Door-Knocking Alarm for the Hearing Impaired

ECE 445 Design Document

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1. Introduction

1. 1 Problem

People who are deaf or hard-of-hearing face unique challenges in their daily lives, one of which being the difficulty in discerning when someone is knocking at their door. This can lead to inconveniences like important notifications being missed and frustration for both parties, but this problem can also be an important safety concern.

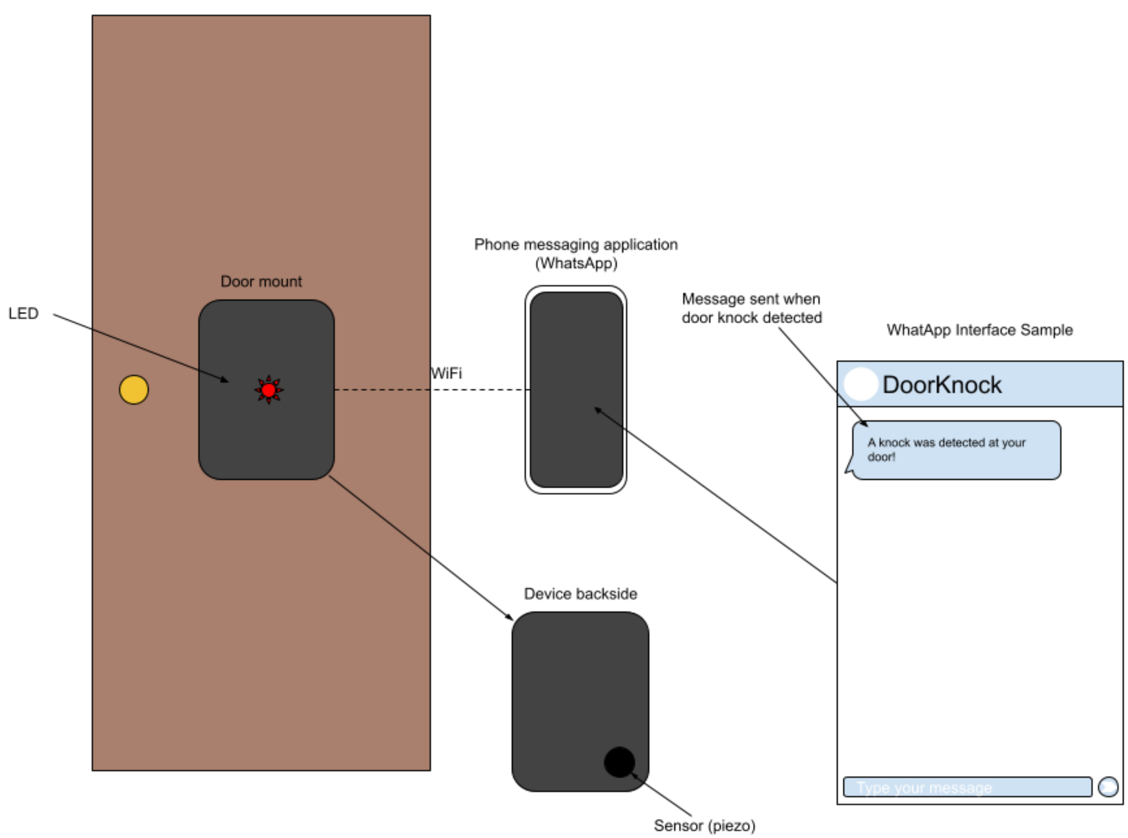
While there are plenty of alarms on the market that show some visual indicator (such as a light) when a doorbell is rung, there is a gap in the market for visual alarms for people with hearing impairments who do not have doorbells. For example, people living in dorms, apartment units (especially across college campuses), and individual office rooms often don't have doorbells installed. These spaces are often rented and so permanent installations are not feasible. Thus, there is a compelling need for a versatile and non-intrusive visual alert system tailored to these diverse environments, one that seamlessly bridges the communication gap and enhances the daily lives of individuals with hearing impairments.

