ECE 445

Senior Design Laboratory Project Proposal

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Voice-Activated Geographic Reference Globe

Team 44

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1. Introduction

This document is a project proposal for the Voice-Activated Geographic Reference Globe project. In this document, we will outline the purpose of the project, set high-level goals, explain the design, and discuss ethics, safety, societal impact, and standards.

1.1 Problem

Many American children and adults struggle with geography. Many of them cannot point out a country on a map or identify the locations of major world events. This lack of geographical knowledge can limit people's global awareness and make it more difficult to understand culture, current events, and international relations. We believe that this gap in knowledge starts at school, where students are not engaged enough to care about what they are learning. When geography is taught through memorization instead of connection, students may not retain the information in the long term.

In addition, many kids are spending a lot of time on screens and online, which is taking them out of the real world. While technology can be educational, learning centered around screens can be overwhelming and distracting. When all aspects of life are turning more and more digital, it may be a good idea to take a step back. However, traditional globes aren't always ideal. Globes often have very small words that are difficult for children to read clearly. It can also be challenging to locate specific countries, especially if a child is unfamiliar with that particular region of the globe. Clearly, a more interactive and intuitive approach to teaching and learning geography is needed.

1.2 Solution

To solve this problem, our group wants to make an engaging product that can help students learn geography without being attached to a screen. That product is the Voice-Activated Geographic Reference Globe.

Our proposed voice-activated globe aims to solve this problem by making learning fun and interactive using a speech-detection mechanism. This mechanism will recognize a spoken country as input and automatically rotate the globe, ensuring that the specified location ends up at a pre-defined center point. This country will be lit up by a laser pointer, illuminating the region that the user wants to search for. This automated rotation makes it so that children do not need to do any manual searching for locations, letting them focus entirely on learning. The speech-based interaction means that the system is intuitive and easy to use for young children in a classroom setting.

Using this device, classrooms can help educate children on geography. Through a combination of the spoken aspect of naming a country and the visual aspect of the globe and laser pointer, the country's name and location will be better absorbed by the user, which will help with recall later. Using a globe rather than just a screen that displays each country also helps with 3D spatial positioning of the countries in the user's mind, which lets them remember countries in relation to each other.

While engaging, this globe will not overwhelm children the way a computer program will. Instead, it will be just interesting enough to keep their attention and excitement about learning, without overexposure to screens.

