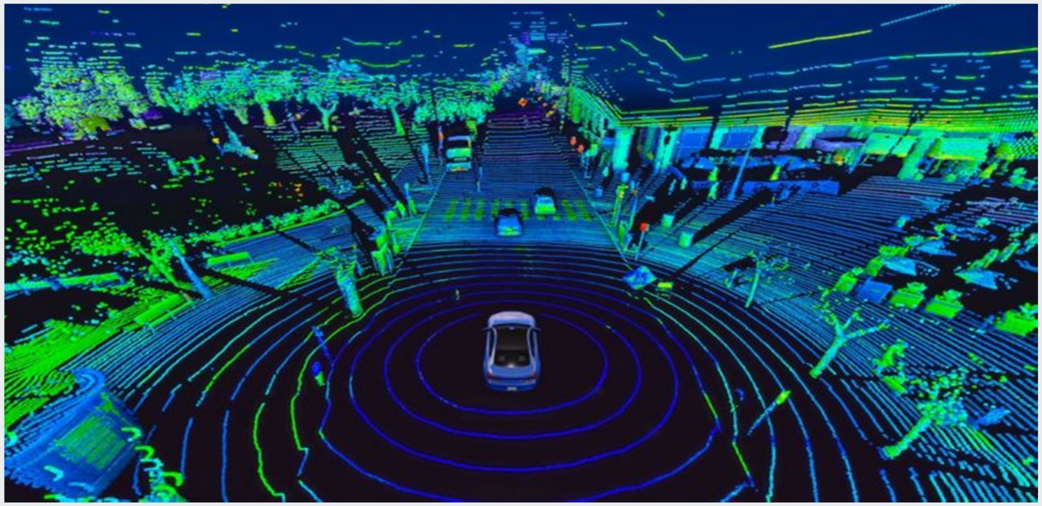
S.L.A.M

(Simultaneous Localization and Mapping)



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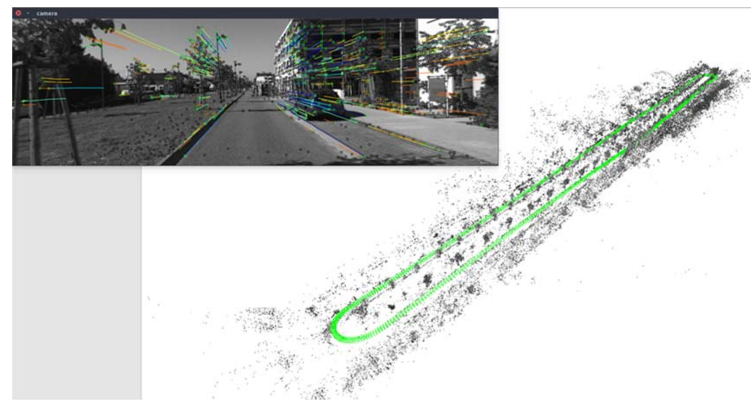
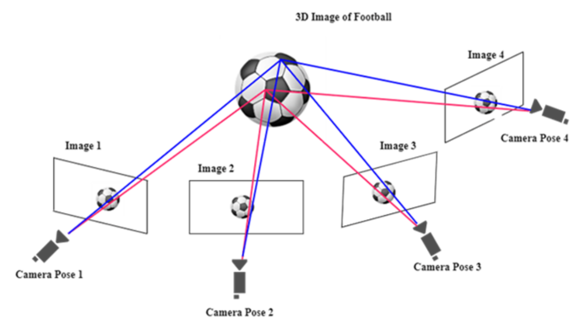
Background

- ORB-SLAM2 is a State of the Art algorithm for autonomous movement in robotic systems.
- At present, real-time identification and tracking of 3D objects is deemed unsuitable for large-scale systems like autonomous vehicles
- Processing bottleneck due to computational complexities from bundle adjustment optimization of 3D maps
- Bundle Adjustment is required to reduce the error of projecting key data points from images to 3D spatial coordinates for 3D Reconstruction
- Our project focuses on creating a hardware-based graph neural network model using an FPGA to significantly reduce the time and space complexity of the bundle adjustment algorithm.