1. 2 Solution

We propose a device that can detect when someone is knocking and send an alert. The design will use batteries for its power supply and will be easily attachable to most doors. Running off of batteries will make it more accessible as not all doors have an electrical outlet readily available.

The Piezoelectric sensor will specifically be aiming to detect vibrations through the door. The differentiation between knocking vibrations and vibrations that may cause vibrations through the door (for example, lots of people running past the door in a dorm setting) will be determined by testing a range of vibrations classifiable as knocking. After the alarm is triggered, it will then send an alert to the user's phone, and also emit a bright light.

1. 3 Visual Aid:



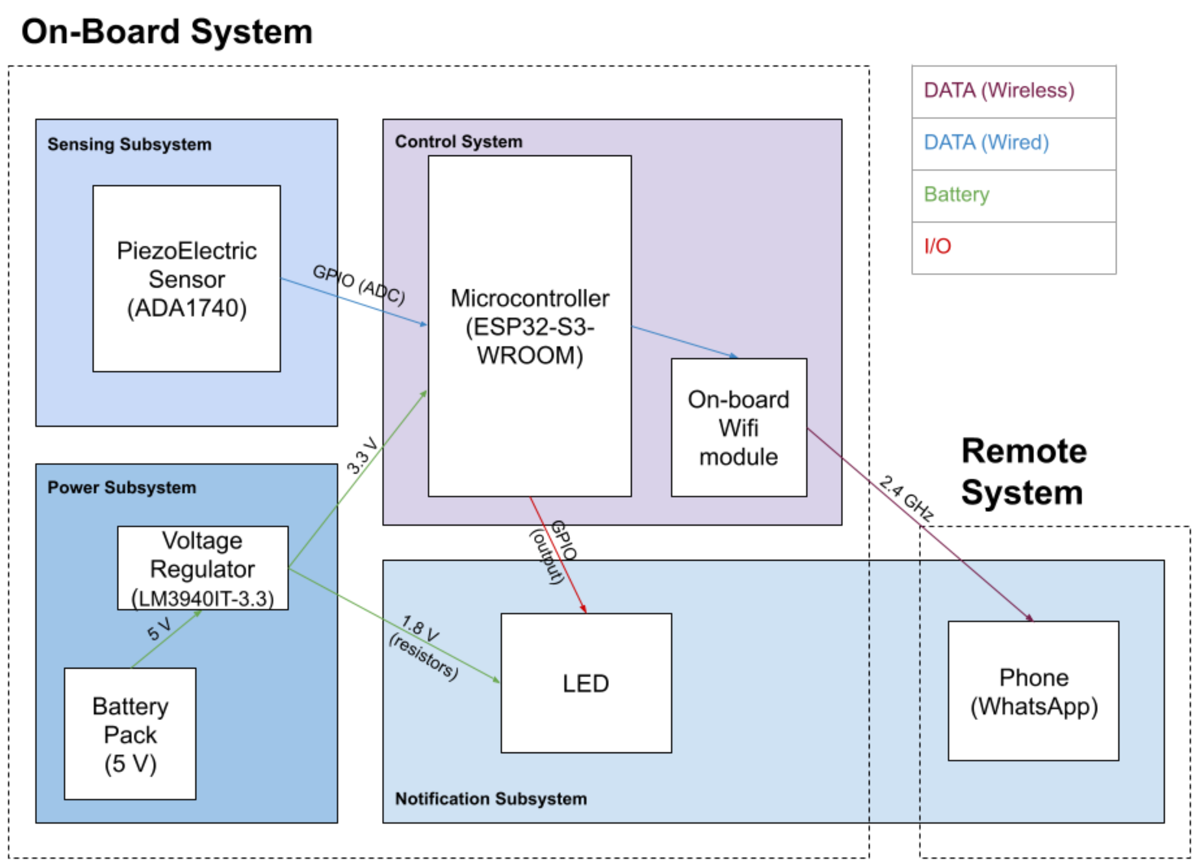
1. 4 High-Level Requirements

Upon completion of the device, success in functionality should be assessed using the following characteristics:

