Radio Receiver Design for Unmanned Aerial Wildlife Tracking

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***Abstract*—The use of radio collars is a common method wildlife biologists use to study behavior patterns in animals. Tracking a radio collar from the ground is time consuming and arduous. This task becomes more difficult as the size and output power decreases to accommodate animals as small as an iguana. Our solution is to fly a low cost Unmanned Aerial System equipped with a sensitive receiver chain to locate several transponders at once. The challenge is that the system needs to be low cost and be able to detect the transponder within a range of tens of feet. Initial ground tests indicate that the system was able to detect a collar 70 feet away for under $100.**

I. Introduction

A. Current Methods

Field Ecology or the study of the environment and its interaction is a study that utilizes radio collars. Tracking wildlife through radio collars is a method dating back to the early 1960s [1]. Doing this gives the researcher more insight into the animal's behaviors and interactions. The capabilities of the collar vary. Some collars have the ability to measure vitals signs of the animal and relay that information via satellite. Other collars record their location through GPS and then transmit that location over a frequency [2]. At the most primitive level of radio collars, a simple pulse is transmitted over a specific radio frequency. While these collars are not always desired, researchers are forced to use them on very small animals. Unlike data rich radio collars, which require a considerable amount of power storage, the radio collars that simply emit a ping can run up to a week on a coin cell battery. To locate these collars, researches employ triangulation techniques. Currently two major methods exist, ground tracking and aerial tracking [3]. Ground tracking is where the field researcher uses a large directional antenna and finds multiple headings where the signal is heard and travels to where they converge. One key problem with this method is that it is very arduous, requiring the research to travel through prohibitive terrain. Aerial tracking is a method that addresses those problems, by flying a fixed wing over an area with a directional antenna as well. This method is very successful and is able to track animals that travel longs distances, but ultimately it requires a ground crew to locate the animal to its' exact location. One large problem with aerial tracking is that it requires a large overhead including: a plane, a pilot, a runway and so on. The expenses of operating an aerial operation add up very quickly, which many of the researchers cannot afford.

The work of * was supported by the NSF REU Program.

B. Proposed Solution

One solution that has recently been introduced involves the use of a UAS (Unmanned Aerial System) [4]. The idea is that the UAS is a low cost and portable platform that would allow for researchers to get the benefits of aerial tracking. Currently we have partnered with the San Diego Zoo to build a proof-of-concept and deploy it in the field to learn if this is a viable solution [4]. Compared to the current methods, this method is different because instead of only tracking one radio collar at a time, we envision that the system will be able to track multiple collars at once with the help of a (SDR) (Software Defined Radio). To do this we have to rethink the way the receiver is built so we can not only track multiple collars, but also have a system that can detect them from an effective range.

II. System Overview

For our system we use a multirotor UAS that has the ability to fly predetermined flight patterns. This system can cover large areas with a 30 minute flight time. On the UAS there is a SDR (Software Defined Radio) connected to an omni directional antenna. Our idea of using the omni-directional antenna is that we can fly a back-and-forth pattern over an area while recording with the SDR, instead of finding a signal and then following it. Once the flight is over we use DSP (Digital Signal Processing) techniques to determine when the SDR received a signal and its power. Then we correlate the time the signal was received with GPS coordinates provided from the UAS autopilot (Fig 1). To help visualize this we overlay a heat map that shows signal strength on a color scale, which is overlaid (Fig 2) with satellite imaging. Doing this will allow the researches to plan their way to the suspected location.

III. Hardware Description

Once the higher level of the system was laid out, the receiver and its components was the next thing to be designed and evaluated. For the system our intent is to have a system that can be built for a versatile frequency range and varying size UAS platform.

A. Antenna

1) Overview: For our antenna we need an omni-directional antenna that will not interfere with the physical UAS flight operations and will have a wide enough bandwidth that can receive all of the collars simultaneously. Each of the collars

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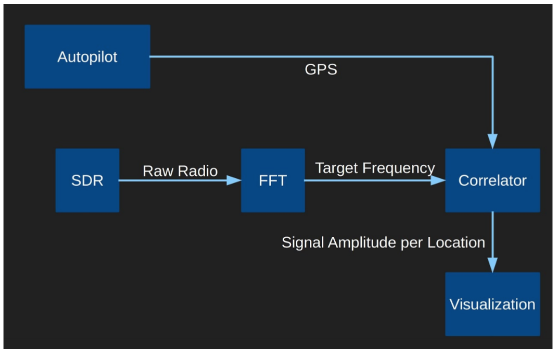


Fig. 1: A block diagram of the system showing the general flow chart of the system.

