ECE 445 Project Proposal
Oxygen Delivery Robot

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I. Introduction

A. Problem

Children's interstitial and diffuse lung disease (ChILD) is a collection of diseases or disorders. These diseases cause a thickening of the interstitium (the tissue that extends throughout the lungs) due to scarring, inflammation, or fluid buildup [1]. This eventually affects a patient's ability to breathe and distribute enough oxygen to the blood.

Numerous children experience the impact of this situation, requiring supplemental oxygen for their daily activities. It hampers the mobility and freedom of young infants, diminishing their growth and confidence. Moreover, parents face an increased burden, not only caring for their child but also having to be directly involved in managing the oxygen tank as their child moves around.

B. Solution

Given the absence of relevant solutions in the current market, our project aims to ease the challenges faced by parents and provide the freedom for young children to explore their surroundings. As a proof of concept for an affordable solution, we propose a three-wheeled omnidirectional mobile robot capable of supporting filled oxygen tanks in the size range of M-2 to M-9, weighing 1 - 6kg (2.2 - 13.2 lbs) respectively (when full). Due to time constraints in the class and the objective to demonstrate the feasibility of a low-cost device, we plan to construct the robot at a roughly 50 percent scale of the proposed solution. Consequently, our robot will handle simulated weights/tanks with weights ranging from 0.5 - 3 kg (1.1 - 6.6 lbs).

As mentioned the robot will have a three-wheeled omni-wheel drive train, incorporating two localization subsystems to ensure redundancy and enhance child safety. The first subsystem utilizes ultra-wide band (UWB) transceivers for triangulating the child's location relative to the robot in indoor environments, this is similar to how Apple AirTags triangulate their location relative to an iPhone [2] (although AirTags use a combination of UWB and Bluetooth triangulation [3]). The second subsystem makes use of a desktop web camera which streams video to a Raspberry Pi where it will leverage open-source object tracking libraries to improve our directional accuracy in tracking a child. The final main subsystem focuses on the drive train and chassis of the robot.

As part of the design, we intend to create a PCB in the form of a Raspberry Pi hat, facilitating convenient access to information generated by our computer vision system, and saving space on our robot. The PCB will incorporate all motor control components, limit switch connections, GPIO pass through for the Raspberry Pi, power distribution and step down converter, and an STM32 based microcontroller serving as the project's central processing unit. This microcontroller will control the drivetrain, analyze UWB localization data, and use the direction vector provided by the computer vision system to calculate the speed and direction of each wheel.

C. *Visual Aid*

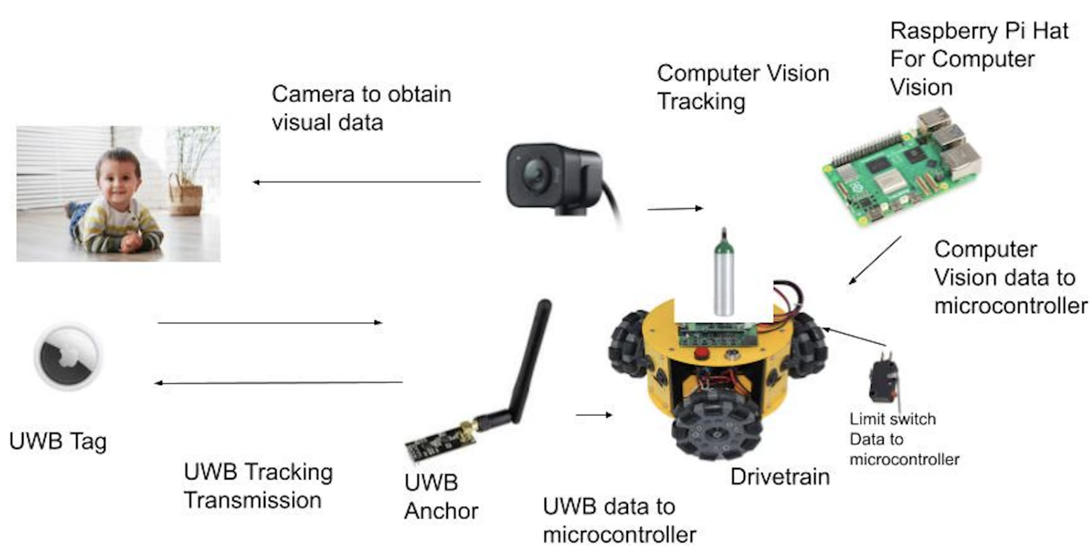

Fig. 1: Visual aid for our project.

D. High-Level Requirements List

- Omni-wheel Drivetrain: The first requirement is the omni-wheel drivetrain's ability to drive in a direction that is defined by the UWB system. This means accurately responding to the commands and having smooth and precise movements in all directions. Our goal is to have a response time of around 500ms. This means from the moment our software determines a direction vector, our robot must begin moving in that direction within 500ms.
- UWB Localization: The second requirement is the UWB localization system's ability to provide accurate positioning information, with a precision of less than 1 meter. We are looking at real-time updates of the child's location relative to the robot.
- Close-range Object Detection: The third requirement is to have close-range object detection to identify obstacles in the robot's path. It should be able to alert the users to prevent collisions. This will ensure the child's safety and allow the user to remove the object.

