HOUSTON TOAD PHONE:

COMPRESSION AND TRANSMISSTION OF TOAD CALLS

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by

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**ABSTRACT**

The Toad Phone project is a collaborative effort to remotely monitor and improve the Houston Toad population. This product will aid property owners in acquiring an agricultural tax exemption appraisal. The operation of the prototype includes being able to record, compress, and transmit audio and environmental data to a cloud server (via a cell phone network) for further research purposes. The goal of my team is to create a cost-effective method and procedure for a device that will transfer recorded data for remote research. From experience with audio data, the size and number of files for this scale of research can become substantially large as recorded intervals increase. This can potentially become a large cost of the research project due to cellular network data transfer rates for large files as well as cloud data storage costs. We have decided to compress the data for better on-board storage as well as for file transfer. We have to consider the desired product's functionality based on researchers' requests for ease of remote monitoring. We must also be mindful of the ethical, environmental, and social constraints and applications of this device being used in a public environment. We designed a procedure on a Raspberry Pi that will automatically compress recorded audio files and use an Internet of Things module to send the files to a cloud data base. The procedure has eased the mode of how often recorded data is physically collected from the field environment, but improvement in transmission and storage costs is still being investigated.

# 1 KEYWORDS

Automated Recording Devices (ARD), Raspberry Pi, Internet of Things (IoT), Python, Cloud data base, Free Lossless Audio Code (FLAC), Short Message Service (SMS), Virtual Network Computing (VNC) viewer

# 2 LIST OF FIGURES



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# 4 INTRODUCTION

## 4.1 Executive Summary

Researchers Dr. Shawn McCracken and Dr. Michael Forstner at Texas State University are monitoring the population of an endangered species, the Houston Toad. The current method of monitoring the Houston Toad population has been an inefficient method due to, but not limited to, frequency extraction of data from audio loggers, routine maintenance of audio loggers, as well as the lack of transmission capabilities and power consumption management. Toad Phone will be a heavily integrated project that involves research resources from the Biology Department of Texas State University concerning Houston Toad vocalizations and resources from the Ingram School of Engineering at Texas State University to help facilitate efficient research efforts. The Toad Phone will be a device that logs audio and environmental data, compresses the data, and transmits the data to a cloud server. From the cloud server, the data can be further analyzed within a laboratory setting, where an audio acoustic analyzer will determine if Houston Toads are in the area.

There are currently three teams from the Ingram School of Engineering working on this project. Team Romeo will enhance the microprocessor to best manage power consumption and incorporate additional data logging features through the use of compatible environmental sensors. Team Juliet will incorporate the features of data compression and data transmission. Team Hamlet will add more generality to the device by incorporating a microphone and sound card that can record frequencies into the ultra-sonic ranges, as well as incorporating a Raspberry Pi as a data server to reduce transmission costs. Teams efforts and collaborations will be conducted at Texas State University facilities as well as known Houston Toad breeding locations. This product will be cost-effective and will aid landowners in obtaining a Texas Agricultural Tax Exemption Appraisal through the Safe Harbor Act. The greater scope of the product will allow researchers to incorporate more sampling locations and will expand the research to include other animal calls for analysis.

## 4.2 Existing System

### 4.2.1 Prototype 1: Automated Recording Devices

The Department of Biology at Texas State University is currently working with the re-population of the Houston Toad. At this point, they have managed the oversight of the Houston Toad through physically surveying the habitat areas as well as from their offices, through the use of Automated Recording Devices (ARDs). These devices are positioned at locations inhabited by the toad, and work by recording the sound in the area. After the samples are collected, they are then run through a software program that determines if a toad's call is recognized. ARD's have been proven useful for the research, however the cost for each device is around $800 and they have to be maintained at least once every 40 days. The ARD system has a capacity to hold 3GB of audio data, and all the systems collect about 6TB to 8TB of audio data within a six-month time scale. Refer to Figure 1 for a visual representation of an ARD.


**Figure 1:** Existing Systems: an ARD is on the left, and Dr. McCracken's prototype is on the right

4.2.2 Prototype 2: Toad Phone Phase 1

Dr. McCracken had designed a device that was cost effective compared to an ARD, but this prototype was specific to the call of the Houston Toad. The components of choice were an Android phone, a microphone, a battery and solar panel power supply system, and a spy-ware program for data uploads. This model was not as intuitive to use as Dr. McCracken had hoped, even though it helped to reduce the amount of time used for data extraction and device maintainability. Therefore, for further work in creating a recording device, simplicity of device operation will be a major consideration when designing and developing a new prototype. Figure 1 also shows the environmental set up of Dr. McCracken's prototype.

4.2.3 Prototype 3: Toad Phone Phase 2 – Expectations

These teams will design a product that not only lowers cost but increases autonomous field deployment time. Dr. McCracken and his team will be saving time, money, and human resources used on the maintenance of the ARD's. This will allow for more time to be spent on the research of the Houston Toad and focusing on its re-population.

The device needs to be simple to use so a wide audience can perform rudimentary tasks such as turning off and on the microprocessor and switching out storage media without needing extensive guidance. The simplicity of the device will help encourage landowners to become a part of the Safe Harbor program, which is a program where landowners who help the preservation of the Houston Toad, or any other endangered species, will receive major tax reductions on their property.

A product expectation of the new Toad Phone system should be able to compress data and store it onto a Raspberry Pi microprocessor. In addition to this, another project expectation of the Toad Phone system is to transmit the compressed audio data to a cloud server for it to be analyzed at a later time. Both of these capabilities will need to be done autonomously, to help reduce the set-up design.

The components of choice, per the request of Dr. McCracken and Dr. Forstner, were the Raspberry Pi model, a cellular transmission module that will need a cellular SD card, and a cloud server. Figure 2 displays the hardware components used for the project. From initial research of the component choices, it was found that the cost of using a cellular network to transmit data will be $60 for the module and a minimum of a $30 monthly rate to send 1GB of data. To reduce transmission cost, the microprocessor will transmit data between the hours of 9 p.m. and 11p.m.