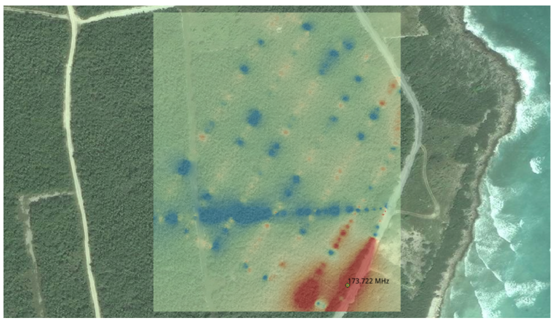


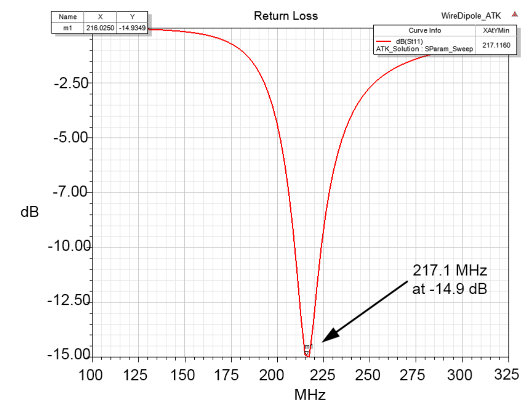
Fig. 2: A generated heat map overlaid on satellite imagery from the prototype system on a deployment in the Cayman Islands

are operating in the 170 to 216 MHz range depending on the specific animal collar. When the system is operating the separation in frequency for each collar is 5 KHz. With all of those constraints in mind a dipole was chosen for several reasons. First is the directivity pattern of the dipole which gives a good omni directional pattern in a shape similar to a toroid. This pattern would take advantage of the flight pattern. The second reason is since the dipole does not require a ground plane and it reduces the risk to interfere with the UAS's flight functionality [5]. The last reason is the impedance of the dipole at its resonant frequency is approximately 73 ohms, which was determined to be adequate enough to use without a matching network.

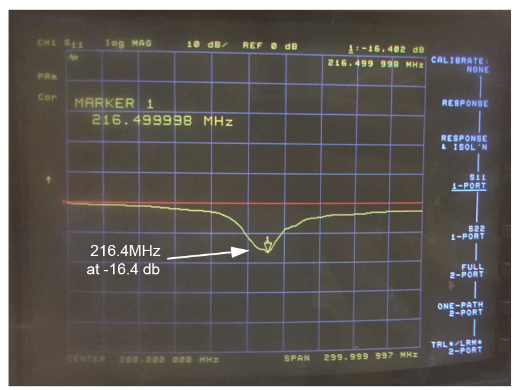
2) Dipole Design: We decided that the most efficient and precise way to design the antenna was through simulation. ANSYS Electronics Desktop was chosen to do that. This tool is a complex high speed electromagnetic simulation software, which is designed to simulate antenna properties [6]. The software also includes tool kits to work from templates to design antennas from known substrates. From there the software can calculate important information like expected scatter parameters, impedance parameters, and radiation patterns [6]. The target frequency for simulation was 216.025 MHz, which is the frequency of a falcon collar that was on hand for testing. Within the physical constraints of material and a reasonable precision of measurement, a resonant antenna was successfully simulated which is indicated from the input loss and standing wave ratio (Fig 3a) and (Fig 4a). From there a physical one was built from the dimensions (Table I) from ANSYS with 14 AWG copper wire and actual measurements were made on a HP Vector network analyzer. The result from actual testing (Fig 3b) and (Fig 4b) showed us that the antenna we built was resonant within 400 kHz of what simulation expected, which was determined as satisfactory.

