*Sensors* **2015**, *xx*, 1-x; doi:10.3390/——

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**sensors**
**ISSN 1424-8220**
www.mdpi.com/journal/sensors

*Article*

# An RFID Based Smart Feeder for Hummingbirds

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*Received: xx / Accepted: xx / Published: xx*

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**Abstract:** We present an interdisciplinary effort to record feeding behavior and control diet of a hummingbird species (*Phaethornis longirostris*, the long-billed hermit or LBH) by developing a Radio Frequency Identification (RFID) based smart feeder. The system contains an RFID reader, a microcontroller, and a servo-controlled hummingbird feeder opener. The glass capsule RFID tag is mounted on the hummingbird. The smart feeder can provide specific diets for predetermined sets of hummingbirds at the discretion of biologists. This is done by reading the unique RFID tag on the hummingbirds and comparing the ID number with the pre-programmed ID numbers stored in the microcontroller. The smart feeder records the time and ID number of each hummingbird visiting or feeding events. The data is stored in an SD card. The system is powered by two 9V batteries. The detection range of the system is about 10 cm centimeter. Using this system, biologists can assign the wild hummingbirds to different experimental groups by regulating their diets. During field testing, the smart feeder system has demonstrated a high reliability of detection for RFID tags on hummingbirds and provides pre-designed nectar to target hummingbirds. The smart feeder can be applied to other biological and environmental studies in future.

**Keywords:** RFID; Passive ID Tag; hummingbird feeder; interdisciplinary application; electrical mechanical co-design

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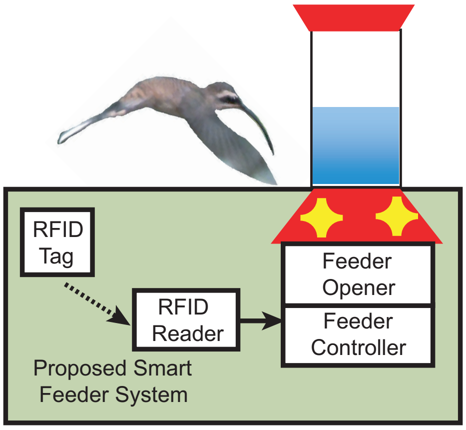



**Figure 1.** Proposed smart feeder system

## 1. Introduction

Recent technological advances are promoting increasing numbers of interdisciplinary studies involving intelligent sensor applications. In ornithology and the poultry industry, there is strong interest in data collecting systems to study behaviors of birds. General expectation of such systems includes low cost, longer detection range, easy implementation and maintenance. Moreover, an intelligent system should also be able to process data from the sensor, and perform certain actions based on the received data with pre-defined algorithms. Furthermore, the system should be flexible to adjust parameters in the pre-defined algorithm. Such systems can greatly reduce labor cost and provide novel insights into animal behavior and responses to environment change. With these design expectations, in this paper we demonstrate an RFID based smart feeder system for hummingbirds.

RFID systems have been widely used in agriculture [1–3], ecology [4–6], and especially ornithology [7–9] studies. It has been proposed or demonstrated that RFID systems can be used in monitoring foraging of free-living birds [10], detecting disease [11], recording mass of birds [12], and studying their social behavior [13]. In current solutions, RFID systems are usually used to automatically record events when the target bird is presenting at certain location, i.e. a feeder or nest. In a typical application, the RFID reader is placed at a predefined location. The passive integrated transponder (PIT) tag is fixed at the target bird. When the bird with a PIT tags approaches the RFID reader, the RFID reader records the timing of this visit. A more extensive review of recent RFID projects can be found in [14]. These systems have potential to perform a predefined algorithm and operate certain equipment when the visit is detected.

Currently some systems have implemented networking and logic circuits [6], but, to our knowledge, systems equipped with mechanical devices, i.e. a servo, are not widely available (but see [4,5]). Some systems still require handheld recording camera to assist the observation [2] because they lack automatic algorithms and controllers. As a result, certain observations are difficult to perform in wild environment because of limited manpower for data logging, and the lack of ability to experimentally control diet for birds. Thus, there is potential to greatly enhance the performance and functionality of RFID based systems by embedding processing algorithms and mechanical devices.

