Molecular Communication Over the Air

ECE4011 Senior Design Project

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Table of Contents

| Ex | xecutive Summary 3 | |
|-----|--|---------------|
| 1. | Introduction | 4 |
| | 1.1 Objective 1.2 Motivation 1.3 Background | 4 5 6 |
| 2. | Project Description and Goals | 6 |
| 3. | Technical Specification | 7 |
| 4. | Design Approach and Details | 8 |
| | 4.1 Design Approach4.2 Codes and Standards4.3 Constraints, Alternatives, and Tradeoffs | 8 12 12 |
| 5. | Schedule, Tasks, and Milestones | 13 |
| 6. | Project Demonstration | 13 |
| 7. | Marketing and Cost Analysis | 14 |
| | 7.1 Marketing Analysis7.2 Cost Analysis | 14 15 |
| 8. | Status | 17 |
| 9. | Leadership Roles | 18 |
| 10. | . References | 20 |
| Ар | opendix A | 21 |
| Ар | opendix B | 22 |

Executive Summary

Molecular communication is a form of communication that uses molecules instead of electromagnetic waves to transmit information. It has a variety of applications in biomedical, military and environmental areas. In situations like earthquakes where traditional EM waves are unable to propagate, molecules can travel past the environmental barriers and achieve successful communication. The most promising application is in the biomedical field, using molecular communications in drug delivery systems.

The project goal is to design and prototype a molecular communication system capable of sending text messages from one machine to another. The system consists of an electronic spray bottle that sprays alcohol to a sensor. The spray rate and concentration of molecules will be controlled by a microcontroller. The sensors that receive the transmitted alcohol measure the alcohol concentration and are connected to a different microcontroller which demodulates the signal. Further analysis of the gathered data will be done in MATLAB.

This prototype will be built at the macro-scale to allow focus on researching how to improve the speed and accuracy of this method of communication. The total cost to build a prototype of this device is expected to be \$300, which covers two Arduino Uno microcontrollers, one spray bottle, three alcohol sensors (with different sensitivities and operating points), and the cost to manufacture PCB boards. Since the primary purpose of this project is research, the device will remain in a cycle of working product and implementing improvements. One prototype will be produced to show that text messages can be encoded into binary and transmitted by sending low or high concentration molecules. All improvements will focus on increasing the rate of communication.

Molecular Communication Over the Air

1. Introduction

Team Molecular will develop a wireless communications system that transmits data by adjusting the concentration of particles of a substance in the air. The team requests \$300 to fund the development of a prototype of the system.

1.1 **Objective**

The goal of this project is to develop a prototype communication system that uses a spray of chemicals to transmit data. The transmitter hardware consists of a bottle to spray the chemicals and a microcontroller which controls the spray bottle. The microcontroller encodes the information message as a binary sequence and then modulate the channel symbols into a carrier signal. The sprayed chemicals then propagate through air and accelerate by a fan to the receiver. The receiver consists of sensors capable of detecting the concentration of the sprayed chemicals connected to a microcontroller. The target is able to send a simple text message using this system. The data is encoded using binary, with a low concentration of chemicals at the receiver representing a zero and a high concentration representing a one. A block diagram of the envisioned prototype is featured in Figure 1.



1.2 Motivation

The main motivation for this project is to develop a new way of wireless communication that can be implemented when traditional wireless methods cannot be used. Some areas where standard electromagnetic communication is difficult include inside tunnels and very small distances [1]. Tunnels are a problem because electromagnetic waves cannot bend around turns, but it is possible to make air flow around turns. Very small distances, on the order of nanometers, are a problem because the antenna size must be on the order of a wavelength of the transmitted signal. Therefore, the signal would have to be transmitted in the ultraviolet region to be detected by a nanometer-sized antenna, which is not feasible because these frequencies do not travel through most materials very well and are potentially hazardous to humans. However, it is feasible to make a device that can detect molecules at that scale.

