Smart Nest Box: IoT Based Nest Monitoring In Artificial Cavities

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***Abstract*—With climate change, habitat loss, and impoverishment of food sources, several species of bird are are threatened today. It is crucial to conserve the biodiversity in ecosystems but the conservation that requires an improved knowledge of these. In this paper, we propose a low-cost connected nest box that make photos of nestling and measures them weight with a load charge. Air temperature and humidity are also regularly controlled to follow environmental conditions and their impact on the nestling.**

***Index Terms*—Bird Nesting, ecosystems conversation, ESP32, conservation of species, nesting monitoring, nest box**

I. Introduction

Understand ecological systems and conserve biodiversity at a time when many are at risk from climate change and habitat loss has become crucial. Thanks to recent improvements in battery efficiency, sensor technology, Internet of Things, and techniques to analyze crowdsourced data, it is today possible to improve our comprehension of ecological systems [1]. Citizen Science (CS) is an approach which places the public in authentic research alongside professional and provides at same time a wide amount of data researchers and educational benefits for the general public. Frequently, CS projects gathers data with a low quality and limited validity and usability.or the methodology cannot be implemented across the society [2]. Some projects such as bee health [3] have permit to collect massive amount of data and provide to general public precious information about bee behaviors.

The use of one or two camera allows to follow the different step of nesting process, bird behaviors such as the diet composition of prey delivery the different parents, the identification of the frequency and timing of parental activities. Camera can also allows the impact of environmental condition such as the the evaluation the effect of outdoor temperature and light intensity on time spent by the female outside the nestbox, and the decrease of the temperature inside the cavity, viz [4].

In this paper, we present a low-cost smart NestBox adaptable to multiple species by removing part of the front face to obtain a semi-open nest box or by modifying the diameter of the entrance hole to adapt it to one or more specific species by inserting a diameter reducer.

The remaining of this paper is organized as follow: In section II, we present a literature review composed of a background that describes our previous work at local and cloud level, and related works concerning bird houses. In section III, we describe our proposition, its conceptualization. We present also the material and its implementation. In section IV, we present the experiment carried out. The results are then discussed in section V. Finally, we conclude and give and overview of future work.

II. Literature review

The main challenges in the elaboration of avian behavior monitoring is on one hand to choose an adapted material able to measure finely and correctly environmental conditions, and on the other hand do not disturb nesting with the material introduced in the artificial cavity or the nesting box. The following paragraph focuses on these aspects and on reviewing existing works dedicated to this field in the literature.

A. Background

a) ***At Local Level:*** In our previous work [5], we have carried out a comparative study of IoT interoperability archi-

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tectures. In this study we described the need of interoperability in IoT architectures. We have then presented the different kinds of architectures used in the field of IoT. The article end up with an analysis of the various recent research proposed to guarantee interoperability between connected objects and their architectures, and a critical study which determine the limits of these architectures. Finally, we concluded that, despite the diversity and usefulness of the proposed architectures, they showed certain crucial limitations and weaknesses. Indeed, most of these architectures do not meet the requirements for mobility, functionality, efficiency and cost optimization; the vast majority of these architectures are limited to a specific field of application; also, these architectural proposals are generally limited to the level of energy consumption; Most of them do not offer the possibility of providing platforms which interact with one or more specified systems. However, none of these architectures presents a generic model taking into account all the protocols and technologies and their use cases.

In [6], we have proposed a prototype of IoTs interoperability models which allows to define all the concepts as well as the relationships between them, in order to define interoperability in the context of Internet of Things.

The work presented in [7] described our generic IoT interoperability architecture allowing to generate other specific physical architectures which perfectly meet the need of best practices for IoT applications. These practices consists of : (1) achieving interoperability between IoT platforms thanks to the automatic generation of specific models and the use of MDA (Model Driven Architecture), especially the bridge element of the architecture. We can therefore benefit from interoperability even between the specific architectures generated, which ensures better interoperability between IoT architecture and platforms.

Another good practice is (2) technical transparency guaranteed by the use of our generic IoT architecture of interoperability. Hence, project leaders can generate their physical architecture proposals specific to their needs, and then estimate materials and implementation costs in advance, and maximize productivity, [5]. Two other good practices are: (3) defining an interoperability meta-model [8] and (4) the study of a new quality model of interoperability for connected objects [9].

