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Project Proposal – Ultrasound Remote Operated Vehicle

I. INTRODUCTION

PROBLEM

Wireless communications predominantly use electromagnetic waves as a means to communicate control and telemetry signals. However, in conductive media such as water, electromagnetic waves do not propagate well. As a result, much of the planet is inaccessible to remotely operated vehicles which communicate with their operators exclusively through electromagnetic waves.

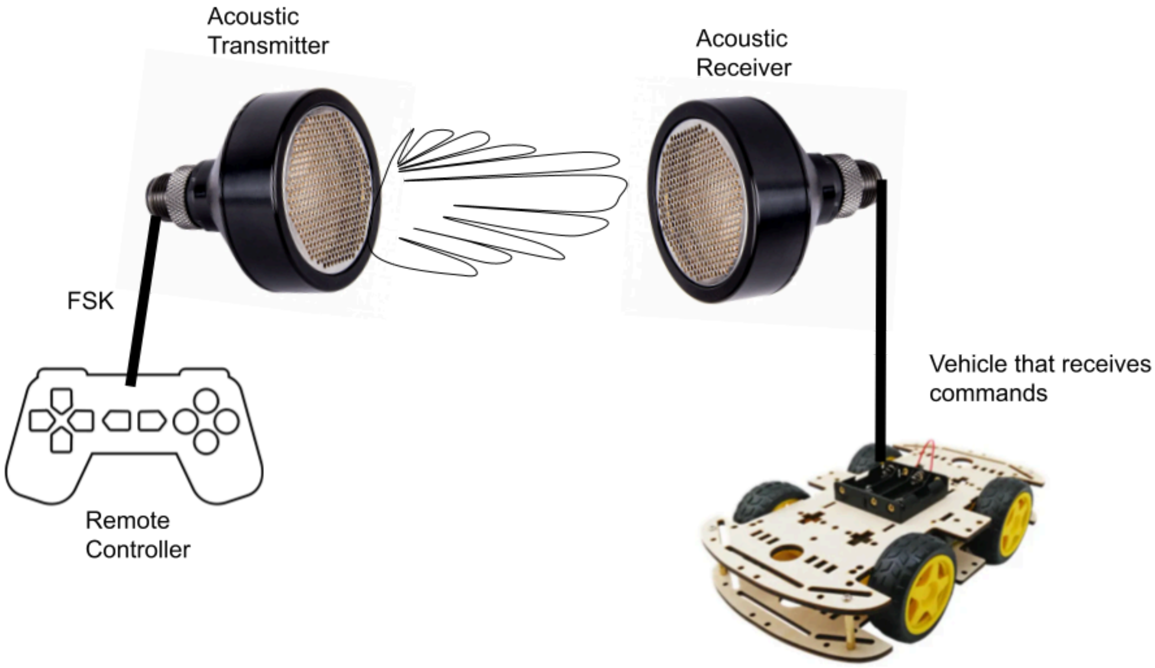
This challenge is particularly posed towards all industries that require the use of submersibles, such as deep sea oceanography and the inspection of underwater structures. As a result, submersibles are either operated directly by a pilot, which poses a safety risk, or are operated through tethered communication. Startups such as OceanComm have explored ROVs that communicate through a controller through acoustics, but these are very expensive.

SOLUTION

We intend to develop a proof of concept for a lower cost acoustically controlled ROV which operates in air, using cheap ultrasonic transducers designed for range finding.

We would like to develop a low-cost method of wireless communication using acoustics for remote control that will fit within the budget of ECE 445. For simplicity of the project, we will use the ECE 110 car as the mechanical basis of our design.

