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TORTOISE@: A SYSTEM FOR LOCALIZING TORTOISES DURING THE EGGS DEPOSITION PHASE

Abstract - A common approach used to protect wild populations of tortoises consists in localizing nests, collecting eggs, and letting them born in captivity. However, this approach requires an early localization of the nesting sites, which may not be easy since tortoises cover the nest after the deposition phase. To allow a timely and easy nest localization, in this paper we propose *Tortoise@*, a sensor-based system capable of localizing tortoises during the deposition phase, and transmitting their geographic coordinates to a remote control center in real time.

Key words - Tortoises, Nest Localization, Environmental Sensor, Accelerometer sensor, Compass, Pattern Recognition.

Riassunto - *Tortoise@: un sistema per localizzare le tartarughe durante la fase di ovideposizione* - Un approccio comunemente utilizzato per la protezione delle popolazioni di tartarughe terrestri consiste nel localizzare i siti di nidificazione, raccogliere le uova deposte, farle schiudere in ambiente protetto, e mantenere in cattività gli esemplari nei primi anni di vita. Tuttavia questo approccio richiede la localizzazione tempestiva dei siti di nidificazione, cosa resa difficile dal fatto che le tartarughe tendono a ricoprire il nido dopo la deposizione. Per consentire una e facile e veloce localizzazione del sito di nidificazione, in questo articolo proponiamo *Tortoise@*, un sistema elettronico, basato su sensori, in grado di localizzare la tartaruga durante la fase di deposizione e trasmettere le coordinate al centro di controllo in tempo reale.

Parole Chiave - Tartarughe Terrestri, Localizzazione del Nido, Sensore Ambientale, Sensore di Accelerazione, Bussola, Pattern Recognition.

1. Introduction

In recent years, there has been a global reduction of plant and animal biodiversity. Due to this reduction, tortoises are – among the different animal species – one of the most threatened ones. Both marine, terrestrial, and pond species are classified as *vulnerable* or *critically endangered* in the *Red List of Threatened Species* provided by IUCN, the International Union for Conservation of Nature [1]. Hence, the protection of terrestrial and pond tortoise is of interest for all natural parks in the world were such species are. Tortoise protection is also supported by the European Union through the LIFE+ program, which is aimed at funding research activities targeted to maintain and increase biodiversity. Even locally, Tuscany homes a population of tortoises (*Testudo hermanni hermanni*) – in the area of Colline Metallifere – and several populations of European pond turtle (Emys orbicularis) – in various wetland areas of the region. The Regional Government of Tuscany actively support the protection, preservation, and reintroduction of these animals.

One common approach that is typically used to protect and enhance wild populations of tortoises, consists in localizing the nesting sites, collecting eggs, letting them hatch in captivity, and keeping the specimens in captivity during the first years of their life, when they are more subject to predation. After this initial protected period, tortoises are re-introduced in their natural environment. This approach, which is also used at the «Charles Darwin» Center [2] in Galapagos Islands, can be applied to all tortoises and turtles. However, it requires an early localization of nesting sites which, however, is made difficult by the fact that female tortoises cover the nest after the deposition phase, thus making it no longer identifiable.

To allow a timely and easy localization of the nesting side, in this paper we propose *Tortoise@*, a sensor-based system capable of (**i**) localizing tortoises in the early stages of their eggs deposition phase, and (**ii**) transmitting their geographic coordinates to a remote control center in real time, through long-range wireless communication. The proposed system can be implemented as a small device, enclosed in a waterproof housing, to be applied to the tortoise's carapace – as shown Figure 1 – using a non-toxic glue. Of course, the size and weight of the device are very limited. In addition, the device has a form that does not interfere with the normal behavior of the (female) tortoises. For instance, it will not prevent the sexual coupling with males, whose plastron cannot reach a so high position on the females' carapace.