In this paper we focus on designing a smart feeder to automatically control nectar diet for individual hummingbirds. We targeted the feeder because feeding ecology has been a key factor in the evolution of

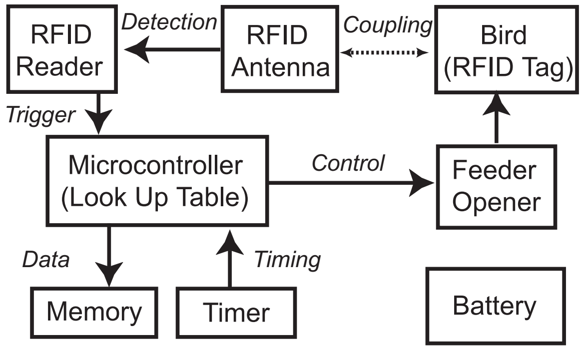



**Figure 2.** System schematic of the smart feeder system

morphology, behavior, and life history traits in birds generally and hummingbird in particular [15,16]. The cues and signals used to locate food have shaped animal sensory systems and cognitive abilities [17,18], and the spatial and temporal distribution of food resources has promoted the diversification of foraging strategies [19] and mating systems [20]. Hence, studying the relation between animals and their feeding resources is critical to understanding their ecology and evolution. Hummingbirds are ideal candidates to study different aspects of foraging [21] and have evolved unusual morphological [22] and physiological traits [23], to exploit nectar-producing flowers [24]. They are also easily attracted to artificial feeders, facilitating observational and manipulative studies. Thus, an RFID based smart feeder for hummingbirds can be a very useful tool for studying foraging-related traits by improving the ability to automatically manipulate feeding conditions and individualize treatments in the field.

This paper is organized as follows. In Section 2 system architecture and subsystem design are presented. Section 3 describes the experiment of a preliminary field study with the recorded data. Section 4 summarizes the system performance.

## 2. System Design and Implementation

The smart feeder is designed to provide food for selected hummingbirds. The operation of the proposed system is shown in Fig. 1. The selected hummingbirds have PIT tag installed on their body. When such hummingbirds with PIT tag approach the feeder, the RFID reader detects the tag ID and the feeder controller decides whether the feeder should be open or not, based on diet selection algorithms which operates a predefined experiment procedures. At the same time, the RFID reader records the PIT tag number and the time of this event for further biological studies. In this section we introduce the design considerations and implementation details of the proposed system.

Because the deployed system is expected to interact with hummingbirds, there are several design considerations implicated. First, we want to alleviate the influence of the extra devices on the target hummingbirds during the feeding process. For example, we need small and light tags that do not affect the behavior of hummingbirds. General guidelines call for tags that weigh no more than 3-5% of a hummingbird's body weight [12]. Second, we want to prevent the feeding mechanism from conditioning the feeding habits of hummingbirds. For instance, while the target hummingbirds used to obtain food from regular feeders, we try to minimize the size of the RFID reader and antenna and have visual block from the view angle of the hummingbirds when they are feeding, so the hummingbirds are not afraid of

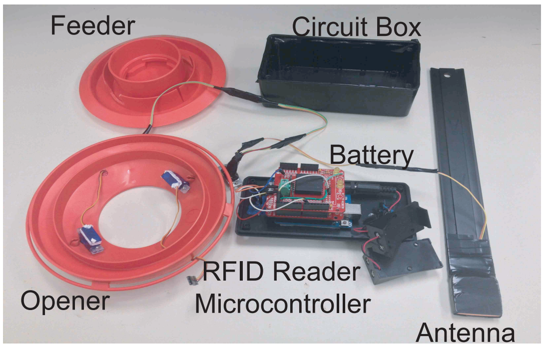




**Figure 3.** System assembly of the smart feeder. Top: all components with the circuit box. Bottom: final assembly.

the feeder. Third, it should ensure that the hummingbirds are not harmed during experiment. The feeder should not close while the hummingbirds are feeding. Fourth, we want to reduce the false detection by optimizing the detection range. In addition, there are size, weight, and power (SWaP) requirements that are imposed by conditions of deployment in the field setting. In particular, the feeder should tolerate high humidity working conditions since they are deployed in rainforest environment. Finally, we want to reduce the cost of the system to enable future mass deployment in the field.

