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DEVELOPMENT OF AN AUTONOMOUS SMALL SCALE ELECTRIC CAR

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ABSTRACT

There has been an increase of attention given on autonomous technology from major players in the autonomous industry lately, due to the fact that this technology can be implemented in both civilian and military applications. The primary goal of an autonomous control development is to make the vehicle easily controllable by an inexperienced user, even in situations where the vehicle is being obstructed. Designing such system requires an effective program that can take real-time inputs from the environment and use them to determine the correct steering angle and speed in order for the vehicle to navigate through its waypoints efficiently. A control system for lateral and longitudinal attitude is configured using ArduPilot Mega micro controller and Mission Planner software, where a test area was used to verify the effectiveness of the developed autonomous control system by testing various firmwares with different parameter values. Then, three cases with different parameter inputs will be tested in the aforementioned test area to collect the essential data to be analysed. The developed AGV managed to collect various data such as yaw motion and floating distance from intended waypoints which can be further analysed by other parties that are interested in this area of study.

Keywords: *Autonomous vehicle, lateral and longitudinal attitude, parameter tuning, configuration via Mission Planner*

1.0 INTRODUCTION

An automotive ground vehicle (AGV) implements a system that enables it to navigate through a series of predefined waypoints without any human inputs. To make this happen, it needs to employ an effective and reliable control system. In the AGV, the control system consists of longitudinal control system and lateral control system. The vehicle will be controlled by an Inertial Measurement Unit (IMU) based board called ArduPilot Mega. The car would utilize the Global Positioning System (GPS), an accelerometer, and a gyrometer on the ArduPilot Mega to pinpoint its position and orientation in a surrounding. The system enables the user to go through a series of predefined waypoints using a simple cross track error trajectory following algorithm. ArduPilot Mega can communicate with a ground control station, where data can be gathered, and the waypoints or even control gains can be updated. It communicates over a wireless serial connection, using a communication protocol. The attitude and heading reference system uses 3-axis gyroscope and accelerometer, together with a magnetometer. The IMU of this board is based on microelectromechanical system, which is the MPU-6000 motion-tracking device that combines three gyroscopes together with three accelerometers.

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Figure 1 shows the flow diagram of the AGV system where a seven-channel radio system and telemetry is used to control and give live feed data from the AGV.

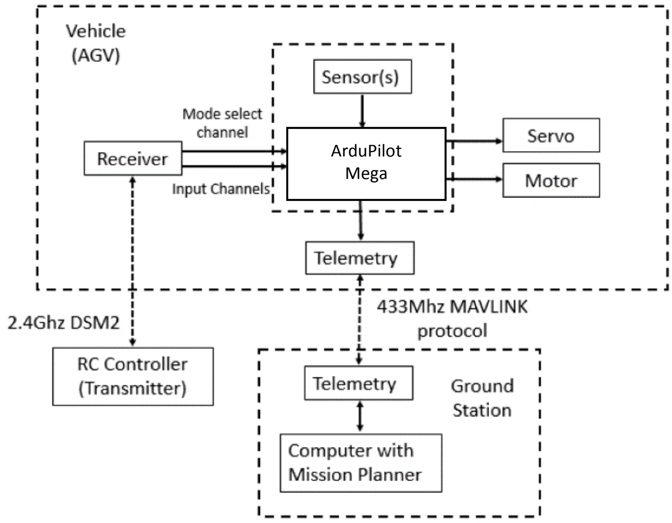

Figure 1: AGV overall system

2. 0 SYSTEM REQUIREMENTS

The main goal of the AGV is to produce an autonomous vehicle by integrating a readily available hardware that is a remote control (RC) car to the APM 2.5 system. It is crucial to replace the original radio system that comes with the RC car with a high range Transmitter-Receiver (Tx-Rx) radio system that enables more than 5 channels to allow the AGV to be placed with sensors and more options for the mode setup.

