Pseudo GPS for Romi

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For Charlie Refvem

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Four Panel Chart

Project Overview	Key Specifications
• Project Objective: Currently, the Romi robots used in the Mechatronics lab have no way of obtaining absolute orientation or location from onboard sensors. The Cal Poly ME 405 instructor, Charlie Refvem, and Mechatronics students need a way to deliver precise and real-time location data for multiple Romi robots for the development of better algorithms. Our aim is not just to improve tracking but also to enhance communication standards among multiple Romis by ensuring geolocation accuracy, precision, range, latency, and update rates. • GPS Prototype Goals: Provide precise, real-time location data for multiple mobile robots, improving tracking and communication standards. • Team Structure: Sponsored by Mechatronics professor Charlie Refvem, the team comprises Emmanual Baez (Communications Lead), Gabriel Coria (Treasurer), Owen Guinane (Secretary), and Conor Schott (Planner). • Documentation and Impact: The project involves comprehensive documentation, including detailed electrical schematics and code explanations.	• The code can be run on C, C++, and Python for the external device. The Romi must be coded on uPython while running on a Nucleo • There should be a microcontroller used to control the external device • The Robots that will be used are Pololu Robotics Romi Chassis • The group must be able to provide a wiring diagram of all components connected • The code must be well-documented • The solution's initial budget is $500 but can be increased with Charlie's approval • The device attached to the Romi should be small and lightweight, whereas the external device should also be lightweight but have more freedom on size • Looking for a system capable of emitting at 5 Hz for a group of six to ten robots • The accuracy for positional data must be within 5 mm (about 0.2 in)

Scope And Deliverables	What’s Next
We will be creating a proof of concept for a system to monitor Romis in real-time along with extensive coding and hardware documentation. The scope of this project encompasses the design, development, and testing phases, with the primary focus on creating a versatile and efficient GPS.	We will explore our ideation models, polish our Statement of Work (SOW), develop our Preliminary Design Review (PDR), and explore the possibility of testing specific sensors at Charlie's discretion.

Problem Statement

Currently, the Romi robots used in the Mechatronics lab use IMUs to get absolute orientation data but have no way of obtaining locational data from any other onboard sensors. The Cal Poly ME 405 instructor, Charlie Refvem, and Mechatronics students need a way to deliver precise and real-time location data for multiple Romi robots for the development of better algorithms. Our aim is not just to improve tracking but also to enhance communication standards among multiple Romis by ensuring geolocation accuracy, precision, range, latency, and update rates.

Overview

This report aims to document our design process as we work to develop a solution to provide a pseudo-GPS system for the robots in the Mechatronics lab. In it, we will establish a background of the project and the results of our research, a scope where we will determine the needs and deliverables of the project, an objectives section that fully defines our problem and design specifications, and a Project Management plan that will explain the process that we will follow going forward.

By the Fall quarter of 2024, we will deliver detailed documentation, including electrical schematics and a written explanation of the code and its functions.

Our group is tasked with providing analysis, testing results, and characteristics of the prototyped sensor, evaluating aspects such as accuracy, precision, range, update rate, and latency. Several existing solutions share similarities with our project. Among these devices are equipped with built-in GPS systems, enabling users to track them via smartphones. Examples include Marvel Mind, the Apple Air tag, the Goodly mini-GPS tracker, and the LandAirSea 54 real-time GPS tracker. While these devices are pricier and come pre-coded for immediate use, unlike our project, studying their functionalities can provide valuable insights for our development. Additionally, there are advanced cameras capable of tracking selected objects, such as indoor positioning systems, the Lumens VC-TR1 auto-tracking PTZ camera, and the Yealink UVC86 4K dual-lens speaker tracking camera. Another option we explored was body-tracking technology, which led us to the Xbox Kinect, renowned for its body-tracking capabilities. This emerged as one of our top choices for tracking Romis. Although certain technologies, like Roombas, infrared sensors, garage door sensors, wireless driveway alarms, and satellites, are beyond our budget constraints, researching their functionalities allows us to integrate innovative ideas into our project.

