# Design and Implementation of an Unmanned Ground Vehicle using Arduino

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## ABSTRACT

This paper presents design and implementation of an unmanned ground vehicle (UGV) with low-cost components. This vehicle can be controlled in two ways, manually using global system for mobile (GSM) in a long distance, or by a mobile phone voice-controlling command via Bluetooth in a short distance. The vehicle can also work autonomously; where It is able to follow specific waypoints, which given by the user. The main brain of the proposed system is Arduino platform, and the navigation of the UGV was designed by utilizing the advantages of global position system (GPS) and digital compass. Furthermore, the guidance of the proposed vehicle was performed using closed-loop control programmed in C language and executed in the main control board. As a result, it controls the steering angle of the UGV through servo motor. In addition, by including Bluetooth shield, the vehicle can be guided using a mobile application as well. The experimental results demonstrate high efficiency of the UGV in the predefined mission.

**Keywords:** unmanned ground vehicle, global system for mobile, navigation, guidance

## 1. Introduction

Nowadays, robots play a significant role in different aspects of our life. As a result, the performance and speed in many applications were enhanced. An example of those robots is unmanned vehicles. These vehicles can be controlled widely. In addition, they are able to move independently and perform several tasks without human inter-action. The unmanned vehicles can be categorized into different types such as an unmanned aerial vehicle (UAV), unmanned underwater vehicle (UWV), unmanned surface water vehicle (USV) and unmanned ground vehicle (UGV). The focus of this study is mainly on the last kind. With the aid of different sensors, these UGVs accomplish their missions. Some of them might utilize a camera and computer vision algorithm to navigate through the environment. For localization, compass and GPS were employed by other machines. The potential benefits of these vehicles are numerous, either in civilian or military applications. In industries, they can be used especially in those tasks that require both speed and accuracy. Moreover, this kind of vehicle can help in situations where are security risks, for instance, transporting chemical samples. There is also preference for running unmanned ground vehicles in hazard areas to discover any possible dangerous before people enter this area. Thus, it leads to improving the safety of the people. The rest of the paper organized as follows: Section 2 will be specified for previous works that have been made in the same area. In Section 3, the proposed design will be introduced. Section 4 consists of various results, and Section 5 presents conclusions of this work, and demonstrates possible future works.

## 2. Related Works

There is growth interesting in unmanned ground vehicles. Thus, many vehicle designs have been presented in this section. Notwithstanding their variety structure and components, the aim of these vehicles is similar. A comparative study of many control architectures in UGV/UAV was presented by Christopher Vo, Arsalan Mousavian, Jyh-Ming Lien [1]. A computer vision was built for crowd detection in this project. They reported the computational latency for each model. Dhanasingaraja R, Kalaimagal S, Muralidharan G [2] introduced a system which combines GPS and IMU for the navigation task. This results in improving in the accuracy. Their vehicle was controlled over the internet by GPRS (General Packet Radio Services) modem. However, this requires a strong network signal. In addition, obstacle avoidance was completed using laser range. Menyhárt J [3] conducted a study about the most common army UGVs. The study focused on the side of the energy management. Ollukaren N, Mcfall K [4] designed a vehicle which consists of Raspberry Pi and Arduino. His vehicle relayed on a computer vision algorithm to track a red target. The vehicle was also operated manually using a joystick. Communicating a vehicle through the internet using a mobile phone application was achieved by L Seyfi, I Akbulut [5]. A live captured video from a mobile camera was sent from the vehicle. The UGV which has been also implemented by Bugaje AI, Loko AZ, Ismail AU, Samuel A was for agricultural applications, particularly, for fumigation purpose. By sending commands using Bluetooth to Arduino UNO and an amounted sprayer in the vehicle [6]. Therefore, it prevented people from exposure to pesticides. Moreover, adding GSM shield provided the capability to control the vehicle from everywhere by SMS (Short message service) and call. Pimple MH, Thool RC utilized a webcam in their car for surveillance purpose [7]. Neuroheadset was connected to Arduino board using various wireless devices, designed by Al-Ayyoub M et al. [8]. The vehicle could receive commands from a cloud server as well.