1.3 Background

Currently, there is at least one group that has built a working prototype. Our design draws some ideas from their work, including the general system architecture. This group has demonstrated that it is possible to send text messages using this system, although it takes around three seconds to transmit a single bit. They used the ITA2 standard for their alphabet, which represents each character as a five-bit sequence. Therefore, it takes an average of fifteen seconds to transmit each character using their system. Part of the reason for this slow transmission rate are the resume and response times of the receiver. The response time is the amount of time the sensor takes to react to a change in concentration and the resume time is the amount of time the transmitter must wait before sending another bit. They also performed several tests which demonstrated that having a fan to blow the chemicals toward the sensor greatly improves accuracy of detecting the signal, even using a fan that generates turbulence. They also showed that their system had some nonlinearities, which caused some errors in reading the signal [1].

2. **Project Description and Goals**

The goal of this project is to create a functioning prototype of a wireless communication system that can transmit data by adjusting the concentration of particles in the air through a transmitter and a receiver. The transmitter consists of a GUI on a laptop to allow the user to input text messages and a microcontroller that controls a mechanized spray bottle. The receiver contains a sensor and microcontroller to record the change in concentration of the particles and convert the analog data to digital data and a laptop to decode and translate data into the text message. Project objectives include:

- Successfully transmitting a message from transmitter to receiver
- Building prototype easily and spending a smaller amount on parts

• Making the platform so the data collected is easily accessible for others to use for research

3. Technical Specifications

Major components of this system are the embedded transmitter and the embedded receiver. Table 1 displays the specifications of the microcontroller that will be implemented in both the transmitter and receiver, an Arduino Uno Rev3, while Table 2 displays the specifications of the three alcohol sensors implemented on the receiver.

| Item | Specification | |
|-------------------|---------------|--|
| Microcontroller | ATmega328P | |
| Operating voltage | 5v | |
| USB | 14 | |
| Digital I/O | 6 | |
| Analog Input Pins | 6 | |
| Flash Memory | 32 KB | |
| SRAM | 2 K | |
| EEPROM | 1 K | |
| Clock Speed | 16 MHz | |
| Length | 68.6 mm | |
| Width | 53.4 mm | |
| Weight | 25 g | |

| Specifications | Model | | | |
|-------------------|-------------------------|------------------------|----------------------|--|
| | MQ-3 [3] | MQ303A [4] | MR513 [5] | |
| Diameter | 16.8 mm | 9.4 mm | 12 mm | |
| Height (w/o pins) | 9.3 mm | 8 mm | 10 mm | |
| Detection Range | 25 - 500 ppm | 20 - 1000 ppm | - | |
| Heater Voltage | 5V ± 0.1V (AC or DC) | 0.9V ± 0.1V (AC or DC) | - | |
| Circuit Voltage | $5V \pm 0.1V$ (DC) | $3V \pm 0.1V$ (DC) | $2.5V \pm 0.1V$ (DC) | |
| Output Voltage | 2.5V < Vo < 4.0V | - | - | |
| Material | Plastic | Metal | - | |
| Cost | \$4.95 | \$5.50 | Request Sample | |

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Design Approach and Details 4.

4.1 **Design Approach**

4.1.1 Text GUI

The goal of this project is to transmit text messages over the air via chemical molecules. The text that the user wants to input into the system is collected by a GUI, Graphical User Interface, on a PC and then the GUI will send it via a serial port to the Arduino microcontroller.

The GUI is planned to be programmed in C# and when the user types in the message and hits the "SEND" button, it will send the text through a serial port to the Arduino microcontroller. The expected layout of the GUI is shown below.



4.1.2 Microcontroller Programming in transmitter

The Arduino microcontroller is designed to constantly check the USB serial port for any incoming text message from the GUI. Once it receives a message, it will decode every character in the message into a binary representation of 0 and 1s. Each character has a corresponding five-bit binary sequence, Baudot-Murray code, according to the International Telegraph Alphabet No. 2 (ITA2) standard [6, 11]. Then, the Arduino will send digital signals to the customized circuit board which is connected to the spray bottle to modulate the channel symbols into chemical signals. The amount of liquid sent in each spray will be used to determine whether the binary bit being transmitted is a 0 or a 1. Specifically, bit 0 is modulated as no spray; bit 1 is modulated as spray.