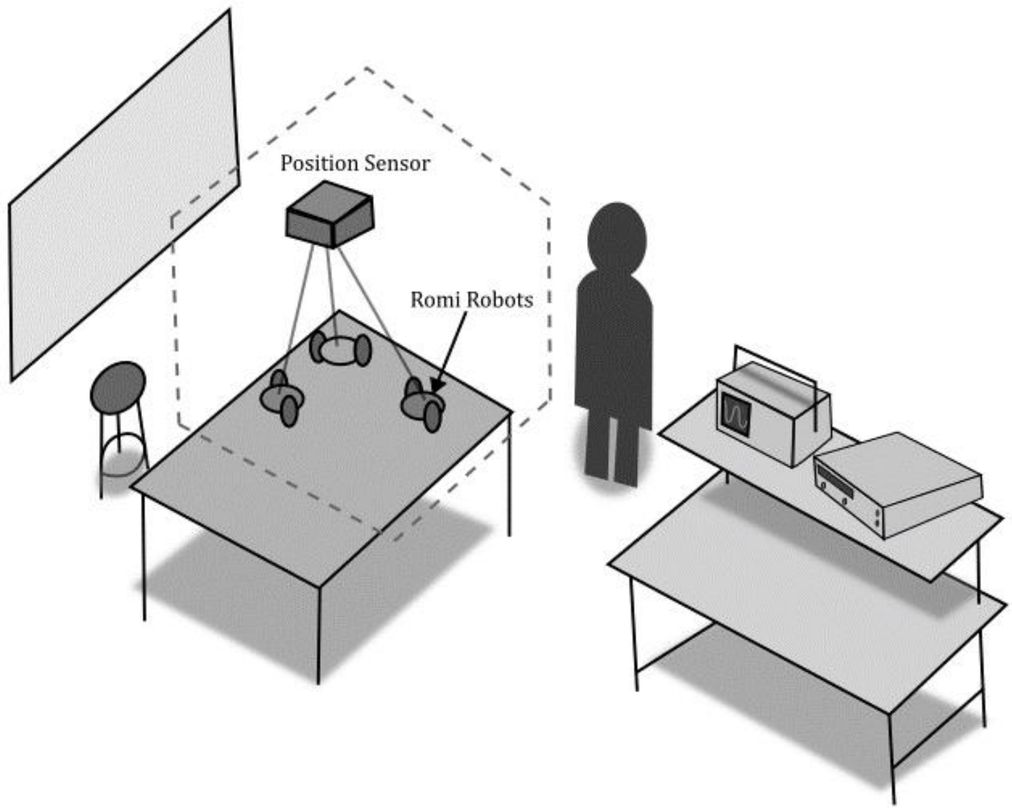


Figure 1: Boundary Sketch

Customer Needs

Table 1: Customer Needs

Customer Needs	Relevant Engineering Specs	Justification
Attachments need to fit on the Romi Robot.	Our geometry should fit on a Romi that is 6.4in x 5.8in x 2.75in	Since we are using a Romi, we need to be able to fit the device on one.
The system needs to track the table's length and width in the Mechatronics lab.	Our table's base should be 46in x 96in.	The customer wants to perform laboratory tests on these lab tables.
The system needs to be powered by an external or internal source.	Devices on Romi must run at either 3.3V,5V, or 7.2V. External parts can be powered from a wall outlet.	Tracking sensors will take power in the form of batteries or a charging outlet. It also requires quick upload and download of data to process.
The system needs to have a good update rate for data transfer.	Our update rate should be 6Hz or more.	Our sponsor suggests an update rate of about 6Hz.
The system should be able to track multiple Romi bots at a time.	The device should be able to track up to six Romis.	Our sponsor has multiple Romis that the students use in the lab.
The system should be easy to take apart and moveable if it is not mounted.	Must be mounted in a non-destructive way when placed on the ceiling. Needs an elevated structure to replace the main component on the ceiling. The main component should also have protected housing against slight vibration and magnets.	Since the assembly will be constantly moving, we do not want there to be significant vibrations between components. Furthermore, we want our sensors to be protected from magnets.
The system should be within budget to produce.	The manufacturing cost should be around $500 but more money can be spent if approved by the sponsor.	Since we will not build our microcontroller and sensor, we will use our funds to buy components from manufacturers.

Table 1 shows the customer needs and the engineering specifications that our group needs to follow. We also added a justification for why the engineering specifications were chosen.

Engineering Specifications

Table 2: Engineering Specifications

Spec #	Specification Title	Specification Description	Target (units)	Tolerance	Risk *	Compliance **
1	Total System Length	The system would prefer to be able to fit onto a Romi.	Romi Size	±0.010 in.	L	A, I
2	Total System Weight	The Romi will also have other sensors attached to it, so we would not want to encumber it further.	2 lbs.	Max	L	A, I
3	Field of View	The system should track a Romi placed on the classroom table.	96x48 in.	Max	H	A, I
4	Max Power Capability	The system should be powered by a wall outlet. Technology on Romi should be powered by a battery.	7.2 V	Max	L	I, T
5	Data Transfer	The system should be able to transfer data at a high rate.	6 Hz	Min	M	A, T
6	Number of Romis being detected	The system should be able to track multiple Romis	6	Min	L	A, T
7	Tracking Resolution	The system should be able to track the position of Romi.	5 mm positioning	Max	H	A, I
8	Production Cost	The budget is $500. (could be higher)	$500	Max	M	A
8	Housing	The system needs to house the microcontroller we will be using as well as the sensors we will be using for detection and data transfer Some type of easy access to the batteries or charging port.	85 L X 56 W X 19 H mm	Min	L	I, T

		Needs to be easy to move if needed.				

* Risk of meeting specification: (H) High, (M) Medium, (L) Low
** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

This table outlines the project’s essential specifications, categorized based on their priority and corresponding compliance methods. Each specification is accompanied by detailed information and our target goal for reference.