The proposed system leverages a number of sensors to monitor environmental conditions (temperature, humidity, and light intensity sensors) as well as movements of the tortoise (accelerometer and compass sensors). It is well known that eggs deposition can occur only under certain environmental conditions, which

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1 http://www.iucnredlist.org/
2 http://www.darwinfoundation.org/english/pages/index.php

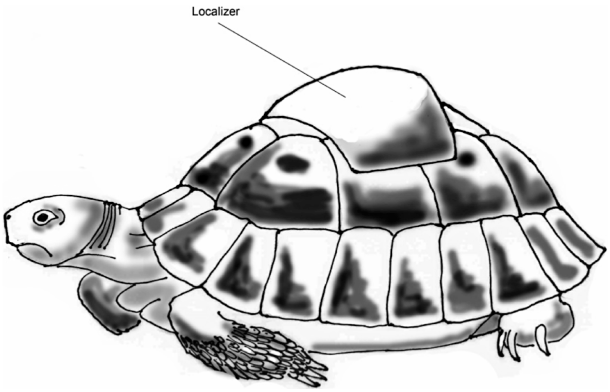


Fig. 1 - Localization system applied to the carapace of a tortoise.

can be easily detected trough environmental sensors. In addition, during the deposition phase, female tortoises perform specific movements, i.e., the excavation of the nest in the ground by means of alternating movements of the hind legs and the progressive inclination of the body. In addition, their orientation remains approximately constant during the whole deposition phase. By a combined analysis of data acquired by different sensors, it is possible to recognize the typical movement pattern of the tortoise during the deposition phase. *Tortoise@* also includes a localization module for determining the location of the tortoise (i.e., the coordinates of the nesting site), and a long-range wireless communication module (e.g., a GPRS/3G transceiver) to communicate the location of the nesting site to a control center in real time. Since the deposition phase takes more than 1 hour, the staff assigned to the collection of eggs have enough time to reach the reported nesting location and identify the animal, even in the presence of (limited) localization errors.

The rest of the paper is organized as follows. Section 2 presents the proposed tortoise localization system. Section 3 describes the implementation of a data logger for (off-line) data collection during the deposition phase. Section 4 shows some experimental data – collected through this data logger – in a field experimentation carried out in Massa Marittima, Grosseto, Italy. This data will then be used to identify the typical movement pattern during the deposition phase. Finally, Section 5 draws some conclusions and presents the future work.

2. Tortoise localization system

In this section we briefly describe the architecture of the proposed tortoise localization system, and the algorithms used to reduce the energy consumption of the system (in order to extend its lifetime) and to recognize the typical movement pattern of tortoises during the deposition phase.

Figure 2 shows the architecture of the proposed tortoise localization system. It includes of the following components.

- *Acquisition Module.* Consists of environmental sensors (temperature, light intensity, humidity), an accelerometer sensor, and a compass. It allows to monitor the external environmental conditions as well as tortoise's movements.
- *Localization module.* Consists of a geographic localization system (e.g. a GPS receiver) and allows to determine the location of the monitored tortoise.
- *Processing module.* Consists of a micro-controller and (RAM + Flash) memory and allows to store and process data received from the sensors and/or the localization module.
- *Communication module.* Consists of a long-range radio to communicate in real time the tortoise's location and motion direction (reported by the localization module and compass, respectively), to the remote control center.
- *Power Supply Unit.* Consists of one or more batteries and feds all the system components.

When the environmental conditions do not favor the deposition process, the radio and the localization component are turned off to save energy. In addition, the accelerometer and the compass sensors are normally switched off for the same reason. Instead, environmental sensors (i.e., temperature, light intensity, and humidity sensors) are always active and acquire data periodically, in order to continuously monitor the external environmental conditions. Additional details on when to switch on and off the various system components are given in the next section.

2.1 **Power Management**

Since the power supply unit consists of one or two small batteries, the available energy is quite limited

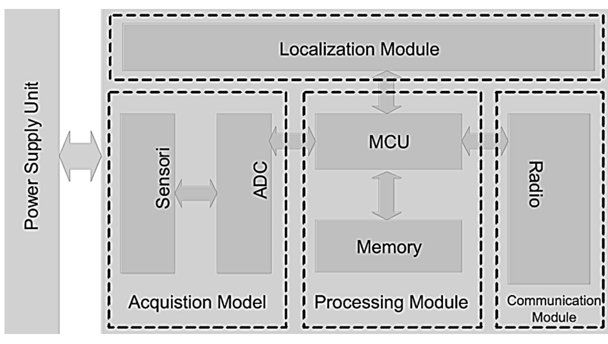


Fig. 2 - System architecture.