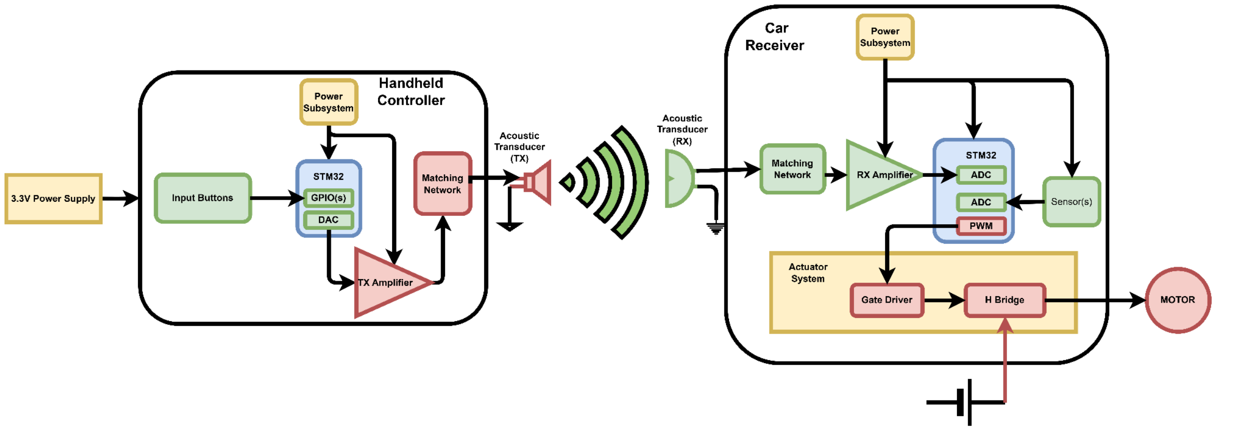
VISUAL AID

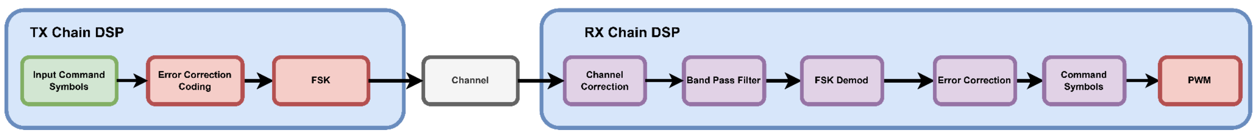


HIGH-LEVEL REQUIREMENTS

- Reliable transmission of control signals over distances of at least 3 meters.
- The acoustic transmitter should be able to use frequency shift keying (FSK) modulation at around the 40[kHz] range.
- The vehicle should be able to demodulate and act from an instruction with a carrier SPL of 100 dB (0dB = 0.02 mPa).

II. DESIGN





Microcontroller

The microcontroller on the transmitter will read the value of the input buttons using its GPIOs and generate throttle and steering commands to be transmitted to the car.

The bits from the receiver will recover the transmitted commands and generate PWM signals for the H Bridge, allowing the operator to control the movement of the car.

Receiver DSP

The ADC on the STM32 microcontroller will sample the incoming signal after it has been amplified by the RX Amplifier. The sampled signal will then be processed to correct for varying channel conditions and other impairments caused by the piezo or the amplifier. The FSK signal will be filtered to remove some noise, and then the transmitted bits will be recovered. Error correction will be applied to the recovered bits.

Transmitter DSP

The STM32 will add error correction bits to the control signals from user input. It will then generate an FSK signal centered at 40 KHz containing coded control signals.

Microcontroller/DSP Unit Testing Procedure

Some of the software for the microcontroller, including the DSP software, can be tested on a PC using channel models. When the microcontroller board is available to test, user input can be simulated using buttons, while the outputs of the microcontroller are observed on an oscilloscope.

Piezo Matching Network and Amplifier

An LC network and Op-Amp or transistor will be used to amplify the signal from the DAC on the microcontroller.

Unit Testing Procedure

The microcontroller can be replaced with a function generator as the signal source, while an adjustable DC supply is used to power the amplifier. The output of the amplifier can be observed on an oscilloscope, and the impedances of the network can be measured using an RLC meter. If high bandwidth microphones are available, the output of the piezo can also be observed on an oscilloscope.

Piezo Receiver

The receiver piezo is matched to an amplifier whose output is sampled by the ADC on the microcontroller.

Unit Testing Procedure

The output of the receiver can be observed on an oscilloscope while the transmitter is being used as described above, and its impedances measured using an RLC meter at the receiver's resonant frequency of 40 kHz.

Power

A non-isolated buck DC-DC converter will be used to step down the input voltage of a 9V battery to power the STM32 at 3.3VDC. This will then be cascaded into a low dropout linear voltage regulator in order to suppress EMI that may propagate around the PCB into the power supply of the STM32. The linear voltage regulator will also serve to step down the voltage from 5V to 3v3 for boards powered over USB-C.

Unit Testing Procedure

From probing with a voltmeter, we will find the steady state input voltage to the microcontroller to be 3.3V. The output voltage waveform of the buck converter cascaded with the linear regulator shall have a peak-to-peak ripple voltage no greater than 90 millivolts at the STM32's specifications. This will be checked using an oscilloscope to probe the voltage input waveform. The power subsystem should supply at least 200 mA from the battery to the proper loads.