- The device must be able to detect when someone is knocking on the door. This means that the vibration detection threshold of the device must be attuned to the vibration of a knock, but not of other possible causes of vibrations in the door (specifically non-contact methods of vibrating a door), such as stomping in front of the door. It should be able to detect vibrations in the threshold of 0.2 to 1 kHz, within a 5% margin of error.
- The device must be able to reliably communicate with the user when it detects a door knock. For the LED component, that means that whenever the device detects a door knock, the LED will light up. For the phone notification component, this means that the device is able to send messages to the phone using WhatApp when connected to the internet. By necessity, this means that the device must also be able to connect to a WiFi network. Given good and reliable internet, the message will be sent within 15 seconds of detecting an initial knock.
- The device should be able to last reliably for the duration of 10 hours. This means that the battery, once attached to the device, will consistently and continuously power the device such that it is able to meet the previous requirements. Since the time in which a battery is able to power the device is variable depending on the frequency of use, the 10 hour metric assumes that the device detects a knock on the door once an hour. For the sake of testing, we will state that over an hour’s use, the battery’s current as measured by a voltmeter will decrease by a maximum of 10%.

2. Design

2. 1 Block Diagram



2. 2 Subsystem Descriptions

2. 2. 1 Power

The power subsystem consists of two main components: an alkaline battery rated at 4.5V that serves as the initial power source for the entire system and a voltage regulator LM3940IT-3.3 to regulate the output voltage from the battery to meet the specific requirements of the system, being 3.3V for the MCU and 1.8V for the LEDs. The voltage regulator will adjust its output voltage as needed to accommodate fluctuations in external load while maintaining the prescribed voltage levels for the MCU and LED. In order to optimize battery life while still maintaining constant power supply, the voltage regulator is used rather than resistors to step down the voltage in order to minimize power lost during voltage conversion.

Requirements	**Verification**
The ESP32 requires a constant supply of 3.3V and the LEDs require a stable voltage of 1.8V, so the voltage regulator must continuously monitor the output voltage to ensure that it remains within the a range of ±5%, even when the system experiences changes in load or battery voltage.	Test with multimeter and oscilloscope to ensure that voltage being received at LED is ~1.8V and the voltage being received at the MCU is ~3.3V.
The battery must be easily accessible, so that the user can replace the batteries without issue.	Demonstrate by removing battery from mount and reinserting - there should be no safety issues like loose wires and power should be immediately restored.

2. 2. 2 Piezoelectric Sensor System

This subsystem will primarily consist of the Piezoelectric sensor ADA1740 that utilizes the Piezoelectric effect to pick up on mechanical vibrations from the door that the device is mounted on. This sensor is chosen due to its ability to measure within the desired frequency range and its cheap and robust design. The detected frequency of vibration will be filtered and compared to tested threshold after it has been sent for processing by the microcontroller. The frequency range that we estimate to detect for a door knock is between 0.2 to 1 kHz [1]. Frequencies outside this range are disregarded, and frequencies within the range will be identified as a valid knock event. Once a valid door knock event is identified, the microcontroller can initiate the appropriate response.

Requirements	**Verification**
Send data to the ESP32 for signal processing at a constant rate and identify frequencies within the range of 0.2 to 1 kHz	Test by adjusting threshold frequency and different levels of knocking. A tone producer (tuner) will be used, holding it against the door to simulate vibrations at specific Hertz to see if the device is able to detect the required frequencies.

2. 2. 3 LED and Phone Notification System

The notification receiving system consists of two parts - an LED and a phone with WhatsApp that gets notifications from the microcontroller. The LEDs are integrated directly with the main sensing unit, and are expected to be a visual indicator and light up when a valid door-knocking event occurs. The LEDs will remain lit for approximately 15 seconds then turn off. The microcontroller will simultaneously send a notification using the on-board wifi module to the phone through WhatsApp when the door-knocking alarm is triggered along with lighting the LED. The LED system will be directly connected to the door-knocking alarm and will receive a signal from the MCU.