The proposed system consists of three subsystems: a microcontroller subsystem, an RFID subsystem, and a mechanical feeder opener. The RFID reader monitors the environment through the antenna and searches for PIT tags nearby. When a tag is detected, the ID number is sent to the microcontroller. The microcontroller along with the supporting electronics, including a clock module and a memory module, records ID number and timing of this detection. The microcontroller also makes a decision based on predefined algorithms, and regulates the response of the feeder opener. Fig. 2 presents the detailed system schematic. Fig. 3 shows the whole system assembly of the smart feeder.

### *2.1. Microcontroller Subsystem*

In this section we describe operation of the microcontroller and its peripheral devices. The microcontroller serves as the main processing unit for the smart feeder. The microcontroller controls the RFID subsystem, the mechanical opener, the timing unit, and the memory card. All circuits are powered by a 5 Volt power supply regulated from the 9 Volt batteries by the Arduino platform. The communication between the microcontroller and its peripheral devices uses universal-asynchronous-receiver/transmitter (UART) serial protocol in order to save power.

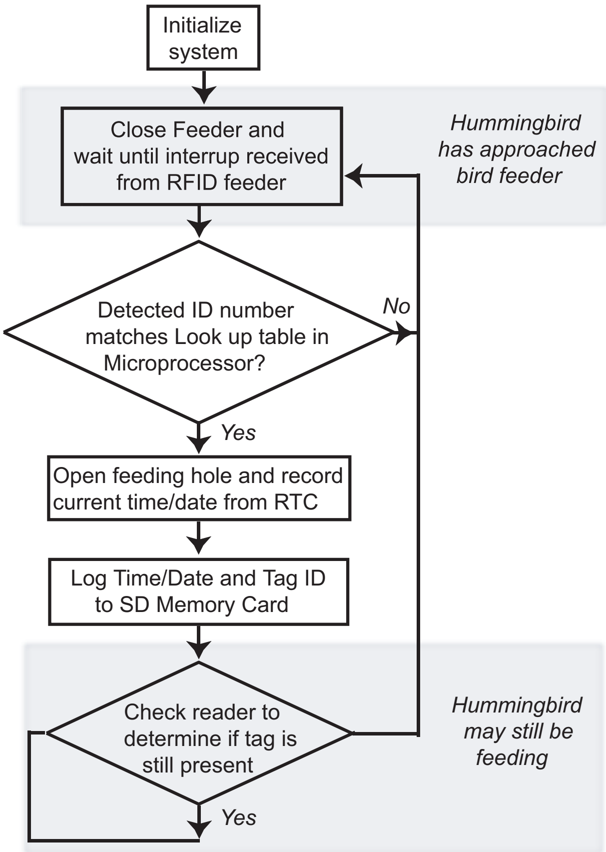



**Figure 4.** Microcontroller software flow chart.

The microcontroller operates according to the algorithm flow chart in Fig. 4. We use *C* language to program the microcontroller. Initially, the smart feeder is powered on with the feeding orifice in the closed position (initialization stage). Next the microcontroller monitors the RFID sensing module, which is continually searching the immediate environment for the presence of an RFID tag. If a tag disrupts the magnetic field, the microcontroller registers the event and proceeds to compare the detected RFID tag number with a look-up table (LUT) that is written in the microcontroller's memory to determine whether the feeder orifice should be open. In a simplified operation, hummingbirds are granted or denied access to feeders according to the LUT. The detected event is then logged into the Secure Digital (SD) memory card, which contains information of timing and the tag ID number. Depending on the study designed by biologists, the hummingbirds diet can also be individually regulated by controlling access to particular feeders in an array.

In the event that the bird remains feeding, we need to protect it from being hurt by the feeder closing on its bill. Therefore during feeding process, the microcontroller continually monitors past/present magnetic field state in order to ensure the bird has left the area. This protects the birds' beak from being damaged by the mechanical arm that regulates access to the feeder. After the software has sensed a safe condition for the birds, the orifice is once again closed and awaits the next trial.