*b) **At Cloud Level:*** In previous papers, we have a semantic driven and modular cloud centric Lambda Architecture [10]. We have implemented LoRaWan and tested it in interaction with our cloud architecture in following uses cases: landslides monitoring [11], bee health [3], irrigation [12].

B. Related Works

Nest boxes are widely used to help birds find suitable places to live during their breeding season. A major drawback of regular nest boxes is the fact that they cannot provide any information whether the house is used or not. Additional details, including the number of birds visiting or living in the nest box, their type, species, etc., are also impossible to obtain unless an on-site visit for inspection and cleaning of the nest box.

In order to solve this problem, several articles have proposed solutions based on IoT, among others we find Jordan Raychev and al. [13] who proposed to build an intelligent nest box connected to the cloud. This house has all the necessities of regular birdhouses, but also has additional smart features. This solution collects information about the birds that visit the house, as well as taking measurements on the environmental parameters of the surrounding area, including temperature, atmospheric pressure, humidity, gases, etc. collected environmental parameters will be used to analyze the behavior of the birds and will ensure that the deployed nest boxes will always be habitable.

Recently, researchers have study avian behavior in artificial nest cavities by means of Raspberry Pi such as Prinz et al. [14] and demonstrates the capability of micro computers to acquire images or video to characterize avian behavior. Other authors such as Lamister et al. [15] have studied the influence of microclimates on avian behavior. But often researchers don't acquire simultaneously environmental data at same time than behavior data. McBide et al. [16] use Raspberry Pi-based devices to collect simultaneously avian behavioral data and associated environmental data. Zárybnická et al. [4] have proposed a smart nest box using a pair of usb industrial monochromatic cameras providing a resolution of 1280 x 1024 pixels up to 10 fps, rfid reader, exterior light sensor, light barrier, interior and exterior temperature sensor functioning with a 60Ah 12V battery during 6-8 days. Afterwards, all this data allows to achieved video analysis process, and statistical analyses.

Ahmad Rizen Ibrahim et al. [17] have proposed an automated LoRawan monitoring and control mechanism for Swiftlet Bird House, this solution aims to prepare an enabling environment for birds to remain in artificial nest boxes, via wireless sensor networks, such as LoRa and the techniques of analysis of humidity, temperature and oxygen data, as they subsequently developed an algorithm for counting birds entering and leaving the bird's nest, with an accuracy of 92.5 %.

Ibrahim et al. [17] proposed an automated system to monitor and control by means of LoraWan and sensing devices to measures indoor temperature, humidity, and oxygen inside nest box.

III. Our Proposition

Our approach aims to conserve biodiversity by following of bird nesting in context where many species are at risk from climate change and habitat loss. We propose a smart nest box that make photos of nestling and measures them weight with a load charge. The temperature and humidity are also regularly controlled.

A. Smart Nest Box conceptualization

Artificial nest box is usually specific for one or a limited number of species. We would like improve the concept of classic wood nest box to adapt it and allows the nesting of chosen species. Moreover, the nest box must be large enough to accommodate electronic equipment. The diameter of the entry hole conditions the species that can use the nest box. On the other hand, other species need semi open shelters to nest.

(a) Classical Nest Box. (b) Opened Nest Box.

Fig. 1: Nestbox configurations.

We are thinking that it is possible to transform easily a big enough nest box with chosen diameter reducer to obtain a specific entry diameter in order to host specific species (See Fig. 1a). On the other hand, a part of the front panel can be also removed to transform it in a semi open nest box (See Fig. 1b). Thus, our versatile birdhouse would be easily adaptable a wide amount bird species.

The following of the nesting can be ensure by a camera place on the top of the nest box and directed to the bottom to make photos of birds, eggs, nestlings but also prey brought by parents. Displacement of parents are quantified to measure the parent activity and thus indirectly evaluate the abundance of prey. A measure of weight in the time allows to measure weight gain of nestlings.

B. Material

In this section, we present different elements which will allow us to build our prototype.