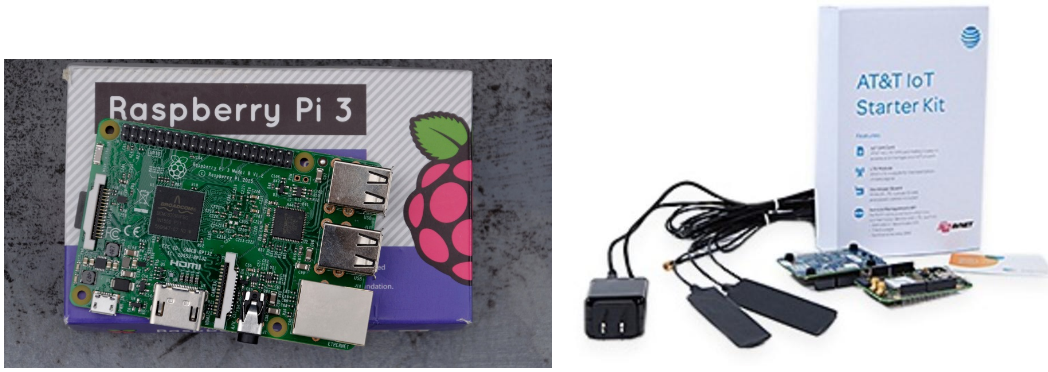


**Figure 2**: Component Choices for Toad Phone: on the left is the Raspberry Pi 3 model and on the right, is the AT&T IoT starter kit.

## 5 PROBLEM DESCRIPTION

The Toad Phone is a project designed to help in the conservation effort of the Houston Toad by gathering audio data on the Houston Toad species. In response to what that data yields, further action can be taken to help aid in the re-population efforts of the Houston Toad. Dr. McCracken's initial Toad Phone design could gather audio data, but power consumption was an issue.

This project will not only improve on Dr. McCracken's design by using a microprocessor to gather the necessary data but the team will design the project to be expandable and be user friendly. By making the project more user friendly, more people will be interested in helping the conservation effort and will be more likely to participate. The project will include a set of instructions on how to reproduce the device and will be readily available to anyone. The expand-ability of the project will allow the Toad Phone device to serve as a tool to help other researchers in their conservation efforts for many other species of animals.

## 5.1 Requirements

### 5.1.1 Data Compression

The temperature, humidity, and barometric pressure will be stored locally on the microprocessor. The sound recordings taken in by the microphone and stored on the microprocessor must be compressed before they are transmitted. Currently six months of pure sound recordings for 80 ARD's are compressed into six to eight terabytes of data. This means that we need to further improve the compression that is done by the current system. The performance target is to compress the audio readings more efficiently, with lossless or lossy compression.

### 5.1.2 Data Transmission

The data that is compressed will be transmitted via a cellular network to a designated cloud server. The current ARD model cannot transmit data. Dr. McCracken's prototype can transmit the data using a cellular network but it is done through a cell phone with a spy-ware program. This form of transmission must now be realize-able by the microprocessor.

### 5.1.3 Stretch Goals

#### *5.1.3.1 On-board Detection*

A library will be incorporated in the microprocessor to allow for on-board frequency detection. Dr. McCracken's prototype does not have on-board frequency detection installed. The current model would record and store data locally as well, and then the data would be analyzed in the laboratory. The frequency detector should be able to recognize the Houston Toad frequency by analyzing ten minutes worth of data and detecting if a call was made by the Houston Toad or by a different animal.

#### *5.1.3.2 Notifications*

The microprocessor will be able to notify a chosen party, via Short Message Service (SMS), when the battery is running low, when a Houston Toad has been detected, or when there is a malfunction with the device. This feature will be a completely new addition to help conservation efforts for the Houston Toad in real time. This will eliminate the need to manually inspect each breeding pond for evidence of reproduction. It will also help to keep track of the device's maintenance, such as the battery level of the power source, without having to physically go to its location and check on it.

#### *5.1.3.3 Error Detection and Correction*

The data being read in by the microprocessor will be analyzed and checked for errors. If errors, such as noise or some type of interference, are detected, the data will be corrected. The current model does not have a way of detecting errors, so this will be a welcomed addition to eliminating false positives or false negatives. The data must have a probability of bit error of less than 1%.

# 6 PROGRESS TOWARDS A SOLUTION

## 6.1 Design Decisions

The Toad Phone will take temperature, humidity, and barometric pressure measurements of the field environment as well as sound recordings of the Houston Toad. These recordings will occur for ten minutes on every hour. This design implementation was put in place due to the fact that having the Raspberry Pi constantly recording all night

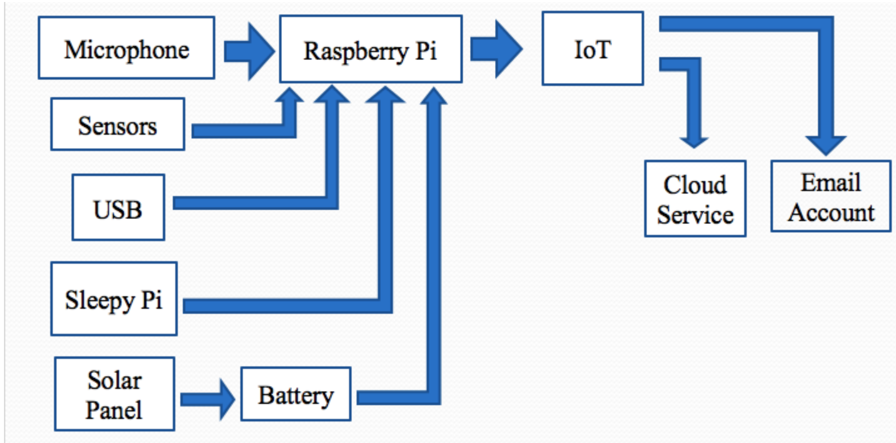


**Figure 3:** Top-Level Toad Phone Design

long will complete deplete the battery of charge. At a minimum, the sound recordings will be compressed to have efficient transmission between the Raspberry Pi and the cloud server. The data that is compressed will be transmitted via a cellular network to a designated bucket folder on a cloud server. The transmission will be sent during the predefined hours set by the administrative user.

The project concept of the next Toad Phone prototype will be a smart device that can handle sampling, processing, and delivery. Toad Phone can do this through the use of a microprocessor and a cellular module where software components are implemented to conduct the on-board compression process. Refer to Figure 3 for a graphical representation of the flow of component operations within the device.

### 6.1.1 Microprocessor

The Raspberry Pi 3 B+ was chosen because it is a powerful processor with a large community of users. Its large acceptance in the engineering community means that many peripherals such as sensors and antennas offer support for the Raspberry Pi.

### 6.1.2 Cellular Module

This leads to the choice of the AT&T Internet of Things (IoT) Cell Module and the Adafruit Fona 3G Cell module. AT&T's cell module allows for simple connection to the LTE network. This makes transmission of data to the cloud feasible for the Pi within remote areas. Alternatively, the Adafruit Fona module could do the same job as well and comes at a lower cost, however the AT&T IoT cell module comes with full support from AT&T and its community.