4.1.3 Circuit switch board and spray bottle

The commercial electronic spray, DuroBlast electronic spray [7] is chosen to be the spray bottle used to transmit liquid over the air. It can store a variety of liquid chemicals which could be sprayed by a battery operated electrical pump. With the custom electrical switch board, the spray operations can be controlled by an Arduino microcontroller [7]. In this way, depending on the binary bit the system needs to transmit, the amount of liquid sent by bottle is controlled by the microcontroller via the customized circuit switch board.

4.1.4 Circuit board and alcohol sensors

The receiver will include three alcohol sensors attached to different pins on a microcontroller. Each of the alcohol sensors acts as a current source, setting the current proportional to the alcohol concentration in the air. The receiver has three alcohol sensors (each with different sensitivity, power and operation parameters) because they will be used to vote on each bit to increase the confidence that the signal is being read correctly. The microcontroller will be used as an intermediary between the analog signals from the gas sensors and the USB signal needed to connect to the computer for demodulation. The selected alcohol sensors include MQ-3, MQ303A, and MR513. The block diagram of the receiver is shown below in Figure 3.



4.1.5 Microcontroller programming in receiver

At the receiver side, the microcontroller with alcohol sensors monitors the modulated signal, alcohol concentration. With acquired real-time signal, the Arduino is programmed to demodulate the signals back into channel symbols and decodes the symbols into ASCII values. Then the computer displays ASCII values.

The microcontroller is programmed to operate in two alternating states: idle state and reception state. As no change of concentration is detected, the microcontroller remains idle and keeps monitoring the concentration. When a surge in concentration takes place, the microcontroller turns to reception state in which a concentration surge is demodulated as 1 and a concentration downfall is demodulated as 0. An extra '10' bit sequence is added to every starting of new message for activating the reception state and synchronize the time between the transmitter and the receiver. When consecutive five 0 bits are detected, the microcontroller turns back into idle state.

The next step, decoding, is straightforward. After the recovered signals get segmented by time windows, one bit is extracted from each segment through averaging and thresholding. Based on the ITA2 table, a binary-to-ASCII conversion can be hard coded.

It's a future concern that effectiveness of signal reception is highly related to the environment. In a laboratory setup, noise and distortion except the diffusion will be controlled. In a complicated environment, like the EXPO, the team should either isolate the system or create a robust rule to reduce the external influence. One may consider model-driving learning algorithm, but due to limited accessible data, training such model with insufficient data may result in bad prediction. Isolating the system is a conservative choice, but design of isolation system hasn't yet been concerned for now.

Codes and Standards

International Telegraph Alphabet No. 2 (ITA2) standard is one of the most significant standards for our design; it is a known encoding/decoding standard for digital communication. The encoder and decoder are programmed based on this standard.

4.2 Constraints, Alternatives, and Tradeoffs

One significant project decision is made on the transmitter side of the prototype. Instead of using a commercial electronic liquid spray bottle, the team considered building an automated spray bottle from a mechanical spray bottle with a handle, a TowerPro MG995 servo and a servo base [8]. The first advantage of building an automated spray bottle from scratch is the cost; the components needed in the design are easily accessible mechanical parts and electronic parts and are more economical than the commercial electronic spray bottle. The second advantage is the built automated spray bottle will be easier to maintain and troubleshoot since it involves only primitive hardware and software units. However, building a transmitter can cause unexpected delays and create unnecessary technical challenges for the project, thus diverting focus away from the main goal of the design project: molecular communication. Given that the commercial electronic spray can immediately transmit liquid once connected to a microcontroller makes it a better candidate for the project prototype.

Another significant design decision is an optimization in the rate of bit transmission. The most limiting factor in the transmission rate is the amount of time it takes for the alcohol to completely dissipate so that no alcohol remains to influence the next reading. Since the gas sensors use a combustion mechanism to determine alcohol concentration, temporarily increasing heater voltage on gas sensor after reading will quickly burn up the leftover alcohol. The trade-offs to this approach are that the current reading will spike during hot periods and the heater's product life will decrease. Overall, the projected speed gains outweigh the decrease in product life because this product will never be manufactured and sold.

Another important design decision was using three is sensors instead of one. Having three gas sensors (each with different sensitivity, power and operation parameters) increases the likelihood that each bit will be read correctly. The downsides to this approach are that the device will \$10 more and be larger. However, since this is used for research purposes rather than to be sold, the additional accuracy outweighs the increased cost and size.

