# Prototyping Non-holonomic Hovercraft for Path Planning and Obstacle Avoidance

Ghulam E Mustafa Abro[1], Zain Anwar Ali[2], Bazgha Jabeen[3]
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***Abstract***— **By definition, autonomous control systems are the systems that sense the physical quantities from their environment and may execute any dirty, difficult, dull and dangerous task without any intervention. These systems are mostly used in the transportation of large packages from one place to another autonomously by selecting the shortest path, accurate speed and obstacle avoidance. This paper describes the development of fuzzy based PID control algorithm to tackle the dynamic constraints of localization for proposed non-holonomic hovercraft. Furthermore, in order to monitor the hovercraft that whether it is hovering in a familiar or strange environment; paper suggests the incorporation of digital image processing technique which will regularly correlate, the images being captured by the prototype. Moreover, paper methodology also provides the deployment way along with the interfacing techniques of some configurable sensors, which will share the information related to the surroundings of hovercraft using internet of things (IoT).**

***Index Terms***—**Non-Holonomic, Fuzzy Based Proportional Integrator and Derivative (Fuzzy-PID), Simultaneously Localization and Mapping (SLAM), Path Planning, Image processing.**

## I. INTRODUCTION

According to one of the recent report generated by International Society of Automation (ISA), states that there will be a rapid demand for autonomous vehicles by the world in the year of 2020. Discussing these vehicles with respect to their applications, one can classify them as Unmanned Ground Vehicle (UGV), Unmanned Aerial Vehicle (UAV) and Unmanned Under-water Vehicle (UUV). All these vehicles have different modes of operation but yet few things are common as mentioned below:

- These vehicles can interact with human being and have an ability to seek the data from its environment.
- Moreover, they have capability to execute any task with their own skill set (digital computer lie in it).
- They do not require any human intervention for completing any task.

The term 'non-holonomic' can be defined as a mechanical structure whose degree of freedom (DOF) will be greater than the number of actuators. There are several structures in which numbers of actuators are more or less than their respective DOF.

These structures are classified as under, over, and fully actuated systems as mentioned in Table I.

**Table I: Classification of Autonomous Vehicles in Terms of Actuators**

| S. No. | Systems | DOF | No of Actuators | Category |
|---|---|---|---|---|
| 1 | Fixed Wing Aircraft | 06 | 04 | Under-Actuated |
| 2 | Train | 01 | 01 | Fully-Actuated |
| 3 | Hovercraft | 03 | 02 | Under-Actuated |
| | | | 03 | Fully-Actuated |
| 4 | Helicopter | 06 | 02 | Under-Actuated |
| 5 | Thruster Autonomous Underwater Vehicle | 06 | 01 | Under-Actuated |
| 6 | Car | 03 | 02 | Under-Actuated |
| 7 | Unmanned Aerial Vehicle | 06 | | |
| | Bi-Rotor | | 02 | Under-Actuated |
| | Tri-Rotor | | 03 | Under-Actuated |
| | Quad-Rotor | | 04 | Under-Actuated |
| | Hex-Rotor | | 06 | Fully-Actuated |

In today's era, the demand for such autonomous vehicles is increasing day by day because of two major reasons i.e., the accuracy in results and easy execution in the areas where human being can never play at their best such as battlefield. This paper focuses on one of the similar types of vehicles having two actuators and three degree of freedom named as non-holonomic hovercraft. This mechatronic system is much efficient in terms of power consumption because of its natural dynamics and less number of actuators hence it is easy to prototype but yet a lot of perfection is required.

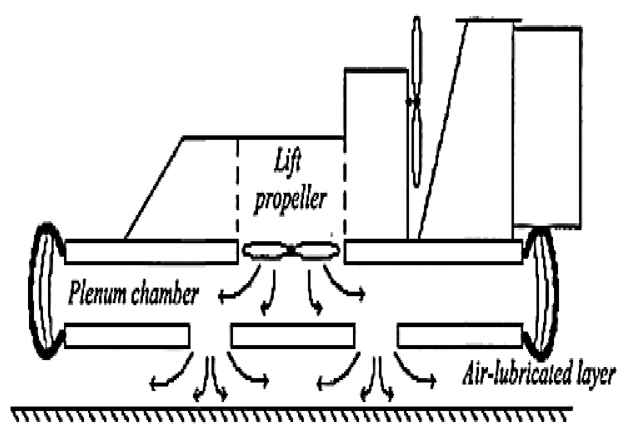



**Fig. 1: Construction of Hovercraft Structure**

Discussing the structure, it has 02 propellers both driven by DC brushless motors, among these two motors one will provide lift by keeping a low-pressure air cavity under the

[1]Lab Engineer, Department of Electrical Engineering, Hamdard University, Karachi, Pakistan. ghulam.engr@gmail.com
[2]Assistant Professor, Department of Electronic Engineering, Sir Syed University of Engineering & Technology, Karachi, Pakistan. zaali@ssuet.edu.pk
[3]Lab Engineer, Department of Computer System Engineering, Hamdard University, Karachi, Pakistan. bazgha.jabeen@hamdard.edu.pk

craft full of air and second one will force it in forward direction. If the air pressure is increased, the air then lifts the craft by filling up the cavity (Plenum). The hovercraft lifts itself when the air pressure in plenum equals to the weight of hovercraft and then this air will escape gradually through the holes made in bottom plate. The hovercraft becomes frictionless and starts hovering when the escaped air makes a layer in between itself and ground surface. The whole idea is illustrated in Fig. 1.