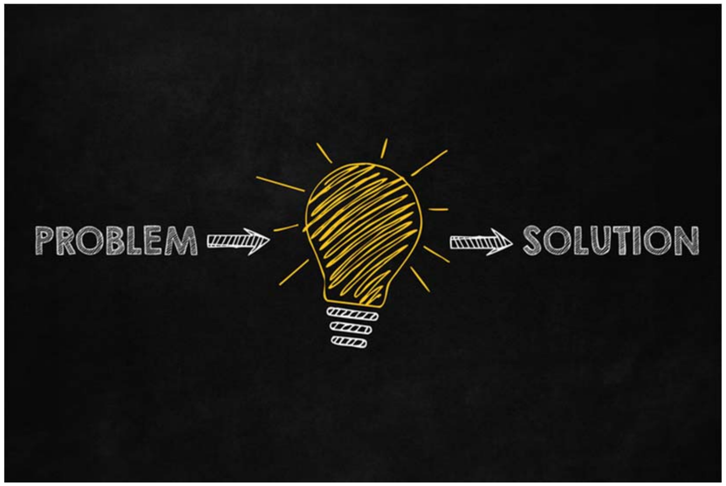
SLAM Landmark/Keyframe Map



Bundle Adjustment Example

Problem Formulation

Problem Statement: We aim to improve autonomous vehicle design with ORB-SLAM2 on a Raspberry Pi 4 and an FPGA based on the Cyclone V architecture. Our implementation significantly improves processing, execution timing, and SWAP-related tradeoffs, therefore prioritizing human safety. By emphasizing hardware-centric design, we optimize precision, efficiency, and navigation, overcoming limitation imposed by software-based approaches. Utilizing hardware-driven principles like pipelining, our system achieves rapid localized mapping critical for applications such as commercial driving.



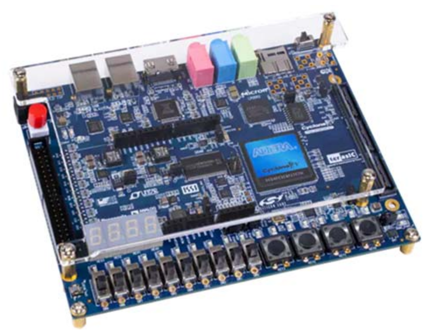
Problem Formulation (cont.)

Design Requirements:

Requirements	Items	Quantity
1. Product Specification	Intel RGB 3D Camera ~3m Range	1
	Intel DE1 SoC	1
	Rasberry Pi 3 Model	1
	Vehicle Frame	1
	Circuitry wiring	1
	24V Li-Ion Battery	1
	Ultrasonic Sensor ~13ft Range	2

Major Physical Components

Intel RGB-D 3D Camera



Intel De1 SoC FPGA

24v Li-ion Battery

Raspberry Pi 4 Model B

Ultrasonic Sensor

Problem Formulation (Cont.)

Environment Constraints:
- U.S Roadways
- Emissions
- Object/Hazard Recognition

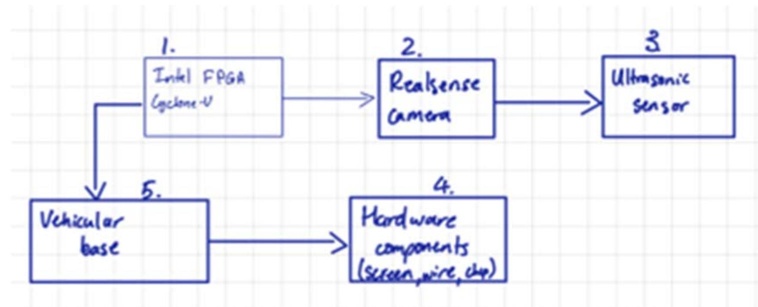
Socio-Cultural Constraints:
- Distrust in Autonomous Technology
- Vehicle Design Preferences