and must be used very sparingly to ensure a system lifetime longer than the whole eggs deposition period, which in the Mediterranean area, last for about 2 months [3]. Hence, efficient power management strategies have been implemented in the proposed system. Since the communication and localization modules are the most power consuming components, they are usually switched off when they are not needed. Similarly, the accelerometer sensor – which has a power consumption significantly higher than that of environmental sensors – and compass are normally switched off to save energy. This is possible because egg deposition can occur only in daily hours and under certain environmental conditions (e.g., in Mediterranean area, sunny day and temperature above 20 °C) that can be easily detected through environmental sensors. To further limit the power consumption of the system, the accelerometer and compass sensors are activated intermittently, even when the environmental conditions are appropriate for deposition. Below we describe in details the operations performed by the system in the different stages of the monitoring process. As a general remark, we would like to point out that the optimal values for the parameters introduced below depend on the specific species of tortoises under observation and, thus, they cannot be decided *a priori*.

Environmental Monitoring Stage

This stage denotes the normal operating condition, where the system operates for most of the time. While in this stage, external environmental conditions are monitored with continuity, to understand whether the deposition phase can occur or not. Since temperature, humidity and light intensity sensors have a very limited power consumption, they are always active and are sampled periodically by the micro-controller, with a period T_{env}. Whenever external conditions are appropriate for deposition, the system enters the *Movements Monitoring* stage (described below).

Movement Monitoring Stage

Upon entering this stage, the system activates the accelerometer and compass sensors to monitor the movements and position (including the inclination) of the tortoise. Specifically, the above-mentioned sensors remain active for a time interval L_{filter}. The duration of this interval is set in such a way to allow the acquisition of a number of samples that allow to decide – by means of a simple analysis of the accelerometer and compass data samples – whether the tortoise is in the necessary condition for the deposition phase or not, e.g. checking if the tortoise is in activity. During the period of work in June and July 2012 at Massa Marittima, we observed that the best value for L_{filter} was forty seconds. This time interval allows the system to establish whether the tortoise is in movement or in rest.
If the detected signals are *compatible* with the deposition phase, the system enters the *Extended Movement Monitoring* stage (see below). Otherwise, the accelerometer and compass sensors are switched off (while environmental sensors remains active), and the system moves back to the Environmental Monitoring stage.

Extended Movement Monitoring Stage

This stage is aimed at ensuring that the tortoise is actually in the deposition phase. While in this stage, the movements and position of the tortoise are monitored for a time interval L_{active}, as in the previous stage.
The L_{active} is about 200 seconds in order to determinate the specific trend of accelerometer values during the deposition phase. We observed that this is the useful interval to have approximately six repetitions of the periodic values, that characterized the right and left paw movements (for the periodic values cf. section four).
Specifically, the duration of L_{active} is set in such a way to allow the acquisition of a number of samples through which the *pattern recognition* algorithm (see below) can decide whether the tortoise is in the process of deposition or not. In addition, this monitoring task, of duration L_{active}, is repeated periodically (for a number of times n), with a period T_{repeat}, over a time interval of duration L_{laying}. This time interval should be long enough to guarantee that tortoise has been continuously excavating its nest. We observed during the period at Massa Marittima over more than four different species of Testudo Hermanni that the necessary time for a nest dig was about two hours. In order to set the value of this time interval, which could take into consideration on the one side the two hours interval observed in nature and on the other the possible discrepancies in the movements, we established that a useful value for the T_{repeat} is 1200 seconds (about twenty minuts) over a time of one hour and half (L_{laying}).
Hence, during the Extended Movement Monitoring stage the accelerometer and compass sensors operate with a duty cycle $\delta_1 = L_{active}/T_{repeat}$. If the pattern recognition algorithm provides a positive response for k, k<n, (even non consecutive) times within the time interval L_{laying}, then the system assumes that the deposition phase has been recognized, and enters the communication phase. Otherwise, the system moves back to the Environmental Monitoring stage. The system relies on the (tunable) accuracy of the pattern recogni-

[3] This period was observed at Massa Marittima during the last year

tion algorithm to reduce the number of false positive and false negative recognitions of the deposition phase. The pattern recognition method is based on neural networks. The robustness and, in particular, the universal approximation property of such method provide guaranties on the flexibility of the approach for the approximation of arbitrary classification functions from experimental data even without a theory of the pattern characteristics.

Data Communication Stage

Upon entering this stage, the system activates the localization module to get the coordinates of the current location, which corresponds to the location nesting site. Finally, the communication module is activated to transmit the reported coordinates to the remote control center.

