Small rotor-craft obstacle avoidance imaging radar

DESIGN DOCUMENT

SDMAY21-07

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Executive Summary

Development Standards & Practices Used

List all standard circuit, hardware, software practices used in this project. List all the Engineering standards that apply to this project that were considered.

- Software practices/standards:
  - Frequency analysis
  - Agile
- Circuit practices/standards:
  - Power Electronics
- Hardware practices/standards:
  - Antenna and Propagation
  - Measuring Electromagnetic Field Strength

Summary of Requirements

List all requirements as bullet points in brief.

- Design and optimization of passive antenna(s)
- Design of power supply and voltage regulators
- Design of RF emitters and receivers
- Programming of ADC and microcontroller
- Signal processing and data presentation

Applicable Courses from Iowa State University Curriculum

List all Iowa State University courses whose contents were applicable to your project.

EE 201, EE 230, EE 224, EE 324, CPR E 281, EE 311, EE 185, CPR E 288, EE 285, COM S 227, EE 333, CPR E 185.

New Skills/Knowledge acquired that was not taught in courses

- RF circuit design

- Frequency optimization for Antenna implementation
- Image processing in Python
- Voltage regulator design
- Radar technology principles

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

1 Introduction

1.1 Acknowledgement

The completion of this project would not have been possible without the assistance of many people. Specifically, the group would like to thank the following:

The Electrical and Computer Engineering Department, the Electronics and Technology Group, and Iowa State University, thank you for the invaluable help and learning opportunities you have presented each member of this group with throughout each member's college career. Thank you for providing materials towards the completion of the project and for giving the team a space in which to collaborate on the project.

To Dr. Mohammad Tayeb Al Qaseer whose knowledge and expertise has provided the group with countless learning opportunities and experience.

Thank you again to all those who have provided assistance to the group throughout this project.

1.2 Problem and Project Statement

When flying any type of vehicle, it is imperative to avoid any collisions with other objects. One of the most dangerous objects that a flying vehicle could hit are overhead power lines and guy-wires. These wires are capable of not only damaging the craft but also causing large amounts of damage through fires. Even though these wires can be quite dangerous, it is difficult to see these wires in everyday conditions.

To avoid potential collisions, a system will be developed that utilizes radar operated antennas to detect and visualize wires and their orientations relative to the vehicle. This radar system will be comprised of a combination of circuitry and programming that will allow an antenna to find and visually recreate a wire's location and orientation for an operator. At the end of this project, we will have a system that can successfully locate a wire and visually recreate it at a computer that is connected to our radar system. This visual recreation should contain enough information so that an operator would know how to avoid the wire with their vehicle.

1.3 Operational Environment

Since this product will be used to locate wires that are normally difficult to see, this product will be required to operate at most outdoor conditions. Specifically, the finished product will be able to operate in both dusty and foggy conditions and must also be able to operate at any time of the day. This solution assumes that an operator will not operate under extreme weather conditions.

1.4 Requirements

When completed, the radar system must be able to detect wires that are within 10-100 meters away. The radar should be able to find these wires and send sufficient data back to a computer so that a picture of the size and orientation of the wire can be seen by an operator. The device will send sufficient data to the computer in a way that an operator may understand the information.

1.5 Intended Users and Uses

The radar system is intended to be used by any company or individual that would like increase security or situational awareness while flying a vehicle or craft. The use of this project would be for remote controlled aircraft to be able to detect small wires and other objects that are either too small to detect by camera or if there are visibility reducing weather conditions.

1.6 Assumptions and Limitations

Assumptions:

-Range of RADAR will be 10-100 meters

-Using a modified horn antenna

-Will use 2.4 GHz operating frequency

-Will use pc to process data and images

Limitations:

-Due to COVID-19, no in person meetings will be conducted during the Fall semester, and possibly the spring

-Research and Development will have a budget of up to $500 without special permission from the department

