Auto-following Luggage Platform

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ECE 445 Senior Design: Project Proposal

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Feb. 7, 2023

1. Introduction

1.1 Problem

Sometimes carrying the suitcase might be the most unsatisfactory part of a trip. This dissatisfaction can also grow into annoyance when the amount of luggage is too large to be carried without the help of transportation tools. Therefore, people have dreamed about a suitcase that can automatically track its owners on its own, without requiring external forces from the owner to steer it. There have been so-called "smart suitcases" made for sale with different features including USB-port for charging, GPS localization, etc. However, the price is too high for the public to afford [1], and only a few with exceedingly high expenses might be capable of achieving the fully automatic following feature. The product currently being marketed online that meets the demands described above with the lowest price of 799 EUR can be found here Functions of Airwheel SR5 Intelligent Suitcase, which is still too costly for normal families.

1.2 Solution

We propose the Auto-following Luggage Platform project that aims to solve the problem with the cost of approximately 300 USD dollars, which is much cheaper than the market price of the "smart luggages" available online. More specifically, our intention is to build a general platform that could identify and follow the owner, while at the same time carrying a wide range of different suitcases. In that sense, the system that we will be building will be of a plug-and-use fashion, independent of the suitcases, and thus can have a more general application than those commercial products.

1.3 Visual Aid

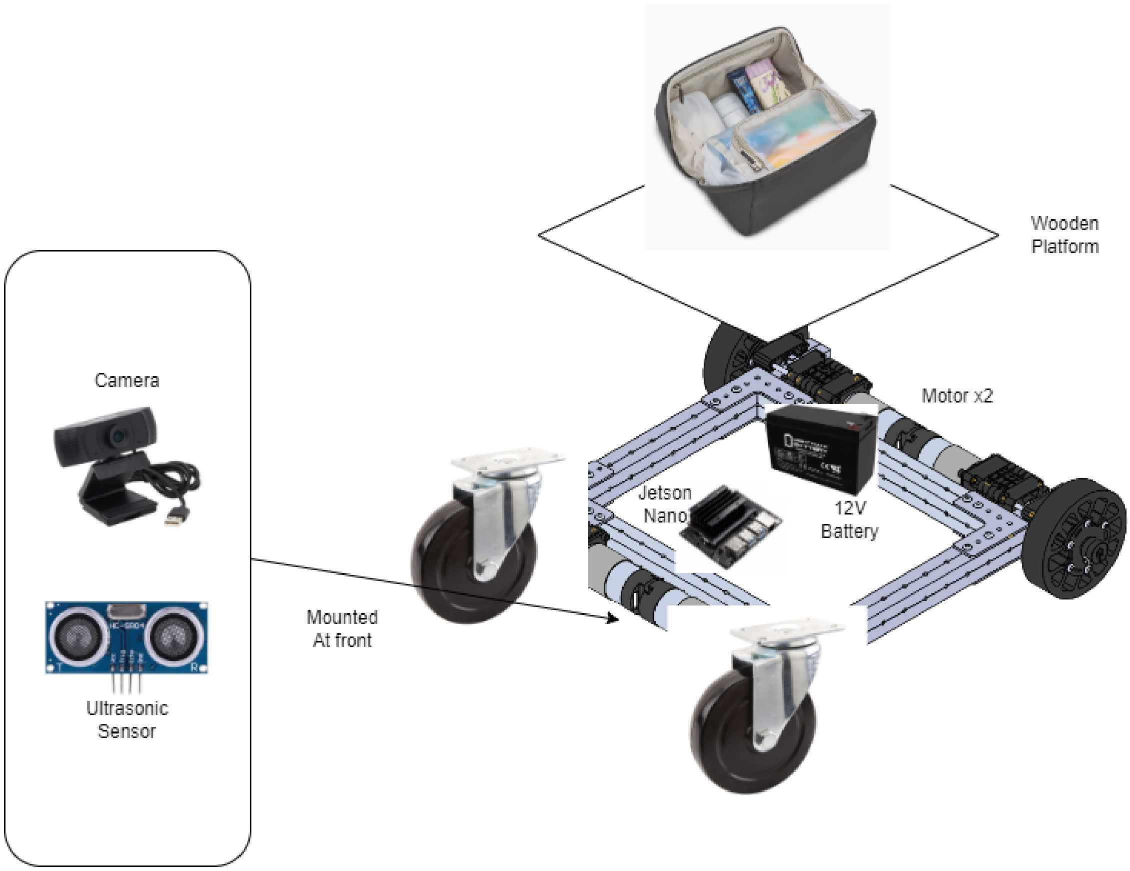

Figure 1: Visual Aid

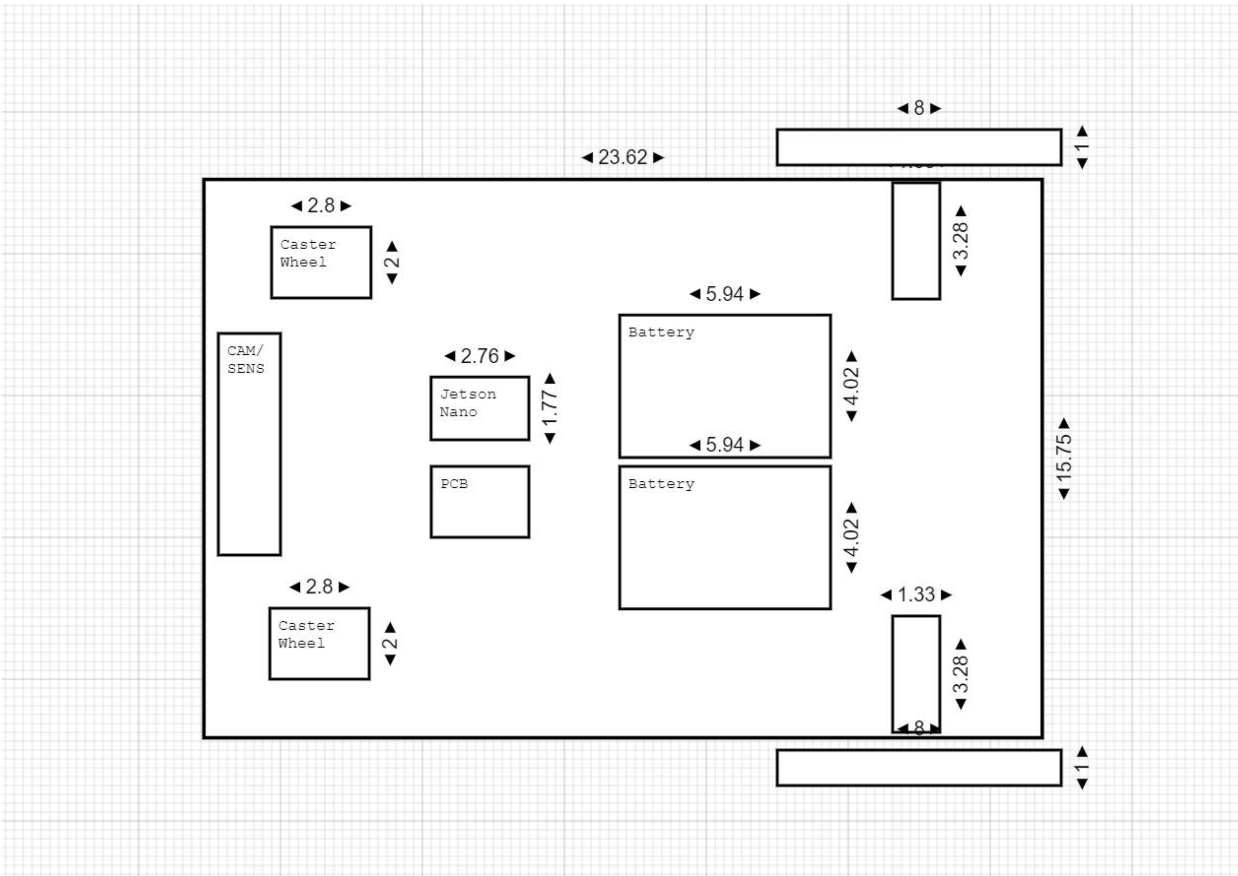

Figure 2: Mechanical Sketch (Looking from the bottom, unit of inch)

1.4 High-Level Requirements List

- The machine is able to carry weights up to 20kg while maintaining a safe speed between 2-4 mph.
- The machine is able to follow the owner when the owner is in the camera frame, and maintain a safe distance of more than 1 meter from the owner.
- If the owner is actually perceivable nearby, the machine is able to locate the owner (put the owner back into the camera frame) autonomously when camera tracking is lost within 10 seconds.
- The machine is able to avoid collisions with obstacles (objects of heights more than 1 inch) and humans 95% of the time.
- The machine is able to remain active (tracking the owner) for at least 30 minutes when the battery is fully charged.