## 3. Proposed Model

This section is divided into two parts. The first part describes UGV components and explains their hardware diagram. Listing number of inputs/outputs for each circuit, including, how each circuit and sensor connected to the main board (Arduino mega2560). The second part of this section is specified for the proposed algorithm, which executed in this model. This algorithm reads values from different circuits, sensors, and responsible for sending commands to actuators.

### 3.1 Hardware

Before explaining hardware separately, Figure. 1 shows the block diagram for the proposed system, where some blocks only send or receive data while other blocks do both processes at the same time. The vehicle with all amounted circuits is shown in Figure. 2. A full circuit of the proposed system is illustrated in Figure. 3.

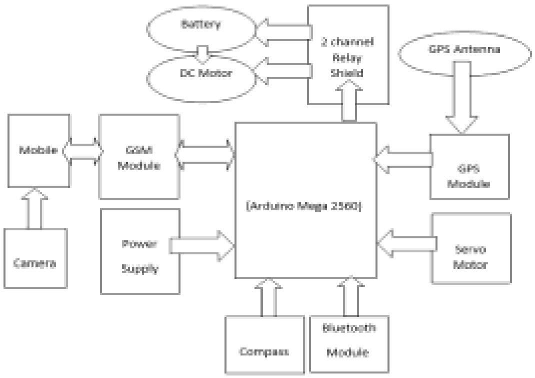


Figure 1. Block diagram of UGV

Figure 2. UGV design

1) GSM Shield: This shield provides communication between the UGV and mobile phone using a SIM card reader. The module that used in the project called SIM900_GPRS_GSM Shield. A SMS text message which consists of the data is sent to the vehicle in order to move in a specific direction. Much information such as vehicle position, direction and speed are also received by the GSM shield. Following this, data are transmitted every period of time to the mobile phone in the same manner. This provides the ability to monitor the vehicle during its mission in case of an emergency situation, as a consequence, it can help in finding the car when the communication is lost. Using GSM shield overcame other wireless methods that have a short-range distance. However, the UGV will work everywhere except those places do not have a network signal. Pin RX1 in Arduino connected to pin 7 in GSM, pin TX1 in Arduino connected to pin 8 in GSM shield.
2) GPS shield: The position of the vehicle which referred to as latitude and longitude are obtained using this shield. It has a GPS antenna to receive data from satellites, and then send them to the GPS shield. A GPS receiver needs at least four available satellites to

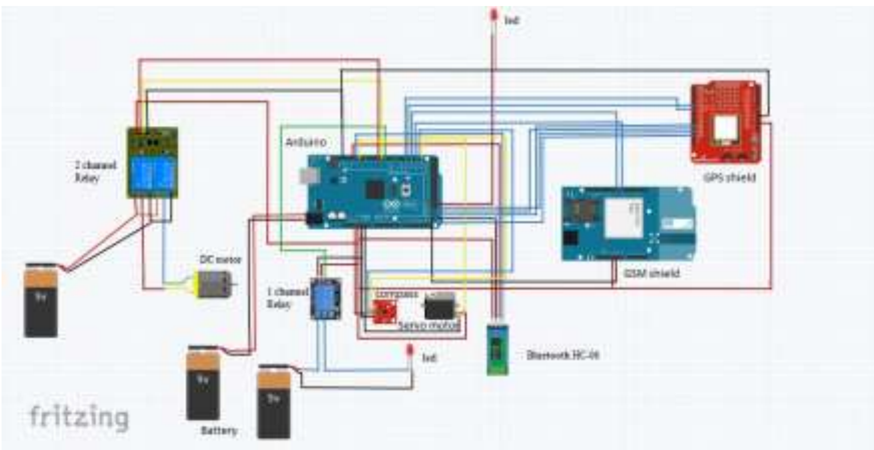


Figure 3. Full circuit of the propsed system

obtain a valid location, that vehicle can rely on in the navigation stage. Arduino obtains the data from this shield to use them for vehicle navigation. After that, the data are sent to the mobile phone via GSM shield. As GPS shield has SD (Secure Digital) card reader, the data, including position, speed, time are stored to use it later in data analysis. Pin RX2 in Arduino connected to pin 5 in GPS, pin TX2 in Arduino connected to pin 6 in GSM shield.