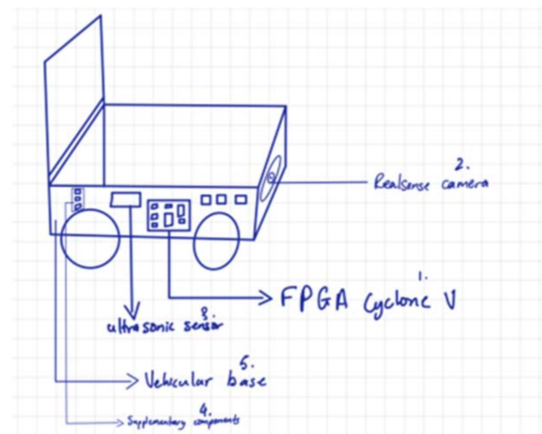
Compliance (Standards and Regulations):
- N.H.T.S.A (National Highway Traffic Safety Administration)
- Regional Traffic Laws

Solution Generation: Design 1

- Intel FPGA hosts the GNN and bundle adjustment algorithms
- ORB-SLAM2 and vehicle frame are operated via a Raspberry Pi 4
- Python programming will be converted to C with Cython, then to VHDL through a High Level Synthesis tool
- Bundle Adjustment algorithm will utilize FPGA multiprocessing techniques such as pipelining

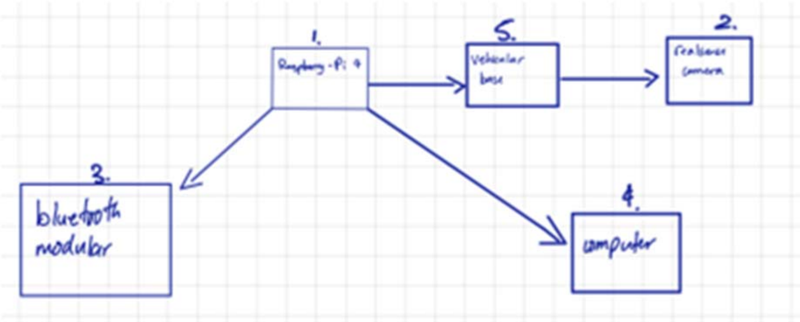
Pros	Cons
• More Power efficient • FPGA Programmability is universal for products • Combines hardware design to mitigate software limitations	• Slightly heavier • Requires an HLS to convert software language to hardware language • Has a higher cost point

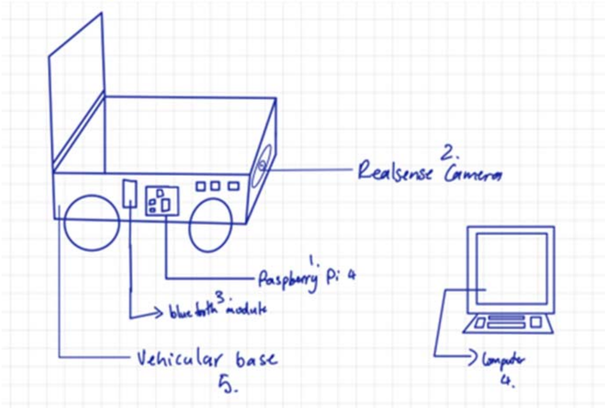




Solution Generation: Design 2

- Traditional software-based approach
- Raspberry Pi 4 responsible for all algorithms and relaying data from Intel RealSense camera
- Computer triggers Raspberry Pi code execution and facilitates communication with Bluetooth module
- Bluetooth module ensures transmission of commands within the Python script to the Raspberry Pi