1) The solar panel of 165x165mm in monocrystalline silicon provides a maximal provides a supply of DC12V 5W (See Fig. 2a).

2) The tension regulator converts an input supply between DC8V to DC40V in a stable tension of DC5V (max 25W) (See Fig. 2b).

3) The TP4056 (NanJing Top Power ASIC Corp.) is a Lithium Cell Charger Module with complete constant-current / constant-voltage linear charger for single cell Li-Ion battery with Battery Protection circuit. Hence This module allows to charge a Li-Ion battery from solar panel or an external DC5V power supply (See fig. 2c).

4) A battery of 3.7V 3400 mAh model 18650 Rechargeable Li-Ion Battery ensures the powering of the microcontrollers and sensors (See Fig. 2d).

5) The ESP32-CAM AI Thinker is an ESP32-WROVER-32 at 240 MHz associated with a 2MP (1600*1200 pixels) Camera Module OV2640 (OmniVision). This microcontroller is also equipped with a SD Card module to store images taken when a event is detected. (See Fig. 2e).

6) The MCP23008 chip is connected to ESP32 I^{2}C bus which add it 8 supplementary GPIO (See Fig. 2f).

7) The Weight Measurement is done by means of a 1kg Load Cell and 24-Bit Analog-Digital convertor HX711 Module (See Fig. 2g).

8) The AM2302 sensor (Aosong Electronics Co.,Ltd) measures the air temperature and the relative humidity at a sampling rate of 0.5Hz. This low-cost sensor operates with a DC voltage between 3 and 5V, and consumes 2.5 mA max current during the measurement. The accuracy on the temperature is $\pm$0.5°C in the range -40°C to 80°C and 2-5% in range 0% to 100% for the humidity (Fig. 2h).

9) The Obstacle Avoidance Sensor allows to detect the passage of birds at the entrance to the nest box (Fig. 2i). This sensor allows to detect a bird over a distance between 2 and 30 cm.

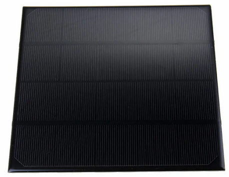
10) A Real-Time Clock (RTC) ds3231 is connected on I^2C bus of the ESP32-CAM. It trigger an interrupt 1 time a day to ESP32-CAM which quit sleep mode, take a photo of nestlings, acquire environmental parameters send them, and returns in sleep mode. The second function of ds3231 is to time stamp data (See Fig 2j).

11) The 10 mm white led allows to light nestlings during photo taking (See Fig. 2k).

C. Implementation

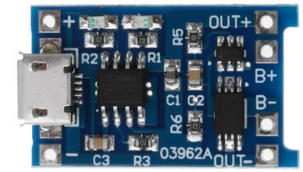
This section is composed of three parts. The first one is the implementation of the Interoperability Architecture. The second is the Device developed, and finally the third is the cloud architecture which aggregate data from local architecture.

a) Interoperability Architecture: In this section, we propose our own architecture of interoperability based on the reference IoT interoperability architecture proposed by Ait Abdeloualid et al [7]. This architecture contains seven layers: (1) Infrastructure Layer similar to the physical layer of OSI



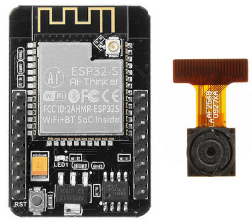
(a) DC12V 5W Mono crystalline Solar Panel.

(b) DC12V-DC5V Converter.

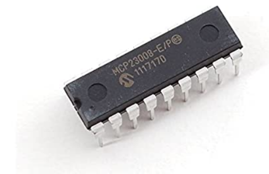


(c) TP4056 - Lithium Cell Charger Module with Battery Protection.

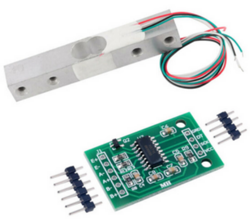
(d) 3.7V 3400mAh 18650 Rechargeable Li-Ion Battery.



(e) ESP32 CAM with OV24640 2MP camera.