Existing Solutions

Table 3: Existing Solutions

Solution Type	Description	Examples
GPS Systems	Technology that relies on satellite signals received by specialized receivers to triangulate the object's precise location. Therefore, it can be used for mapping, route planning, and real-time positional monitoring.	Marvel Mind utilizes GPS technology in their Starter Set Super-MP-3D for precise indoor positioning and navigation, achieving an impressive accuracy of ±2cm. By integrating multiple frequency options and IMU sensors, Marvel Mind enhances update rates and provides a versatile solution for autonomous indoor navigation of robots, surpassing the limitations of traditional ultra-wideband and BLE systems [15],[3].
Lidar Technology	Lidar is a technology that sends out a laser to a targeted object and measures the time it takes to return to the receiver to get the range.	Steam VR Base stations and HTC Vive Trackers are used by people in Virtual Reality to track the location of their full body in games [1], [9], [12].
Motion Detection	Technology that sends out sound waves at frequencies above the range of hearing. The sound waves bounce back off the objects and come back to the transducer which sends and receives the sound waves when an object comes in front of the detecting area.	The Xbox Kinect, a device that adds motion controls to Xbox game consoles, can be used to track objects in space using its variety of sensors [13].
Infrared Technology	Technology that emits and receives infrared radiation, bounces off objects and goes back to the receiver. This technology can tell how far objects are as well as detect motion.	Roomba Vacuums use infrared stations to help navigate back to their charging ports [24].
Beacons	This technology emits a signal that a device can use to determine its location based on its distance from the source.	Magnetometers use the strength of a magnetic field to determine its relative position [12]. Apple Air tags use a Bluetooth signal to

		determine how far away an iPhone is from it [14].
Optical Technology	This technology uses light signals to transmit data through optical fibers. Camera lenses take light rays that bounce around and use a glass to redirect them to a single point to take a picture.	Cameras can be used to take a video of the field which can then be processed by a computer to determine an object’s location. [4], [7].

This table presents diverse solution options for our group to explore and research. While there are various possibilities, the challenge lies in narrowing down choices based on feasibility and compatibility with our technology. Each solution is accompanied by a brief description of its working, along with examples of products that have successfully implemented them.

Annotated Bibliography

Relevant Articles

[1] M. Eisoldt *et al.*, “A fully integrated system for hardware-accelerated TSDF SLAM with LiDAR sensors (HATSDF SLAM),” *Robotics and Autonomous Systems*, vol. 156, p. 104205, Oct. 2022, doi: https://doi.org/10.1016/j.robot.2022.104205.

HATSDF SLAM, an energy-efficient TSDF SLAM implementation for mobile robots, achieves real-time performance with 18 times lower energy requirements per frame than a state-of-the-art PC by leveraging embedded ARM processors and FPGA-based hardware accelerators. Its integrated ROS bridge enables online mapping inspection and offline evaluation of datasets, demonstrating accurate pose estimation with minimal drift in various scenarios compared to established SLAM algorithms. Future developments aim to implement runtime hardware reconfiguration for automatic adaptation to changing environmental conditions, enhance TSDF volume resolution, and reduce registration time for high-resolution LiDAR data using memory-efficient data structures and potentially incorporating feature-based SLAM methods.

[2] A. Geiger, P. Lenz, C. Stiller, and R. Urtasun, “Vision meets robotics: The KITTI dataset,” The International Journal of Robotics Research, vol. 32, no. 11, pp. 1231–1237, Aug. 2013, doi: https://doi.org/10.1177/0278364913491297.

The article introduces the KITTI dataset, a comprehensive resource for research in mobile robotics and autonomous driving, captured from a VW station wagon. Noteworthy aspects include 6 hours of diverse, calibrated, and synchronized traffic scenarios recorded with a range of sensors. The dataset provides 3D object labels and benchmarks, contributing significantly to the development and evaluation of computer vision and robotic algorithms for autonomous driving.

[3] T. T. Do and H. Ahn, “Visual-GPS combined ‘follow-me’ tracking for selfie drones.” *Advanced Robotics*, vol. 32, no. 19, pp. 1047-1060, 2018, doi: https://doi.org/10.1080/01691864.2018.1501278.

The paper proposes a hybrid approach for the 'follow-me' mode in camera drones, specifically selfie drones, aiming to improve targeting accuracy. Current commercial drones rely on GPS data for tracking, but this can lead to unsatisfactory results due to GPS inaccuracies. The proposed approach combines the short-term accuracy of a visual tracking algorithm with the long-term reliability of GPS-based tracking, demonstrating superior accuracy in follow-me operations compared to GPS-based methods. The system also exhibits quick recovery from visual tracking failures and Wi-Fi disruptions in short-term scenarios.

[4] E. Bostanci, B. Bostanci, N. Kanwal, and A. F. Clark, “Sensor fusion of camera, GPS and IMU using fuzzy adaptive multiple motion models,” Soft Computing, vol. 22, no. 8, pp. 2619–2632, Feb. 2017, doi: https://doi.org/10.1007/s00500-017-2516-8.

The paper addresses the challenges in user tracking for augmented reality (AR) applications, emphasizing the importance of accuracy and frame rate. It explores a fusion approach, combining vision-based estimates with GPS and IMU measurements to enhance tracking accuracy in outdoor environments. The use of Fuzzy Adaptive Multiple Models, a novel fuzzy rule-based approach, is investigated to improve accuracy and convergence speed in the fusion filter. The results demonstrate the developed tracking system's superior accuracy compared to conventional GPS–IMU fusion approaches, with applications highlighted in cultural heritage contexts.