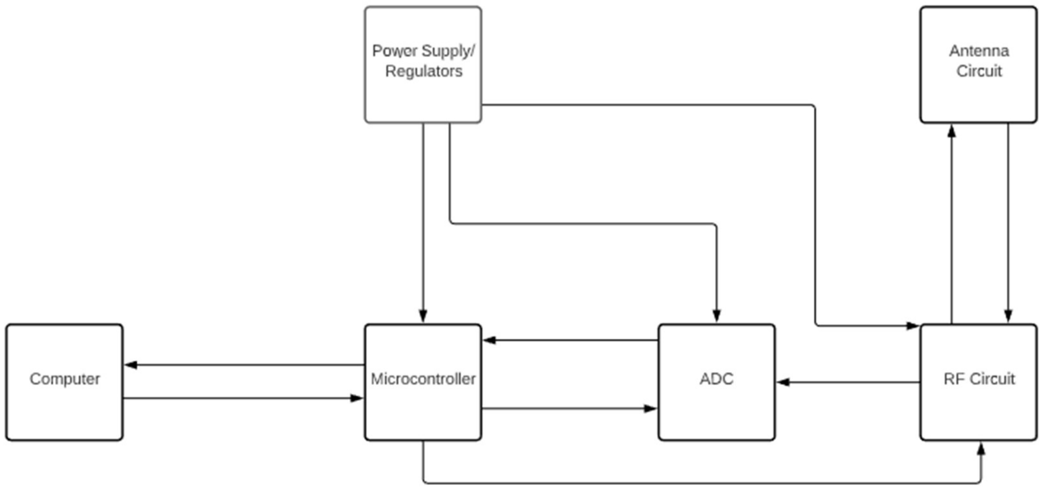
-Antenna will initially be constructed with 3D printer material, so structural integrity might be reduced compared to an aluminum antenna

1.7 Expected End Product and Deliverables

The expected end product will be a prototype system that will use a horn antenna together with integrated technology to detect wires from 10-100 meters away. The system will consist of a RF circuit, power regulators, ADCs and a microcontroller. The prototype will take a signal received through the antenna and will convert it from an analog signal to a digital signal. This digital signal will be transmitted to a PC for an operator to use and make decisions from. The prototype system will be ready by April 2021.

2 Project Plan

2.1 Task Decomposition



Task 1: Antenna Design

Antenna design will be done through CST Studio. The design of the antenna has already been completed beforehand, so the main amount of work will be done to optimize the antenna design through CST.

Task 2: Image/Data Processing using Python and/or MATLAB

Development of algorithm to interpret data coming from the microcontroller and retrieving meaningful information from it. The goal is to be able to identify the following parameters with the given data: orientation and location.

Also, develop an image of the expected powerline overlayed with an original image of the powerline location.

Task 3.1: Circuit Design - (Power Supplies/Regulators and ADC)

As seen in the block diagram, the power supply/regulators will provide power to almost every component in the radar system. It is crucial to have a variety of voltages to supply since each component's requirements may vary. Circuit design will be done through Altium Designer.

ADC implementation will also be carried out in Altium Designer and will feed data from RF receiver (task 3.2) to microcontroller.

Task 3.2: (RF Circuit, Microcontroller – physical layout, pins, port connections)

Design of 2 RF circuits: an emitter and a receiver. These will utilize the Antenna as part of the circuit in order to attenuate radio frequencies. Design will be done in Altium Designer.

Also, clear physical layout of pins and port connections will be decided upon at the end of this task.

Task 4: Design and program RF Microcontroller for specified parameters

The RF Microcontroller will be programmed to the specifications need for the project, such as the operating frequency. There will also be phase loop locking to ensure that the microcontroller is operating at the correct frequency.

Task 5: Serial connection between PC and Microcontroller

The microcontroller on the embedded system will communicate with the PC using SPI serial lines. The microcontroller will take data in from the radar system and will translate the information to the PC.

2.2 Risks and Risk Management/Mitigation

Task 1:

The current plan for antenna fabrication is to use a 3D printer. This process may create an antenna that is not sufficiently sturdy or rigorous enough for the operations that we need. The risk factor for this is relatively low since the testing environment will be controlled enough to prevent any dangerous conditions for the radar system. The risk factor is somewhere around 0.1.

Once the antenna has been constructed, we will be use conductive spray paint to coat the outside of the antenna. This paint may not be able to get down into the channels of the antenna thus potentially reducing the conductive capabilities of the antenna. Overall, the conductive spray paint should suffice but a risk factor of approximately 0.2 does exist.

Task 2:

The current plan for the PC algorithm development and image processing is to use Python as the main language. Python has strong image processing libraries, such as OpenCV with convenient Python wrappings. However, there is a chance that Python does not support our desired tasks. If that happens, the group will use MATLAB and some already pre-defined algorithms to accomplish the desired tasks. Risk factor: **0.1**

When testing the algorithm, which will be designed before the system is completely built, there is a chance that the algorithm does not work as intended. If that is the case, the group will evaluate the situation and decide if the algorithm needs to be re-worked. Depending on the magnitude of the problem, the group will set a wider error margin and try to work from there. Risk factor: **0.2**

Task 3:

Power regulators are designed improperly thereby leading to an incorrect amount of power supplied to the circuit which causes damage to other existing components on the board. Risk Factor: **0.1.**

The RF design may prove faulty in early design stages and provide unreliable outcomes. This in turn will feed bad information to the microcontroller leading to incorrect detection for the radar system. The risk factor assigned to this task is around .30 since there exists ample literature on the subject for us to follow.