Quarter wave element length (cm)	32.25
Port gap (cm)	1.0
Wire Radius (cm)	.0815

TABLE I: Design Parameters determined from Simulation



(a) S11 Parameters Simulated from ANSYS

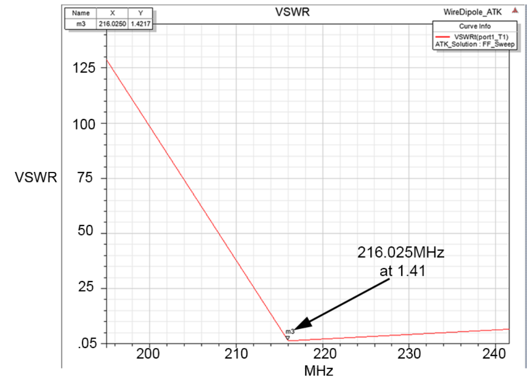


(b) S11 Parameters Results from Vector Network Analyzer

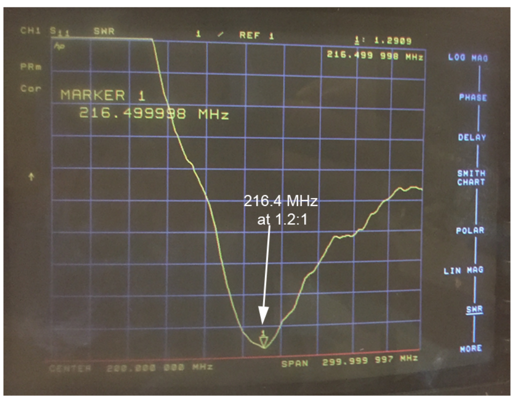
Fig. 3: S11 Parameters Simulated Versus Measured. These measurements were taken in a low noise laboratory

B. Band Pass Filter

Since the radio is being tuned a very specific frequency range depending on the collars being tracked, a bandpass filter was considered so out of band noise would be filtered out. Because we are flying in mostly remote areas, we do not expect strong external RF interference. Using a spectrum analyzer and a monopole antenna placed near the UAS, we



(a) VSWR Parameters Simulated from ANSYS



(b) VSWR Parameters Results from Vector Network Analyzer

Fig. 4: VSWR Parameters Simulated Versus Measured. These measurements were taken in a low noise laboratory

did not find any discrete signals that would be subtable for bandpass filtering. We concluded that the bandpass filter should not be focused on at the moment. If this system were to be deployed in a an urban environment this topic should be further investigated because we believe it would be necessary.

C. *Low Noise Amplifier*

We also investigated another piece of hardware, which is an in line amplifier between the antenna and the SDR. In section *SDR* we discuss the details of SDRs, but we will talk about their LNAs here. While the higher end Airspy SDR has a controllable LNA (Low Noise Amplifier), the RTLSDR and NooElec do not have one. The LNA amplifies incoming signals without significantly amplifying the noise floor. Doing this increases the signal to noise ratio, so that signals can be detected at lower power. We used the Mini-Circuits, PSA4-5043+, which has a reported gain of 22.1 db at 500 Mhz and noise figure of 0.65 db at 500 Mhz. The chip is powered through a bias tee circuit. The board requires 5-10 volts DC and a maximum draw of 76 mA, which make it suitable to be powered by a typical DC to DC converter on the UAS. To test how the effective the LNA is, we fed a constant signal at 216.025 MHz into the each SDR and LNA. We recorded the noise floor and signal power in GNU Radio. From the results in Table II we found that the LNA was the most effective on the RTLSDR/NooElec dongles, but still improved the SNR on the Airspy as well.

Radio	Noise Floor (dBm)	Signal Power (dBm)	SNR
Airspy	-74.1	-60.0	14.1
Airspy LNA	-74.1	-36.9	37.2
RTLSDR	-65.0	-59.6	5.4
RTLSDR LNA	-65.0	-36.0.	29.0

TABLE II: LNA SNR Measurements

D. *SDR*

1) Overview: For the system we chose to use a SDR for many reasons. 1). The frequency range of the radio would allow us to deploy this system for different frequency ranges of collars. Most of the SDRs investigated ranged from 20 MHz to 2 GHz. 2). The instantaneous bandwidth of the radio will allow us to sample multiple frequency of the collars at once. The typical bandwidth on the SDRs we looked at spanned 2 MHz. 3). With personal computing becoming powerful enough to process high sample rates, many low cost consumer and research oriented SDRs have become available for use. Keeping the hardware at a low cost is key to making this system competitive to the field researcher. 4). Using a SDR allows us to save raw data and then apply (DSP) Digital Signal Processing to it later. Doing this will allow us to apply different DSP techniques in post processing to determine which methods are better at dealing with the signal.