[5] L. Veronese, F. AuatźCheein, T. Bastos, A. FerreiraźDeźSouza, and Edilson de Aguiar, “A Computational Geometry Approach for Localization and Tracking in GPS-denied Environments*,” Journal of Field Robotics, vol. 33, no. 7, pp. 946–966, Jul. 2015, doi: https://doi.org/10.1002/rob.21594.

The paper proposes a hybrid approach for the 'follow-me' mode in camera drones, specifically selfie drones, aiming to improve targeting accuracy. Current commercial drones rely on GPS data for tracking, but this can lead to unsatisfactory results due to GPS inaccuracies. The proposed approach combines the short-term accuracy of a visual tracking algorithm with the long-term reliability of GPS-based tracking, demonstrating superior accuracy in follow-me operations compared to GPS-based methods. The system also exhibits quick recovery from visual tracking failures and Wi-Fi disruptions in short-term scenarios.

[6] A.-T. Popovici, C.-C. Dosoftei, and C. Budaciu, “Kinematics Calibration and Validation Approach Using Indoor Positioning System for an Omnidirectional Mobile Robot.” *Sensors*, vol. 22, no. 22, p. 8590, 2022, doi: 10.3390/s22228590.

The paper proposes an extended calibration approach to enhance the motion response of Omnidirectional Mobile Robots (OMRs) in indoor environments, specifically addressing mechanical imperfections such as misalignment. Utilizing an Indoor Positioning System (IPS) based on ultrasound technology, the study demonstrates significant reductions in motion errors, particularly in rotation correction factors. The research contributes to the advancement of precise and reliable navigation for autonomous mobile robots, crucial for applications in coordination and warehouse management.

[7] Zhu, Yu, and Xiao, “An Unconventional Multiple Low-Cost IMU and GPS-Integrated Kinematic Positioning and Navigation Method Based on Singer Model,” *Sensors*, vol. 19, no. 19, p. 4274, Oct. 2019, doi: https://doi.org/10.3390/s19194274.

The paper introduces an unconventional multiple low-cost Inertial Measurement Unit (IMU) and GPS-integrated kinematic positioning and navigation method based on the Singer acceleration model. The individual modeling method, a key component of this approach, dynamically adjusts systematic error estimations for each IMU in real-time, offering a more accurate representation of the actual situation. Despite the success of the proposed algorithm, the study highlights challenges related to the high computation load caused by frequent measurement updates in the Kalman filter, especially with IMUs operating at a high rate of 100 Hz. The paper concludes by suggesting future work on developing a more precise fusion algorithm using carrier phase information from the GPS.

[8] A. Saha, B. C. Dhara, S. Umer, K. Yurii, J. M. Alanazi, and A. A. AlZubi, “Efficient Obstacle Detection and Tracking Using RGB-D Sensor Data in Dynamic Environments for Robotic Applications,” *Sensors*, vol. 22, no. 17, p. 6537, Aug. 2022, doi: https://doi.org/10.3390/s22176537.

The paper proposes an efficient obstacle detection and tracking method using depth images, specifically with RGB-D camera sensors, for autonomous navigation in dynamic and cluttered environments. The approach employs a u-depth map for obstacle detection, with dynamic thresholding to enhance accuracy. Additionally, a restricted v-depth map technique is introduced for improved prediction of obstacle dimensions, and a novel algorithm facilitates obstacle tracking within the field of view. The system's performance is evaluated on various datasets, demonstrating its superiority over vision-based state-of-the-art methods in terms of state estimation of dynamic obstacles and execution time.

[9] Z. Liu, F. Zhang, and X. Hong, “Low-cost Retina-like Robotic Lidars Based on Incommensurable Scanning,” *IEEE/ASME Transactions on Mechatronics*, pp. 1–1, 2021, doi: https://doi.org/10.1109/tmech.2021.3058173.

The paper introduces a novel lidar sensor designed for mass production in autonomous robots, utilizing incommensurable scanning for straightforward manufacturing. Inspired by the human retina's fovea, the lidar exhibits a peaked central angular density, making it well-suited for applications requiring eye-like attention. Its unique design allows for higher resolution than conventional lidars, with demonstrated advantages in sensor calibration and potential upgradability, providing a promising solution for the development of cost-effective and efficient autonomous robots.

[10] T. Zhe, L. Huang, Q. Wu, J. Zhang, C. Pei, and L. Li, “Inter-Vehicle Distance Estimation Method Based on Monocular Vision Using 3D Detection.” *IEEE Transactions on*

Vehicular Technology, vol. 69, no. 5, pp. 4907-4919, 2020, doi: https://doi.org/10.1109/TVT.2020.2977623

The paper addresses challenges in autonomous vehicle perception systems, focusing on cost-effective solutions using monocular vision for inter-vehicle distance estimation. While traditional systems rely on expensive sensors, the proposed driving assistance system (DAS) leverages monocular vision-based methods. The study introduces a novel approach, combining 3D detection and an area-distance geometric model to enhance accuracy and robustness in inter-vehicle distance estimation. The method demonstrates superior performance in complex traffic scenarios, outperforming existing methods, with an accuracy deviation below 2% for vehicles with different visual angles.