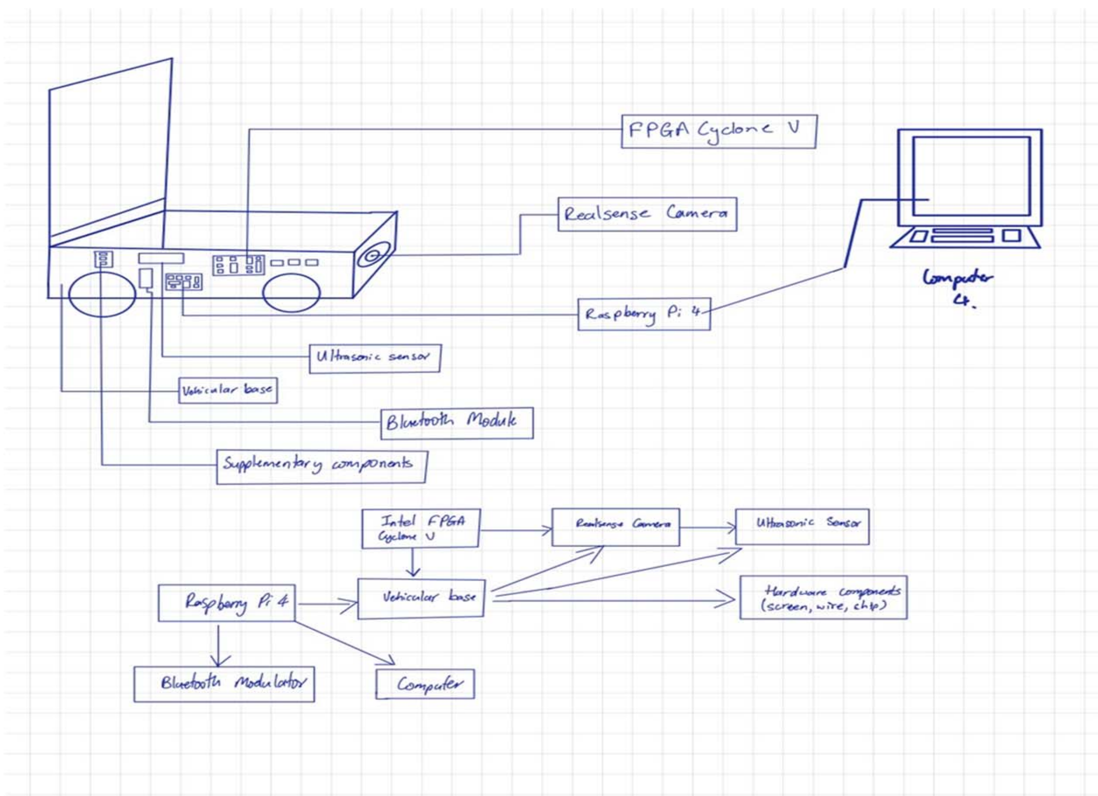
Pros	Cons
• Native Python programming increases ease of algorithm customization • More cost efficient • Slightly lighter • Easier to make circuit changes • Easier to troubleshoot	• Less power efficient • No parallelization for computing processes • Incompatible with most hardware components • Requires triggering via computer terminal • Subject to limitations of software processing for speed, latency, etc.

Decision Matrix

	Wt.	Design 1	Score	Agg. Score	Design 2	Score	Agg. Score
Functionality	55	FPGA S.L.A.M	9	495	Raspberry Pi 4 S.L.A.M	7	385
Compatibility with other components	15	RealSense Camera, Raspberry Pi, Hardware Driven Components	8	120	RealSense Camera, Software driven processes	7	105
Weight	10	5.3 Lbs	8	80	5.2 lbs	8	80
Power	15	More Power efficient	9	135	Higher Power Requirement	7	105
Convenience	5	Use HLS to convert software language (python) into hardware (VHDL)	6	30	Only requires use of software language design (python)	8	40
Total	100		37	860		38	715

Top Solution Design

- The Intel RealSense 3D camera records/captures nearby objects on the camera in 1080p along with IR radar depth imaging
- Using bundle adjustment, the Intel De1 SoC FPGA processes batches of viewpoints from images to reproduce the most accurate 3D rendition
- A Graph Neural Network will optimize parameters of the BA to reduce processing time(shown in similar works to achieve a reduction of ~98%)
- Location & spatial status of the vehicle is then mapped using the SLAM generated 3D Reconstruction map via the Raspberry Pi 4
- Ultrasonic sensors use sound waves to measure distance of surrounding objects & sends the response to the FPGA to be processed
- Collaborative effort between the RealSense camera and the sensors further improves the vehicle's ability to determine position and distance in regards to nearby entities
- The final optimized 3D Reconstruction maps are used for computer vision tasks like object identification and determining travel path