Requirements	**Verification**
The LED will light up and the phone will receive a WhatsApp notification when the door-knocking alarm is triggered and only then.	-Assemble the device with the complete sensor, microcontroller and LED systems. -Knock on the Piezoelectric sensor and ensure the notification is sent within 15 seconds and the LED lights up and then turns back off after 5 seconds.
Power supplied to the LED should not result in a loss of power and functionality to the sensor system. The maximum current draw to the system during heavy use should be ~20 mA.	-Assemble the device with the complete sensor, microcontroller and LED systems. -Connect an ammeter between the microcontroller/LED and power. -Check that the current draw to the LED does not pass ~20mA, and current to the microcontroller stays around 355mA. (High current while the WiFi module is active)

2. 2. 4 Control

The control subsystem consists of the microcontroller (ESP32) and its connections to other components (PCB) as the main controller of how the subsystems interact. The microcontroller is in charge of taking the frequency/vibration data from the sensor subsystem, filtering noise, comparing it to a tested and validated threshold, and deciding whether or not to send notifications using the above notification subsystem on the basis of whether the noise was identified as a door-knocking event.

Requirements	**Verification**
Correctly determine whether vibrations are background noise or knocking.	This will be tested by knocking and checking detection ability as well as talking, walking, stomping past, and making various noises outside the door, further testing detection in those scenarios.
Communicate with WhatsApp to deliver notification and light the LED with a maximum delay of 5 seconds to light the LED and 15 seconds for the phone notification (provided good/reliable internet).	Initial test (without sensor detection first) to send sample messages to WhatsApp will be conducted to test ability to send messages. LED will be tested after sensing, with a timer to test how long the LED remains on after the last knock/vibration. This will

	cross-checked with the message notification to ensure that both are reacting to sensor detection.

2. 3 Tolerance Analysis

The success of the project is dependent on the capability of the piezoelectric sensor to be able to accurately detect when someone is knocking on the door. This means that the project is dependent on a piezoelectric sensor's frequency detection range corresponding to the frequency range of door knocking. According to a database of information on everyday sounds constructed by Leila Abdoune and Mohamed Fezari, door knocking produces frequencies in the range of up to 1 kHz, with most of the knocking noise falling around the 0.2 kHz range [1]. The piezoelectric sensors on the market are capable of detecting up to 1 kHz of vibration frequency, thus door knocking can be reasonably said to be detectable using the mentioned parts and mechanisms listed in this proposal.

Another important aspect of our design is ensuring that too much power isn't being dissipated inside the regulator. Overheating can become potentially dangerous and will cause the circuit to stop working and cause permanent damage.

Part	**Worst Case Current Draw at 3.3V**	**Comment**
RGB LED	15 mA	Based on LED forward voltage

		drops and resistor values
Processor	335 mA	The ESP32-S3-WROOM's current draw at 3.3V is closer to 30mA while idle. When the WiFi modemison, we get peak current draw. [4]
Total	350 mA	

Variable	**Value**	**Comment**
Max(T(j))	125 C	Maximum operating junction temperature of a LM3940IT-3.3 [3]
I (out)	350 mA	Maximum current draw of components on 3.3V power
V (in)	4.5 V	Source is a 4.5 V Alkaline Battery
V (out)	3.3 V	Operating Voltage of components
Θ (jc)	16 C/W	Taken from the LM3940IT-3.3 datasheet [3]
T (a)	38 C	A really hot day

$$T(j) = i(out) * (v(in) - v(out)) * (\Theta(jc)) + T(a)$$

$$T(j) = 47.52\ C < max\ (T(j)\ )$$

From this we can see that our device is well below the maximum operating threshold and will not overheat.