Other crucial requirements include the expected functions of autonomous control algorithms, primarily the throttle control and heading or yaw reference system, measuring of speed and acceleration, GPS behaviour and on board voltage stability. The system should be capable to implement complex control laws and sensor fusion algorithms via Mission Planner software.

Additional requirements include the identification and setup of the parameters to be uploaded to a firmware of the vehicle for test runs and data acquisition from the latter.

3.0 SYSTEM SPECIFICATIONS

The microcontroller in the AGV, which is the APM 2.5, should be able to record data from all sensors on board in relation to time. The IMU of the APM system must detect minute changes in yaw, position, and the acceleration of the AGV in order to calculate the errors. Then, the PID controller embedded in the system is used to recalculate its heading and give the appropriate Pulse Width Modulation (PWM) signals to the motor and steering servo of the vehicle.

4.0 COMMUNICATIONS

The MAVLink protocol has been used to link the components used in the system. It is a simple protocol which encodes the data structures which flows within the system into high efficiency data packets of binary data can be used by any Arduino device. Any device of component which uses the MAVLink protocol can be integrated with the

ArduPilot by creating a C++ wrapper of the protocol within the Arduino coding (or known as sketch). By doing this the data transmission and communication can be performed using the communication over serial, TCP/IP, UDP, and Write to file [1, 2]. Hence, this will ensure a smooth data transmission during the testing.

An optional communication, in this case is the 3DR Radio for telemetry, converts a serial stream to wireless using the same MAVLink protocol. A large outdoor 20 dBm (100mW) omni directional 433 MHz antenna is used on the ground, and a 121 dBm receiver is used on the rover. This means that the small 100mW power of the telemetry can communicate with the rover at almost 1.6 km away in any directions and orientations, and features optional bi-directional amplifier for even more range. The 3DR telemetry uses Frequency Hopping Spread Spectrum (FHSS) that ensures the continuity of data transmission. A number of vehicle types are possible and would be helpful for further research. Additionally, a 4MB data log is also available on the APM 2.5 board to collect a number of parameters from a mission such as ground speed, GPS glitch and power data. The 2.4 GHz Tx-Rx radio is used for mode switching and offers manual manoeuvrability for the user.

5.0 METHODOLOGY

System identification analysis is conducted to obtain a more accurate transfer function for the RC's servo and motor. At the same time, AGV platform was fabricated and the board and sensors are integrated with the Ardupilot Mega micro controller. PID controller gains of the firmware were tested using Mission Planner to gather real time information on the behaviour of the AGV. Following that, the PID gain values were computed using the method structured by the developer of the Mission Planner. These autopilot controller systems were transformed into programmed coding using C language in Arduino Environment with varied parameters. A test field was designed to test the effectiveness of the autopilot controller for both steering and forward motion. Ardupilot Mission Planner software was used to log the data during tests.

For the AGV to have the APM as the microprocessor that acts as a medium between the signals given from the radio to the dynamic components of the car (which is the brushless motor and the steering servo), a lightweight platform needs to be designed and built. Figure 2 shows the platform with no components attached and Figure 3 shows the rendering of the AGV produced complete with all the required hardware.