3) Compass: The compass is important in the navigation stage because it provides orientation of the vehicle. This orientation will be compared with the destination of the vehicle to find the right steering angle. The compass is mounted on a stick at the back side of the vehicle. Therefore, it can be prevented from interference which comes from other circuits on the car. The noise can affect compass reading due to magnetic fields generated by those electronic components. A Compass with a specific module HMC5883L is used in the vehicle. Pins SDA, SCL in both Arduino and compass is wired to each other.
4) Servo Motor: The angle of the used servo is in the range between 0-180 degrees. The aim of using this kind of motor is to change the steering angle of the vehicle, which connected to its wheels. The signal wire of the servo motor connected to pin 9 in Arduino.
5) 2-Channel Relay Module: This shield is used to control DC motors in the vehicle in both directions. Therefore, the car is able to move forwards and backwards. The shield contains an H-bridge in its internal circuit. Pin 3 and pin 4 in Arduino are connected with this shield. Bluetooth HC-06 module was added to communicate with the vehicle in the short range using one of the available mobile phone applications.

### 3.2 Software

The software section is divided into two stages. The first stage is related to short-range communication with the vehicle using, and by adding specified GSM shield, we can control the vehicle in places where a mobile network signal is available. The second stage concerns the autonomous mode of the UGV. In this mode, the navigation of the UGV is established using GPS and compass, and then implemented using a servo motor connected to the car wheels for the guidance of the vehicle to its next destination.

1) Manual Mode: In this stage, all data are sent via GSM every 10 minutes to the SIM card in a mobile phone. These data include vehicle position as latitude and longitude, vehicle speed, altitude and satellite number. This information is sent to the GSM shield via GPS once every second. In addition, these data will be stored on the SD card in the GPS shield. Thus, it is assisted with parameters tuning after each experiment by analysing the stored data using MATLAB platform to understand what happened during that experiment. On the other hand, Arduino receives data from the mobile phone to use that data for controlling the vehicle movement. This was performed by sending SMS to

the SIM card in GSM shield which connected to Arduino. The SMS contains a digit which can be interpreted using code executed in Arduino.

After SMS is decrypted using Arduino code,Arduino sends commands to DC motor in the vehicle to control its speed, and to the servo motor as well to control its angle.Stop command is used to stop UGV at some point or in an emergency situation in the autonomous mode. Figure. 4 shows a flowchart specified for controlling the vehicle via SMS. The system also has an option to control the vehicle using mobile phone application via Bluetooth in the manual mode.

2) Autonomous Mode: The aim of this part of the proposed algorithm is to make the vehicle perform a mission by following specific waypoints. The destination angle of the UGV is calculated from the current GPS position and next waypoint location as in equation (1). Therefore, the vehicle should go in that direction.

$$\beta = tan^{-1}\frac{x}{y} \quad (1)$$

Where $x$ , $y$ can be calculated as in (2)

$$x = \cos\theta_b * sin\Delta l \quad (2)$$

$$y = cos\theta_a * sin\theta_b \text{-} sin\theta_a * cos\theta_b * cos\Delta l \quad (3)$$

Where $\Delta l$ is latitude difference between two locations, $\theta_a and\ \theta_b$ are two longitude points.

The compass is used to compute the current heading of the UGV. By subtracting the current heading from the target heading, it results in an error. This error will be multiplying by P-controller value (proportional factor), and then mapping the obtained value to an appropriate steering angle of the servo motor, which represents the maximum angle of the vehicle wheels in both directions. The closed-loop control of the system is shown in Figure. 6.

The data of each mission are saved to the SD card for data analysis. During the mission, the distance between the current location of the vehicle and target waypoint is calculated in meters once per second until becomes about 3 meters radius around the target waypoint, then the algorithm uses the next waypoint as a target location, and the previous procedure will be repeated. All the steps of this part are explained as a flowchart in Figure. 5.

## 4. Results and discussion

Various experiments were conducted to obtain optimum performance for waypoint tracking. The procedure in this experiment was to test the UGV's ability to follow a predefined path. The path consisted of three waypoints. It began at point A, proceeded to point B, and then continued until

Arriving At the final destination, point C.

