Introduction

Humans tend to make every effort to facilitate their lives and hence the demand in autonomous systems which would provide lots of conveniences is growing rapidly in recent years. Under high investment from IT and automotive giants, self-driving vehicle, which is an emerging application of autonomous control systems, is being developed to satisfy this demand. Although there are different methods to implement self-driving in terms of different companies, the common issue that primarily needs to be solved is navigation. A typical solution for navigating an autonomous vehicle is Simultaneous Localization and Mapping (SLAM) which provides more accuracy and faster response than the commonly used GPS [1]. Accordingly, this project focuses on the algorithm of SLAM and its implementation on a mini experimental vehicle to achieve mapping out a simple space. Generally this proposal will outline the relevant backgrounds, the aims and objectives, the deliverables, milestones and risks, as well as a detailed time plan for this project.

Background

Autonomous systems

Basically, systems that have the ability of self-governance without external intervention are defined as Autonomous Control Systems [2]. Additionally, these systems are required to deal with unknown events during their operation [3]. These systems are controlled by specific controllers called 'Autonomous Controller'. Looking into the system, the hierarchy of this controller's architecture can be divided into 3 levels in general (*Figure 1*). The lowest is the 'execution level' containing sensors and actuators, while the highest is the 'management and organization level' providing communication with the onboard systems. They are connected by the middle level which is called 'coordination level'. At each level, control functions could be multiple but the functions at lower levels are normally more than those at higher levels [2].
Autonomous systems have already been applied to various fields for decades (e.g. autopilot, unmanned aerial vehicle, unmanned marine…) [3]. However, since the complexity of road traffic is incomparable, self-driving vehicle requires a more advanced autonomous system with more powerful hardware supporting more complex algorithms.

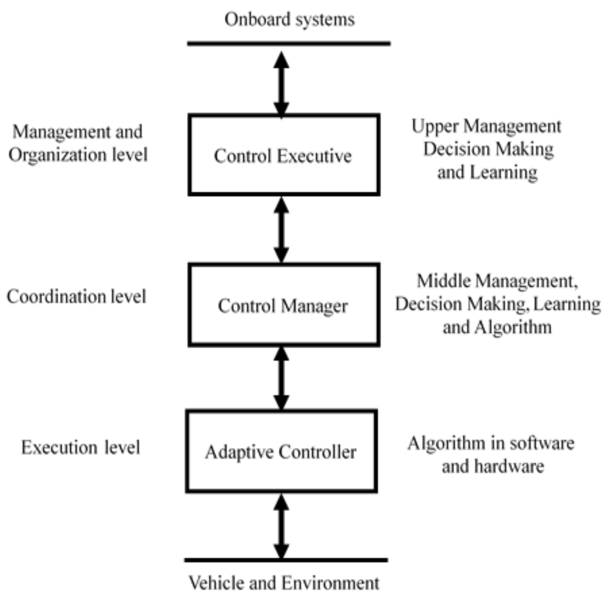

Figure 1, Autonomous controller functional architecture [2]

Simultaneous localization and mapping (SLAM)

To implement autonomous control, particularly on an autonomous vehicle located in a complex environment, it is a fundamental task for the vehicle to understand its position in a certain space (probably an unknown area).

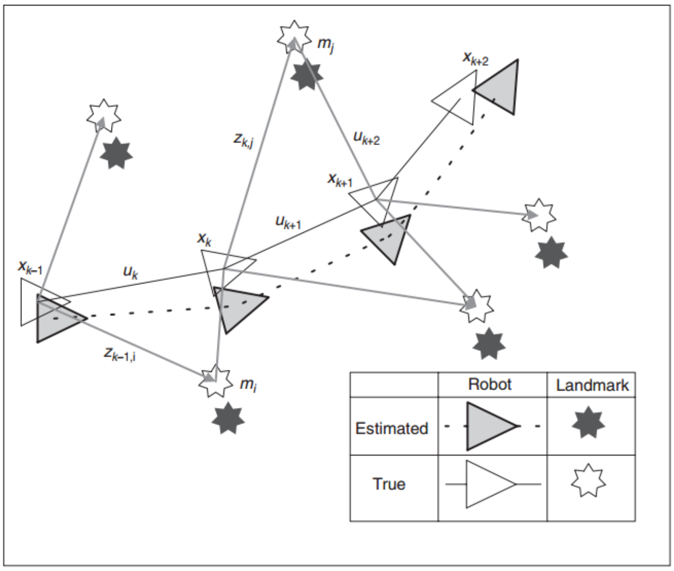

Figure 2, the basic principle of SLAM [4]