[11] YoungWonks, "An introduction to magnetometers, where they are used and how they work," *YoungWonks*. https://www.youngwonks.com/blog/What-is-a-Magnetometer-and-How-Does-It-Work#:~:text=Based%20on%20the%20principle%20of

This article provides an overview of magnetometers, describing their function, working principles, applications, calibration methods, and types. It offers a detailed exploration of magnetometers, devices crucial for measuring magnetic fields' strength and orientation. It elucidates their devices working principles, including the Hall effect, magneto-induction, and magnetoresistance, each method discerning changes in current or resistance when exposed to magnetic fields.

[12] "What is Lidar? Learn How Lidar Works," *Velodyne Lidar*. https://velodynelidar.com/what-is-lidar/#:~:text=and%20weather%20conditions.-

The article introduces lidar (light detection and ranging), highlighting its use of eye-safe laser beams to generate a 3D representation of the environment. It explains the working principle of lidar: the sensor emits pulsed light waves, which bounce off objects and return to the sensor. By calculating the time taken for each pulse to return, the sensor determines the distance traveled, creating a real-time 3D map known as a point cloud. Overall, the article provides a clear and concise overview of lidar's functionality and applications.

[13] "How It Works: Xbox Kinect," *Jameco.com*, 2019. https://www.jameco.com/jameco/workshop/howitworks/xboxkinect.html

This article delves into the inner workings of the Xbox Kinect, a revolutionary gaming device eliminating the need for a traditional controller and enabling full-body interaction within games. It describes the Kinect's intricate software and hardware components. The software leverages extensive motion-capture data and utilizes artificial intelligence and machine learning algorithms to interpret real-life movements and map them onto virtual avatars. The hardware consists of an RGB color VGA video camera, a depth sensor, and a multi-array microphone, which collectively track various points on the player's body. Overall, the article provides a comprehensive overview of the Xbox Kinects technology.

[14] "Apple AirTags: Everything You Need to Know" PCMag. https://www.pcmag.com/how-to/apple-airtag-tips

Apple AirTags are compact trackers designed to help users locate misplaced or stolen items using the Find My app. Priced at $29 each or $99 for a pack of four, AirTags use ultra-wideband technology and Apple's device network for precise location tracking. Setup is straightforward, requiring a compatible iPhone or iPad running iOS 14.5 or above. The device boasts a one-year battery life and uses standard CR2032 batteries. Security measures include end-to-end encryption, alerts for unwanted tracking, and NFC functionality for Android users to connect to lost AirTags. The product provides a blend of precision, security, and privacy for tracking personal belongings.

[15] "Starter Set Super-MP-3D" Marvelmind robotics. https://marvelmind.com/product/starter-set-super-mp-3d/

The Starter Set Super-MP-3D is a cutting-edge indoor positioning and navigation system designed for precise tracking in industrial settings. With ±2cm accuracy, it is ideal for automation, safety, and productivity applications. The versatile set supports multiple configurations, including 1D, 2D, and 3D, and offers Multi-Frequency support for increased update rates. Utilizing Super-Beacon technology with 6D IMU, the system provides superior performance compared to previous versions. It operates in license-free radio bands and includes advanced features such as ultrasound frequency selection and sharp DSP filters. The set is easy to deploy, with no manual calibration required, making it a comprehensive solution for indoor tracking of robots, vehicles, and drones.

Relevant Patents

[16] Teleoperator system with master controller device and multiple remote slave devices, by William T. Townsend. (2011, Aug 11.). US20120041599A1. [Online]. Available: https://patents.google.com/patent/US20120041599A1/en?oq=US20120041599A1

This patent describes using a master system to control multiple connected robots. The idea presented in this patent could be used as the GPS sensor developing could be the master system that streams data in cartesian space to its subordinate devices. We learned that multiple robots can be controlled from a master device rather than on-board hardware.

[17] Magnetic vector sensor positioning and communication system, by Larry W. Fullerton. (2016, Mar 24.). US9566599B2. [Online] Available: https://patents.google.com/patent/US9588599B2/en?oq=US9588599

This patent describes a magnetic vector positioning system that uses magnetic vector sensors to determine position or to transmit data. This has potential use of determining Romi orientation and position using magnetometers. We learned that magnetometers can also be used to transmit data and locate an object.

[18] Celestial navigation system for an autonomous robot, by Mark Joseph Chiappetta. (2005, Jul. 7). US7706917B1. [Online] Available: https://patents.google.com/patent/US7706917B1/en?oq=US7706917

This patent describes an onboard celestial navigation system for indoor robots. This could be used as a basis for mounting an external tracking system or an alternate way to obtain navigation data on board the Romis. We learned that a series of multiple beacons can be used for orientation and location data through relativity.