### 6.1.3 Compression

Compression for the Toad Phone can be done with Free Lossless Audio Codec (FLAC) or with Lossy compression methods. FLAC is an open-source software with a large community and an improving program. Because it is open source, it will allow for future manipulation of the code if needed. Implementing FLAC is more desirable, due to the feature that "Lossless" compression in a sense does not lose as much data as "Lossy" compression. Dr. McCracken and Dr. Forstner would like these files to be transferable between different animal research projects.

## 6.2 Design Approach – Component Choices

The Toad Phone system is a combination of sensors, a processor, and a transmitter. Figure 4 and Figure 5 display the flow of communication between components and how the software interacts within the device. To encompass all capabilities from the three main components, the use of a Raspberry Pi was chosen. The Raspberry Pi will be responsible for being the system controller for collecting, compressing, storing and transmitting data to a cloud server. Transmission, from a Raspberry Pi, involves the use of an LTE capable antenna. Thus, it was conceived to include a 3G cellular module that will allow for reliable transmission. AT&T's IoT Starter Kit consists of the module and antenna needed for the project. This comes with the full support of AT&T and its large 3G network coverage as well. Raspberry Pi operates with the operating system Raspbian, which can be handled with Python. Specifically, Python 2 was chosen because it is the most commonly used and supported version of Python. This will allow for integration of devices in the present and future to be handled easily.

These ideas for the Raspberry Pi were allowed to come into fruition through experience with four main Electrical Engineering Courses at Texas State University. Microprocessors gave the knowledge of processors and how they could be paired with peripherals to achieve actions which would make life simpler. Signal and Systems and

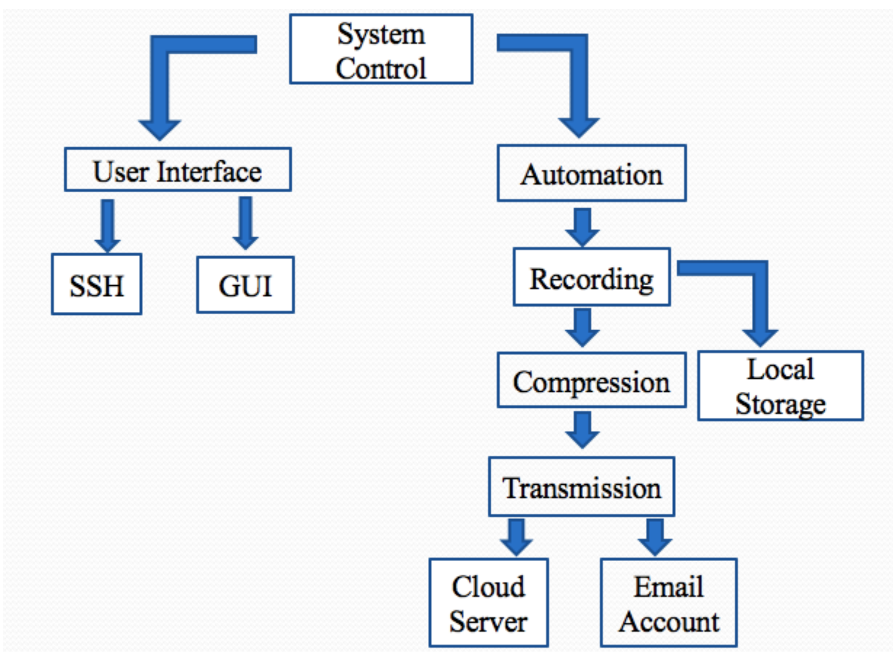


**Figure 4**: Software Level Design for Toad Phone

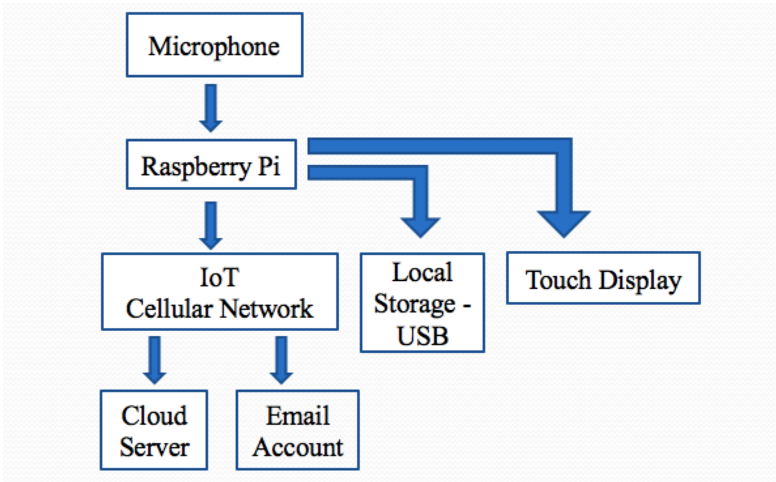


**Figure 5**: Hardware Level Design for Toad Phone

Communication Systems showed how transmission and compression techniques should be handled and chosen given our scenario. Network Systems is the backbone of our Pi to Cloud design in how we handle the protocols.

## 6.3 Users

### 6.3.1 Use Cases

The user community will initially consist of Dr. McCracken, Dr. Forstner, and research students from Texas State University. When the system is ready to be implemented in a larger scale, homeowners, ranchers, and other parties interested in the conservation of the Houston Toad will be additions to the user community.

The user community's education will range from PhD holders all the way to individuals who have finished high school. Their skills will also vary largely from tech-familiar individuals to others who have never used a microprocessor. The areas that the user community members may reside will be in Houston, Austin, and San Marcos.

The systems functions will vary widely depending on the user. The levels of access from highest to lowest are Administrator and Regular User.

Homeowners, ranch owners and other parties interested in the conservation of the Houston Toad will be labeled as Regular Users. The teams have assumed that the many Regular Users will not know how to operate a microprocessor. The professors will be classified as Administrators with administrative functions. It will be assumed that the Administrators and the students know how to operate the microprocessor well enough to change system parameters, such as frequency range.

## 6.4 Interface

### 6.4.1 User

The user will interact with the microprocessor via a generated user interface such as putty. The classifications of users will be the only limiting power for interacting with the microprocessor.

### 6.4.2 Software

Python will be used to interact with the Raspberry Pi.

### 6.4.3 Hardware

The Raspberry Pi will be connected to an IoT Add-on kit to allow for data to be transmitted through a cellular network.