5. Schedule, Tasks, and Milestones

The Gantt chart in Appendix A shows the specific tasks that need to be completed for this project, a visual representation of how much time has been allotted to each task depending on perceived difficulty, the division of labor, and milestones that are set. The PERT chart in Appendix B shows the tasks, the division of labor, and the critical path highlighted in red.

6. **Project Demonstration**

The platform, once successfully built, should be capable of transmitting text messages through a liquid medium such as isopropyl alcohol that is sprayed in the air towards the receiver. The platform will adopt a horizontal setup. Demonstration of the capabilities of the platform will consist of one user performing the following:

1. The user inputs a text message through the text input GUI, which will then be sent over to the Arduino Uno open-source microcontroller and converted to a sequence of binary bits.

- 2. After the conversion, the microcontroller will modulate the electronic spray bottle to spray isopropyl alcohol at different rates. During this time, the fan will be operating to help propagate the alcohol over to the receiver side.
- 3. The receiver, which can detect a chemical signal, will capture the concentration of alcohol received.
- 4. The receiver is connected to another Arduino Uno open-source microcontroller, and the data received will be transmitted to the said microcontroller and demodulated through decoding algorithms.
- 5. On the rightmost side of the platform will be a computer connected to the Arduino Uno opensource microcontroller using serial-port connection. The decoded characters will be displayed and the demonstration is a success once the displayed characters on the computer side match the characters that the user inputted at the beginning.

With the project being more research-oriented, there would be minimal adjustments to the prototype in terms of its hardware and external design. Instead, more time would be dedicated to the correct implementation of microcontroller programs and efficiency of the overall process.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

This system would be useful anywhere standard methods of electromagnetic communication are not feasible. One example would be in micro- and nano-scale technology where the antenna would need to be larger than the actual device. It is, however, possible to make a chemical sensor at this scale, making this technology useful for communication between nanoscale devices.

Currently, only prototypes of this system exist, and it will probably not be marketable for

several years as it is still in the very early stages of development. It is still large-scale, so not useful for nanoscale technology and it is still very slow.

7.2 Cost Analysis

Taking advantage of resources on campus and requesting samples online, the total cost for materials to build the prototype will be \$60.35. The breakdown of material costs is shown in Table 3.

| Product Description | Quantity | Unit Price (\$) | Total Price (\$) |
|------------------------|----------|-----------------------------|------------------|
| Arduino Uno Rev3 | 2 | \$24.95 | \$49.90 |
| MQ-3 | 1 | \$4.95 | \$4.95 |
| MQ303A | 1 | \$5.50 | \$5.50 |
| MR513 | 1 | Request sample | \$0 |
| rinting PCB | 2 | Free at Invention Studio | \$0 |

The total number of labor hours were calculated assuming an 8-hour work day for the worstcase-scenario time allotted shown in Appendix A. Total labor costs were calculated by taking the number of work hours, the hourly salary assuming each engineer earns \$47.41/hour [10], and the number of engineers working on that section. The total development costs were calculated assuming the fringe benefit to be 30% and the overhead to be 120%. Developing and producing the circuits board will have the highest number of labor hours due to prototyping a unique board for the transmitter and the receiver. The overall cost of producing this prototype will be \$405,825.83 as shown in Table 5.

| Project Component | Labor Hour | Labor Cost | Part Cost | Total Component Cost |
|------------------------|------------|--------------|-----------|----------------------------|
| Transmitter | 240 | \$22756.80 | \$24.95 | \$22,781.75 |
| Receiver | 240 | \$22756.80 | \$35.40 | \$22,792.20 |
| Circuit Board | 424 | \$20101.84 | 0 | \$20,101.84 |
| PC Host Environment | 168 | \$7964.88 | 0 | \$7,964.88 |
| Data analysis | 240 | \$68270.40 | 0 | \$68270.40 |
| Total | 1312 | \$141,850.70 | \$60.35 | \$141,911.07 |

| Fable 5. Total Development Costs | | |
|----------------------------------|--|--|
| \$60.35 | | |
| \$141,850.72 | | |
| \$42,555.22 | | |
| \$184,466.29 | | |
| \$221,359.54 | | |
| \$405,825.83 | | |
| | | |