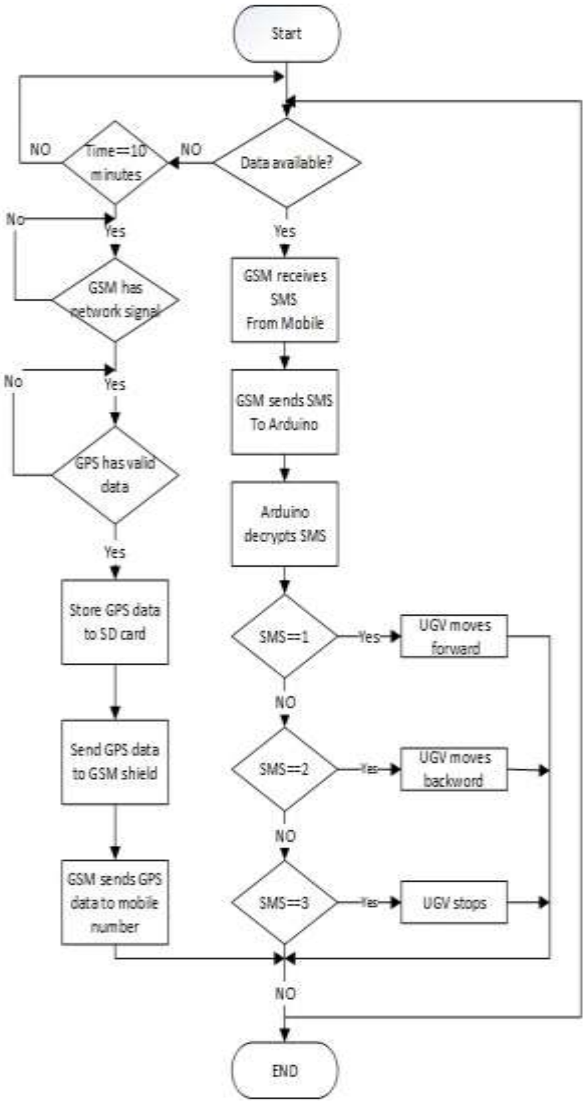


Figure 4. Manual mode of the UGV

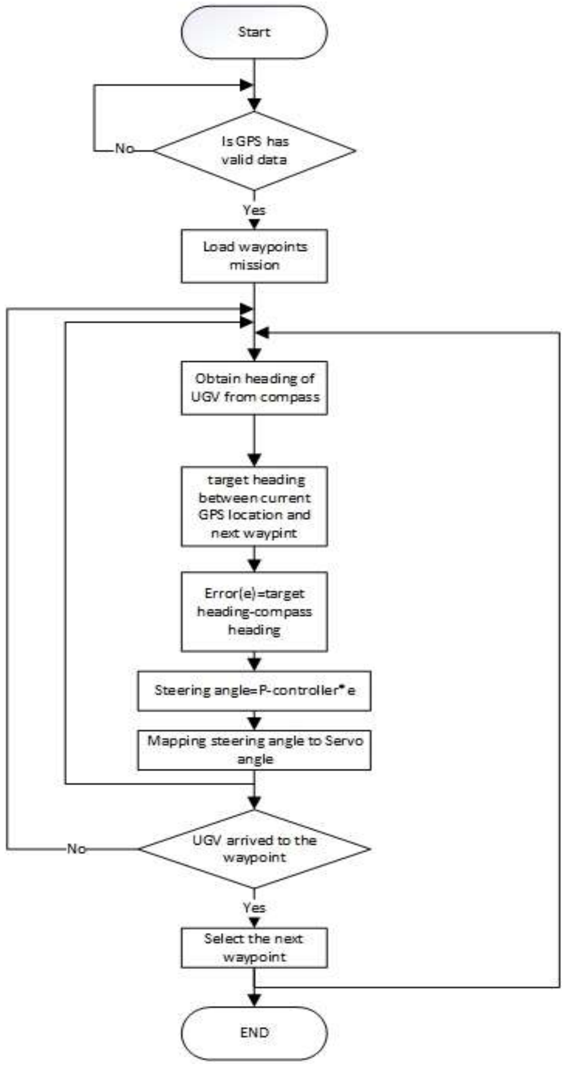


Figure 5. Autonomous mode of the UGV

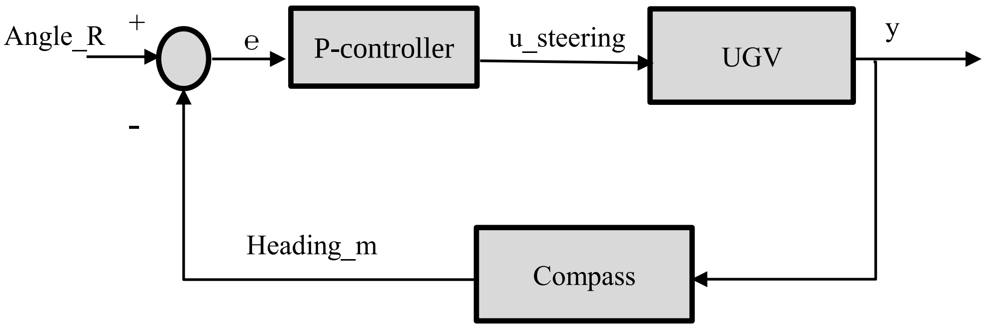


Figure 6. Closed-loop control of the system

The experiments were performed at the University of Zawia, behind the main building as shown in Figure. 7. As mentioned in the previous section regarding the autonomous mode of the UGV, the P-controller value multiplied by the error between the current and target heading was computed, in order to control the steering angle of the wheels. Qualitative analysis was performed in MATLAB by drawing the vehicle paths stored on the SD card for each experiment and comparing them. The best value of the P-controller with the least deviation was found to be 0.8, after being experimented with different values (0.5,0.8,1,1.2).

Figure.8 shows UGV path, which contains a real-time vehicle position in terms of latitude and longitude. The second factor was the radius around each waypoint, where the vehicle switch to the next waypoint. The optimum value of d was found empirically to be 3 m. Choosing a large d, causes the car to turn well before arriving at the current waypoint. However, small values of d, resulted in sharp turn. Consequently, there was a high oscillation in the path of the vehicle.