Simultaneous localization and mapping is an algorithmic technique that allows robotic vehicles to build a map of its environment and simultaneously deduce its position from this map [4]. Both of these processes are completed internally without any aids of human. Notably, this technique is achieved in real-time which implies that autonomous vehicles with this technology are able to self-navigate only relying on its surroundings rather than a pre-generated map.
The basic principle of this technique is to continuously observe unknown landmarks (*m*) around the vehicle (*x*) and estimate its position according to the relationship between its tracks (*u*) and landmark observations (*z*) while it is moving (*Figure 2*). The true location of the vehicle and landmark is unknown so estimations should be made for both of them. Hence as shown in Figure 2, there would be discrepancies between the estimated and true locations for both vehicle and landmark. [4]

The error between the estimated and true locations could be caused by the number of sensors, the error of *u* and the error of *z*. Since the process of localization and mapping is accomplished simultaneously, the estimated location will determine the mapping and, vice versa, the mapping result will be a reference of localization. This implies that even if the location error is initially small the error could be accumulated to a surprisingly large value later. This could be improved by FastSLAM algorithm using a Rao-Blackwellized particle filter (*Figure 3*). Vehicle poses (the ellipsoids) are sampled from a proposal distribution to minimize the error of *z* which means that the accuracy is only determined by the vehicle trajectory (*u*) [5]. Additionally, other solutions are available to solve the problem as well (e.g. EKF-SLAM, D-SLAM, C-SLAM…)
Nowadays, the technique of SLAM has already been extended to visual SLAM which could generate 3D maps. With this technology, the developments for VR and AR are being boosted further. Apart from visual SLAM, other 3D mapping technologies including Google's LiDAR-SLAM that could be equipped on their self-driving vehicles are accelerating the autonomous industries.

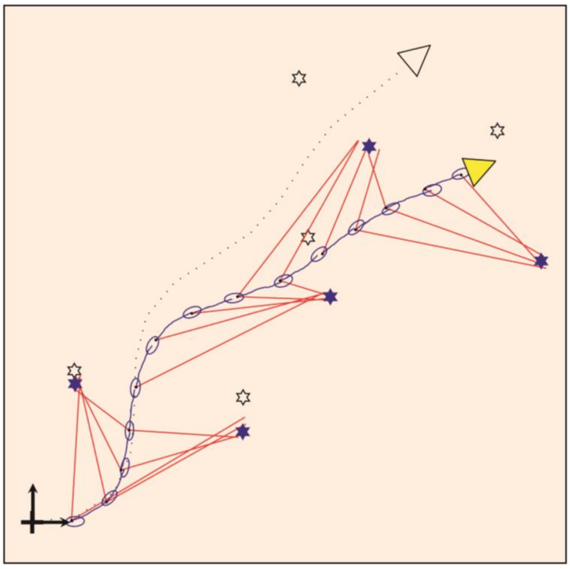

Figure 3, vehicle trajectory after applying FastSLAM [4]