The microcontroller is supported by the real-time clock (RTC) and SD card to record timing of detected visiting and feeding events. We selected the microcontroller, the RTC and the memory card from the off-the-shelf components by considering their physical size, weight, power consumption and performance. We choose ATmega328 on an Arduino board as the microcontroller for ease of portability.

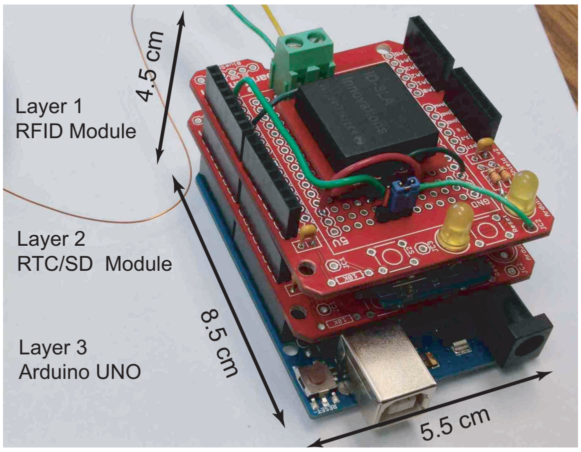



**Figure 5.** Electrical subsystem in the smart feeder system. The three layer board hosts RFID reader, RTC/SD module, and the Arduino microcontroller module.

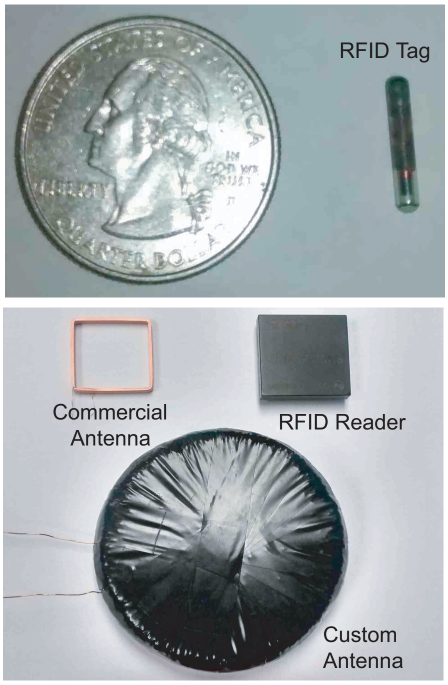



**Figure 6.** PIT tag (top), RFID reader, and reader antennas (bottom) in the proposed smart feeder system

The Maxim DS1307 is selected as the RTC since it has a life expectancy of 5 years on a single 3V 25mAh coin cell battery. The storage solution is a single 8GB microSDHC memory card, which granted the ability to log over the period of deployment. The assembly of electrical subsystem is shown in Fig. 5.

### *2.2. RFID Subsystem*

In this section we present design of the RFID subsystem. The RFID subsystem consists of the RFID reader, RFID antenna and PIT tag. An RFID reader detects the nearby PIT tag via the RFID antenna. Detection begins with the inductor being excited by a signal at the frequency of interest. Detection of the

PIT tag is achieved with a coil antenna, which is equivalent to an inductor. As the inductor oscillates, a magnetic field is induced due to the current flowing through the conductor. This magnetic field couples with the PIT tag. At the tag, the magnetic field induces a current, which provides power to the PIT tag. When the tag is powered on, on-board circuitry affects the magnetic field by switching an extra load in the tag on and off. When the load is switched on, the amplitude of the signal at the primary is reduced. When the load is off, the signal is unaltered. The tag provides its unique key by switching on/off in the appropriate pattern. By demodulating the envelope of the waveform at the primary, the unique ID of the tag can be determined.

In our design, the size of the RFID tag and the detection range are the most important considerations. A 125kHz RFID system is selected due to the miniature size of its PIT tag. The detection range is determined by the size of the antenna and the supply current to the antenna by the RFID reader. In this project, we need a 5-15cm detection range and the size of the antenna should be small enough to be implemented on the feeder, which has a diameter of 40 cm. Based on the above considerations, we choose the ID Innovations ID-3LA reader module as the RFID reader, which requires an external antenna. The reader module provides 125mA of fixed output current to the external antenna. The optimization is achieved by engineering the antenna geometry and impedance.