II. Design

A. Block Diagrams

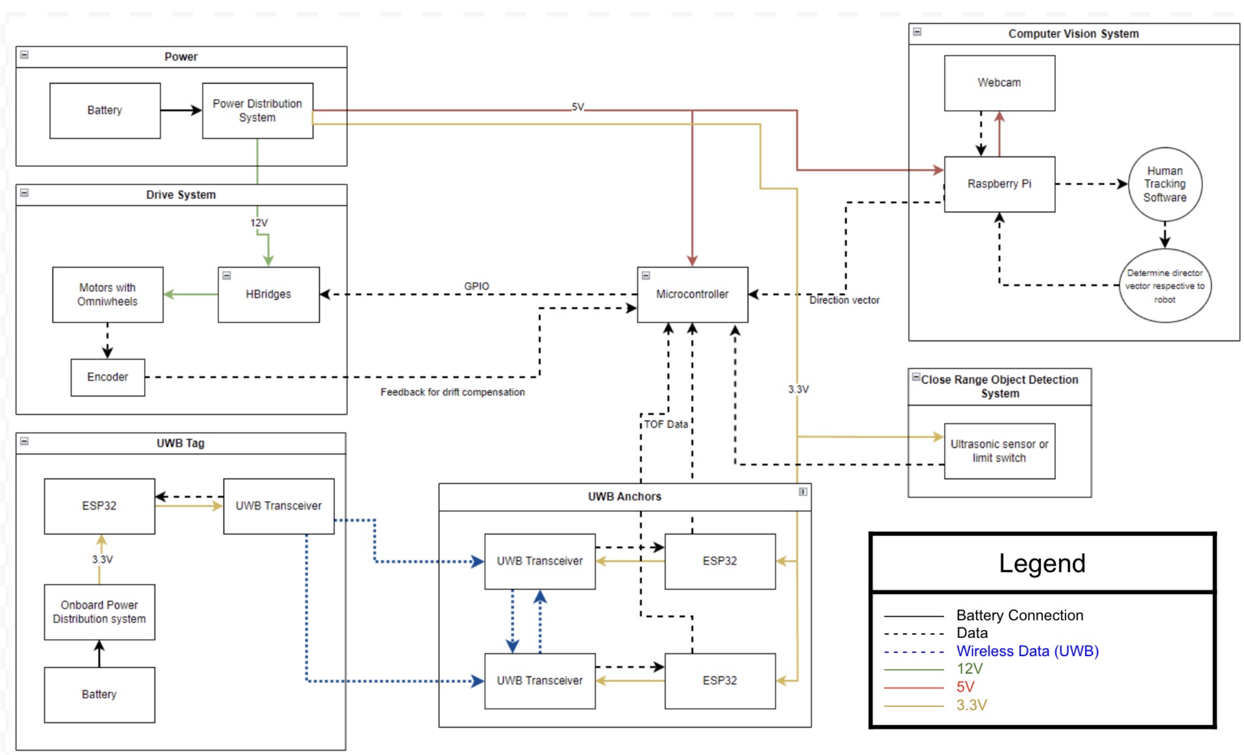

Fig. 2: High-level block diagram for our project.

B. Subsystem Overview

- **Power**: The power subsystem is responsible for supplying power to all other components of the robot. It will include a battery and power distribution system. This subsystem will supply 12V power to the drive system. It will supply 5V to the microcontroller and computer vision subsystem. Lastly, it will supply 3.3V to the close-range object detection system and the UWB anchors.
- **Drive System**: The drive subsystem will encompass the motors, omni-wheels, encoder, and H-bridges. It will receive instructions from the microcontroller for the proper motor movements and feed back encoder data for drift compensation (three-wheeled omni-wheel bots are easily affected by drift if it is not compensated for).
- **UWB Tag**: The UWB tag subsystem will consist of the UWB transceiver unit, battery, ESP32, and onboard power distribution system. It will attach to the child that is being tracked. The UWB signals emitted are received by the UWB anchors. It will work with the UWB anchors subsystem to determine the location of the tag relative to the robot. This system will utilize transceiver boards based on Decawave DW3000 ICs [4].
- **UWB Anchors**: The UWB anchors subsystem will consist of the UWB transceivers and ESP32s. Signals will be received from the UWB Tag subsystem. This subsystem communicates with the microcontroller to relay accurate information related to positioning. This will be used for navigation and control. This system will also utilize transceiver boards based on Decawave DW3000 ICs.
- **Computer Vision System**: The computer vision subsystem will include a web camera connected to a Raspberry Pi. It will utilize an image processing algorithm using OpenCV or OpenPose. It will analyze data from the web camera to track the child's movements and detect obstacles. It will connect to the microprocessor and provide direction vectors. The velocity vector will be decomposed into its components to obtain the value for each omnidirectional wheel.
- **Close-Range Object Detection System**: This subsystem, consisting of ultrasonic sensors or limit switches, communicates with the microcontroller to provide information about nearby obstacles. When an obstacle is detected, the user will be alerted to adjust the robot's path or clear the obstacle. This feature will ensure effective obstacle avoidance and will enhance the safety of the robot.