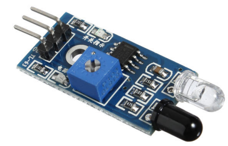


(f) I^{2}C 8 input/output port expander.

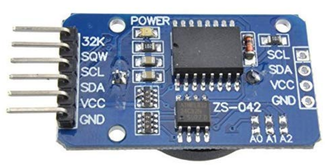


(g) 24-bit ADC with load cell.

(h) Temperature and Humidity Sensor.



(i) Obstacle Avoidance Sensor.



(j) Real-Time Clock.

(k) White Led 10 mm.

Fig. 2: Components and sensors.

model. it interfaces the different connected objects which acquire environmental information, actuators, real life objects; (2) Information Layer allows objects discovery, identification and data format definition to transmit to the up layer via microcontrollers; (3) Communication Layers allows to switch data between different communication protocols such as Wi-Fi, Li-Fi, Z-Wave, NFC, TCP/IP, Bluetooth, MQTT, 4G, and 5G; (4) Connectivity Layer contains a gateway to transfer collected data by means of different communication protocols and interoperability platforms i.e.: OpenHAB, Home Assistant; (5) Middelware Layer ensures data processing such as cloud storage of data retrieved from IoT sensors; (6) Service Layer provides reliable and crucial services for heterogeneous application in various domains; (7) Application Layer presents data on their final form in a dashboard to end users and control and view objects activity remotely (See Fig. 3).

b) Developed Device: The Fig. 4 presents a high level implementation of the components in the developed device.

All sensors and the micro controller are powered by means of one solar panel DC12V (5W) of 165x165mm, installed on the roof of the nest box.

The developed device is built around an ESP32-CAM with a GPIO expander (MCP23008) and a Real Time Clock (DS3231) connected on its I^2C bus. The ds3231 triggers an interrupt 1 time a day to ESP32-CAM which quit sleep mode, take a photo of nestlings, acquire environmental parameters send them, and returns in sleep mode. The second function of ds3231 is to time stamp data (See Fig 2j).