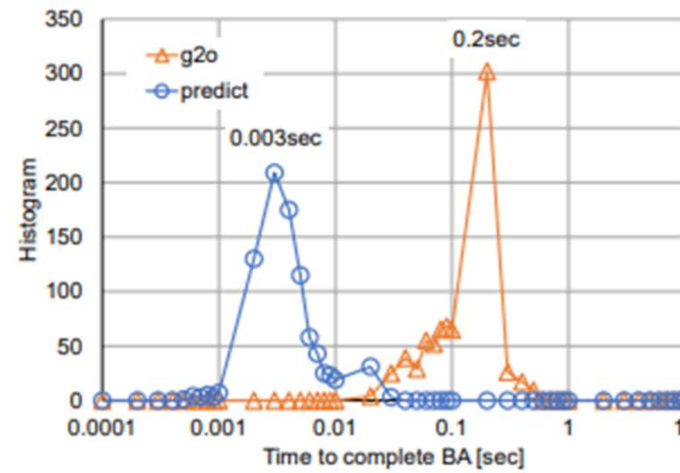


Figure 9. Computational time (erapsed real time) needed for each BA run by the proposed method and the g2o BA.

Future Works

May 2023
Necessary Research Done

June 2023
Identified Potential Problems & Solutions

July 2023
Create GN in Python

August 2023
Identify Fundamental Challenges in autonomous navigation

September 2023
Cloned ORB-SLAM2 on Raspberry Pi

October 2023
Created Sample RGB Dataset;

November 2023
Built Smart PiCar; Collected data using RGB camera & processed in Raspberry Pi ;

December 2023
Run ORB-SLAM2 with Sample Data ;

Future Works

Develop HDL from Python Code (HLS)

January 2024

February 2024

Place developed HDL onto FPGA

Establish optimal communication and processing between FPGA and Raspberry Pi4

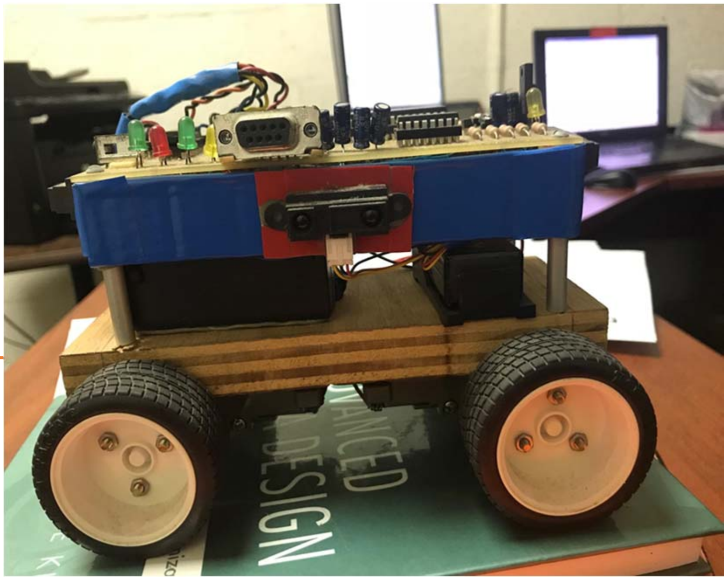
March 2024

April 2024

Practice Trials of autonomous navigation utilizing location mapping and depth imaging via RealSense camera

Autonomous vehicle is demo ready to be presented at the final presentation.

May 2024



Conclusion

The intent of our project is to introduce a significant innovation to a pre-existing technology. Autonomous vehicles and their various designs exist in many different forms within the market today. However, none of them have been established as the standard of the design because they are not up to the requirements necessary to navigate autonomously among human traffic. The most prevalent issues are the response time and the time required to map the environment of the vehicle in the software saturated design field. Our project is to use hardware in tandem with software to address the speed/response time necessary to navigate in real-time in addition to mapping the dynamic environment of the vehicle with respective depth and proximity information to ensure adequate space from surrounding vehicles and objects while driving. Our design was chosen because it encapsulates the best of both designs pitched to accomplish the goal.