Autonomous vehicles

Self-driving car seems extraordinarily intelligent even judging from its name. As technology breakthrough, these smart vehicles are approaching to be commercially used. Numerous companies are racing to release a remarkable product that could replace the job of human drivers including Google, Tesla, Uber, Baidu and Toyota with many other IT giants and automotive enterprise [6]. To better demonstrate the current progression, the "Autonomy Levels" in terms of autonomous vehicles, which was originally proposed by SAE [7], are listed below:
Level 1: The vehicle can either control the steering wheel OR the pedals.
Level 2: The vehicle is able to control both the wheel AND the pedals but only under partial conditions.
Level 3: The vehicle can be fully controlled by the system under most of the conditions but requires human as fallback.
Level 4: The system completely control the vehicle without any human intervention under most of the conditions.
Level 5: The system is capable of fully governing the vehicle without fallbacks under any road conditions.
Up till the year of 2017, the most advanced autonomous vehicle (Google's Waymo) is still maintained at Level 4, and other relevant technologies that have already been commercially used are even at lower levels including Tesla's autopilot (Level 2) as well as adaptive cruise control and park assist (Level 1) [8]. In order to achieve the top level of autonomy (Level 5), more cutting-edge techniques have to be applied on the vehicle, for instance, visual SLAM and even Artificial Intelligence. However, other non-technological factors is also affecting the development of self-driving vehicles and would probably block its promotion towards Level 5, such as the legal framework, public faith, cost, and issue disposing [9]. In spite of these challenges, autonomous vehicles are generally identical to the tendency of global evolution so they should have been realized sooner or later.

Project relevance

As an emerging application of autonomous control systems, the research in self-driving vehicles is a popular subject among institutions. Moreover, the mapping and localization are crucial to implement autonomous control for a self-driving vehicle, as mentioned above. Therefore, this project intends to simulate the development of a real self-driving vehicles with the aids of a mini vehicle platform, sensors and cameras focusing on the mapping methodologies in a relatively simple environment.

Aims and Objectives

Project aim

The aim of this project is to construct and develop a mini experimental vehicle that is capable of autonomously mapping the layout of simple spaces. Through this project, the quintessence of autonomous systems would be acquired and the methodologies of solving electronic engineering problems would be familiarized.

Project objectives

From low to high levels, five general objectives in order to achieve the project aim are outlined below. Each of these objectives is split into more detailed tasks to step by step fulfill the corresponding objective. Several tasks that marked with [Advanced] are for additional research which would not affect the accomplishment of objectives.

1. Review the state-of-the-art on autonomous systems and relevant emerging applications.
   - Study the technological and commercial prospects of the development of autonomous systems.
   - Research the underlying theories and relevant technologies applied on a typical autonomous system.
   - Investigate the development and implementation of the most recent applications of autonomous systems for civilian use (e.g. home robotics, self-driving vehicles…)
2. Construct a robotic vehicle platform that can perform basic movements as directed by the user implementing key commands on an Arduino microprocessor.
   - Assemble the provided off-the-shelf kits to build up a mini vehicle platform.
   - Investigate the rationale for H-bridge and servo motors, then integrate them on the constructed platform.
   - Familiarize the structure, variables and special functions in Arduino programming language, and produce simple codes that select and control the desired motor to perform forward and reverse rotation.
   - Test the vehicle under the control of Arduino to achieve forward, backward, left and right movements, then combine these actions to follow predefined routes.
   - [Advanced] Research deeper on the Arduino board (e.g. I/O ports, system frequencies, timers, PWM modules…) as well as the implementation of PID control algorithm on microcontrollers in order to accurately regulate the velocity, turning angle and displacement of the vehicle.
3. Incorporate sensors onto the vehicle platform and interface them with the Arduino in order that the vehicle can ‘sense’ its environment and log its position as it moves.
   - Research the available Arduino sensors including sharp IR distance sensors, ultrasonic range measurement module, crash sensors and gyroscopes to familiarize their behavior, applications, usability and cost.
   - Determine appropriate sensors that would be integrated on the vehicle and develop relevant codes that allow Arduino to manage them.
   - Design, in both hardware and software, a user interface containing an LCD screen and buttons (or joystick if necessary) that provides man-machine interaction to command the robot or read internal data in real time.
   - Develop algorithms that enable the vehicle equipped with sensors to automatically avoid obstacles, hitting the wall or dropping from height, then test them in an open space with its position data recorded.
4. Implement appropriate control algorithms so that the vehicle can autonomously map out the extent and major features of simple spaces.
   - Customize a coordinate system to record the track of the vehicle.
   - Develop algorithms that initially detect the surroundings to predict the optimum starting point of mapping then find and follow the edges of the wall and finally travel back to the starting point.
   - Record the entire traveling track of the vehicle (in the form of discrete coordinates), and sketch it on the coordinate system to obtain the map of this room.
   - [Advanced] Explore various techniques of SLAM and compare between their feasibility and efficiency.
5. Implement a vision system that allows the vehicle to capture images as it autonomously maps out a space.
   - Research on the Raspberry PI microcontroller and its camera module to apply a visual system on the vehicle.
   - Develop codes to enable the Raspberry PI camera and capture a 360 °image to map out the room.
   - [Advanced] Apply image recognition on Raspberry PI to autonomously recognise the feature of the space.