#### 6.4.4 System Help

The Toad Phone project will contain a detailed construction report in order to help users replicate the project. The construction report will include a parts list, a procedure for assembly of the parts, the code needed for the microprocessor, as well as instructions on how to navigate the interface. The users that are taking advantage of the agriculture tax cut will also be guided by the faculty at Texas State University on how the device will be used and placed. The users will also have contact with the faculty for further questions at any time if issues arise.

### 6.5 Security

Security will not be an issue with the Toad Phone. This project will display all the source code in a designated open-source location, such as GitHub. This is because the main objective of this project is to help in the conservation of the Houston Toad, with the project scope incorporating expand-ability functionality to include a wide variety of other animal species. The best way of doing this is by giving a set of guidelines for others who want to follow suit in the conservation effort.

### 6.6 Error Handling

A user error occurs when the Administrator inputs a frequency range that the device is not equipped to handle. In this case, the user will be prompted that the new frequency range is invalid. For a user's privacy, a regular user may turn off the Toad Phone to prevent having a recording of a social event, hosted by a regular user, to be sent and stored on a remote server. In this event, there is a high probability that the device will not be turned back on, which will result in a loss in possible collected data. To handle this situation, there is a significant consideration to incorporate Witty-Pi hardware as well in the device to help create settings for the device to be turned back on after an extended amount of time.

A system error occurs when the microprocessor does not transmit data, receive data, or loses a functionality. In this case, there will be a monitoring system that will incorporate periodic ping messages between the Administrator and the device. After a period of time, if there are no messages being received from the device, the administrative user can decide on the next course of action for the device's maintenance.

## 6.7 Boundary Conditions

The Toad Phone will need to function properly in all areas that the Houston Toad resides. It will need to work within the temperature range from 20°F to 100°F. According to the Texas Organization for Amphibian Diversity, the Houston Toad lives in woodland areas that contain deep sand and a body of water nearby for breeding purposes. Since the Toad Phone will be outside, it will need to be weather resistant to maintain functionality. The IoT-add-on and the Raspberry Pi will require 5 volts to run, and the Raspberry pi will require a 2A microB USB power supply.

## 6.8 Constraints

With Toad Phone being the budget friendly solution to a current costly device, the desired final cost for each Toad Phone device is constrained by a budget of $250. Hardware and carrier service will be the bulk of the expense. Toad phone will be transmitting through a cellular network since the device will be in remote areas, where the most reliable form of transmission will be through a cellular carrier.

A fully assembled Toad Phone with prototype software is projected to be accomplished in May 2017. This will be necessary so that enough time in the fall semester can be spent on working with any issues brought up during in-lab and field testing. This leads to a fully functioning Toad Phone in December 2017.

## 6.9 Performance

### 6.9.1 Hardware Performance Parameters

Raspberry Pi 3 Model B - This is the computer responsible for the compression of audio and transmission on the cellular network. This device runs on a 5V power supply and implements Python Code to run commands for desired features. This is the main control component for the device.

LTE IoT Add-on-Kit - The antenna will transmit the data via a LTE network. The device runs on a 5V power supply.

### 6.9.2 Software Performance Parameters

Storage - The sampled audio will be stored on a Cloud service for the convenience of readily available access. The Cloud service will be accessed through a web page to allow for thorough verification of the uploaded samples.

Transmission - The cell module will send out recorded audio after every 10-minute length sound sampling by using the LTE network. The cloud service will also verify the success of the transmission.

Compression - FLAC or Lossless compression will be used to compress audio samples for more efficient memory storage. An Acoustic Audio Analyzer software will analyze the compressed files to verify if the samples will create false indicators of toad calls.

### 6.10 Portability

1) Toad Phone will be able to interface with both Mac OS X and Windows OS.
2) Toad Phone uses FLAC to compress its audio files. FLAC is a widely supported open-source program which can see its compression be improved upon as more updates are released.
3) Toad Phone uses Python to run its operating system. Python is a widely supported language with a large community that has used Python in many areas of engineering which involve various types of systems.

### 6.11 Expand-ability

Toad Phone is a device that will be used in the field environment for the observation and research of the Houston Toad. It is specific to the Houston Toad because the recordings caught by the Toad Phone are run through an Acoustic Audio Analyzer which is configured to recognize the Houston Toad. Therefore, the Toad Phone could be configured to listen in on other frequencies which can be ran through the Acoustic Audio Analyzer to recognize other animals.

Toad Phone is a smart audio recorder. Its Raspberry Pi processor allows for Python code to run the hardware necessary to record, compress, and transmit audio. Python is a language with a large community who have designed code for similar systems.

## 6.12 Customization

Source code is provided for the user to allow for the integration of programs which will aid in the process of detecting the Houston Toad. For example, an Acoustic Audio Recognizer could be added. If the recognizer detects a toad's call, the Toad Phone could send a message in real time to an Administrative user notifying that a Houston Toad is within its proximity.

Two levels of configuration menu's will exist. The higher of the two levels will allow for the modification of frequency detection range, sampling times, sample sizes and transmission times. The lower of the two will be a simple interface for the landowners who will be hosting the Toad Phones. This interface will consist of a power on and off button.

## 6.13 Support and Maintenance

A stretch goal for Toad Phone would be for the device to send status updates on the device's storage and battery capacity via text or email to an administrator. This would be done on a weekly basis.

## 6.14 Configuration Management

Toad Phone is a stand-alone device which will not see the update of its software by its original team. Although there are plans outside of the scope of this project to allow for more features to be added, the Toad Phone device produced by this project will not see further support from Team Juliet and Team Romeo after December 2017 to incorporate additional features. The duties and responsibilities to continue improvement and additional features will be tasked for Team Hamlet and other future design teams to implement.

### 6.15 Documentation

Documentation will come in the form of:

1. An assembly manual for Toad Phone.

2. Full code with detailed comments describing the purpose for each section and instructions to upload and install the software onto additional devices.

The Toad Phone project is intended to be adopted by as many individuals as possible in order to help in the Houston Toad recovery effort. This means that the whole design process will need to be documented. The documentation of a particular design aspect of the Toad Phone will be performed by the individual that implements the design. For example, Regino Lopez will be doing the compression of the data, so he will be documenting all the code he will use for compression. Jose Hernandez will be doing the interface with a team member from Team Romeo, so they will be in charge of documenting the code and the process to set up the interface. Laura Adams will be in charge of documenting how she managed to get the IoT module to interface with the Raspberry Pi and document the code used for transmitting data to the cloud server. All the documentation needs to be done before senior design day which is on December 11, 2017.