2. Design

2.1 Block Diagram

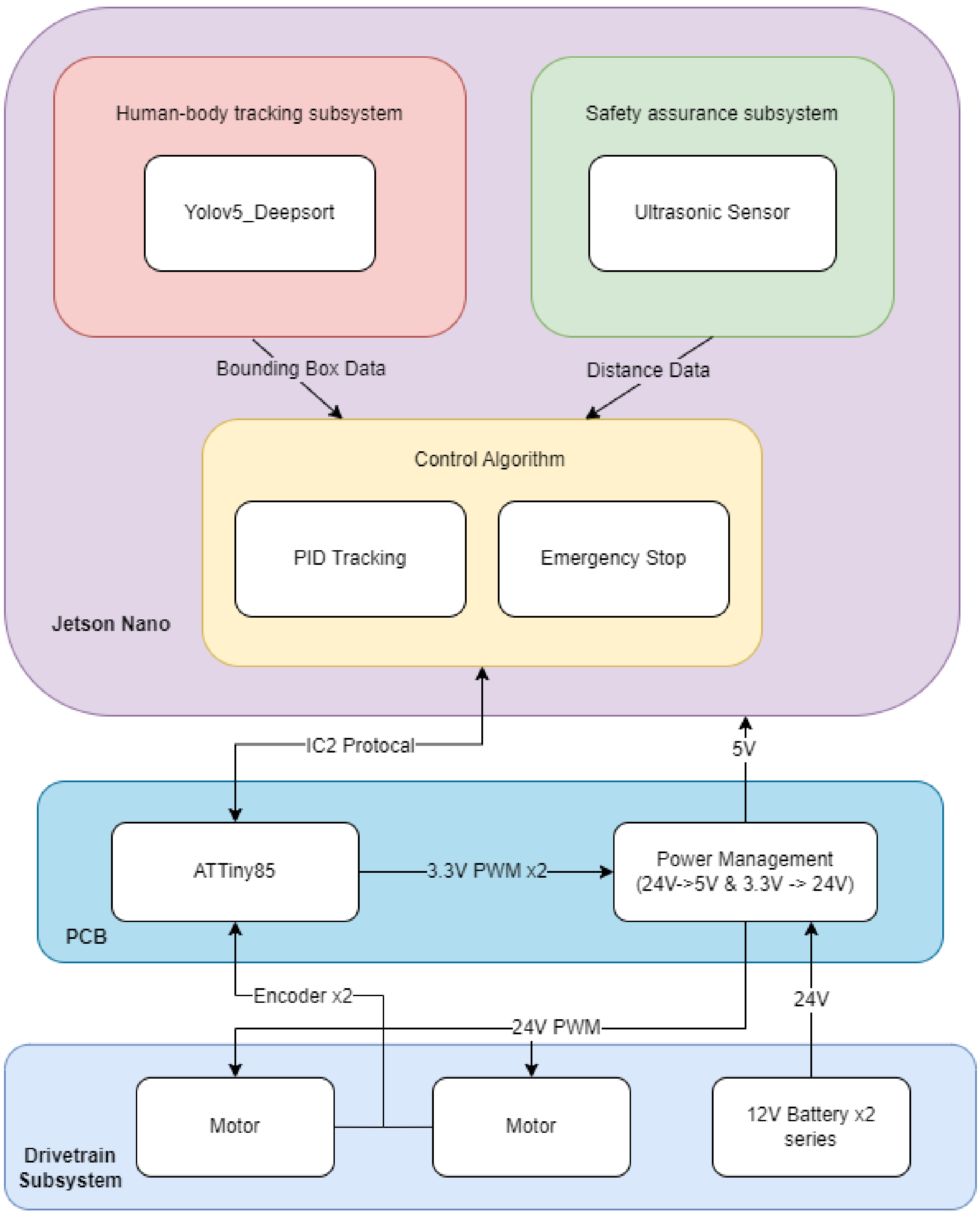

Figure 3: Block Diagram

2.2 Subsystem Overview

2.2.1 Drivetrain

The drivetrain will consist of two motors and two casters. The motor will take input PWM signals given by Jetson Nano and drive the motor accordingly. The drivetrain's left and right motors will be independent, allowing the robot to turn at different speeds on the left and right. In addition, the drivetrain is also responsible for supply power to the entire the entire platform via connected battery.