2) NooElec SDR: The first SDR we looked at is the NooElec NESDR Mini (Fig 5). This dongle is a re-purposed digital TV dongle. The dongle utilizes a Raphael Micro R820T tuner IC and a RTL2832U IC, which contains an 8 bit ADC (Analog to Digital Converter). The data stream that the computer receives consists of 8 bit samples of In-phase (I) and Quadrature (Q) signals. These two ICs are the backbone for what makes up the majority of low price SDRs that are seen on Amazon and other vendors [7]. The SDR can be controlled from graphical software like SDR# which lets you view the frequency content of the incoming signal. More complex software like GNU Radio allows the user to manipulate, visualize, and interpret the IQ signals with a drag and drop pipeline. There are also C libraries as well as Python wrappers, so the SDR can be directly integrated into ones software.

3) RTLSDR: Another low cost USB dongle looked at is the RTLSDR-blog branded dongle, which has the exact same hardware as the NooElec one, except the RTLSDR has a temperature controlled oscillator and a metal casing.

4) Airspy: Unlike the NooElec and RTLSDR, other SDRs have been built for decoding low power signal protocols. This has required manufacturers to build sensitive radios. One radio that is popular is the Airspy, a sub $200 SDR with similar hardware to the NooElec NESDR Mini, but is built with several additional features including more comprehensible gain control, bias tee control to feed power through the transmission line to power devices, and a 12-bit ADC, which allows for more dynamic range in the sampling.

Fig. 5: The Airspy SDR and the NooElec SDR

5) SDR Frequency Drift: A temperature controlled oscillator is important because the temperature can affect the rate of the oscillator. Not having a temperature controlled one will allow oscillator drift to occur. Oscillator drift will shift the actual frequency tuned, which could lead the system to sampling the wrong frequency. An experiment was conducted to analyze the drift. The radio was tuned to a specific frequency, receiving a signal from a signal generator for a duration of 30 minutes in a climate controlled room and the drift was recorded (Table III). The results from the Airspy and the RTLSDR were expected to return similar values, because the oscillator is built to a similar specification. It was also expected that the NooElec would drift the most. Overall we would probably not choose to use the NooElec because of the uncertainty of the tuned frequency in post processing.

Radio	PPM Drift	Change in Frequency (Hz)
Airspy	0.5	108
RTLSDR	0.5	108
NooElec	14	3000

TABLE III: PPM Drift Results

6) SDR Noise Floor: Another consideration that was looked at was the ambient noise floor of the SDR itself. With the low power signal from the radio collar, a low noise floor figure from the radio itself will impact the UAS's ability to detect the signal. A test in GNU radio was used to measure the instantaneous power of the noise floor. The radios were measured in a low noise environment and the method was verified with a USRP SDR and a calibrated signal generator. The values from each radio in GNU radio were calibrated against a signal generator and normalized, so the SDRs could be accurately compared to each other. From this test it can be concluded that the Airspy preformed much better than the RTLSDR and the NooElec.

Radio	Noise Floor (dBm)
Airspy	-76.4
USRP	-80.6
RTLSDR	-65.2
NooElec	-62.4

TABLE IV: Noise floor measurements

7) UAS Noise: For the implementation of the receiver, the UAS and its subsystems need to be taken into account to determine if any EMI (Electro-Magnetic Interference) is being generated and is affecting the SDR. On a typical UAS deployment, several sources, including the autopilot telemetry, the control receiver, and the electronic speed controllers need to be looked at to determine if they are significantly affecting the SDR. An experiment was assembled to see if any devices or the combinations of the devices running, raised the noise floor on the SDR. For the experiment, a 3DR Iris quadcopter was the UAS, which is equipped with a 2.4 GHz control receiver and a 433Mhz, 100mW telemetry radio. The four brushless motors are powered by four ESCs (Electronic Speed Controller), which generate a three phase AC signal to run the motors. A dipole antenna tuned for 215.025 MHz, which is the frequency of the radio collar that was on hand, was attached between two of the arms of the quadcopter, connected to each radio under test. We decided that since the NooElec and RTLSDR have the exact same hardware and casing except for the oscillator, they would be tested as one. A generated signal from a NI USRP was fed into a dipole antenna tuned for 215.025 MHz, which is placed several wavelengths away from the UAS. Each receiving radio fed into GNU Radio, where instantaneous power was read as well as a FFT (Fast Fourier Transform) of the frequency to verify that the radio had not drifted. Several iterations of this test were conducted, turning each UAS component on and off to see if the power measurement changed by a dBm or more. For each radio a test was done with the SDRs gain increased to within 10 dBfs (dB Full Scale) of the ADC maximum range, which was verified from SDR#. This increase in gain is where the most visible results were found. Each radio was found to be affected by the UAS when all of its systems were running regardless of gain, but the NooElec/RTLSDR dongle was affected the most. From the results on the Airspy, it was inconclusive if the UAS actually raised the noise floor because the readings varied by 0.2 dBm (Table V). This result is not conclusive enough to suggest that the UAS was causing that change. We anticipate that the majority of the noise will be suppressed by replacing the plastic casing with a metal one similar to the one the Airspy is contained in.