1.3 Visual Aid

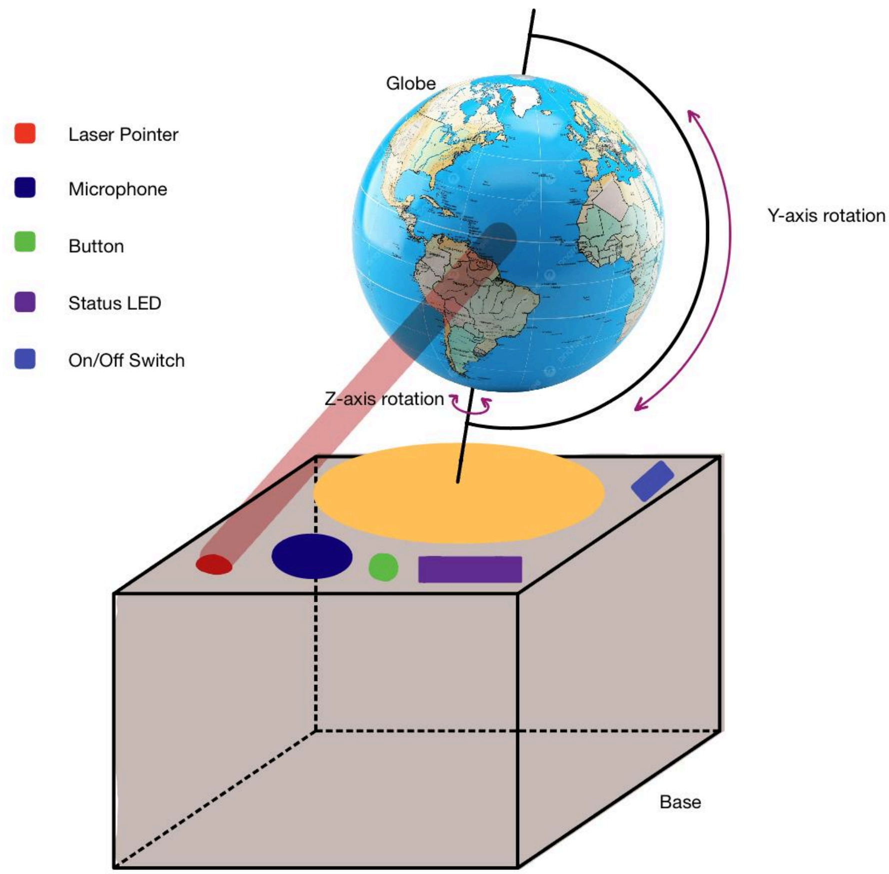


Fig 1. Project Design

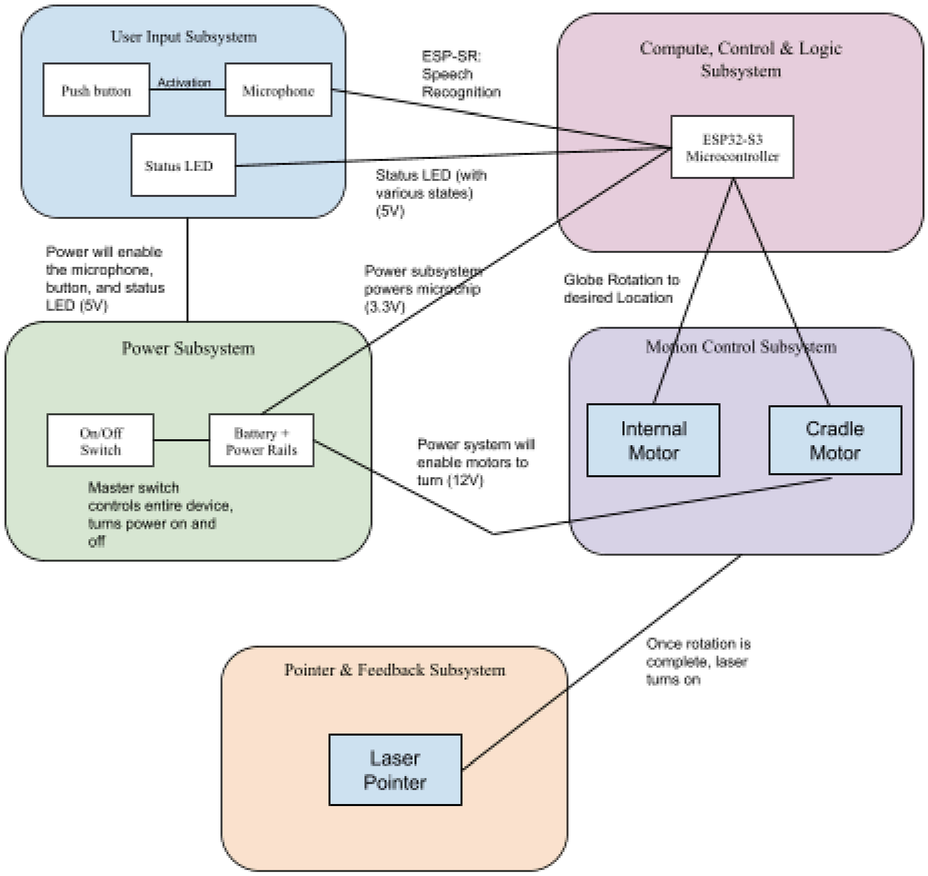
Our design consists of two main elements: the globe and the base. The base will be custom-built by the machine shop and will hold the microphone, button, and the status LED that make up the User Input Subsystem (2.2.1). Additionally, it will contain the pointer that highlights the chosen country, which comprises the Pointer & Feedback Subsystem (2.2.4) and the on/off switch that belongs to the Power Subsystem (2.2.5).