[19] Video image-based control system by Francis MacDougall. (1991, May 11.) US5534917A. [Online] Available: https://patents.google.com/patent/US5534917A/en?oq=US5534917

This patent describes a video-based tracking system where a video is converted to data to control a device. This can be used as a low-cost way to track multiple robots simultaneously. We learned that to process video, a computer performs and functions on a bitmap to determine whether an object is in an area of interest.

[20] Indoor robot positioning method integrating visual odometer and physical odometer, by 周唐恺. (2017, Jun 2.). CN107356252B. [Online] Available: https://patents.google.com/patent/CN107356252B/en?oq=CN107356252B

This patent illustrates a tracking method by way of using visual and on-board odometers to determine the location of a robot. This may be a more accurate way of tracking compared to solely digital tracking and it complements Romi's native odometer tracking. We learned that we could combine multiple existing solutions to improve location accuracy.

[21] Distributed localization systems and methods and self-localizing apparatus, by Marcus Hehn. (2016, Mar 7.). US20160259032A1. [Online] Available: https://patents.google.com/patent/US20160259032A1/en?oq=US20160259032A1

This patent describes using transceivers as a localization network that a device could use to determine its position relative to. This could be used as a solution where the robots would use the transceivers to compute its relative location on-board.

[22] Image-based georeferencing, by James M. Janky. (2009, Sep 14.). US20110064312A1. [Online] Available: https://patents.google.com/patent/US20110064312A1/en?oq=US20110064312A1

This patent describes an image-based system, which georeferenced features based on the difference between two pictures. This could be implemented by comparing a picture feed with Romi robots versus a reference picture with no robots.

[23] Triangular interferometric light-source tracker, by Brett Alan Bordyn. (1974, Jul 26.). US4003658. [Online] Available: https://patents.google.com/patent/US4003658A/en?oq=US4003658

This patent describes a system that tracks a light source using orthogonal triangular interferometric systems on a gimbaled platform. This can be used to track the position of a Romi by attaching a light source to the robot, though the mechanisms required are complex.

[24] Autonomous coverage robot navigation system, by Daniel N. Ozick (2008, Dec 23.). US8380350. [Online] Available: https://patents.google.com/patent/CN107356252B/en?oq=CN107356252B

This patent describes an autonomous robot that uses aa base station with three infrared emitters to guide the robot. This could be used by the Romi robots to determine their position based on their location from the emitter.

[25] Vision based location estimation system by . (2017, Jun 2.). CN107356252B. [Online] Available: https://patents.google.com/patent/CN107356252B/en?oq=CN107356252B

This patent describes using multiple Kalman filters to process data from an ultra-wideband positioning system, pressure sensors, temperature sensors, and inertial measurement data, to obtain precise location data. This process could be used to combine several onboard sensors already implemented on the Romi with the prototype to further increase the precision of positional data.

Appendices

QFD House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

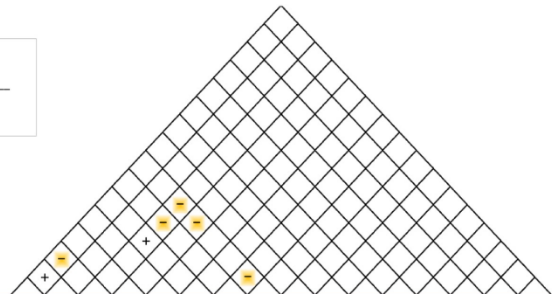
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: GPS for Romi