## 7 PROJECT APPROACH

The Toad Phone project was originally divided into two main parts, where one part is assigned to each team. Team Juliet took the role of compressing and transmitting data to a cloud server. Team Romeo was tasked with environmental data collection and power supply management. In continuation from these two teams, Team Hamlet was tasked with incorporating a microphone that can record call frequencies in the ultrasonic ranges as well as incorporating a data server to reduce use of a cloud server. The project is meant to entail not only the Houston Toad but many different species of animals, however Team Romeo and Team Juliet chose to focus on the Houston Toad but the design decisions left room for expand-ability.

## 7.1 Progress towards goals

Progress on the Houston Toad project in Spring 2017 had been in research. The team has decided on what parts to use for the project and how they will go about testing them. Additional research in the different types of compression methods and cloud servers had been done. The Raspberry Pi was set up with a Windows computer and was ready for initial programming by May 2017. The team had begun to explore different Pi libraries to help implement the project needs.

## 7.2 Verification

Current practices of recorders in the field already allow for analyzing toad calls after the physical collection of data. Toad Phone's purpose is to eliminate the necessity of a physical collection of data while still ensuring user confidence in the data. The Toad Phone team will confirm this by verifying the transmission of reliable field data to the cloud through side by side comparison of data. The data will be collected through a week stay in an area of Texas to be determined. Samples from current devices out in the field will run against Toad Phone samples collected from the cloud. This will be done on acoustic analyzers that are currently being implemented in the lab at the Department of Biology at Texas State University.

## 7.3 Iterations and Redefinition

By the end of the Spring 2017 semester, there has not been a redefinition of the project's deliverables. The only redefinition that happened was for a stretch goal. Instead of pinging the Raspberry Pi to transmit a set of data, the Raspberry Pi will be set to automatically transmit a specific set of data regularly. This was done to facilitate this design of the Toad Phone.

# 8 CONSTRAINTS

## 8.1 Budgetary

The Toad Phone design is intended to be deployed at a large scale in the future. This means that cost is a critical aspect of the design when a future goal is to reach a large audience of users. Due to this, many of the components of the Toad Phone are intended to fulfill their purpose to the bare minimum required. For example, a module that just transmits data through a cellular network was chosen and the cellular network will be chosen to be the most affordable for the area.

## 8.2 Design Feasibility

The main goal of the Toad Phone is to gather data, compress the data, and send it to a cloud server. The initial design included a notification method for communication between the users and the system. The Toad Phone would be functional for other species of animals as well. Due to the complexity of the overall goal of this project, we narrowed our approach to be directed towards Houston Toads and made a stretch goal to incorporate research for other animals.

## 8.3 Maintainability

The operating system for the Raspberry Pi, Raspbian, will need to be maintained for the Toad Phone to run smoothly. A set of instructions to download the latest software will be provided to each user of the Toad Phone.

## 8.4 Environment

The Toad Phone is intended to be implemented on a large scale within the environments that the Houston Toad resides. This means that the Toad Phone cannot cause any fire hazards or any type of poisoning to the wildlife.

## 8.5 Health and Safety

The Toad Phone has the capability to record audio, so it could be used to detect when a property owner is not home. Also, if an unqualified user is tampering with the Toad Phone setup, this could lead to injury by getting shocked from the current running through it.

## 8.6 Social

The social constraint for the Toad Phone is privacy. With the capability to record and transmit data, the Toad Phone is open to abuse. The Toad Phone will be placed on select individuals' property. This means that the Toad Phone could be used to listen in on these individuals' conversations, for which they did not give their approval. In summary, when the Toad Phone should be on and off and what should it be allowed to record are the main social constraints to be analyzed and maintained to avoid usage abuse.

# 9 PROJECT DELIVERABLES

**Table 1**: Schedule for Design and Project Documents

| **Document** | **Date** |
|---|---|
| Statement of Work | 1/30/2017 |
| Functional Specification | 3/22/2017 |
| Initial Design Review | 3/27/2017 |
| Test Plan | 9/13/2017 |
| Lab Tests | 10/2/2017 |
| Field Tests | 10/30/2017 |
| Characterization Report | 11/9/2017 |
| Final Report | 12/4/2017 |

# 10 INITIAL DIVISIBILITY OF WORK

## 10.1 Roles and Responsibilities of Team Members

**Table 2**: Division of work and responsibilities for Team Juliet

| **Name** | **Responsivities** |
|---|---|
| Laura Adams | 1) Project Manager: Conduct meetings, status reports, liaison, assign team tasks.<br>2) Head Raspberry Pi programmer: Programming Raspberry Pi to function with IoT module and to program the Raspberry Pi to transmit data, |
| Jose Hernandez | 1) Secondary programmer: Design the interface for each user, cloud interaction and help the main program in various tasks. |
| Regino Lopez | 1) Design Engineer: Design module for compatibility, data compression and power consumption monitoring.<br>2) Test Engineer: ensure that the Toad Phone is transmitting data correctly to the cloud and is compressing the data correctly. |

## 10.2 Tasks

Hardware: Laura Adams will undertake the bulk of the hardware elements. She will program the IoT module to interface with the Raspberry Pi. This will be one of the priority tasks because this will need to be done before transmission to a cloud server is possible. In order to accomplish this, Laura will begin to work on it as soon as the Senior Design 2 course gets underway.

Software: Jose Hernandez will be in charge of programming the interface alongside one of the members from Toad Phone Team Romeo. This means that in order to finish the interface on time both teams will have to meet their deadlines. Regino Lopez will be in charge of programming all the data compression. In order to accomplish this, he will need to continue his research on compression methods and consult Dr. Stern on the compression approach. Testing compression through software should begin as soon as the Senior Design 2 course is underway. Laura Adams will need to finish her hardware implementation of the IoT module in order to commence programming the transmission of data to the cloud.

# 11 FEATURES TO BE TESTED OR NOT TESTED

The following are the major functionalities of the application that need to be tested:

1) Data Transmission: Connectivity of Raspberry Pi to LTE module

2) Data Transmission: LTE module sending data to cloud server

3) Data Compression: Lossless and Lossy compression methods

4) Data Compression: On-board data Storage.

### 11.1 Connectivity of Raspberry Pi to LTE module

LTE allows the Raspberry Pi to be connected to the internet via cellular services, so that the Raspberry Pi can work in rural areas where Wi-Fi accessibility is limited.

### 11.2 LTE module sending data to cloud server

Once the Raspberry Pi has access to internet services, data stored on the Pi can be sent to a cloud server. This data can then be used and seen from a remote location. There is a possibility that data can be lost or changed within the transfer protocol, therefore accuracy and reliability of data transfer methods will be tested.