Deliverables, Milestones and Risks

Deliverables

The specific deliverables are summarized in Table 1 below:

Label	Deliverables	Date of delivery
D1	Project proposal	Fri 27/10/2017 (Week 5)
D2	Vehicle platform without sensors & Relevant codes	Tue 14/11/2017 (Week 8)
D3	Vehicle platform with sensors and user-interface	Tue 12/12/2017 (Week 12)
D4	Codes regarding algorithms of autonomously mapping	Tue 13/2/2018 (Week 21)
D5	Completed vehicle with Raspberry PI camera	Tue 20/3/2018 (Week 26)
D6	Sketches of the layout and photos of the room	Tue 20/3/2018 (Week 26)
D7	Final project thesis	Fri 18/5/2018 (Week 34)

Table 1: Descriptions of the deliverables and delivery dates

Deliverables are significant evidence of project progressions and they are concrete outcomes that could be inspected by the supervisor. Each of the deliverables is essential for achieving the project aim. The project proposal (D1) is the outline and plan of the long-term project and it should be promptly produced to activate the project. The experimental deliverables (D2~D6) are the major achievements of the project and they are closely linked together so that the delivery dates should be strictly obeyed otherwise the progression would be delayed affecting the final outcomes. The final project thesis (D7) is a literal demonstration of the entire project and its achievements, hence it is a vital deliverable requiring careful treatments and additional time consumption.

Milestones

Milestones are helpful flags that could mark the project progression and they are listed in Table 2 below:

Label	Milestones	Date of accomplishment
M1	Vehicle kits and components have been received	Tue 24/10/2017 (Week 5)
M2	Vehicle platform has been assembled	Fri 4/11/2017 (Week 6)
M3	Codes have been developed to control the motors	Fri 10/11/2017 (Week 7)
M4	Sensors have been integrated on the vehicle	Fri 24/11/2017 (Week 9)
M5	User-interface has been built and interaction is enabled	Fri 8/12/2017 (Week 11)
M6	Algorithms that enable autonomously mapping have been developed	Fri 9/2/2018 (Week 20)
M7	Raspberry PI camera is capable to capture photos	Wed 14/3/2018 (Week 25)
M8	Position data of the vehicle and captured photos have been collected	Fri 16/3/2018 (Week 25)

Table 2: Descriptions of the milestones and accomplishing dates

Risks

Risk 1 (R1): The off-the-shelf vehicle platform does not meet the requirement (e.g. the bad performance of the motor, the inadequate holes or supports for accessories, the inappropriate mechanical structure of the vehicle)

- Best Solution: Directly modify on the design of the vehicle platform and alter to the desired one.
- Other Solutions: Change to another provided off-the-shelf vehicle, or design and construct a new one.

Risk 2 (R2): The selected sensor is inappropriate to achieve the tasks.

- Solutions: Change to use another suitable one or design and build up a customized one.

Risk 3 (R3): The performance of autonomously mapping is unstable which depends on the surroundings.

- Best Solution: Change the sensors or amend the codes to gain more accuracy.
- Other Solutions: Initially test the vehicle in a simplest environment then gradually increase the complexity.

References

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Time plan

Specific objectives are organized in terms of time consumption and they are scheduled in the Gantt chart below. (Advanced tasks are only for interest and they could be skipped if time is limited)