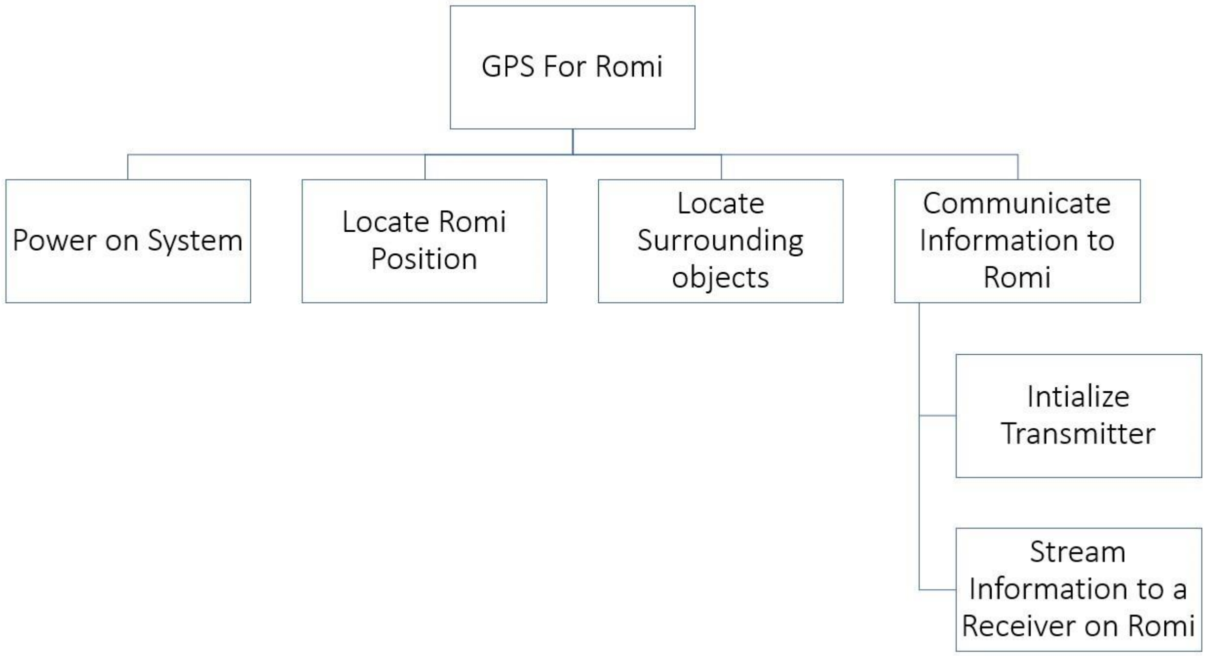
Revision Date: 2/26/24



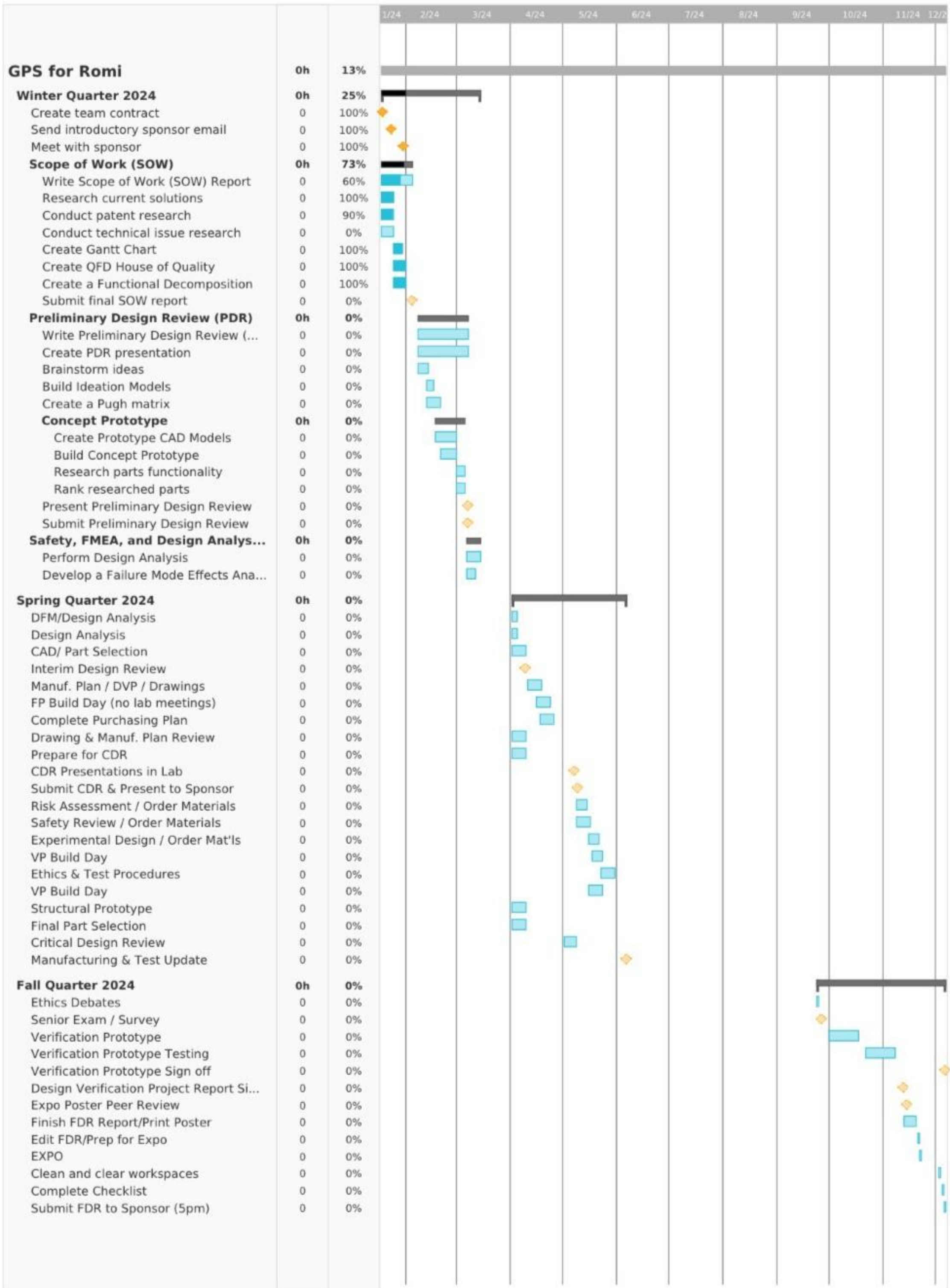
Row #	Weight Chart	Relative Weight	Charlie Refvem	Mechatronics Students	Colleges with Mechatronics Pro	Other Romi Customers	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) \ HOW: Engineering Specifications (Tests)	Total Length	Total Weight	Field of View	Max Power Capability	Data Transfer	Number of Robots Detected	Tracking Resolution	Production Cost									Our Current Product	Competitor #1: MarvelMind	Competitor #2: Romi Encoders	Competitor #3: BNO55 IMU	Competitor #4: N/A	Row #
	WHO: Customers							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Curr. Products					
								Direction of Improvement	▼	▼	▲	▼	◇	◇	◇	▼														
1		10%	4	4	3	3	9	Attachment fitment	●	●	▽	▽	▽	▽	▽	▽									3	3	5	4		1
2		16%	6	6	5	5	9	Tracking Range	●	●	○	▽	▽	▽	●	○									5	0	2	3		2
3		3%	1	1	1	1	9	System Power	▽	▽	▽	●	▽	▽	▽	○									3	3	3	3		3
4		19%	9	9	5	5	9	Update Rate	▽	▽	●	▽	●	●	●	●									3	3	4	5		4
5		17%	6	6	6	6	9	Multi-Robot Tracking	●	●	●	▽	▽	●	▽	●									4	4	4	4		5
6		14%	5	5	5	5	9	Ease of Setup	▽	●	▽	▽	▽	▽	▽	●									5	3	5	4		6
7		21%	8	8	7	7	9	Cost	▽	▽	●	▽	●	●	●	●									3	0	5	4		7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target Values	(6.42"x5.87"x"2.75")	2 Lbs	48-96 in	7.2 Volts	6 Hertz	6 Robots	5 mm Positioning	$500								
Max Relationship	9	9	9	9	9	9	9	9								
Technical Importance Rating	439.1	552.9	591.9	122.8	424.4	560.9	548.4	711.4	0	0	0	0	0	0	0	0
Relative Weight	11%	14%	15%	3%	11%	14%	14%	18%	0%	0%	0%	0%	0%	0%	0%	0%
Curr. Products: Our Current Product	5	3	4	2	3	3	4	2								
Competitor #1: MarvelMind	1	1	5	5	3	3	1	0								
Competitor #2: Romi Encoders	5	2	5	5	4	3	0	5								
Competitor #3: BNO55 IMU	5	1	5	4	4	3	1	2								
Competitor #4: N/A																
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Functional Decomposition