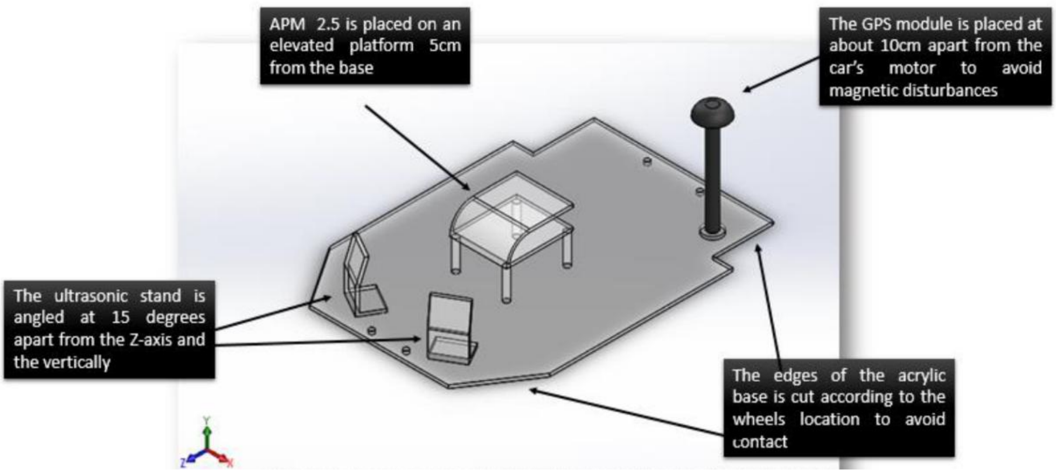

Figure 2: Platform made of Acrylic material

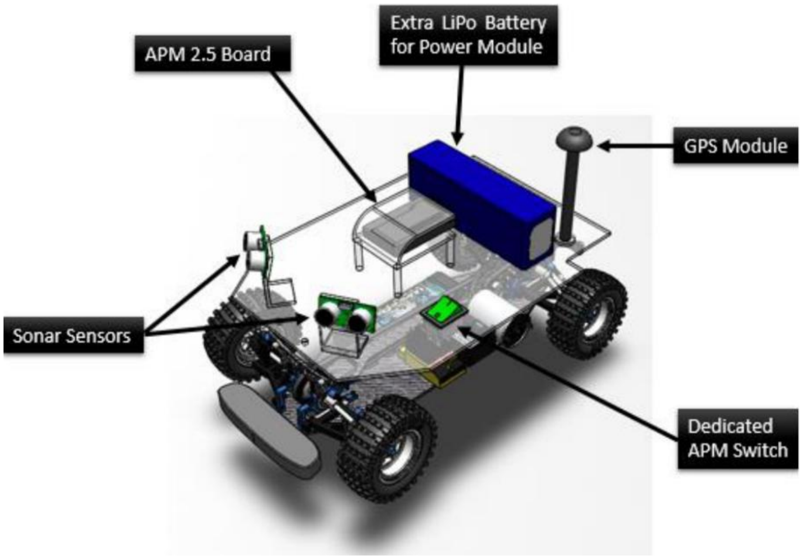

Figure 3: Completed AGV with hardware installed

The next step of the construction of the platform was the configurations of the transmitter and receiver where the PWM values of each channel of the radio system must be calibrated. Tx-Rx system on the AGV is crucial in selecting various modes that can be set to the vehicle. The main purpose of the radio system is to read the input given to the toggles and switches on the transmitter and converts the analog input into digital command in the form of pulse width modulation. The receiver, on the other hand, receives the signals and channels it to the Electronic Speed Control (ESC) and servos. In this car setup, the radio system is also being used as a safety switch in case of any unexpected behaviours of the AGV during a mission or test. Figure 4 shows the assigned function of each channel on the 2.4 GHz radio system being utilized.