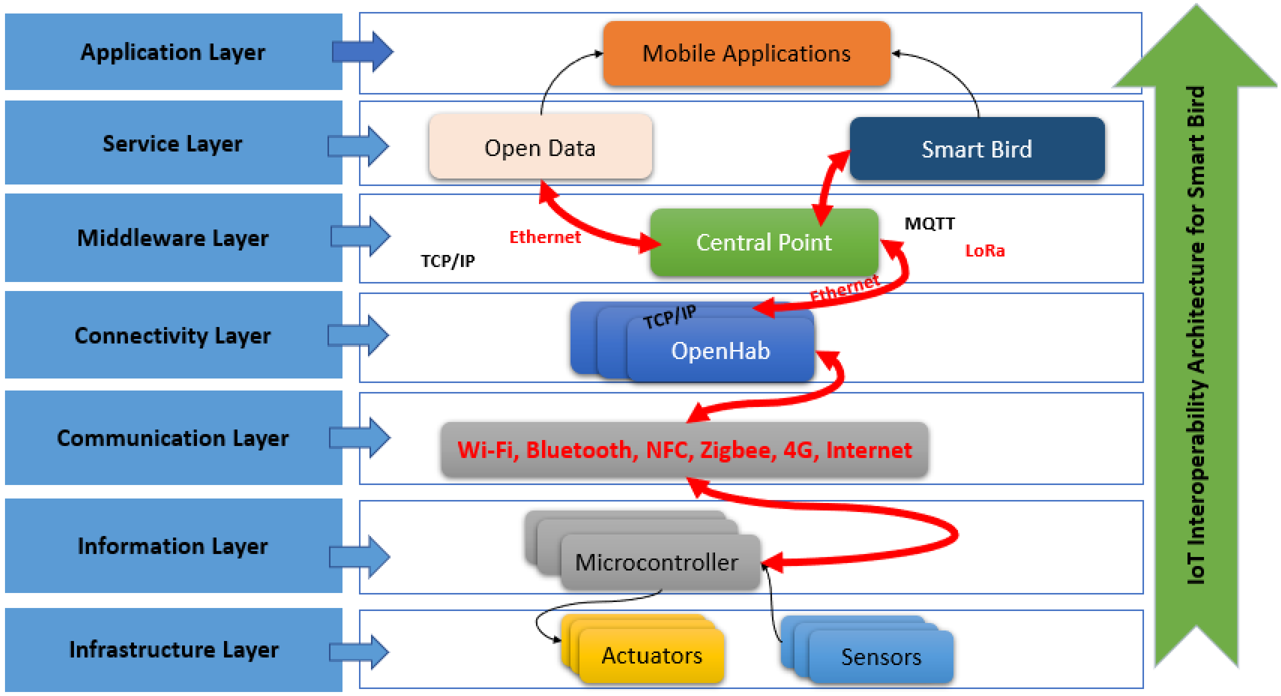


Fig. 3: Proposed Architecture.

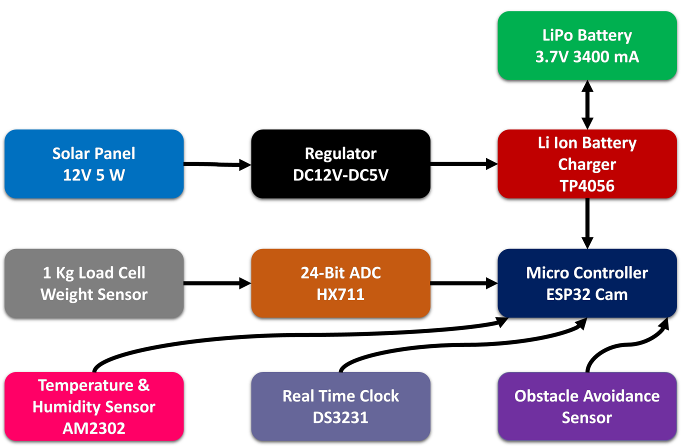


Fig. 4: A block diagram of the nestbox electronic showing the components and interconnections.

The microcontroller is powered by the charge module (TP4056) connected on one hand to Li Ion battery of 3400 mAh 3.7V and on the other hand to a tension regulator DC12V-DC5V joined to DC12V 5W solar panel as illustrated at Fig. 5.

The Fig. 5 shows an electrical schema of the interconnection between the solar panel, the dc-dc converter, the charger module, the Li-Ion rechargeable battery and the micro controller ESP-CAM.

A DHT22 (AM2302) temperature and humidity sensor, a HX711 (Avia Semiconductor Co., Ltd), 24-bits Analog-Digital convertor joined to a load cell weight sensor with a max load of 1 Kg is connected to the MCP23008. Two white led with a diameter of 10 mm are also connected to the MCP23008 and are activated when photo are taken.

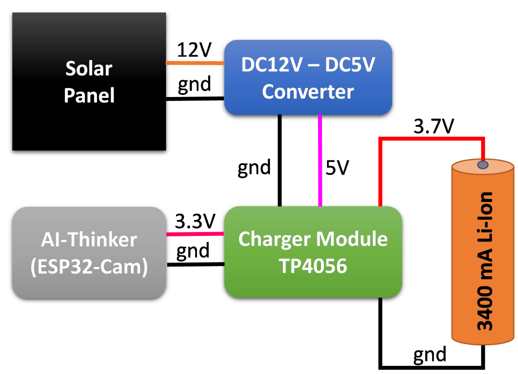


Fig. 5: Partial electrical schema.

The obstacle avoidance sensor is directly connected to the ESP-CAM. When a movement is detected the ESP32 CAM is wake up and the weight is measured. The ESP32-CAM is then put into deep mode.

The Fig. 6 presents an electrical scheme of sensors connected on the ESP32-CAM / MCP23008.

c) Cloud Application: On Our cloud architecture, we have developed and deployed a web application named ”Data Nest Analyzer” to collect, store, process, and visualized acquired data by each smart nest box (See Fig. 7).