Gantt Chart


1/24 2/24 3/24 4/24 5/24 6/24 7/24 8/24 9/24 10/24 11/24
GPS for Romi 0h 13%
Winter Quarter 2024 0h 25%
Create team contract 0 100%
Send introductory sponsor email 0 100%
Meet with sponsor 0 100%
Scope of Work (SOW) 0h 73%
Write Scope of Work (SOW) Report 0 60%
Research current solutions 0 100%
Conduct patent research 0 90%
Conduct technical issue research 0 0%
Create Gantt Chart 0 100%
Create QFD House of Quality 0 100%
Create a Functional Decomposition 0 100%
Submit final SOW report 0 0%
Preliminary Design Review (PDR) 0h 0%
Write Preliminary Design Review (... 0 0%
Create PDR presentation 0 0%
Brainstorm ideas 0 0%
Build Ideation Models 0 0%
Create a Pugh matrix 0 0%
Concept Prototype 0h 0%
Create Prototype CAD Models 0 0%
Build Concept Prototype 0 0%
Research parts functionality 0 0%
Rank researched parts 0 0%
Present Preliminary Design Review 0 0%
Submit Preliminary Design Review 0 0%
Safety, FMEA, and Design Analys... 0h 0%
Perform Design Analysis 0 0%
Develop a Failure Mode Effects Ana... 0 0%
Spring Quarter 2024 0h 0%
DFM/Design Analysis 0 0%
Design Analysis 0 0%
CAD/ Part Selection 0 0%
Interim Design Review 0 0%
Manuf. Plan / DVP / Drawings 0 0%
FP Build Day (no lab meetings) 0 0%
Complete Purchasing Plan 0 0%
Drawing & Manuf. Plan Review 0 0%
Prepare for CDR 0 0%
CDR Presentations in Lab 0 0%
Submit CDR & Present to Sponsor 0 0%
Risk Assessment / Order Materials 0 0%
Safety Review / Order Materials 0 0%
Experimental Design / Order Mat'ls 0 0%
VP Build Day 0 0%
Ethics & Test Procedures 0 0%
VP Build Day 0 0%
Structural Prototype 0 0%
Final Part Selection 0 0%
Critical Design Review 0 0%
Manufacturing & Test Update 0 0%
Fall Quarter 2024 0h 0%
Ethics Debates 0 0%
Senior Exam / Survey 0 0%
Verification Prototype 0 0%
Verification Prototype Testing 0 0%
Verification Prototype Sign off 0 0%
Design Verification Project Report Si... 0 0%
Expo Poster Peer Review 0 0%
Finish FDR Report/Print Poster 0 0%
Edit FDR/Prep for Expo 0 0%
EXPO 0 0%
Clean and clear workspaces 0 0%
Complete Checklist 0 0%
Submit FDR to Sponsor (5pm) 0 0%