### 11.3 Lossless and lossy methods

The type of compression methods to be used must not distort audio samples to the extent that the acoustic analyzer cannot recognize the Houston Toad calls. The results will be used to illustrate the quality control between the original and compressed audio files. At a minimum, FLAC will be tested, but other compression methods will also be tested to show which methods will deliver the most reliable results for analysis.

### 11.4 On-board data storage

Audio recordings will be stored on multiple local memory storage units on the Raspberry Pi. This will be used as a redundancy check as well as a back-up access point for data records.

### 11.5 Features not to be tested

All these features will be tested by Team Romeo, but Team Juliet will need to be mindful of how their features may impact Team Romeo's ability to test their features effectively.

1) GPS Module

2) Sensor components: temperature, barometric pressure, and humidity

3) Solar Power and Power consumption

4) Weather Proofing

# 12 TESTING APPROACH

## 12.1 Connectivity of Raspberry Pi to LTE module

Approach: The connectivity of the Raspberry Pi to the LTE module will need to be tested in two environments. The initial test will take place in the Texas State University Labs and the second test will take place out in the Houston Toad environment near Bastrop, Texas. Team Juliet will need to set up an automatic process using a python script so that the Raspberry Pi will automatically connect with the LTE module.

Pass Criteria: The Raspberry Pi is connected to internet, we will be able to successfully ping Google.

Fail criteria: There is no connection. There is no successful ping to Google.

Verification Method: We can access the Raspberry Pi through the VNC viewer, and from here we can visually see if we are connected to the internet.

## 12.2 LTE module sending data to cloud server

Approach: After connectivity to the internet is established, we will create both a text file and a small audio file to send to the cloud server.

Pass criteria: Cloud sees the data, and we can download the data from the cloud.

Fail criteria: Cloud server does not receive any data or the Cloud server sees data but user cannot access data.

Verification Method: We will access the cloud server through a separate computer or device to see if the data was received and if the user can access the data.

## 12.3 Lossless and lossy methods

Approach: Team Juliet will create and test various compression methods and run the resulting files through the analyzer software to test if the compressed files are recognizable or if they result in false positives or false negatives. Team Juliet will compare our results to the Biology Department's control group of audio files, which are uncompressed .wav files.

Pass criteria: The rate of false positives or negatives for the compressed data is the same as the control group or within a 5% margin error.

Fail Criteria: The margin of error of the false flags is outside 5% margin error.

Verification Method: We will be using the analyzer software from the Biology department to determine if the compressed files can produce as many flags within a 5% margin of the uncompressed .wav files.

## 12.4 On-board data storage

Approach: We will test multiple USB drives or multiple SD cards. We will need to be checking for storage unit functionality and storage being used.

Pass criteria: Checks if a storage unit can be accessed, such as the card is readable and still has space to be used.

Fail criteria: Storage card cannot be accessed or cannot detect that the card is full.

Verification Method: The files on the USB drives or on the SD cards can be viewed and accessed when connected to another separate device.

### 12.5 Testing Timeline

**Table 3**: Test Plan Schedule for Toad Phone

| Test Dates | Case Number | Test Name |
|---|---|---|
| 9/15/2017 | #1 | Connect Raspberry Pi to Cell Network in Lab |
| 10/15/2017 | #2 | Connect Raspberry Pi to Cell Network in Field |
| 9/22/2017 | #3 | Connect Raspberry Pi to AWS S3 Cloud Storage |
| 9/29/2017 | #4 | LTE module sending text file to AWS S3 |
| 9/29/2017 | #5 | LTE module sending audio file to cloud server |
| 10/6/2017 | #6 | Lossless and Lossy compression methods |
| 10/13/2017 | #7 | On-board Storage with SD cards |
| 10/13/2017 | #8 | On-board Storage with USB drives |

## 13 TEST RESULTS

### 13.1 Connectivity of Raspberry Pi to LTE module: Test #1 and Test #2

System Function: Cellular connectivity with the AT&T cell module was tested on the Raspberry Pi, both inside a lab environment and in a field environment. The connection has to be fast enough to transmit a 10-min audio file to a cloud server within 40 minutes. The cellular connection also has to be stable to allow a continuous flow of data. The testing environments were an outdoors environment in the San Marcos area and in a Texas State University research lab.

Functional Capability: The audio file was transmitted to the cloud server within five minutes. The connection was not severed, which lead to the conclusion that it was considered stable and continuous. The testing has not been done where Houston Toads reside, due to Houston Toads being inactive in the fall and winter seasons. Connectivity at those more remote locations will vary, due to the distance between the cell module and a cell tower.

Performance Capability: The cellular connection of the AT&T module was established in an area with a dense population of residents, so it is expected to have very good performance. Many of the areas that the Houston Toads reside will not be as populated, so the cellular performance could vary significantly.

### 13.2 LTE IoT module sending data to cloud server: Test #3 and Test #4

System Function: The Raspberry Pi has to be capable of transmitting both audio and text files to the Amazon Web Services Sever. The functionality of transmission to the cloud sever was first tested using a desktop to transmit both audio and text files to the AWS Server. Next, the Raspberry Pi connected to the AT&T cellular module was tested in its ability to send both audio and text files.

Functional Capability: As long as the text and audio files were transmitted and stored in their intended bucket and folder within the AWS, the test was considered a success.

Performance Capability: Both text and binary files were stored with 1:1 ratio of bits in each case.