2.2 Deposition Pattern Recognition Algorithm

The predictive algorithm used for recognizing the tortoise deposition pattern includes the following components/steps:

- **Input**: acquisition of data, in the form of numerical measurements, from sensors, including the steps of preprocessing (encoding signals, scaling, normalization, ...).
- **Input-Output transduction**: a dynamic discrete-time nonlinear model, of neural network type, with internal memory and free parameters with which to weight the temporal data for the recognition of the pattern. The off-line (out of the device) learning and validation stages optimize the values of free parameters used in the embedded classifier, based on the examples obtained from sampling in real situations, with different individuals and different environmental conditions. Through a proper training, the pattern recognition algorithm is therefore tailored to the specific real-world deployment conditions. In particular, we consider the classes of Time Delay Neural Networks and Recurrent Neural Networks (Haykin 2008, Kolen *et al*. 2001), i.e., learning models able to deal directly with temporal and sequential type of data.
- **Output**: final response of the recognition of the deposition pattern, including the classification of the sequences of input signals, in the form of 0/1 signals, and the selection filter of significance and permanence of the deposition conditions.

The machine learning algorithm is characterized by the introduction of a flexible and adaptive mechanism for the deposition pattern recognition. In particular, the following characteristics allows to achieve this objective:

- the learning of the model-based on actual sampled conditions, which do not require/assume an *a priori* analytical description of the phenomenon to predict;
- the capability to process sequential data and the sensitivity of the response to the temporal context;
- the tolerance of the learning system to noise and uncertainty of the data received from sensors.

3. System implementation

At the current stage of the implementation, the final device is not fully available. In particular the localization module based on GPS is not integrated in the hardware device, and the communication modules in the current implementation uses a radio subsystem able to cover only a few hundred meters (in the final implementation we plan to replace this communication module with a GSM subsystem able to cover several kilometers). On the other hand, the device, which is built based on a Iris node[4] (mote module used for enabling low-power, wireless sensor networks), already embeds an 8MHz processor, 8Kbytes RAM memory, 128KBytes flash memory, and temperature, light and a two axes accelerometer sensors. In order to train the learning system to detect the eggs deposition pattern, we used this device in a log configuration and we used it in an experimentation conducted in Massa Marittima, as explained in Section 4.
The system for data acquisition comprises a Graphical User Interface (GUI) and a logger component. The GUI runs on a standard PC, while the logger runs on a Iris sensor node. A sink node is necessary to establish a communication with logger. PC and sink are connected to each other through a USB2 port and the sink communicates with logger through a RF signals. The Graphical User Interface (GUI), shown in Figure 3, provides a simple and intuitive user interface to control the data acquisition. Specifically, it provides functions to initiate a new data collection task, to stop it, and to show the collected data. The GUI offers two modes of controlling a logger: *on-line* and *off-line*. In on-line mode the logger sends the data in real time to the interface. In off-line mode the logger stores the data in its flash memory, and they can be retrieved later by the GUI. To set a new task, the user can act on the following parameters:

- *Sampling frequency*: Indicates the frequency at which the logger reads data from its sensors.

[4] http://www.xbow.com

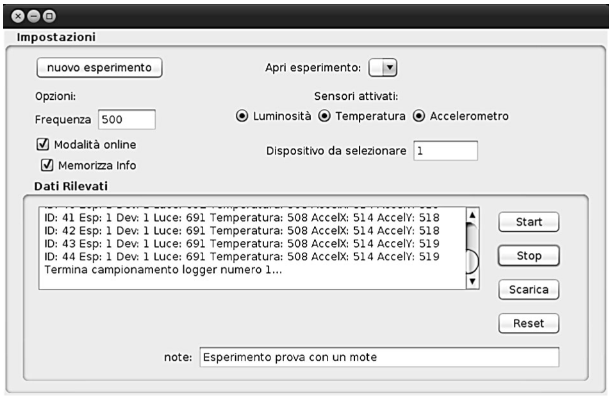


Fig. 3 - Graphical User Interface.

- *Sensors*: Indicates which transducers should be read by the logger. Currently the logger supports only two-axes accelerometer, brightness and temperature.
- *Mode*: Can be either on-line or off-line.
- *Recipient*: Identifier of the physical device on which the logger should be activated.
- *Commands*: Either start, stop, download or reset. Commands start and stop initiate and terminate a logging task. Download retrieves the data stored by a logger in the flash memory, and reset cleans the flash memory of the logger.
- *Note*: this field enables the user to associate free text to a logging task.