Requirements	Verifications
Torque provided by each motor must be at least (with coefficient of friction of) 150 N*m to drive the entire machine forward under full load of 20kg with speed above 2 mph but not exceeding the 4 mph.	We will hang weights using a string at the edge of the tire and then turn the motor on. We will keep adding weights and examine whether the motor is capable of lifting the weights up. If the motor failed to lift the weights up as we slowly increasing the total weight, then torque of the motor can be calculated as total_weights * wheel_diameter. The requirement is met if the calculated torque exceeds 150 N*m.
When the battery is fully charged, the machine should be able to actively perform tasks (either tracking the owner or locating the owner) for at least 30 min.	We will first fully charge the battery before the verification process. Then, we will activate the machine while hiding it from its owner, such that the machine will always be in the mode of locating the owner and spinning around. The requirement is met if the machine can remain active for more than 30 minutes.

2.2.2 Control Subsystem

The control subsystem has two modes: tracking and locating. In the tracking mode, the human-body identification subsystem has found the owner and therefore the control subsystem should instruct the drivetrain to track the owner. Using the bounding box data calculated from the Human-body identification subsystem, we can calculate the deviation angle, and use PID to track and minimize this error. We will also use a separate algorithm to control the speed of the robot. Using an estimated distance value, we will speed up and slow down the robot accordingly as well. In the locating mode, the human-body identification subsystem failed to find the owner in the camera frame and therefore the control subsystem should instruct the drivetrain to locate the owner. This is done by instructing the motors to run at different speeds to turn the platform around circularly in order to locate the owner in frame.

Requirements	Verifications
In the tracking mode, the machine should follow the trajectory stably, with oscillation within 5%.	To verify the oscillation requirement in the tracking mode, we will simulate the tracking scenaria via asking the platform to track the owner along a straight line with tapes on the both sides to indicate the maximum deviation allowed when tracking. The requirement is met if the platform is able to track the owner without leaving the region bounded by the tapes.
In the locating mode, the machine should turn around circularly with angular speed of less than 0.314 rad/ sec, such that the human-body identification subsystem can process each frame before the next critical frame comes in.	To verify the angular velocity requirement under the locating mode, we will place the platform with its head aligned to a tape on the ground that indicates the starting orientation. Then, we will calculate the time it takes for the platform to finish a circular turn when its head re-aligns with the tape. An average completion time over 5 trials will be calculated. The requirement is met if the calculated angular velocity is within the specified range of below 0.314 red/ sec.

2.2.3 Human-body identification subsystem

We will use Yolo5 for human recognition and segmentation to produce bounding boxes. Each bounding box will be made into gait silhouettes and used for a gait-matching algorithm to identify the owner of the suitcase. This subsystem will return a boolean value that represents whether the owner is found in the current frame, and, if true, the correct bounding box of the identified owner. This boolean value and the offset will be sent to the control subsystem for controlling the drivetrain.

Requirements	Verifications
With the pre-trained model on the owner's biometrics, the identification subsystem should be able to achieve at least 90% accuracy on identifying the owner within the camera frame, with obstacles and other humans present.	We will perform the verification under 4 scenarios: single human with no obstacles, single human with obstacles, multiple humans with no obstacles, and multiple humans with obstacles. The owner may or may not be present in the frame, and the positions of the humans and obstacles are randomized for each trial. Each scenario will be tested for 10 trials. The requirement is met if the platform is able to correctly identify the owner with more than 90% accuracy for all 4 scenarios.

2.2.4 Safety assurance subsystem

The ultrasonic sensor equipped will report the distance to obstacles as well as a boolean value that represents safety with respect to possible collisions. The robot will stop immediately if the returned value is false to avoid collisions.

Requirements	Verifications
The robot should immediately brake whenever an obstacle is within a safety distance of 1 m, and the distance between the robot when it's stopped and the obstacle should be more than 90% of the safety distance.	We will perform the verification by running 10 trials, each with different obstacles placed at arbitrary distances away from the platform before the test. During the test, we will drive the platform towards the obstacles at arbitrary orientation and following arbitrary trajectory. If the platform stopped before the collision, the distance between the obstacle and the platform will be measured using a meter stick. The requirement is met if the measured distance for all 10 trials is more than 50 cm (90% of safety distance of 50 cm).