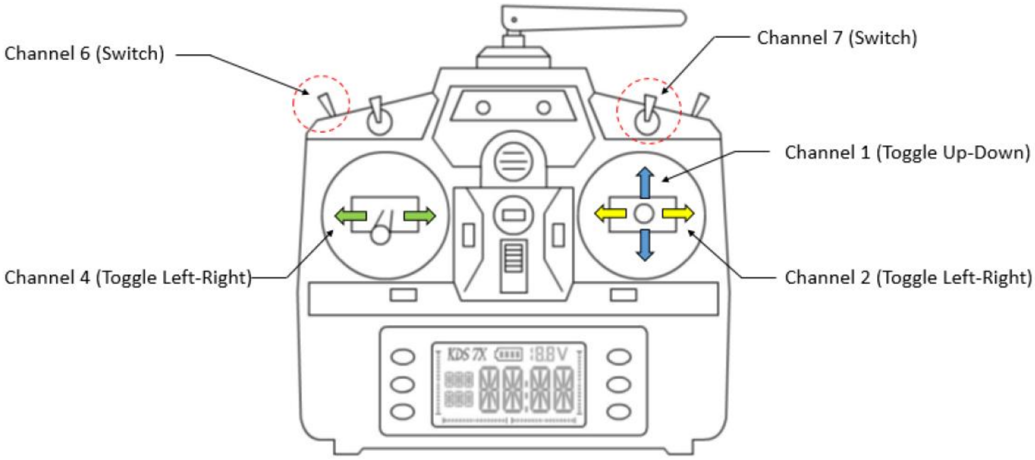

Figure 4: Configured Channel on the Transmitter

The receiver (Rx) of the radio system is directly connected to the APM board’s input pins to transfer the signal given by the transmitter (Tx) to the paired receiver. Servo cables that readily come with the ground (GND) black/brown wire, power (V+) red wire and signal (S) white/yellow wire. The polarity of the servo wires must be ensured before power is supplied to the board. The receiver of the radio system could detect signals with the range up to 400-500 meters; if it goes out of that range, the AGV would rely solely on the telemetry that offers greater range. Table 1 shows the input channel of the receiver in relation to the APM board input.

Table 1: Input channel of receiver to APM input pin

Receiver Channel	APM Input Pin
1	1
2	3
4	8
6	7
7	8

The output pins of the APM 2.5 board will be connected to the car's steering servo and ESC, which in turn controls the motor. The configuration of the AGV's input and output channels are shown in the Figure 5.

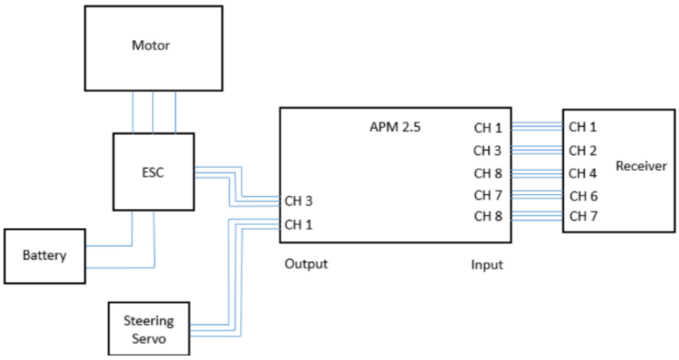

Figure 5: The configuration of the AGV input and output

The modes can be assigned to the intended channels of the radio system after all the connections are made from the receiver to the APM and from the APM to the motor and servo. Mode selections are explained in Table 2.

Table 2: Modes description

Mode	**Description**
Auto	The UGV will follow GPS waypoint set by configuration utility
Learning	Channel 6 (Channel 7 in APM) of the radio can be triggered at multiple locations to save the current latitude and longitude reading for Auto mode.
Manual	Used for emergency situations where the AGV needed human intervention/input.
Steering	Used for ultrasonic range tests.

Prior to any test runs, the input parameters need to be adjusted and uploaded to the system. The firmware is divided by a number of programs controlling specific components of the car, which can either be the sensors or the mechanical parts of the car. The controlling parameters shown in Table 3 have to be tested either by using Simulink or trial-and-error tests. The optimal values are crucial to ensure that they are suitable to the car.

Figure 6 shows the overall methodology flow of this development, which includes the software configuration of the system via Mission Planner. Meanwhile, Figure 7 depicts the block scheme of the AGV controller.