Radio	Gain	UAS Off NF (dBm)	UAS off SNR
Airspy	0	-76.4	2.2
Airspy	19	-55.4	19.6
NooElec/RTLSDR	0	-65.2	5.4
NooElec/RTLSDR	19.6	-58.0	17.5
		UAS On NF (dBm)	UAS On SNR
Airspy	0	-76.2	1.9
Airspy	19	-55.6	19.0
NooElec/RTLSDR	0	-65.1	4.0
NooElec/RTLSDR	19.6	-51.8	13.2

TABLE V: UAS Noise measurements

E. System Evaluation

While all of these systems have been tested individually, a field test was put together to look at all of the systems together to better determine if these improvements found in the lab translate into the field with actual radio collars. Due to recent logistics, flying a UAS for research purposes have become difficult, so all of these tests were done not on a UAS. The test was to see at what distance the signal could not be detected from the ground. We designed this to look at the all of the iterations of the system and compare them in a relative manor. For the comparison three systems were compared: 1) NooElec and ARRL Antenna, 2) the RTL-SDR, antenna built from simulation and the LNA, 3) the Airspy, and the antenna built from simulation. Note an ARRL antenna is built based on the formula: $Length = 468/frequency(Mhz)$ We wanted to see how the Airspy performed without the LNA because the Airspy's SNR improvement was not as large as the RTL-SDR's improvement. The same method of measuring instantaneous power was implemented on a Raspberry Pi 3, which output the data stream over a TCP connection. This will allow future tests of the system to be elevated or remotely conducted. The test took place on a sports field in the local San Diego area. The antenna was placed so its lobes would face the direction of the collar to maximize the area it can detect. The collar was placed on the ground with the antenna parallel to the ground. We measured both the noise floor and the power of the signal for each SDR. This measurement was at 10 foot intervals. The results in (Fig 6) a very obvious improvement was made between the NooElec and the system with the RTL-SDR. The results from the Airspy were the most interesting but confusing because it was expected to perform better than the NooElec, but only did marginally.

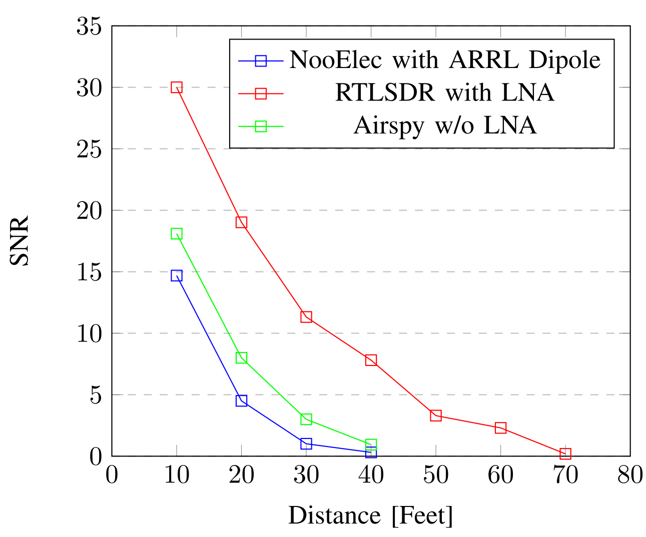


Fig. 6: SNR to Distance of each Configuration

IV. Conclusion

From simulation and physical testing, we demonstrated that building a low cost and sensitive receiver chain is attainable. The field tests demonstrate the potential of the system. In order to determine if this is a competitive alternative to aerial tracking, additional tests in the next field season will have to be conducted.

Acknowledgment

The authors would like to thank the San Diego Zoo for providing valuable support, insight and the specific hardware that is currently used for VHF tracking. This work was funded in part by NSF REU Site: Engineers for Exploration, Grant #1560162 and Grant #1544757.

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