2.3 Tolerance Analysis

2.3.1 Maximum Velocity

Our motor is rated for 200 rpm along with a 20cm diameter wheel. So we can derive its maximum velocity:

$$V_{max} = \omega\pi d = 200 * 3.14 * 0.2m/60 = 2.09\, m/s = 4.66mph$$

2.3.3 Battery Life

We will use a 12V 9 Ah battery to power our entire platform. Using an estimated 80% efficiency in the circuits, we can derive the maximum possible battery life of our platform:

$$T = \frac{E_{battery}\eta}{P_{motors} + P_{jetson}} = \frac{2*12V*9\,Ah*0.8}{12W*2+20W} = 3.9\,h$$

2.3.4 Challenges

Our main challenge would be maintaining tracking of the owner. At this point, we are not sure how well our identification and control algorithms can perform together under the real scenario. Specifically, we are not sure how much impact the estimation errors of the bounding box from the identification algorithm could affect the accuracy of the control algorithm. Also, a huge uncertainty will be imposed on the capability of the drivetrain subsystem before it's actually built and tested, as the above tolerance analysis involves too many assumptions and estimations. We will first focus on building the physical platform out, then building the drivetrain, and then moving on to tuning our tracking algorithms.

3. Cost and Schedule

3.1 Cost analysis

Parts

Name	quantity	total price
NVIDIA Jetson Nano Developer Kit	1	149.0
LaView 32GB Micro SD Card	1	8.99
ML9-12 - 12 Volt 9 AH, F2 Terminal, Rechargeable SLA AGM Battery	2	45.98
8 Inch Wheels Replacement for Oregon 72-108	1	19.99
CQRobot Ocean: 50:1 Metal DC Geared-Down Motor	2	67.98
2 inch Swivel Caster Wheel	4	15.99
Total		307.93

Labor

We assume a typical ECE engineer can earn $50/hour, and we also estimate to work 20 hours per week on the project, throughout a span of 11 weeks.

Salary ($/hour)	Number of Engineers	Total Work hours	Total Cost ($)
50	2	220	11,000

Grand Total = 11000 + 284.94 = 11284.94

3.2 Schedule

Week	Task	David	Lyuxing
Feb 20 - Feb 26	Placing orders for the drivechain and power		X
	Finish PCB design for board review	X	
Feb 27 - March 5	Placing orders for chips for the PCB and sensors needed	X	
	Edit PCB design for first wave of PCB order		X
March 5 - March 12	Start YOLO pipeline integration	X	
	Start safety assurance subsystem design		X
March 13 -March 19	Finish YOLO pipeline integration	X	
	Finish safety assurance subsystem design		X
March 20 - March 26	Start control subsystem design	X	
	Start human identificatio algorithm design		X
March 27 - April 2	Finish control subsystem design	X	
	Finish human identificatio algorithm		X
April 3 - April 4	Subsystem integration on the physical robot	X	X
April 5 - April 9	Overall Debugging	X	X
April 10 - April 16	Perform verification procedures	X	X
April 17 - April 23	Demo	X	X

4. Ethics and Safety

As progress through the project, we will firmly adhere to the Code of Ethics described in IEEE and ACM. We'll ensure a fair distribution of workload and a healthy working environment free of discrimination and racism according to IEEE Code of Ethics II [2]. Equal rights and mutual respects will be valued the most as we are working on the project. In addition, we'll also respect and appreciate all external helps we receive. We will seriously consider and sincerely appreciate any advice given by course TAs and professors. We'll also carefully cite and give credit to all the external works done by others that have helped us along the way.

Regarding the safety of the project, one potential hazard will be the usage of a lithium battery. Therefore, we'll perform all the safety protocols to prevent any hazardous events arising from the lithium battery [3], including but not limited to keeping the temperature of the battery within the safety range of 32 to 130 Fahrenheit, avoiding sudden and drastic movement of the battery carrier, etc. Moreover, since the project involves a moving component at the ground level, there exists a possibility that it could crash on humans unexpectedly. Therefore, we'll limit the max movement speed of the project to 4 mph to prevent injuries if collisions happen. We'll also put a high priority in the safety assurance subsystem to prevent such collisions from happening under any conditions.

5. References

[1] mygita.com, 2023. [Online]. Available: https://mygita.com. [Accessed 8 Feb. 2023]

[2] "IEEE Code of Ethics," IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed 8 Feb. 2023].

[3] Batteryuniversity.com, 'Safety Concerns with Li-ion Batteries – Battery University', 2023. [Online]. Available at: http://batteryuniversity.com/learn/article/safety_concerns_with_li_ion. [Accessed 8 Feb. 2023].