Table 3: APM 2.5 Main Controlling Parameters

Parameter	**Function**
STEER2SRV_P	Tells the rover code what the turning circle (as a diameter in meters) is for your rover. It will also set the steering angle of the car. Unit: Meter (m)
TURN_MAX_G	Tells the rover the maximum G force in multiples of gravity pull to stabilize car. Unit: Gravity(9.81m/s^2)
NAVL1_PERIOD	Controls the aggressiveness of the navigation algorithm. Essentially adjusting the PID values. Unit: Seconds (s)
SPEED_TURN_GAIN	Decides how much the rover should slow down while turning, as a percentage of current target speed Unit: Percentage (%)
CRUISE_SPEED	To control the target speed in meters/second in automatic mode. Unit: Meter/Second (m/s)
CRUISE_THROTTLE	Sets the initial guess at what throttle is needed to achieve CRUISE_SPEED when driving straight ahead. Crucial for stable speed control. Unit: Percentage (%)
SONAR_ENABLE	To turn on or off ultrasonic sensor attached to input A1. Unit: Binary (1 or 0)
SONAR_MAX_CM	The furthest distance the sonar can read which is 500cm for HRLV sensor is. Unit: Centimetre (cm)
SONAR_MIN_CM	The minimum distance sonar can read which is 30cm for HRLV sensor Unit: Centimetre (cm)
SONAR_TRIGGER_CM	The distance at which the AGV will automatically stop or make a deviation Unit: Centimetre (cm)

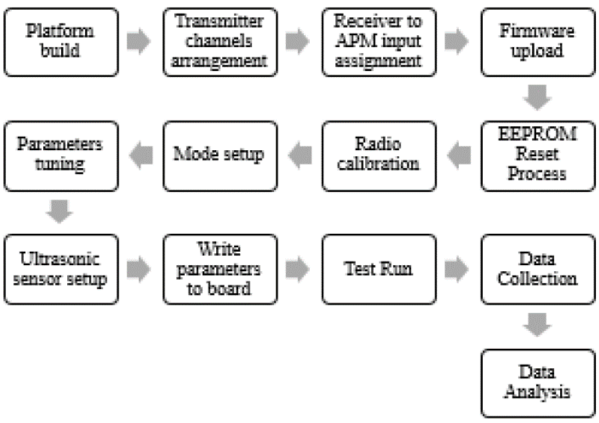

Figure 6: Overall methodology

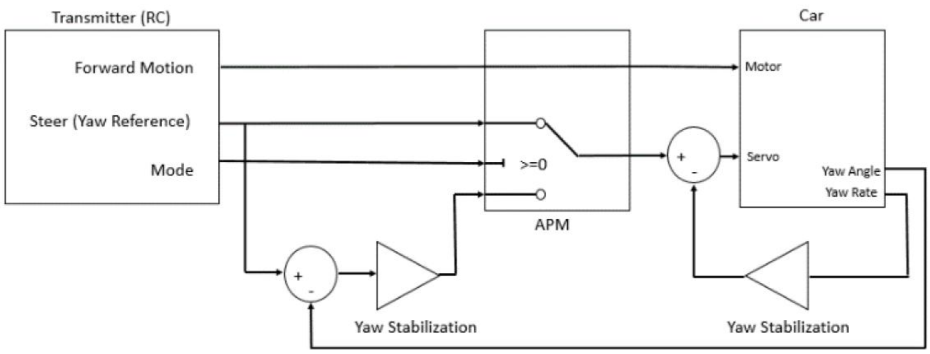

Figure 7: AGV controller scheme

6.0 ACQUIRED DATA

From the test conducted, various data were collected in real time. Among the data collected are the yaw motion, velocity, acceleration, horizontal dilution of precision (HDOP) value, number of locked GPS, and distance from current waypoint.

6.1 Yaw Motion Data

The yaw axis is defined to be perpendicular to the vehicle with its origin at the centre of gravity directed towards the bottom of the AGV. A yaw motion is a movement of the roll axis of the AGV from side to side. The pitch axis, which has little significance in this reading, is perpendicular to the yaw axis and the width of the body with its origin at the centre of gravity. The centre of gravity of this AGV can be assumed to be near the absolute centre of the car due to the small size and the relatively low weight. From the graph obtained (Figure 8), it can be observed that the yaw motion is directly influenced by the waypoints being assigned. The graph tends to have a "zig-zag" like form which represents the actual motion of the car during missions that sways rapidly from left to right due to the PID control that is trying to re-correct the UGV's position from calculated errors.