1.4 High-Level Requirements

- Our vocabulary will be limited to the 195 countries on Earth. We will start with 50 countries, then move to 100, then 150, then 200. Our target accuracy initially is a 75% detection rate.
- The status LED will light up:
    - Red if the word spoken is not a recognized country.
    - Yellow while the button is being pressed.
    - Green when the country is recognized and matched with a known country in our country database.
- Once given a country as input, the globe correctly rotates to display, which ensures that said country ends up at the pre-defined center reference.
- The laser pointer accurately points to the pre-defined center reference point. It turns on automatically once the globe is done rotating. It will turn off when a new country is specified and remain off until rotation is complete to the new country.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview and Requirements

2.2.1 User Input Subsystem

This subsystem will implement the speech recognition mechanism of the globe. A simple push button and microphone (I2S Digital Microphone (INMP441)) will be connected to the GPIO pins of the ESP32-S3 MCU. While the button is pressed, the microphone will collect audio from the user, capturing the specified country the user wants to find. The MCU uses this audio and transfers it to the Compute, Control, and Logic subsystem, where it uses ESP-SR to help determine which country the user wants to find, motor logic, and status LED control. Additionally, while the button is pressed, the status LED will be set accordingly, recording when the globe is capturing audio, processing audio, or if there's an error. The states of the status LED are country recognized, audio currently being captured, and error. This will be done using addressable LED strips (WS2812B). This will help the user know the status of their audio request to the globe.

Requirements:

- The user input subsystem will only capture audio while the push-to-talk button is being pressed, and will not record audio while the user is not pressing the button
- The INMP441 microphone will stream audio to the ESP32-S3 over the I2S interface using a sampling format compatible with ESP-SR, which is a 16 kHz sampling rate and a mono channel format [4]
- The user input subsystem will set the WS2812B LED accordingly, and the status LED must update to the correct state within 1 second of any state change

2.2.2 Compute, Control & Logic Subsystem

This subsystem is responsible for telling the Motion Control Subsystem how and where to move the globe. It takes the audio input collected by the User Input Subsystem and extracts the country input using the ESP-SR speech recognition framework. This subsystem will then match the given country input with our database of countries to find its location on the globe. We will be using a coordinate system similar to the latitude and longitude system to identify each country on the globe. After that, the subsystem will take the current position of the globe and the goal position and calculate the movement along each axis (in number of steps) needed to get the globe to its goal position, and send that information over to the Motion Control subsystem.

Requirements:

- The subsystem must process upcoming audio data from the User Input Subsystem using the ESP-SR framework to identify the spoken country name.
- The subsystem must determine whether the recognized country name exists in the database, and:
    - Should generate an error state and send that information over to the User Input Subsystem to be displayed on the status LED if the recognized country name doesn't exist in the database.
    - Must match the recognized country name to the database of countries and retrieve their corresponding z and y coordinates, if the recognized country name exists in the database.
- The subsystem must calculate the difference between the current globe position and the target globe position, convert the difference into motor steps along the z-axis and y-axis, and send that information.
- The subsystem must maintain and update a record of the current position of the globe after each completed movement.

2.2.3. Motion Control Subsystem

This subsystem will implement the motion control of the globe. This refers to the rotation of the globe, both along the globe's axis as well as the cradle's movement. The globe's axis will control rotation around the z-axis (the actual Earth's axis of rotation), while the cradle will control rotation around the y-axis (the axis perpendicular to the frame of view). When a desired country is recognized as an input (from the User Input subsystem and the Compute, Control & Logic Subsystem) and a desired destination is calculated, this subsystem will control the rotation of the globe to that location. The stepper motor embedded inside the globe will allow the globe to rotate around the z-axis precisely to the degree needed to point the desired country at the frame of view, and the stepper motor on the outside cradle track will rotate the entire cradle system around the y-axis to do the same. The GPIO pins of the ESP32-S3 MCU would be connected to the stepper motors, enabling rotation. The motors have the capability to calculate exact rotation, so we can use this to make sure the globe rotates to exactly the desired position.

Requirements:

- The motion system must rotate the globe on both axes to the location specified by the Compute, Control & Logic Subsystem.
- The motion system must have a full range of motion, 360 degrees for the z-axis, and 180 degrees for the y-axis.
- The globe must rotate to the desired position within 10 seconds.
- Once rotation is complete, the system must send a signal to the Pointer & Feedback Subsystem to turn on the laser.