- **Microcontroller**: The velocity vector will be decomposed into its components to obtain the value for each omnidirectional wheel. The vector will be calculated using a vector dot product between the omnidirectional wheel coordinates set in the algorithm and the velocity vector coordinates of the target. These values will be stored in an array and be sent to the STM32 PWM output to control the motor.

C. Subsystem Requirements

- **Power**: This subsystem must be able to continuously supply the following for roughly 15 minutes:
  - 500mA @ 12 ± 0.5V
  - 10mA @ 3.3 ± 0.1V
  - 500mA @ 5 ± 0.25V
- **Drive System**: Should fulfill the following requirements:
  - Maintain a speed between 0-5 MPH regardless of payload.
  - Follow a given direction vector allowing for drift of ± 4" on each side of the path of travel.
- **UWB Tag + Anchors**: Should fulfill the following requirements:
  - Calculate ToF from incoming packets between UWB transceivers.
  - Triangulate the location of UWB Tag relative to the anchors with an accuracy of < 1 meter.
- **Computer Vision System**: Should fulfill the following requirements:
  - Utilize OpenCV or OpenPose to assist in tracking the human body's key points, which will aid us in keeping track of the child.
  - Provide microcontroller with a direction vector to correct for minor inaccuracies in UWB triangulation
- **Close-Range Object Detection System**: Should fulfill the following requirements:
  - Detect object in the path of travel.
  - Implement a warning system to alert a human of the object.
- **Microcontroller**: Should fulfill the following requirements:

- Properly derives an array of velocity vectors for each omni-wheel from direction vectors provided by the UWB and Computer Vision subsystems.

D. Tolerance Analysis

1) Maximum Velocity: Due to the safety concerns of having a moving robot near a young child, we are planning to limit the max speed of the robot in both software and hardware.

We are currently planning on utilizing an AndyMark 245 RPM 12V Gear Motor connected to a wheel with a maximum diameter of 4in through an axle. Therefore a simple initial analysis on our top speed is as follows (note: the tolerance is left at 20% to compensate for the change in weight as the oxygen tank gets depleted):

$$Robot\,Speed\,(mph) = RPM\,(\frac{rotations}{1\,minute}) * WheelDiameter\,(inches) * \pi * \frac{60\,minutes}{1\,hour} * \frac{1\,mile}{63360\,inches}$$

$$= 245\,(\frac{rotations}{1\,minute}) * 4\,(inches) * \pi * \frac{60\,minutes}{1\,hour} * \frac{1\,mile}{63360\,inches}$$

$$= 2.915 \pm 20\%(mph)$$

III. Ethics and Safety

A. Ethical Considerations

As we continue through the development of our project, we are unwavering in our dedication to abide by the ethical and safety principles outlined by the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineers (IEEE). As we embark on this project, we pledge our commitment to adhere to these standards, ensuring that our actions and choices uphold the highest level of professionalism and integrity.

As outlined in Section I of the IEEE Code of Ethics, we pledge to "uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities" [5]. We will prioritize safety in our design and adhere to ethical design practices. Educating the parents and caregivers about the robot's use and limitations will allow for informed decision-making. Following relevant laws and regulations regarding this technology will also be a high priority.

In the same Code of Ethics, outlined in Section III, we pledge to "strive to ensure this code is upheld by colleagues and co-workers" [5]. We will support each other in ethical conduct and foster a culture of ethical behavior. Open communication will be established and encouraged to raise concerns and provide guidance to team members.

B. Safety Considerations

This project aligns with the safety principles outlined in the ACM Code of Ethics and Professional Conduct. Safety remains our number one priority and as outlined in Section 1.2 [6], we will avoid negative consequences, especially when those consequences are significant and unjust. We will take careful consideration of potential impacts and minimize harm. In the context of this project, we will ensure that the robot's design and operation prioritizes safety, especially to the children this product aims to assist. We will work to analyze potential risk and consider the robot's mobility and interaction with its environment.

As well as promoting safety, privacy is also a very important guideline that will be followed, which is outlined in Section 1.6. As professionals, we must safeguard the personal information of our users, especially if it involves children. As it relates to this project, we will ensure that no data will be collected and stored in an external location. Data collection will be minimized to only what is necessary for the robot to operate.

One aspect of our project where safety must be considered is regarding the use of lithium batteries. We acknowledge the potential risks associated with the misuse of lithium batteries. We are committed to following the safety guidelines associated with the batteries we plan on using. More specifically, maintaining the battery's temperature within the recommended range. Also, we are dedicated to the responsible disposal of batteries to ensure sustainability.

Since we are incorporating motors into our design, we will deploy essential control systems to mitigate potential hazards such as collisions with the environment. Safe operation will be ensured with the use of sensors, vision systems, and warning systems.

REFERENCES

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[6] "Acm code of ethics and professional conduct," Jun 2018. [Online]. Available: https://www.acm.org/code-of-ethics