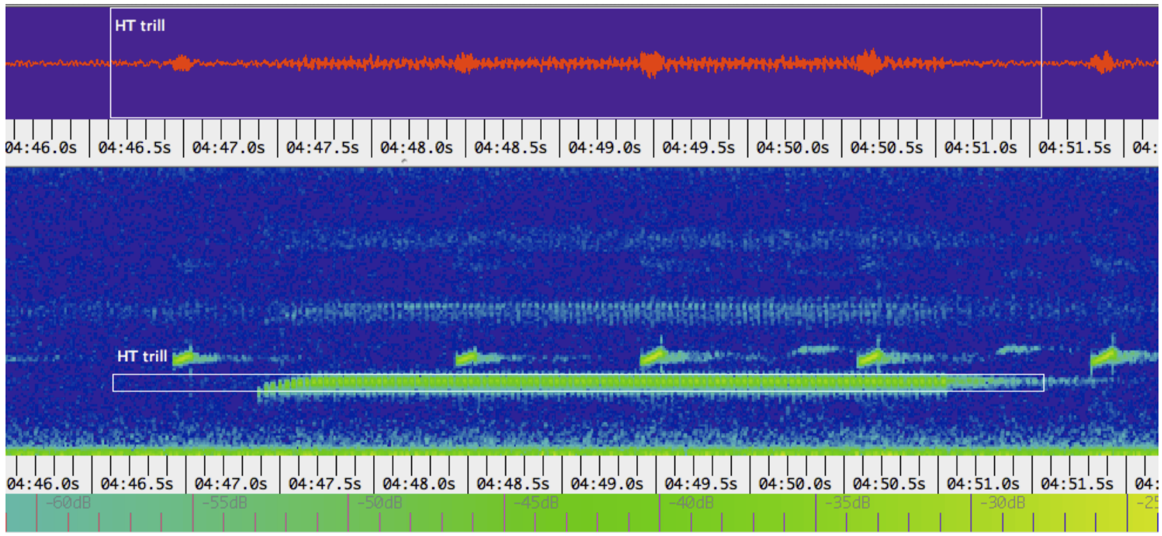


**Figure 6**: Spectrogram of a sound recording of a Houston Toad call

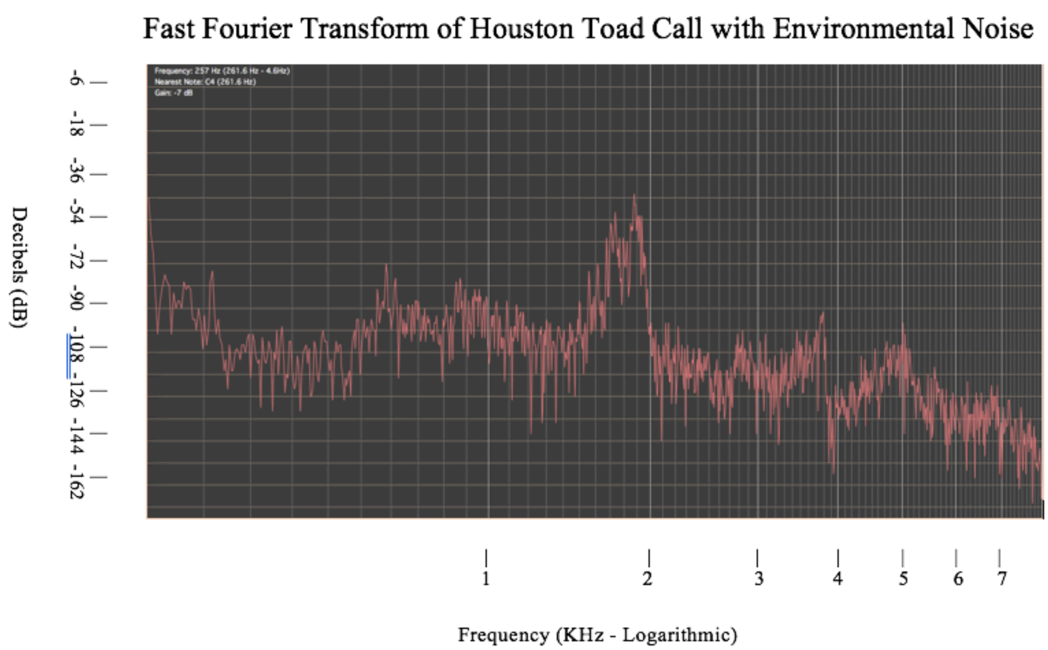


**Figure 7:** Result of Uncompressed Sound file in Frequency Domain

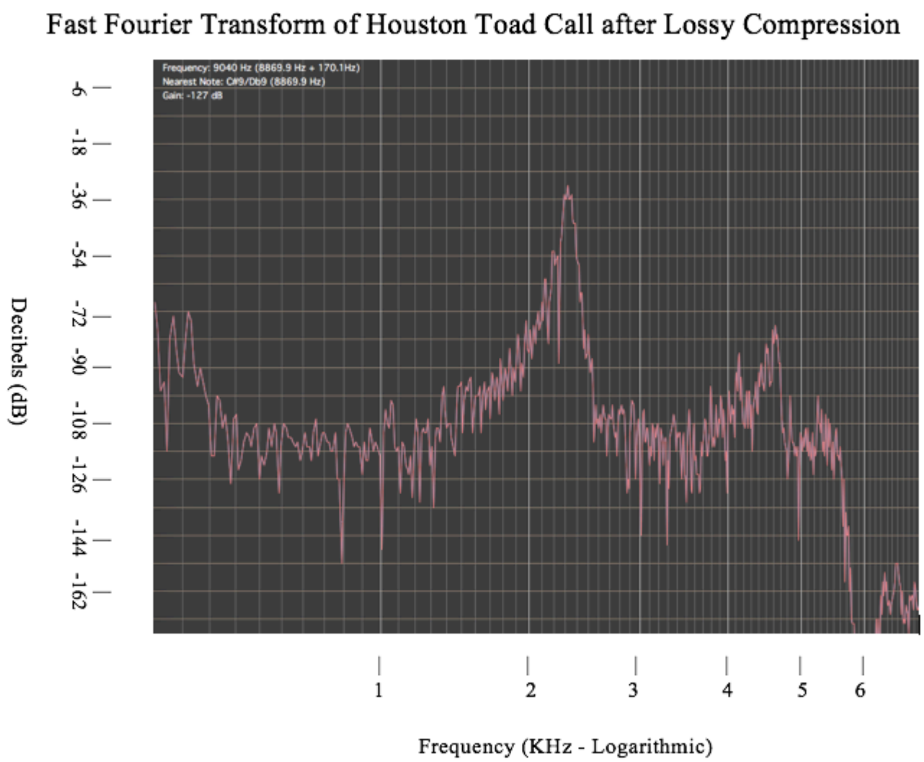


**Figure 8:** Result of Compressed Sound Files in Frequency Domain

### 13.3 Lossless and lossy compression: Test Case #5

System Function: Audio was recorded with the Blue Snowflake Microphone at a sampling rate of 44.1 kHz and 8-bit depth. Refer to Figure 5 for how the spectrogram of the original audio looks within the time domain. When the Raspberry Pi is needed to transmit data, the files themselves should ideally be as small as possible. For lossy compression, we used a lower sampling rate method and decreased the number of bits used to store the data. This is achievable because the spectral importance of the signal lies within the 2 kHz region. We reduced the sampling rate to 22 kHz and reduced the bit depth to 8.

Functional Capability: A file that comes out of the compression at a fourth of the size of the original file and is audibly the same will be a pass.