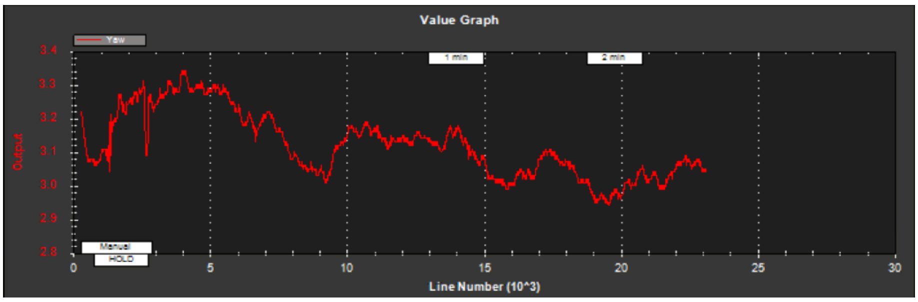

Figure 8: Sample of yaw motion data

6.2 Velocity Data

For the velocity data (Figure 9), the unit on the y-axis is in the division of 10 meter per second (m/s). The graphs demonstrate rather non-uniform velocity reading. The throttle adjustment made to the initial velocity and during mode change may have caused the UGV to have a rather fluctuating velocity during a mission. The throttle percentage set for 'auto' missions may have a direct influence to this particular behaviour. The 'CRUISE_THROTTLE' value was set at a level of 20% for the data in Figure 10, where it can be observed that although the average velocity is set to 1m/s, the throttle percentage might not be sufficient or excessive for the car to maintain that velocity.

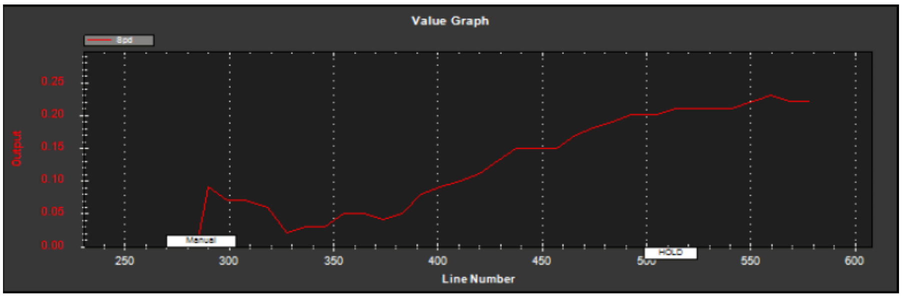

Figure 9: Sample of velocity data

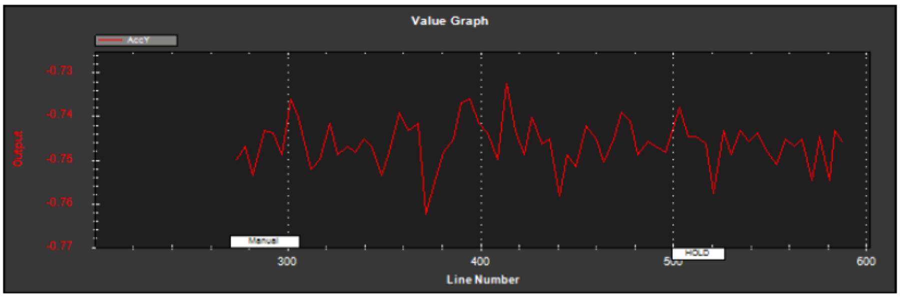

Figure 10: Sample of acceleration data

6.3 Acceleration Data

In the test runs, the AGV can be seen to move at a very slow speed when the mode is switched from manual or learning to auto. The car will then increases its speed at a steady state. From the graph obtained, deceleration is observed at a very slow pace in most of the cases. Figure 10 shows that the majority of the time the car is accelerating at a decent pace which is a normal behaviour as the car is moving with a sway. Optimally, the data should produce a flat graph, which means that the UGV is travelling at a constant velocity.