If the on-line mode is used, the GUI remains focused on that task (it not allows to retrieve or create another task) until the task is stopped. During this time, the data produced by the logger are shown by the GUI in real time (and they are also stored in a local database). In this case, for each new data the GUI reports the following information:

1. the sequence number of the data;
2. identifier of the task (it is a sequence number for the tasks);
3. identifier of the device on which the logger is running;
4. values of brightness, temperature, acceleration on X axis, and acceleration on Y axis.

The GUI can also manage different logging tasks concurrently (in this case all the tasks must be off-line). To this purpose, it enables the user to define and start different off-line tasks. The user can retrieve an off-line task that was initiated earlier and that is not yet concluded. In this case the GUI enables the user to stop the task and to download the data stored in the flash of the logger. Also in this case, all data are also stored in the local database.

The logger, which is implemented in NesC with the TinyOS operating system [5], implements all the functionalities that can be set by the user interface. In particular it supports both the on-line and off-line modes. The logger reacts to the commands of start, stop, reset and downloads issued by the GUI, and each of these commands is associated to an internal procedure. In particular, the start command initiates a loop that reads the light, temperature and accelerometer transducers, and associates these data to a sequence number and a timestamp. Then it stores the data in the flash memory, if off-line method is used, or send a data packet to the GUI with the sampled data, if the on-line method is used. Finally, it waits for the next data sampling. The loop is terminated when a stop command is received. The download command reads all the data (along with their sequence number and timestamp) from the sensor flash memory and send each of these data to the GUI by using a reliable stop-and-wait communication protocol that relies on acknowledgements and retransmissions.

4. Experimental measurements

In this section we present some experimental results, derived through the data logger described in the previous section, showing the movements of the monitored tortoise in the early stage of the deposition phase, i.e., during the excavation of the nesting site (see Figure 4). The experimental measurements have been carried out on different species of tortoises hosted Massa Marittima, namely *T. hermanni boettgeri*, *T. hermanni hermanni* (from Venice, Puglia, and Sicily),

(a) (b)

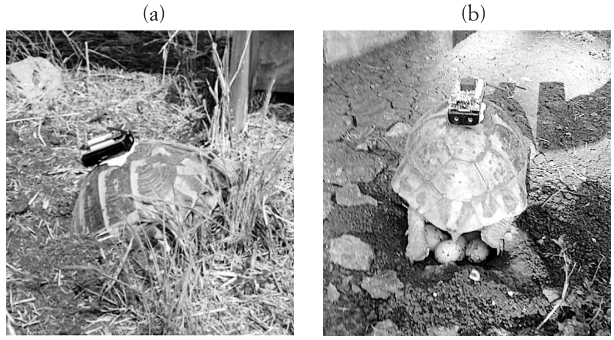


Fig. 4 - A tortoise during the nest excavation phase (a) and the eggs deposition phase (b).

[5] http://www.tinyos.net

T. marginata and *T. graeca.* In our experimental analysis we mainly focused on monitoring the tortoise's activity during the excavation of the nest, as this operation is preliminary to the deposition phase. We also monitored other activities of tortoises (e.g., eating, walking) which, however, are not shown here for the sake of space. We performed 53 measurements during the nest excavation phase in particular. In 13 cases this operation was really followed by the eggs deposition, specifically we have nests with eggs of *Testudo hermanni hermanni* from Sicily (1 nest), *Testudo graeca* (1 nests), *Testudo graeca* from Libya (1 nest), *Testudo hermanni boettgeri* (2 nests), *Testudo hermanni hermanni* from Veneto (1 nest) and *Testudo hermanni hermanni* (7 nests). The tortoises in this 13 cases were all different. In the remaining 40 cases, the tortoise left the nest without deposing eggs. There are different reasons for such a behavior, such as a very high temperature, the presence of rocks during the excavation, the disturbance from other specimens, etc. However living in captivity is responsible for this lack of deposition.