Task 4:

Electric noise can cause data to become inaccurate. External sources can cause false data if magnitude of the signal is great enough. Proper filtering, both digital and analog, can help mitigate interference of this sort. Risk Factor: **0.1**

Task 5:

An improper communication setup will be devastating to the outcome of the system as the PC would be unable to correct for any info found from the antenna, but with proper debugging this should not be a problem. Risk Factor: **0.1**

Another potential problem would be the lack of proper libraries to communicate between the python on the PC and whichever microcontroller we choose, although many have access to an assortment of SPI libraries. Risk Factor: **0.1**

2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Task 1:

For task 1, the main measurement of progress will be related to the optimization of the antenna. The optimization must reach a certain threshold to for the antenna to be usable. So, progress on the antenna will be measured against the level of optimization needed for the antenna to properly measure from 10-100 meters.

Task 2:

The first milestone should be the ability to receive data from the SPI protocols established on the microcontroller. The group needs to make sure that data coming from the microcontroller is correctly transmitted to the PC as is. The second milestone would be to interpret the data from the microcontroller and design an algorithm to output "line distance" and "orientation". The third milestone would be to create an algorithm to output a visual representation of the data coming from the microcontroller and be able to overlay it with an image from a camera input (The goal is to have the camera pointed at where the horn antenna would be pointed at).

Task 3:

The first milestone for the power regulator and RF circuits portion will be a completed circuit developed using Altium Designer. The measurement for this goal will be quantified as the virtual circuit passing every required task when tested through the design software. The second milestone will be completing construction of the power regulator circuit in coordination with the RF microcontroller circuit. To measure this progress, the group will run the final circuit through multiple tests and observe the results getting sent back to the PC. If the results align correctly with our expected values, the circuit design is complete.

Task 4:

The milestone for the RF Microcontroller program will be to have a testable program by the time physical prototyping occurs. This will be measured by the progress of the program, e.g. making sure registers have correct values in them to initialize the microcontroller to behave exactly how we want it. We can evaluate this by observing the data that is sent from the RF microcontroller to the microcontroller that interfaces with the computer.

Task 5:

The milestones for the microcontroller communications to the PC will first be the ability to set up communications through SPI. This will be measured through a series of "Hello World" tests, and will be simple to accomplish. The second is to be able sort and understand all incoming data from the RF circuit. This will be measured through a process of testing the antenna while connected to the microcontroller, and be able to translate this data into a readable format. Finally, a protocol will need to be devised to communicate this data between the microcontroller and the PC. The success of this will be measured by the response of the PC given certain input data.

2.4 Project Timeline/Schedule

ACTIVITY	Assigned To	Progress %	START DATE (m/d/y)	END DATE (m/d/y)
Optimize antenna through CST Studio	Matt	0%	10/5/20	10/19/20
Aid with circuit design in Altium	Matt	0%	10/26/20	11/25/20
Aid with algorithm design for image processing	Matt	0%	11/1/20	11/25/20
Learn power regulator circuit design	Matt	0%	10/5/20	10/25/20
Design and test python library for image processing (openCV)	Felipe	80%	9/23/20	10/4/20
AId with circuit design in Altium	Felipe	0%	10/4/20	11/1/20
Design flowchart for data annalysis algorithim	Felipe	0%	10/7/20	10/12/20
Write software to test and fine tune flowchart	Felipe	0%	10/12/20	10/20/20

Write software to read data from serial port	Felipe	0%	11/1/20	11/20/20
Develop software for reading and interpreting data. Develop image processing algorithim	Felipe	0%	11/20/20	2/20/21
Research RF IC Chips and MIMO Antenna Control	Josh	0%	9/30/20	10/14/20
Design program for RF IC Chips for selected controller	Josh	0%	10/14/20	11/4/20
Test RF controller for functionality	Josh	0%	1/25/20	3/1/20
Learn Power regulator circuit design	Matt McD.	0%	10/5/20	10/12/20
Power Regulator Circuit Design	Matt McD.	0%	10/12/20	11/25/20
Choose Microcontroller and corresponding ADC	Mike	25%	9/23/20	10/7/20
Write code to understand RF data	Mike	0%	10/8/20	11/1/20
Establish SPI serial and generate protocol	Mike	0%	10/8/20	11/1/20
Connect RF Data and Serial Protocol	Mike	0%	11/2/20	11/20/20
Study RF circuits from datasheets	Leon	25%	9/25/20	10/13/20
Design RF emitter circuits in Altium Desginer	Leon	0%	10/13/20	11/1/20
Design RF transmitter circuits in Altium Designer	Leon	0%	10/13/20	11/1/20
Aid in the implementation of ADC(s)	Leon	0%	11/1/20	11/22/20

2.5 Project Tracking Procedures

For this project, the group members have decided on several different methods for project organization. The group will use Discord for communication between members, and it will also serve as the method to make announcements to the group. Cybox will be used for file storage for all non-code work. This will include drawings, schematics, important emails and written documents. Github will be used for code storage. Finally, Microsoft Excel will be used for official scheduling and to keep track of progress made on the project.