6.4 Horizontal Dilution of Precision (HDOP) Value

A value of 1 or less for HDOP as presented in Figure 11 means that it is at the highest possible confidence level to be used for applications demanding the highest possible precision at all times. In the other hand a value of 1 to 2 gives positional measurements that are considered accurate enough to meet all but the most sensitive applications. 2-3 HDOP value will reflect a value that indicates that the AGV is at the minimum appropriate navigation decisions. A HDOP value of 4 or more would usually happened in a very cloudy sky, if the HDOP value is at this level the AGV would be drifting uncontrollably up to 15-20 meters [2].

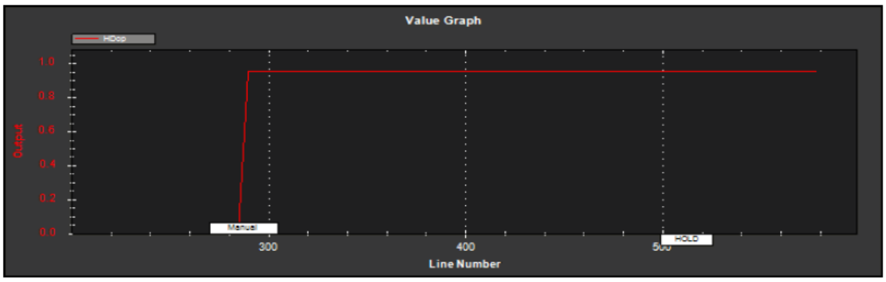

Figure 11: Sample of HDOP value

6.5 Number of Locked GPS Satellite

The data shown in Figure 12 is rather self-explanatory; the higher the number of satellites locked, the better the positional data that the UGV obtains. The accuracy of a satellite reading may depend on the aerial condition at a particular time [4]. A good aerial condition is required in order to detect the signals coming from the GPS satellites. The strength of a GPS signal is often expressed in decibels with reference to one milliwatt (dBm). In a good GPS, module receiver can acquire signals down to −155 dBm and tracking can be continued down to levels approaching −165 dBm [3]. In this work, the Mediatek MT3329 provides -165 dBm that means it is able to track signals even if the signal strength is poor.

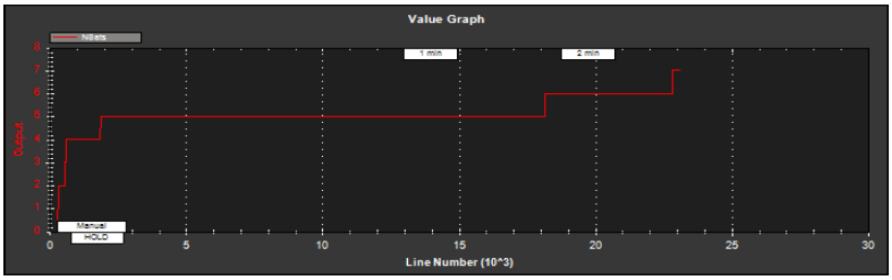

Figure 12: Sample of number of locked GPS satellite

6.6 Board Voltage Input

The normal operating voltage of the APM 2.5 board is 5.37V. Any sudden drop of voltage supply to the board would cause glitches and even sudden restart to happen. If the UGV is powered directly by the power source from the RC car's ESC, the possibility of the occurrence of brown outs are inevitable. Brown outs are intentional or unintentional drop in voltage in an electrical power supply system. Brown out will occur if the voltage supply is lower than the threshold voltage of 4.30V. Based on Figure 13, it is evident that the average reading of the voltage in the board is 4830 mV or 4.83V. Although this value is lower than the optimum voltage, the UGV can operate relatively fine.

