2 Introduction

2.1 Background

Simultaneous localization and mapping (SLAM) is a popular technique used by autonomous vehicles for creating maps of an environment while tracking the location of the vehicle within the environment (Maxwell, 2013). This technique was pioneered in 1986 by R.C. Smith and P. Cheeseman in their article "On the Representation and Estimation of Spatial Uncertainty" and has been further advanced by Hugh F. Durrant-Whyte. In one of his articles published in the IEEE, Whyte described SLAM as the "Holy Grail" of autonomous vehicle research because "it eliminates the need for artificial infrastructures or *a priori* topological knowledge of the environment" (Durrant-Whyte, H. F., 2001, June). There have been several theoretical techniques developed to do SLAM including EKF SLAM and FastSLAM, but there is not a technique or system that can successfully solve all facets of SLAM in a real-world environment (Milford, M. J., 2008).

2.2 Statement of Problem

Current SLAM systems use sonar, pressure sensors, and/or infrared sensors to preform SLAM. The pressure sensors help the robot adjust to barriers that the sonar and infrared sensors may have missed. Our client, Dr. Choi, has requested a physical robot, Thumper, be designed to perform SLAM in an unknown environment. Our client has also requested we use two new devices, the ZED Stereo Camera and Jetson TX1 Graphical Processing Unit (GPU) that have been developed to perform SLAM faster and more accurately than earlier systems. In order to confirm a SLAM system using these two devices would be optimal to preform SLAM, we will analyze the system along with two other systems against feasibility and merit criteria determined by our client and our team to either confirm or reject this claim.

3 Project Description

3.1 Project Goal

The goal of this senior design project is to provide Dr. Choi with an optimized SLAM system. The operational goal of the completed SLAM and Thumper system is to be able to map an unknown environment while simultaneously localizing its position within the given environment.

3.2 Mount Feasibility Criteria

To determine if the methods for manufacturing and assembly are feasible, feasibility criteria were determined. Three categories of feasibility criteria were determined: Technical, Payload, and Operational. Technical feasibility is closely related to the overall goal of the project. Simply put, it is if the product will function from an engineering perspective. Payload feasibility is if the product exceeds the allowed payload of the Thumper. Operational feasibility is related to how well the product will be received by the end-user.

3.2.1 Technical Feasibility

Using the developed manufacturing plans, the mount must be able to be produced by someone with an intermediate level of machining experience. The mount produced by the developed manufacturing plans must meet all criteria set forth by the client, Dr. Choi.

3.2.2 Payload Feasibility

In terms of payload feasibility, keeping the weight of the mount low is critical to the success of this project. To maximize the efficiency of the Thumper mechanics, the mount must be constructed with lightweight construction in mind. The maximum payload of the Thumper is 11 pounds. If the weight of the mount combined with the other components exceeds this amount, it will not be considered feasible.

3.2.3 Operational Feasibility

The mount must adhere to operational guidelines set forth by our client, Dr. Choi. The mount must be able to rotate to provide the system a full 360-degree view of the surrounding area in the case of the Thumper being in a tight area where it cannot alter the direction it is facing. The mount must also be at a low enough height to provide the system a view of the floor so that it can detect ledges and other dangerous obstacles. Adherence to these factors is critical for the success of this project.

3.3 Mount Merit Criteria

To determine the best design alternative, merit criteria were determined. Five merit criteria were developed and tested against: aesthetics, material density, arm length, ease of attachment, and cost of material.

3.3.1 Aesthetics

Aesthetics is important because it contributes to the overall satisfaction of the project. The way the mount looks reflects the quality of engineering performance but is not critical for the project's success.

3.3.2 Material Density

Keeping the overall payload under 11 pounds is a strict requirement of the mount, but minimizing the weight is also key to retaining proper balance and functionality of the Thumper. Since weight varies with length, it is more appropriate to use density as a merit criteria. Choosing a material with an appropriate density will also relate to the strength of the material.

3.3.3 Arm Length

Arm length is important because the camera must be able to spin without hitting any of the other components mounted to the top deck of the Thumper chassis. With that in mind, if the arm is too long, it will cause shaking and vibrating when the robot is moving or coming to a sudden stop. Limiting length to only what is necessary will help to keep the weight of the attachment to a minimum.