Over a five-year period, it is assumed 50 units will be sold. Table 6 shows the calculation of the expected profit and selling price assuming this system goes into production. Fringe benefits were assumed to be 30%, overhead was assumed to be 120% and sales expense was assumed to be 2%.

| Table 6. Selling Price and Profit per Un | nit |
|--|----------|
| Parts Cost | \$150 |
| Assembly Labor [12] | \$20 |
| Testing Labor | \$35 |
| Total Labor | \$55 |
| Fringe Benefits, % of Labor | \$16.50 |
| Subtotal | \$221.50 |
| Overhead, % of Matl, Labor & Fringe | \$265.80 |
| Subtotal, Input Costs | \$487.30 |
| Sales Expense | \$10 |
| Amortized Development Costs | \$25 |
| Subtotal, All Costs | \$522.05 |
| Profit | \$400 |
| Selling Price | \$922 |

8. Status

With regards to Appendix A, which is the Gantt chart drafted earlier in the semester, this proposal serves as an effective starting point for the oral presentation taking place next semester. Since the presentation revolves mostly around this proposal, therefore, approximately 50% of the presentation is accomplished through the completion of this proposal.

There is currently 15% completion towards building the physical prototype with the design of the platform established as well as hardware selection chosen. Progress in software building has yet to

commence.

9. Leadership Roles

Leadership roles are summarized in Table 7.

| Team member | Leadership role | |
|-------------------|-----------------------------------|--|
| Jacob Callahan | Lead hardware engineer | |
| Nick Fahrenkrog | Expo coordinator | |
| Constance Perkins | Lead firmware engineer, Webmaster | |
| Zhongyang Shi | Documentation coordinator | |
| Jun Xiang | Lead signal processing engineer | |
| Siyan Yu | Lead embedded system engineer | |

Technical roles are summarized in Figure 4. Team members' names are next to the component of the prototype that they plan to contribute to.



10. **References**

[1] Farsad, Nariman, Weisi Guo, and Andrew W. Eckford. "Tabletop Molecular Communication: Text Messages through Chemical Signals." *PLOS ONE*. Public Library of Science, 18 Dec. 2013. Web. 11 Apr. 2017.

[2] "Arduino - ArduinoBoardUno", Arduino.cc, 2017. [Online]. Available: https://www.arduino.cc/en/Main/ArduinoBoardUno. Web. 11 Apr. 2017.

[3] Seeed Studio, "Grove - Gas Sensor (MQ3)," MQ-3 datasheet, Sept. 2015

[4] Seeed Studio, "MQ303A Alcohol Sensor," MQ303A datasheet, Jan. 2009

[5] Zhengzhou Winsen Electronics Technology Co., Ltd, "Hot-wire Type Gas Sensor (Model : MR513)," MR513 datasheet, June 2015. [Revised Aug. 2016].

[6] The International Telegraph and Telephone Consultative Committee (CCITT) (1988) International Telegraph Alphabet No. 2. Blue Book, Fascicle 7–1.

[7] Frbiz, "Duroblast electric Sprayer images, view Duroblast electric Sprayer photos of item 42681500," 2011. [Online]. Available: http://amazingnokout.en.frbiz.com/images/p42681500

duroblast_electric_sprayer.html

[8] TowerPro, "High Speed Metal Gear Dual Ball Bearing Servo" MG995 datasheet

[9] Scharf, L. L. (2002). Statistical signal processing: detection, estimation, and time series analysis. Reading, Mass.: Addison-Wesley.

[10] "Occupational Employment and Wages, May 2016," U.S. Bureau of Labor Statistics, 03-Mar-2017. [Online]. Available: https://www.bls.gov/oes/current/oes172071.htm. Web. 11 Apr. 2017.

[11] "The "Baudot" Code". dataIP Limited. Archived from the original on 26 August 2010. Retrieved 9 October 2010

[12] "Electronic/Soldering Technician Job - Latitude Inc. - Marietta, GA." *Indeed.com*. Indeed, 13 Apr. 2017. Web. 14 Apr. 2017.

Appendix A



Appendix B