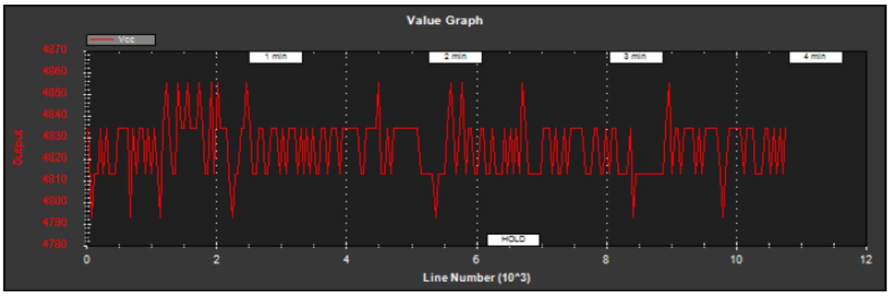

Figure 13: Sample of board input voltage data

6.7 Distance From Current Waypoint

Figure 14 shows the deviation of the UGV's current location to the next intended waypoint. From the tests done, it is found that it was quite difficult to get the AGV to go through the pre-set waypoints, although at times it was possible. There are too many external factors that could interfere with the AGV's overall operation such as the radio waves, etc.. The distance will always be different as the same thing can be said with the yaw heading data. The different shape of the waypoints being set will always cause different dynamic motion that the car needs to handle. The dynamic motions will cause the 3-axis gyro and the accelerometer to read different patterns of errors in the form of input signals, which will give a cumulative error that is unique from one mission to another.

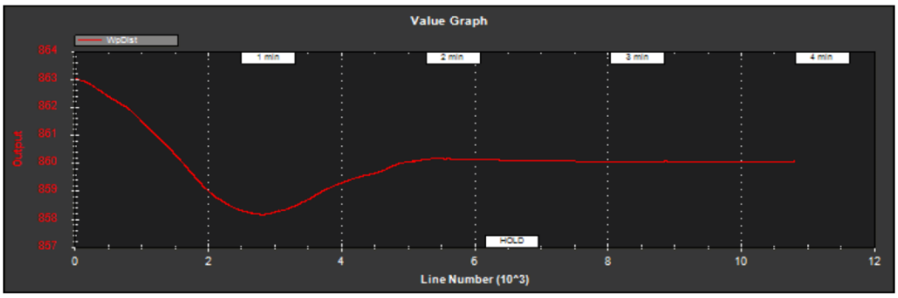

Figure 14: Sample of Sample distance from current waypoint data

7.0 CONCLUSIONS

It can be concluded that the APM 2.5 autopilot board has a big potential to be used in low-cost autonomous segment as it allows the user to tweak their program and continue to improve the usability and widen the functionality of this amazing autopilot system. The amount of information that this small board can offer is just overwhelming and could become a crucial platform in future military usage and even civilian purposes. But the lack of information on how a data should be analysed and the fact that the APM 2.5 was introduced in 2012 makes it challenging in data comparison and analysing as there are insufficient reliable sources as reference.

Although the error measured for distance is quite high, which is 8 meters from designated waypoint, the AGV can still manoeuvre through the designated waypoints with a drift value of less than 50cm most of the time. Further fine-tuning and control configurations could improve the effectiveness of this system. All in all, the main objective of this project that is to configure and develop an autonomous ground vehicle is achieved. Although the AGV does a mission with a small error, it can still complete the mission assigned to it and collect many valuable data that can be further analysed to improve the usability of this vehicle.

The transfer function of the autonomous controller of this autopilot system needs to be scrutinized to further understand the operations of this board. All the 108 parameters in the Mission Planner of should be studied and tested even further in order to come out with better AGV operations. The full utilization of telemetry for data acquisition is highly beneficial in recording crucial live data being sent to the AGV rather than just depending solely on the logged data. A better firmware should be fully developed to be fully employing Kalman filter for this particular AGV to reduce errors in the GPS readings.

ACKNOWLEDGEMENTS

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