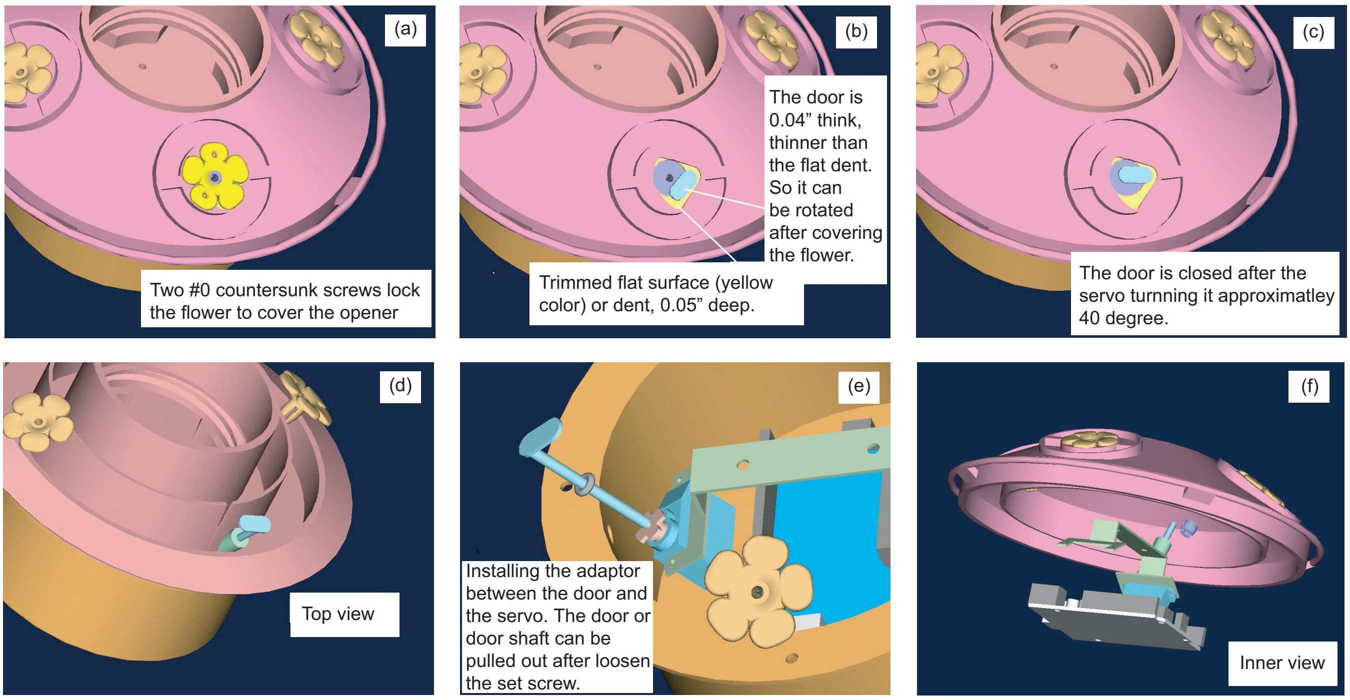



**Figure 7.** Computer aided design models of installing custom feeder opener on an off-the-shelf hummingbird feeder. The main steps include modifying the flower opener, resurfacing the flower opener, installing the door, and installing the servo motor.

We compared different antenna solutions for the RFID system. The antenna selected for the system was chosen after a trade study that addressed risks pertaining to performance and manufacturability with respect to the RFID transceiver. Three antennas were initially considered. The first was the ID-Innovations ID-20 transceiver. This module is similar to the ID-3LA with the exception of including an internal antenna. The second antenna was a commercial machine-wound rectangular coil. Lastly, a custom hand-wound circular coil was fabricated. Although the custom antenna achieved longer detection distance compared to the other two antennas, due to the reliability concern we choose the commercial antenna for the smart feeder, which had a longer detection range than the internal antenna of ID-20. The RFID tag, reader, and antennas are shown in Fig. 6.