## 5. Conclusions and future work

This paper presents an implementation of a process whereby an unmanned ground vehicle is able to track various waypoints. The proposed system achieved reasonable accuracy. A live video stream was sent via a webcam mounted on the vehicle, to explore the working environment. The UGV could be controlled manually using SMS text. Furthermore, a voice-controlling command was sent by mobile phone via Bluetooth, and then received by the Bluetooth shield connected to Arduino, allowing control of the vehicle movement. Despite the acceptable performance of the UGV in waypoint tracking, future work will focus more on path tracking, which is an extended task where the vehicle should follow a specific line between waypoints instead of going directly to predefined points. Ensuring the UGV avoids obstacles while executing its mission will be a challenging task. Finally, due to the low GPS frequency (once per second in this project), increasing the speed of the UGV may require more advanced navigation technique.

Figure 7. Experiments location

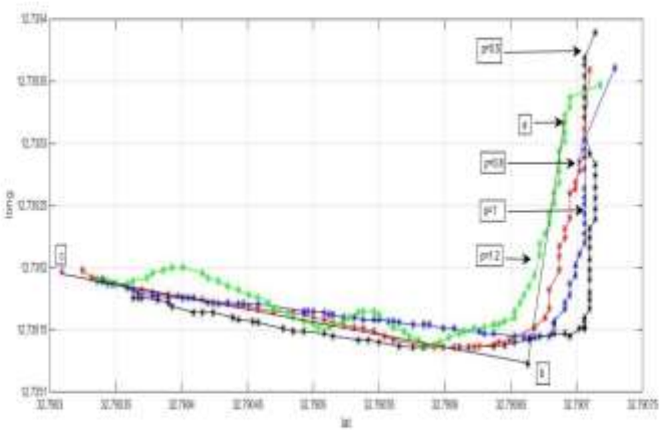

Figure 8. Path of the UGV

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