3.3.4 Ease of Attachment

Another important factor is simple attachment. If the mount is too complicated to fit onto the Thumper or another rover of sorts, less will be able to be seen. The mount should be simple to attach and adjust with the tools on hand.

3.3.5 Cost of Material

The cost of the materials must be considered while designing the mount. The materials will be chosen keeping a $300 budget in mind.

3.4 System Feasibility Criteria

To determine whether or not the selected systems are feasible, feasibility criteria were determined. Three categories of feasibility criteria were determined: Technical, Financial, and Operational. Technical feasibility is closely related to the overall goal of the project. Simply put, it is whether or not the product will function from an engineering perspective. Technical feasibility is whether or not the product can be afforded by the client. Operational feasibility is related to how well the product will be received by the end-user.

3.4.1 Technical Feasibility

The system must be able to be configured and programmed by team members with extended knowledge of software languages and electrical hardware. The developed program must meet all criteria set forth by the client, Dr. Choi.

3.4.2 Financial Feasibility

In terms of financial feasibility, the systems researched as alternatives for this project are relatively expensive compared to other projects. The cost of the proposed alternative must be presented to the client and approved before moving forward with the purchase and implementation of the chosen system. If any design alternative is rejected by the client due to cost, it will not be considered feasible.

3.4.3 Operational Feasibility

In order to pass operational feasibility, the system must be able to pass the requirements set by the client, Dr. Choi. The system must be able to map its surroundings, localize its current position, navigate through the environment, and control the Thumper. If the system cannot pass these criterion, it will be deemed unfeasible.

3.5 System Merit Criteria

To determine the best design alternative, merit criteria were determined. Five merit criteria were developed and tested against: cost, data processing rate, weight and size, and memory.

3.5.1 Data Processing Rate

The data processing rate determines how quickly the system is able to process its surroundings and run the algorithms written in the software package. Faster is preferred.

3.5.2 Weight/Size
The weight and size of the system determines how well it fits onto the Thumper chassis and whether or not it impedes the balance and desired movements of the Thumper. Smaller and lighter is preferred.

3.5.3 Memory
Memory determines how much data the system can store while running the developed algorithms and camera system. Higher memory is preferred.

3.5.4 Cost
Cost is the deciding factor if all other merit criteria are balanced between the design alternates. Lower cost is preferred.

4 Design Alternatives

4.1 SLAM System Alternatives
Three SLAM Systems were analyzed to determine the optimal system to implement to successfully do SLAM in an unknown environment. Each system – ZED and Jetson TX1, GMapping, and eDVS – was analyzed according to its advantages and disadvantages. All the systems would be implemented on a Thumper chassis with a 75:1 gear box and a Pixhawk Autopilot with a 3DR UBlox GPS + Compass Module which can be seen in Appendix A.

4.1.1 System 1 – ZED and Jetson TX1
System 1 uses the ZED Stereo Camera by Stereo Labs and Jetson TX1 Developer Kit GPU by NVIDIA, shown in Figures 1 and 2 respectively, to solve the SLAM problem. The ZED Stereo Camera is the first device in the industry to offer real-time depth sensing, positional tracking, and 3D mapping capabilities. It will be controlled by the Jetson TX1 which is a powerful graphical processing unit (GPU) with 4GB of RAM, a quad-core ARM Cortex Processor, and Linux OS that can easily control the ZED, Pixhawk, and Thumper. These devices are compatible and work together by installing the ZED SDK on the Jetson TX1. This system will also utilize ROS which is a software framework used on embedded robotics platforms. The SLAM technology that has been designed and integrated into the ZED Stereo Camera is available for use through the ZED SDK and ROS nodes. A node is simply a process that involves computation.

Since this is a relatively new system, there is little documentation of these two devices being used together to perform SLAM and the cost is on the upper end of our budget at $1,098 for just these two devices. However, the ZED Stereo Camera is capable of producing 3D maps, can be used in all environments, and is very accurate.