### *2.3. Power Budget*

Biologists require an observation period of the smart feeder experiment to be 2 hours. This sets the power budget of the system. The system consumes 53mA of current when it is in an idle state (i.e. when no birds are present). When a bird visits the feeder, the system demands additional current in order to move the lever-arm of the servo. This current draw was determined to be 155mA consumed over a duration of 450mS (open and close). A generous estimate is to expect a bird to visit the feeder once per minute. Thus, given that the experiment is executed in 2-hour segments, the equivalent duration of the current draw is 54 minutes (or 0.9 hours). The total energy requirement is calculated to be 245.5mAh. Given that the system operates off of two 9V batteries in parallel with a total capacity of 600mAh, the system is able to meet the minimum operating time of 2 hours per experiment. More operation time can be achieved by adding more batteries.

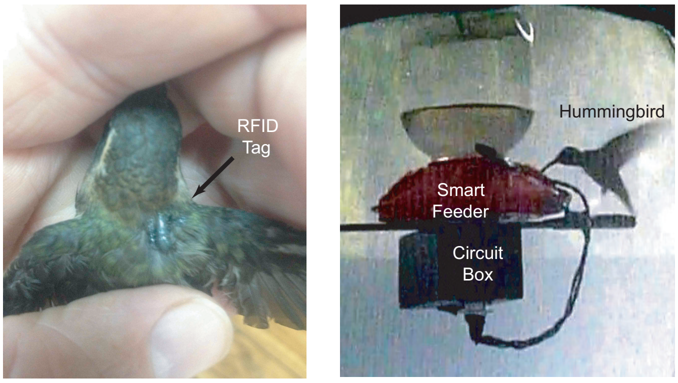
### *2.4. Mechanical Feeder Opener*

The servo-controlled feeder opener is another key component of the smart feeder. The opener contains a servo controlled by the microcontroller, and the opening lever arm controlled by the servo. Both the servo and opening arm are installed on the feeding tray of an off-the-shelf hummingbird nectar feeder (16 oz Clean Feeder, Dr. JBÕs Hummingbird Products). In the mechanical design, we need to ensure that the lever arm can move freely in grooves machined underneath the standard flower-shaped openings. We also have to minimize the noise created by the movement of the lever-arm during the servo operation. These criteria dictate custom machining on the feeder.

We used a CAD tool Pro/ENGINEER to build a 3D model of the feeder, and locate host of the servo and the orifice for the opener. The design reduces the risk of clogging the opener and obstructing the bird from reaching the nectar. In this design we used a trap door architecture. CAD modeling defines the size of the servo. In this design, we deployed the servo POLOLU Corp 1053 sub-micro servomotor, which had a torque of 8 oz-inch. This was sufficient for operating the smart feeder. With the servo dimensions known, the model was transferred to a four-axis CNC mill using a CAM software CAMAX. The design sketch and details in the mechanical drawing are shown in Fig. 7. The custom machining of the mechanical design was performed at Manufacturing Technology and Engineering Center (MTEC) in New Mexico State University.

## 3. Experiment Result

### *3.1. RFID Tag and Mounting*




(a) (b)

**Figure 8.** (a) PIT tag adhered to Hummingbird. (b) Hummingbird consuming nectar food from the proposed RFID smart feeder.

The PIT tag used in the experiment is an industry standard glass capsule. The cylindrical capsule has an approximate volume of 12x2x2 $mm^3$, a mass of 0.095g and is resonant at 125 kHz. While several factors contributed to the selection of the tag, the deciding factors are the tag's mass, availability, and price. Tag mounting procedure is another key factor in the experiment. Instead of implantation, leg-mounting, and leg-bands, we find that direct attaching the PIT tag on the feathers worked very well when adhered the tag to feather using a non-toxic adhesive, as shown in Fig. 8 (a). This mounting process is easier than fabricating leg-bands for each tag. It also provides a high probability of detection when tested with RFID reader.