We started our activity monitoring analysis with a *Testudo hermanni boettgeri* tortoise whose sizes are as follows. The length of carapace and plastron are approximately 20 cm and 16.5 cm, respectively, while the maximum width and the maximum height of the carapace are about 14.8 cm and 10.4 cm, respectively. Figure 5 shows the typical movements, as measured by the 2-axes accelerometer (along the X and Y axis), during the nest excavation phase. For the sake of clarity, in Figure 5 we only show the initial part of our observation (i.e., the time interval 0-1200s). The X axis indicates the movements of the carapace of the tortoise on the short side and, then, the motion due to the oscillation of the legs that bring alternately the left and right side of the carapace to perform movements from bottom to top. The Y axis indicates the inclination of the long side of the carapace due to the depth of the hole. From the analysis of the plots in Figure 5, it emerges that the movement pattern during the excavation phase is quite regular, even though noisy. Specifically, we can observe an almost periodic variation in the values along the X axis, with a period of approximately 25s, which are due to the change of tortoise's leg during the excavation of the hole. The descent phase of the step lasts, on average, about 10 seconds.

Figure 6 shows the movements during the nest excavation phase of a *Testudo hermanni hermanni* from Sicily (again, we only show the time interval 0-1200s). In this

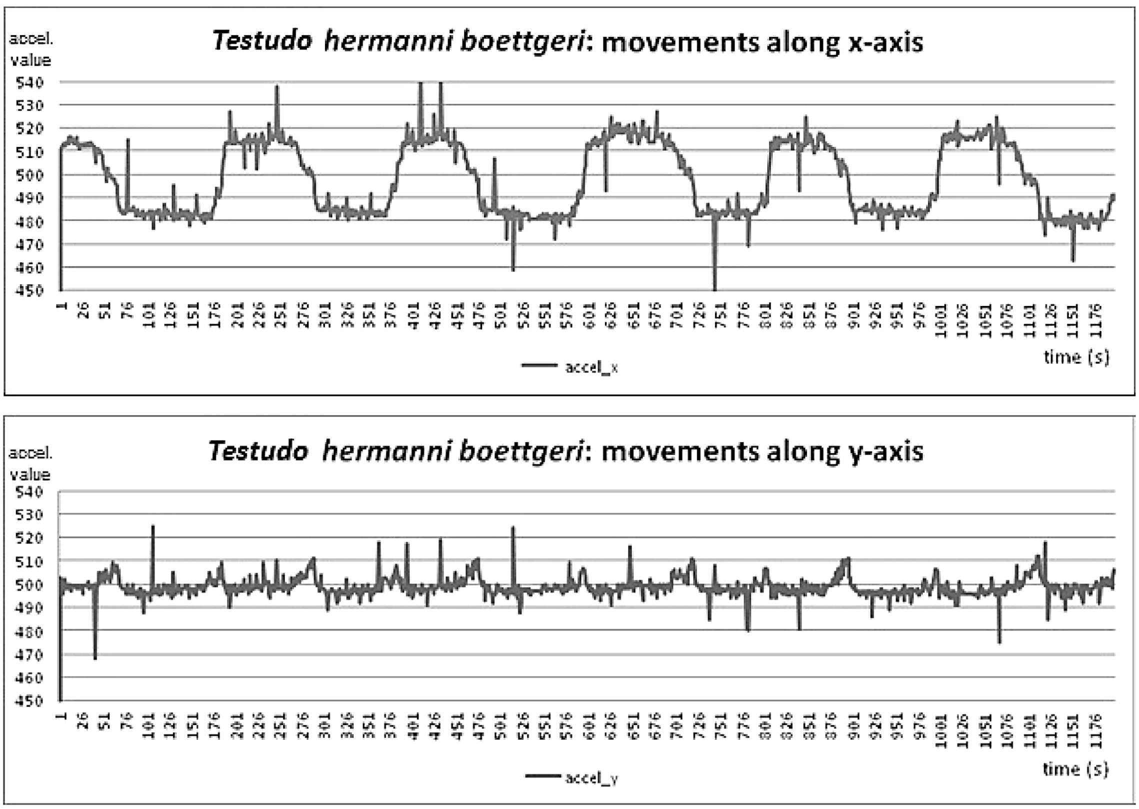
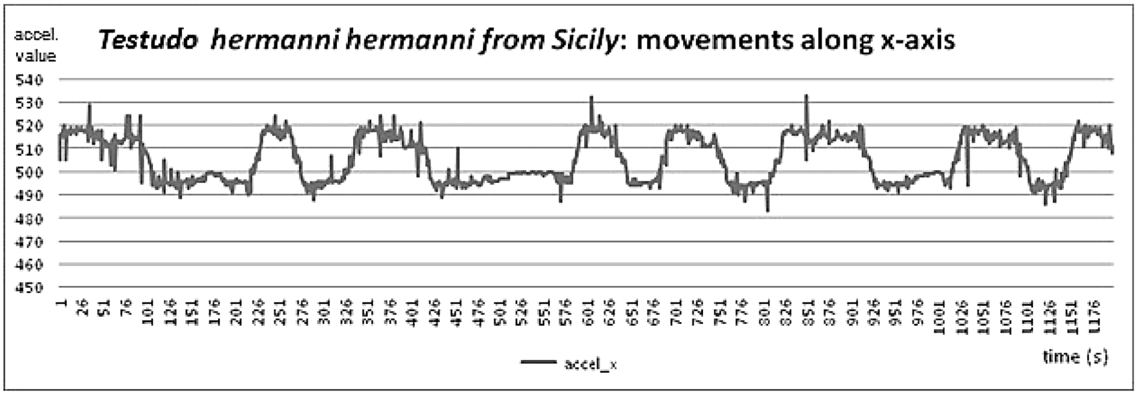