Performance Capability: Files that went into the compression came out at a fourth of the size of the original file and were audibly similar to the original. Files can even be sampled at lower rates given a specified scale down factor. Figure 7 and Figure 8 show that a compressed and uncompressed audio file can still detect the first harmonic of the Houston Toad call.

### 13.4 On-Board Storage: Test #6

System Function: The collected data has to be stored locally on a USB. The USB device also has to be monitored to check its available storage.

Functional Capability: The USB should be monitored and data must also be written onto it without any complications.

Performance Capability: The USB functioned as planned. Data could be stored onto it and it could be monitored as intended.

### 13.5 Notifications: Test #7

System Function: The script to run Toad Phone's main operations will contain a function that transmits an error message via email to a specified user when a function was not able to be completed. This function will also serve to notify the user when data was able to be transmitted to the AWS server. The email must be sent within five minutes of either the error occurring or the data being uploaded to the cloud server. Also, a notification will be sent once the USB storage device reaches a capacity of 50%, 70% and 90% of its maximum available storage.

Functional Capability: A message is transmitted to the user within five minutes of the error occurring or the data being uploaded will be considered a pass.

Performance Capability: The email can only be sent to Gmail accounts, so this feature has very limited capabilities. Also, a user must allow for less secure apps to access their Gmail account, which has been considered a security risk. Currently, there is no concern for the security of the project because all that is being transmitted is sound files of Houston Toads to a project specific Gmail Account.

### 13.6 Automation: Test #8

System Function: To allow the Toad Phone to be used by many users, it has to work with minimal effort from the lowest level of users. In order to do this, it will be a 'plug-and-play' type of device, where all of its corresponding components are hooked up properly and then connected to power. Once this happens, it will run its specified functions without the need of outside help. This means that the USB has to be booted up without authentication. The main python script that contains all the Toad Phone's functions has to boot on power and a scheduler has to be run within the python script so certain functions will run at a specified time each day.

Functional Capability: Toad Phone being able to run autonomously for days at a time without the program failing will be considered a pass.

Performance Capability: The Raspberry Pi was capable of running on its own. Therefore, it must record, compress, and transmit files as scheduled. This is done through Linux's 'systemd' tool which allows for 'services' to be scheduled parallel to boot up. It is also capable of sending error messages to an email account when either the recording, storing, or transmitting of audio was not successful.

## 13.7 System Deficiencies

Email Notifications: The email notification is only able to work with Gmail accounts at the date of this document.

Cellular Service: Due to having to use the AT&T IoT cellular module, the only cellular service provider is AT&T, which comes at a higher cost than other providers. It is debatable if this a true deficiency, because other providers do not have as large of a spread of cellular coverage as AT&T.

Compression: Toad Phone currently uses a lossy compression method.

## 13.8 System Refinements

Automation of the code on boot was not originally foreseen to be implemented in a different environment than the code running in the Python IDE. After initial testing, it became clear that a graphic user interface (GUI) could not be implemented into the automation of the program on boot. This was due to dependencies on a user being in an SSH shell upon the initialization of boot, which was not possible to implement co-dependently at all times. Therefore, a move to separate the GUI program from the main automation program became desirable. The automation program continues to run on boot every time whereas the GUI has to be called through SSH.

Only Lossy compression was achieved. Further research needs to be done on "Lossless" compression. The team sought to implement FLAC using python but was unsuccessful.

# 14 FUTURE WORK

The current prototype was successful in fulfilling the minimum project requirements from the specifications of the researchers' requests and expectations. From the testing results, system refinements, and system deficiencies, Team Juliet devised a list of features and capabilities that Team Hamlet can consider improving or make the feature more generalized.

## 14.1 Cellular Service

The AT&T system is a more reliable module compared to the Adafruit Fona IoT module. However, transmission costs through AT&T are more expensive compared the cellular service provided by Ting, which is a partner of Adafruit. It was recommended to Team Hamlet to verify the capabilities of the Adafruit Fona IoT module with the Raspberry Pi 3.

Time for Correction: It took at least two weeks to brute force the Raspberry Pi 3 to successfully connect to the AT&T IoT module. Therefore, it is advised that 3 to 4 weeks should be used to successfully connect the Raspberry Pi 3 to the Adafruit Fona 3G.

## 14.2 Cloud Storage

As more data is being transmitted, more data needs to be stored, which will increase cost of storage as cloud storage limits are continuously being reached. Therefore, it was recommended to Team Hamlet to incorporate a data storage server into the project by implementing the server capabilities of the Raspberry Pi.

Time for Correction: 4 to 6 weeks at a minimum will be required to find further research to successfully implement a Raspberry Pi as a data storage server.

### 14.3 Compression

The compression being used currently is a lossy compression that is achieved through bit depth reduction of 16 to 8 bits and down sampling of 44,100 Hz to 22,050 Hz. However, a functioning lossless method of compression was not achieved.

Time for Correction: 7 to 8 weeks should be used to research and test the ability of lossless compression.

### 14.4 Email Notifications

Notifications are only sent to Gmail accounts. To add more generality to this project, other researchers may be more comfortable with other email services.

Time for Correction: 2 to 3 weeks at a minimum would be advised in preparing and implementing the notification feature to other email services.

### 14.5 Field Tests

Current field tests were done by playing a pre-recorded call of the Houston Toad. Live recording could not be done since the testing phase was outside the mating season of the Houston Toad.

Time for Correction: 4 to 5 weeks should be used to effectively collect, test, and confirm that the live recordings through the Raspberry Pi are comparable to the original sounds files saved by the Biology Department at Texas State University.

### 14.6 GUI - SSH

To use the SSH feature on the Raspberry Pi, a keyboard with a monitor or a laptop with an Ethernet connection must be implemented. There is a touch screen component that can be attached to the Raspberry Pi to improve the ease of setting up a Raspberry Pi in the field.

Time for Correction: 3 to 4 weeks is advised to be able to implement the functionality of the touch screen without completely changing the pin connectivity of the environmental sensors.

## 15 CONCLUSION

Toad Phone Juliet Project is capable of its basic requirements. It can record, store, and transmit audio as scheduled. Audio is recorded at a sampling rate of 44.1 kHz with a 16-bit depth and it is stored locally. After recording is complete, it down-samples the original file to 22 kHz where the 2 kHz Houston Toad call can still be deciphered and it decreases the number of bits used to store the data to 8-bits. These files are sent via an AT&T LTE module over the AT&T network. Looking further into transmission abilities, the AT&T LTE device is only capable of working with the AT&T network, which is a subscription service that allows you to pay as you use. Therefore, other services are not compatible with the module.


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