### *3.2. Field Experiment*

The completed system was tested in the field at La Selva Biological Station in Costa Rica with wild LBH. The hummingbirds were fed manually for several hours to a full day to allow them to adapt to the feeders. Once the hummingbirds were observed feeding unassisted, then the hummingbirds were fitted with the PIT tags. Testing consisted of monitoring the feeder with a digital camera as a means of confirming visits to the smart feeders. Fig. 8 (b) shows a hummingbird having nectar from the smart feeder. During the testing, the smart feeders were very reliable for recording detection and offering nectar. An example of testing data is shown in Fig. 9. After reviewing the video of the experiment, it was observed that the sound and movement of the servo did not alarm the hummingbirds.

## 4. Conclusion

In this paper we demonstrated an RFID based smart feeder system, which can be used as an effective means of monitoring hummingbirds and performing experiments with controlled diets. The system contains an RFID subsystem, a microcontroller subsystem, and a mechanical opener subsystem. The RFID reader detects the tag ID attached on the target hummingbird. The microcontroller automatically records tag ID and the visiting event timing to a SD memory card, and makes a decision of whether the feeder should be open based on a pre-programmed look up table. Based on the command of the microcontroller, the mechanical system operates the feeder and provide pre-designed nectar to specific individual hummingbird. The whole system is integrated on a commercial RFID reader. The

**Table 1.** Measured parameters of the proposed RFID smart feeder.

| Parameters | Value |
|---|---|
| RFID Tag size | 1.3 x 0.8 x 0.6 mm |
| RFID Tag weight | 0.095g |
| RFID Antenna range | 10 cm |
| RFID Antenna size | 3.6 cm x 3.6 cm |
| System power supply voltage | 9 V |
| logging timing resolution | 1 sec |
| Feeder opener response time | 0.5 sec |
| RFID frequency | 125 kHz |

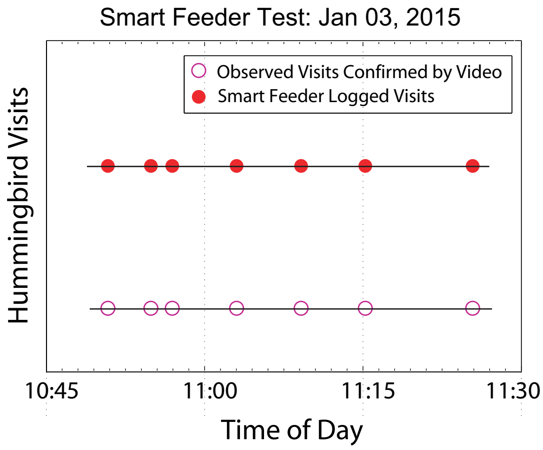



**Figure 9.** Example recorded feeding time from the smart feeder confirmed by video observation. This experiment was performed in seminatural conditions in the rainforest of Costa Rica.

system has been successfully tested in rainforest environment in Costa Rica. The measured parameters of the smart feeder is summarized in Table 1. Table 2 compares recent published RFID systems for ornithology study applications. More behavioral studies using this RFID-based smart feeder are planned.

## Acknowledgments

For W.T. and T.F.W., this work was supported by the Interdisciplinary Research Grant (IRG) program from the Office of the Vice President for Research at New Mexico State University.

## Author Contributions

W.T. and T.F.W, both directed the overall work. W.T. directed system design and implementation. T.F.W directed system testing. V.I. designed and implemented the electrical system. V.I. and M.A-S. performed system testing, and obtained the data. Y.T., C.P., and A.H. designed and implemented the mechanical system. W.T. was responsible for the writing of the paper. T.F.W. was responsible for proof-reading the manuscript.

**Table 2.** Comparison of recently reported RFID based ornithology applications.

| | [6] 2013 | [2] 2009 | [12] 2014 | This work 2015 |
|---|---|---|---|---|
| Target Bird | Seabird Shearwater | Emu | Humming -bird | Humming -bird |
| RFID Frequency | 13.56MHz | 915MHz | 125kHz | 125kHz |
| Detection Range | 28 cm | 100 cm | 1-9 cm | 10 cm |
| Application | Data Logging | Data Logging | Data Logging | Data Logging & Diet control |
| Mechanical Devices | No | No | No | Yes |
| On device signal processing | No | No | No | Yes |

## Conflicts of Interest

The authors declare no conflict of interest.

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