fig. 3, the blue one is able to filter that kind of movements.

It is important to highlight that a strict filter can ignore some movements and then it would be lost part of the information.

The algorithm works properly against an external magnetic distortion. In order to test this, we have used a magnet while the IMU moves. Although the reads went soared, the algorithm was capable to filter that noise.

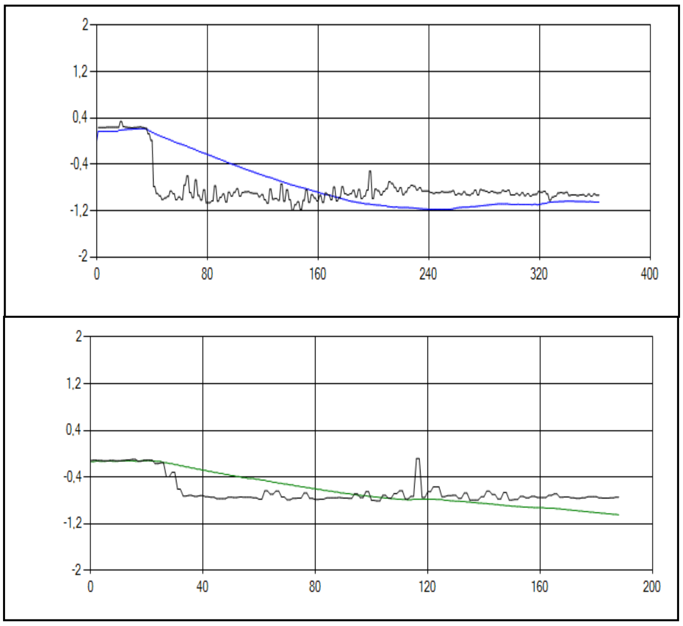

Fig. 3. Top: Pitch variation fusion algorithm (blue) vs raw values (black) over time. Bottom: Roll variation fusion algorithm (green) vs raw values (black)) over time.

As it was said before, there is a variable that is difficult to calculate without a fusion algorithm, called yaw. In Fig. 4 the yellow line represents the yaw variation. This variable depends considerably on gyroscope and magnetometer readings.

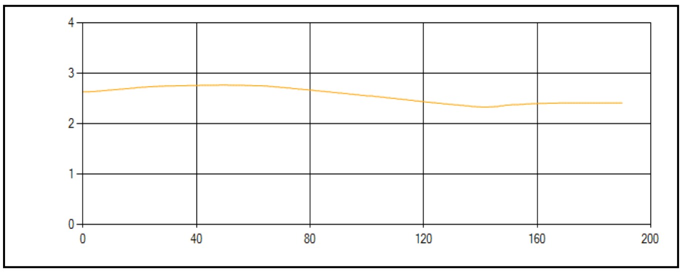

Fig. 4. Yaw estimation from fusion algorithm.

Measuring time of functions (real time mode and logging mode) we obtained a time of 52ms to write in the SD card and 63ms just sending the information for one sample, it includes all raw data from sensors and pitch, roll and yaw.

These values allow us to determine the operation mode as a function of requirements. Therefore, if the target is a fast system where timing is critical, logging information will reduce execution time but this decreases the number of data packets that are being sent. Despite the time to send data packets, the low energy mode of ZigBee makes up for more execution time, so batteries will last longer than logging data.

V. Conclusion

This work presents an inertial measurement system based on a microcontroller and ZigBee (IEEE 802.15.4). This study has been tested in laboratory by simulating changes on the IMU, checking the correct behavior in pitch, roll and yaw. The results ensure that the system will work over animals.

In a near future we will integrate a training algorithm, i.e.: neuronal networks, to recognize and classify behavioral patterns from animals (like hunt or sleep). And it will be changed the communication network topology: from point to point to a mesh network able to identify several collars in real-time.

This system has been designed to measure the orientation of an animal but it could be used on other rigid body, for example a drone to equilibrate it.

Acknowledgment

This work has been developed by the support of Andalusian Council Excellence grant MINERVA (P12-TIC-1300).

References

[1] Tomasz M Kutrowski, Turgut Meydan, John Barnes, Noor Aldoumani, Jonathan T Erichsen "Instrumentation for Monitoring Animal Movements", 2014.

[2] Han-Pang Huang 1, and Lu-Pei Hsu2."Development of a wearable biomedical heath-care system"2005.

[3] Doñana National Park UNESCO.http://whc.unesco.org/en/list/685, 1994.

[4] M. Dominguez-Morales, A. Jimenez-Fernández, D. Cascado-Caballero, A. Linares-Barranco, R. Paz, G. Jiménez-Moreno, "Technical viability study for behavioral monitoring of wildlife animals in Doñana",University of Seville 2011.

[5] Vishwas Raj Jain, Ravi Bagree, Aman Kumar, Prabhat Ranjan." Wildcense: GPS based animal tracking system",2008.

[6] So-Hyeon Kim, Do-Hyeun Kim, Hee-Dong Park,"Animal situation tracking service using rfid, gps, and Sensors",2010

[7] Gergo Santha, Gyula Hermann,"Accelerometer based activity monitoring system for behavioural analysis of free-roaming animals",2013.

[8] Richard Ribón Fletcher, Ken-ichi Amemori, Matthew Goodwin, Ann M. Graybiel "Wearable Wireless Sensor Platform for Studying Autonomic Activity and Social Behavior in Non-Human Primates",2012.

[9] Subramaniam Venkatraman, John D. Long, Kristofer S. J. Pister and Jose M. Carmena "Wireless Inertial Sensors for Monitoring Animal Behavior"

[10] Zigbee Alliance, http://www.zigbee.org.

[11] Fatemeh Abyarjoo1, Armando Barreto1, Jonathan Cofino1, Francisco R. Ortega "Implementing a sensor fusion algorithm for 3D orientation detection with inertial/magnetic sensors"pp 2.

[12] R. E. KALMAN, "A new approach to linear filtering and prediction problems" 1960

[13] Sebastian O.H. Madgwick, "An efficient orientation filter for inertial and inertial/magnetic sensor arrays," 2010.