3 Cost and Schedule

3. 1 Cost

The average hourly salary of a graduate computer engineer is $40. Working for 10 hours a week for 13 weeks, the cost of labor is:

$40/hr * 10 hours/week * 13 weeks = $5,200 per engineer

A total of $15,600 for the three engineers

We will be using help from the machine shop. The cost of that is $22 for hourly labor, with work being done for 48 hours over the course of the project, the cost of labor is:

$22/hr * 48 hours = $1056 for 1 unit

The cost of parts is as follows:

Item	Description	Manufacturer	Part Number	Quantity	Total Cost
ESP32	Microcontroller unit with Wi-Fi and Bluetooth capabilities	Espressif Systems	ESP32-S3-WROOM	1	$3.20
PiezoElectric sensor	A sensor that detects vibration using the PiezoElectric effect	Adafruit	ADA1740	1	$3.95
Battery	4.5V Alkaline Battery	Exell	A21PX	1	$11.75
Linear voltage regulator	A linear voltage regulator for maintaining required voltage to power the project	Texas Instruments	LM3940IT-3.3	1	$2.52

3. 2 Schedule

Week	Task	Assignment
Sept. 4	Project Approval	Team
Sept. 11	Project Proposal Team Contract Initial conversation with machine shop	Team Team Pax
Sept. 18	Design Document	Team
Sept. 25	Design Document Create initial code for ESP32 Obtain initial parts (breadboard, wires, etc.)	Team Ji Yoon Ji Yoon and Pax
Oct. 2	Obtain the rest of the required parts Test ESP32 and Piezoelectric Sensor Design first PCB Board Talk to machine shop (changes to design doc)	Ji Yoon Ajay Team Pax
Oct. 9	Submit PCB Board design for first round of ordering Teamwork evaluation 1 Finalize design for project exterior (machine shop) Test PCB and make changes to initial design	Ajay Team Pax Ji Yoon
Oct. 16	Submit PCB Board design for second round of ordering Test PCB and make changes to design if necessary Fine tune thresholds and hardware adjustments	Ajay Pax and Ji Yoon Ji Yoon
Oct. 23	Submit PCB Board design for final round of ordering Continue fine-tuning detection thresholds Test power/battery limitations (work to reduce if necessary)	Ajay Ji Yoon Pax
Oct. 30	Do final thorough unit testing Construct/assemble final project (if exterior obtained) Create demo materials	Team Pax + Machine Shop Team
Nov. 6	Create demo materials Practice for demo Test to make sure that nothing needs to be replaced	Team Team Team

Nov. 13	Mock demo Team contract fulfillment due	Team Team
Nov. 27	Demo the final project Finish Final Paper	Team Team

4. Ethics and Safety

Our main ethical concern with this project is in Section 7.8.9 of the IEEE Code of Ethics, which pertains to the protection of property of other people [2]. One of the main purposes of our device is to allow people to have an easily installable, non intrusive device to use on other people's property. Therefore, our team will ensure a design that will not lead to permanent damages on whatever door surface it is mounted onto. Furthermore, it will be important to use proper battery and power safety techniques to prevent overheating or damaging the LEDs.

Regarding safety, since our device does house electrical components, we will make sure that these components are properly enclosed. In addition, our project will include an LED component, which will be used to notify the user of knocking. We will ensure a safe level of brightness and consistency to avoid photosensitive seizures.

References

[1] Mohamed Fezari. “Everyday Life Sounds Database: Telemonitoring of Elderly or Disabled.” ResearchGate, March 2014, https://www.researchgate.net/publication/273187267_Everyday_Life_Sounds_Database_Telemonitoring_of_Elderly_or_Disabled?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoiX2RpcmVjdCJ9fQ [Accessed: Sep. 13, 2023].

[2] IEEE code of ethics. IEEE Policies, Section 7 - Professional Activities. https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed Sep. 14, 2023].

[3] Texas Instruments, “LM3940 1-A Low-Dropout Regulator for 5-V to 3.3V conversion,” LM3940 datasheet, May 1999 - Rev. Feb. 2015, [Accessed 27 September 2023]

[4] Espressif Systems, “ESP32-S3-WROOM-1,” ESP32-S3-WROOM datasheet, July 2021 - Rev. March 2023, [Accessed 27 September 2023]