2.6 Personnel Effort Requirements

The hours assigned to each task in the table below is based on a rough approximation. Each team member will be able to adjust their hours once they know the full scope of work required for their portions of the project.

Matthew Bahr	Antenna CST Studio Design – 20 hours
Leonardo Bertoncello-Machado	Altium Designer – 30 hours
Matthew McDermott	Altium Designer - 30 hours
Michael Ostrow	Microcontroller Serial Communications –25 hours
Felipe Varela Carvalho	Algorithm development – 25 hours
Joshua Welton	RF Circuit Controller – 20 hours

2.7 Other Resource Requirements

To complete this project, the group will require a 3-D printer along with the necessary material to use the printer. A microcontroller will be purchased as well. Various electronic parts will be used to create the circuitry needed for the project.

2.8 Financial Requirements

Iowa State University's College of Engineering has provided the group a budget up to $500 to work with. The budget will cover all costs associated with the project including various parts and fees necessary to build the required components.

3 Design

3.1 Previous Work And Literature

Include relevant background/literature review for the project

– If similar products exist in the market, describe what has already been done

– If you are following previous work, cite that and discuss the **advantages/shortcomings**

– Note that while you are not expected to “compete” with other existing products / research groups, you should be able to differentiate your project from what is available

Detail any similar products or research done on this topic previously. Please cite your sources and include them in your references. All figures must be captioned and referenced in your text.

3.2 Design Thinking

Detail any design thinking driven design “define” aspects that shape your design. Enumerate some of the other design choices that came up in your design thinking “ideate” phase.

3.3 Proposed Design

Include any/all possible methods of approach to solving the problem:

- Discuss what you have done so far – what have you tried/implemented/tested?
- Some discussion of how this design satisfies the **functional and non-functional requirements** of the project.
- If any **standards** are relevant to your project (e.g. IEEE standards, NIST standards) discuss the applicability of those standards here
- This design description should be in **sufficient detail** that another team of engineers can look through it and implement it.

3.4 Technology Considerations

Highlight the strengths, weakness, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

3.5 Design Analysis

– Did your proposed design from 3.3 work? Why or why not?

– What are your observations, thoughts, and ideas to modify or iterate over the design?

3.6 Development Process

Discuss what development process you are following with a rationale for it – Waterfall, TDD, Agile. Note that this is not necessarily only for software projects. Development processes are applicable for all design projects.

3.8 Design Plan

Describe a design plan with respect to use-cases within the context of requirements, modules in your design (dependency/concurrency of modules through a module diagram, interfaces, architectural overview), module constraints tied to requirements.

4 Testing

Testing is an **extremely** important component of most projects, whether it involves a circuit, a process, or software.

1. Define the needed types of tests (unit testing for modules, integrity testing for interfaces, user-study or acceptance testing for functional and non-functional requirements).
2. Define/identify the individual items/units and interfaces to be tested.
3. Define, design, and develop the actual test cases.
4. Determine the anticipated test results for each test case
5. Perform the actual tests.
6. Evaluate the actual test results.
7. Make the necessary changes to the product being tested
8. Perform any necessary retesting
9. Document the entire testing process and its results

Include Functional and Non-Functional Testing, Modeling and Simulations, challenges you have determined.

4.1 Unit Testing

– Discuss any hardware/software units being tested in isolation

4.2 Interface Testing

– Discuss how the composition of two or more units (interfaces) are to be tested. Enumerate all the relevant interfaces in your design.

4.3 Acceptance Testing

How will you demonstrate that the design requirements, both functional and non-functional are being met? How would you involve your client in the acceptance testing?

4.4 Results

– List and explain any and all results obtained so far during the testing phase

- Include failures and successes
- Explain what you learned and how you are planning to change the design iteratively as you progress with your project
- If you are including figures, please include captions and cite it in the text

5 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3.

6 Closing Material

6.1 Conclusion

Summarize the work you have done so far. Briefly re-iterate your goals. Then, re-iterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

6.2 References

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

6.3 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar data that does not directly pertain to the problem but helps support it, include it here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc,. PCB testing issues etc., Software bugs etc.