Actuator

A finite state machine will be used to set the vehicle to move forwards, backwards, and allow it to turn. This system will be driving an H bridge to control two DC motors to drive. It will be taking a 9V input from the battery. The STM32 will synchronously drive a MOSFET H-Bridge using a gate driver and a dead time circuit.

Unit Testing Procedure

We can first test the state machine through software, and later test it, using Scopy to ensure that the state machine works on hardware. We can test the H bridge with Scopy alone as well. We will then unit test both the H bridge and the statemachine together. We can then test the state machine, H bridge, and motors together, ensuring that the voltage delivered to the motors is correct when the load is attached.

Tolerance Analysis

The component that will be the most challenging to implement will be piezoelectric transducers and the amplifier gain needed to properly modulate and demodulate the signal while considering attenuation over air. This will be the highest risk to the completion of the project. The component of attenuation we want to consider mostly will be absorption. In air, we have a shear viscosity at room temperature of 1.813E-5 [Pa s], a density of 1.204[kg/m^3], and a pressure wave velocity of c = 343 [m/s]. This will result in a coefficient

$$\tau = \frac{4}{3}\left(\frac{1.813E-5\ [Pa \cdot s]}{1.204\ [kg/m^3] \cdot (343\ [m/s])^2}\right) = 1.706\, E - 10$$

From here, we want to find our absorption coefficient (α) knowing our carrier frequency at $f_{carrier} = 40[kHz]$ where

$$\alpha = \frac{2\pi f_{carrier}}{c\sqrt{2}}\left(\frac{\sqrt{1+(2\pi f_{carrier}\tau)^2} - 1}{\sqrt{1+(2\pi f_{carrier}\tau)^2}}\right) = 0.0157$$

Therefore, we find the absorption to be the rate at which the amplitude decays over space from the equation.

$p(x) = P_0 e^{-\alpha x} e^{j(\omega t - kx)}$ where x is the distance from the transmitter to the sonified point in meters[1] (Kinsler et al, Fundamentals of Acoustics).

Furthermore, with the transducer type we are working with, we would want to align the directivities of the transmitter and receiver in order to ensure that scattering and absorption from the walls of the room we are working with make it more difficult to receive the command signal.

III. ETHICS AND SAFETY

The design intent of underwater acoustics must consider the bioacoustics of wildlife that inhabit the bodies of water that we intend to communicate through. Animals such as dolphins and whales use ultrasound as methods of communication and echolocation in order to navigate bodies of water, hunt, and avoid incident obstacles. Using carrier frequencies within their audible range of up to 200 kHz can disrupt their migratory patterns which may have negative effects on their population and prey populations that they balance. As a result, a water-based redesign will need to consider a transducer that can operate at a much higher carrier frequency.

During development, in regards to safety, we will need to use soldering irons which are hazardous and motors which are potentially hazardous. We will make sure to always wear proper protection and have two people in the lab at the same time in case of emergencies. We do not consider our power systems to cause harm as the power systems are not powerful enough to cause significant harm. Additionally, regular lab procedures will be followed in case of emergencies.

During deployment of the project, in regards to safety, the car may present a tripping hazard, so proper zoning must be established. Otherwise, there is little harm that the car does in terms of the safety of people around it. Similar to development, the deployment of the project in its current scope will be done in a lab where there are safety measures available.

The ethics of this project may not be vast, but there are important ones to note such as credit for work and data collection. For example, if we take designs from an outside source to be used on our own, the source must be cited in our reports. Similarly, if there is work or problems that have been solved by our members, it must be established so. This is to avoid the issue of stealing work, and keeping the project honest. We will also ensure that the data we present is not faked, but running multiple experiments and proving how our systems work. This also means aiming to develop our project's technology further than what is currently present.

When we make decisions, it will be democratic as if two-thirds of the vote goes towards one decision, it will be followed through, similar to what is discussed in the IEEE code of Ethics. If there are conflicts or tension, there will be a meeting held to address it. If problems cannot be resolved we will involve a third party that will likely be the teachers assistant. We will make sure that no disrespectful comments, harassment, or threats will be made towards each other. Members will be held accountable through the meetings and check-ins, which is where adjustments, if necessary, will be made. We will avoid many of these problems by dedicating a section of time of 10 minutes to each meeting to discuss any ethical, interpersonal, logistical, and safety concerns.