Fig. 5 - Typical movements of a *Testudo hermanni boettgeri* tortoise during the nest excavation phase, along the x-axis (top side) and y-axis (bottom side).



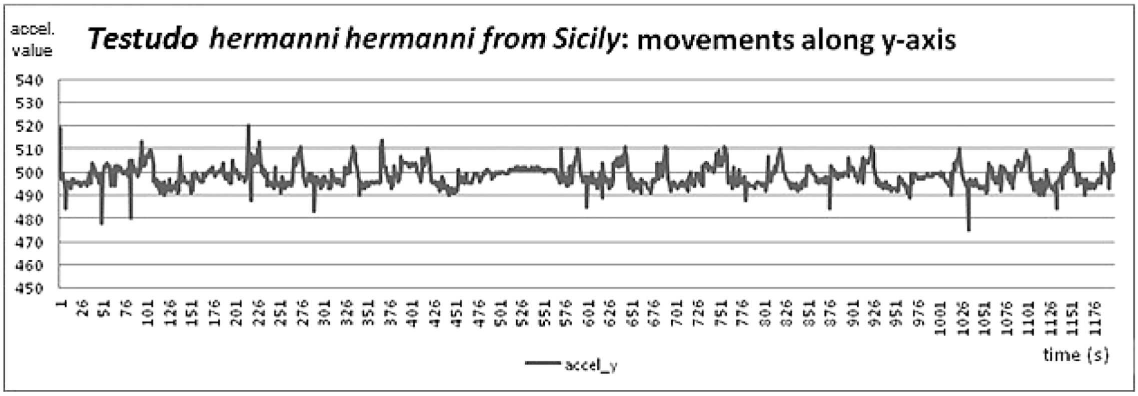


Fig. 6 - Typical movements of a *Testudo hermanni hermanni* from Sicily during the nest excavation phase, along the x-axis (top-side) and y-axis (bottom side).

specific case, the sizes of the tortoise are as follows. The length of top and bottom carapace are 16.4 cm and 13.1 cm, respectively, the maximum width of the carapace is about 10.9 cm, while the height of the carapace is about 7 cm. The tortoise behavior is very similar to that observed in the previous case (*T. hermanni boettgeri*). Again, we can see an almost periodic pattern, along the X axis. The duration of the period is now, on average, about 20s, while the descent phase of the step is, on average, about 3 seconds.

We also performed other measurements with other species (namely *T. marginata* and *T. graeca*), which are not shown here, due to the limited space. In all the cases we observed an almost periodic pattern, similar to those shown before. However, the period size and the duration of the descent phase depend on the specific specie.

5. Conclusions

In this paper we have proposed a sensor-based system for early localization of tortoises during the eggs deposition phase. The proposed system is capable of (**i**) recognizing the typical movements of tortoises during the deposition phase (**ii**), localizing the nesting site, and (**iii**) communicating its coordinates to a control center in real time. Therefore, the staff assigned to eggs collection can reach the reported nesting location, even in the presence of (limited) localization errors. We are currently implementing the proposed system. Specifically, we have already implemented a data logger to acquire data during the deposition phase, and we have actually used it to perform a number of experimental measurements on different tortoise species. The experimental measurements show a very regular movement pattern during the nest excavation phase. This experimental data will then be used to train the pattern recognition algorithm in the real system.

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