2.2.4 Pointer & Feedback Subsystem

This subsystem will implement the pointer and feedback systems. This is the subsystem that controls when the laser pointer will turn on or off, which highlights the specified country. When the globe has rotated to the desired position (as calculated by subsystems 1 and 2 and reached by subsystem 3), the ESP32-S3 MCU will send a signal to the laser pointer to turn on. The laser pointer will remain turned on while the desired country is in the target position to face the frame of view, and will turn off as soon as the target is not in said position. This would be when a new country is recognized via the input subsystem 1, which would change the target country to another one that is not in the final location, thus turning off the laser.

Requirements:

- The laser pointer turns on when rotation is complete and turns off when a new country is specified.
- The laser pointer points directly at the specified country.

2.2.5 Power Subsystem

The power subsystem is responsible for powering the full system (MCU, microphone, LED, motors, laser) by providing regulated DC power using an external wall adapter. The wall adapter converts the AC power from the wall outlet to a regulated 12V DC power supply, which serves as the main input into the system. Voltage regulators will then convert the 12V power supply into 5V and 3.3V rails to power the various devices in our project. A master on/off switch will be placed between the wall adapter and the rest of the circuitry so that the user can safely turn the system on and off.

Requirements:

- The subsystem must generate a 5V rail and a 3.3V rail.
- The subsystem must include a master on/off switch between the wall adapter and the rest of the circuitry.

2.4 Tolerance Analysis

For the rotation component, we will be using two stepper motors: one for the embedded rotation in the globe and the other on the external cradle. A stepper motor has up to 5% error per step in the motor's rotation. Each step rotates the motor by 1.8 degrees. However, because of the motor's design, after 200 steps, it is guaranteed to move exactly 360 degrees, which means that the error does not accumulate. This means that each step will cause a maximum of 5% * 1.8 = 0.09 degrees. This value of 0.09 degrees is small enough that on a large globe, it should not have much of an impact on our rotation for most countries, meaning that the country will still be able to be positioned correctly; however, it could have a slight impact on certain countries like Luxembourg or Vatican City, where the small size of the country requires the positioning of the globe to be extremely precise.

3. Ethics, Safety, and Societal Impact

3.1 Ethics

There are several ethical considerations that need to be taken during the design and testing process. According to Principle 1.6 in the ACM code of ethics, one important consideration that will be raised is respecting privacy [3]. Since we are recording audio and using that to handle motor control logic, we need to ensure that the audio isn't being stored, collected or transmitted elsewhere without the consent of the user. Therefore, even though the audio processing is happening locally on the ESP32 MCU, we will discard audio data immediately after performing detection logic. Additionally, Principle 1.3 from the ACM code of ethics also states that we need to be honest and trustworthy [3]. One issue that can arise with this design is that it might not accurately pick up the words from users with accents or speech impediments, as the ESP-SR has limited speech recognition capabilities. Therefore, we must disclose this clearly in the instructions for usage to be transparent with the users about the limitations of the project's capabilities.

3.2 Safety

Since this product is intended for younger kids, in a classroom setting, we need to heavily prioritize safety considerations. Since we are using a laser to illuminate the specified country, we need to ensure that there is no risk of eye damage or misuse of the laser. To combat this, we will ensure that the laser is mounted in the base of our globe system and the beam of light exits through a hole in the base. This will ensure that the laser position cannot be altered and has to point towards the surface of the globe. Additionally, we will be using a low-power Class 1 laser, which is safe even for long-term intentional viewing [1], or a Class 2 laser, which is used extensively in classroom settings. If we use a Class 2 laser, we will also ensure to have a warning label to guarantee compliance with IEC 60825-1, which is the FDA's standard for laser compliance [2]. Additionally, our design of the base will have no sharp edges and will use non-toxic materials to ensure the full safety of the users. Our design will also consider full electrical safety regulations, such as ensuring no wiring is exposed, ensuring proper insulation for motors, and more.

3.3 Societal Impact

There are several societal or ethical issues that this voice activated globe helps impact. For example, since this is a screen-free and offline tool, this can be used in areas with limited internet or screen access. This helps promote educational equity, since schools are developing a higher reliance on screens and the internet for educational purposes, providing an offline interactive learning tool can help those with fewer resources have an equal opportunity to learn. In addition to reducing screen dependencies, this can also be more collaborative and engaging, using a physical globe to learn geography. This can help those who prefer hands-on learning methods by providing a hands-on learning tool.

4. References

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