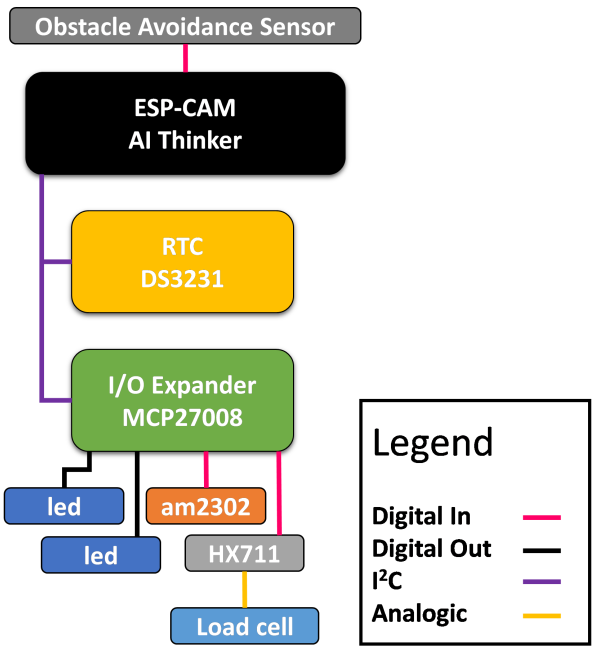


Fig. 6: Electrical Scheme.

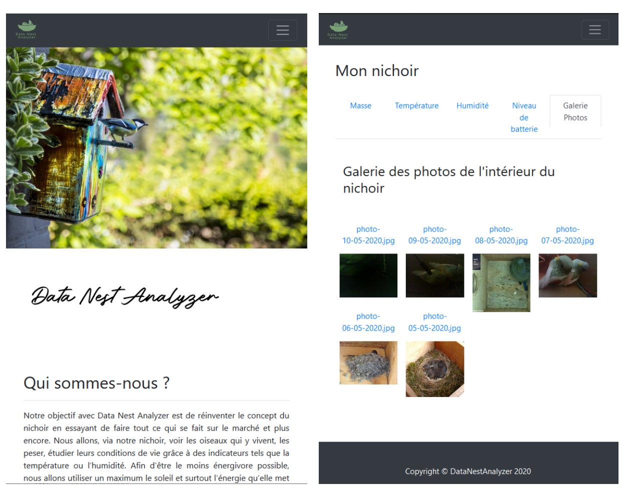


Fig. 7: Data Nest Analyzer.

IV. Experimentation

For our experimentation's, we have used an Amazon Basics Wooden Birdhouse with dimensions (l,w,h) of 16 x 15.2 x 30 cm adapted as illustrated in Fig. 1a. This nest box has been modified to be adaptable in semi opened configuration as illustrated in Fig. 1b. A false ceiling has been added to accommodate most of the electronic equipment. The obstacle avoidance sensors has been implanted under the entry hold and and headed up the birdhouse. A mobile false floor has been added to the bottom of the nest box and fixed to the load gauge, the other end of which is fixed with the bottom of the nest box. The birdhouse has been configured to accommodate blue tits with a 42mm diameter hole. Indeed, a 28 mm diameter hole is more suitable for blue tit (*Cyanistes caeruleus*) and marsh tit (*Poecile palustris*), a 30 mm diameter hole will favor the great tit (*Parus major*) and the sparrow.

V. Results & Discussion

The nesting box hosted the nesting of blue messages. We first configured the esp cam in streaming to verify that the obstacle detection sensor is capable of measuring the entry and exit of birds. We were able to determine that 86% of the passages were correctly detected. The load cell measures the weight during the nest building phase, the bridge, the hatching and the growth of the birds. However, the surpluses accumulated in the nests are also to be counted. It is therefore difficult at this stage to distinguish the actual weight of nestlings from that of organic waste.

VI. Conclusion & Future Work

In this paper, we present a low-cost connected nest box, built with on open source and an open hardware using IoT Compatibility Architecture to manage and able to interoperate various protocols of communication. The community has also the possibility to send data to a cloud centric architecture and contribute to species conservation and ecosystems monitoring . Thanks to the proposed architecture, we are able to employ any installation using MQTT protocol and integrate it in existing home system such as Home Assistant, OpenHAB, etc.

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Supplementary Material

All script source codes for installing, setting up our prototype and Fritzing schema are publish under MIT license on Github at url: https://github.com/Smartappli/IoTDemonstrators /tree/master/NestBox.

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