Before implementation it is better to study different research manuscripts related to Simultaneously Localization and Mapping (SLAM), where one can easily find lane tracking of autonomous vehicles using computer vision or image processing [1]. In such papers the term 'Path Planning' can be defined, as a task comprises of some numerical computation that will lead any UGV to reach at its final position. Moreover, one may find majority algorithms for mapping and localization based on the recognition of lane markings and sign- boards etc., [2]. The most common algorithm for path computation is Kruskal's or Dijkstra algorithms which are quite similar to two point distance formula but difficult to manipulate [3]. In addition to this, there are several autonomous vehicles that provide the real information related to their surroundings such that GPS, velocity, temperature and humidity. If one may look into such literature; very few are suggesting the platform of Internet of Things (IoT) to acquire the data from their respective UGV through internet protocol [4], [5].

Furthermore, many papers related to embed systems have proved that they all are in high demand because of power efficiency in most of the cases [6]. In this regard, one may find the focus of majority papers on deploying an electronic circuit or propulsion systems that can maneuver non-holonomic system precisely and accurately [7]. Discussing further about the application of wireless communication, one may see smart baby incubators demonstrating the data acquisition through wireless communication [8]. This proves that such type of parameters can be monitored wirelessly using IoT. Looking over the mechatronic structures, it is suggested that the structures with less weight may consume less power and are very much beneficial in maneuvering hovercraft on any surface [9].

## II. SYSTEM MODELING

This section covers the derivation by which the six equations have been noted down for further modeling of hovercraft. In order to develop the mathematical model, the first and most important step is to represent its movement on a two dimensional plane as shown in Fig. 2.

The hovercraft has two thrust propellers (for the motion and direction of hovercraft). This thrust fan offers two different sources of input (Fx and Fy) along with the orientation (x,y, $\theta$) of the hovercraft as illustrated below:

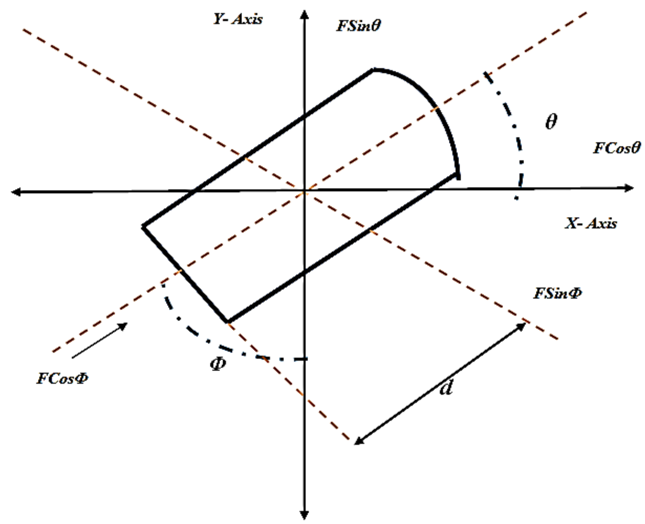



**Fig. 2: Non-Holonomic Model of Air Cushion Vehicle**

The equations of motion have three variables for velocity ( $\dot{}$, $\dot{y}$, $\dot{z}$ ) and three variables for acceleration ( $\ddot{x}$, $\ddot{y}$, $\ddot{z}$ ). Their relationship can be defined with derivation from Newton's second law of motion:

$$\sum F = ma \tag{1}$$

Considering this law at x and y axis along with turning effect applied to hovercraft, this paper finds below mentioned six equations:

$$x = u \tag{2}$$

$$y = v \tag{3}$$

$$\theta = \omega \tag{4}$$

Whereas, their derivatives are,

$$u = \frac{Fcos\Phi \cos\theta - FSin\Phi \sin\theta - bu}{m} \tag{5}$$

$$v = \frac{Fcos\Phi \sin\theta + FSin\Phi \cos\theta - bv}{m} \tag{6}$$

$$\omega = \frac{dF\ Sin\Phi - b\omega}{I} \tag{7}$$

Hence, converting these equations into standard state space matrix form as shown below:

$$\begin{bmatrix} x \\ y \\ \theta \\ u \\ v \\ \omega \end{bmatrix} = \begin{bmatrix} 000 & 1 & 0 & 0 \\ 000 & 0 & 1 & 0 \\ 000 & 0 & 0 & 1 \\ 000 & (-\frac{b}{m}) & 0 & 0 \\ 000 & 0 & (-\frac{b}{m}) & 0 \\ 000 & 0 & 0 & (-\frac{b_\theta}{I}) \end{bmatrix} \begin{bmatrix} x \\ y \\ \theta \\ u \\ v \\ \omega \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 1/m & 0 \\ 0 & 1/m \\ 0 & d/I \end{bmatrix} \begin{bmatrix} F_x \\ F_y \end{bmatrix} \tag{8}$$

$$C = [1\ 1\ 1\ 0\ 0\ 0] \quad (9)$$

$$D = [0\ 0] \quad (10)$$

This paper suggests simple but very effective methodology to implement non-holonomic hovercraft model. At first the approach starts to derive the mathematical model and apply the Fuzzy Based Proportional, Integrator and Derivative (Fuzzy-PID) control algorithm for stabilization of non-holonomic structure. Secondly it addresses the SLAM algorithm for path planning and obstacle avoidance and lastly the monitoring of some important parameters is also included using Internet of Things (IoT).

## III. CONTROLLER DESIGN

Discussing the various control schemes, one may first of all think about very basic controller known as Proportional, Integrator and Derivative (PID). This scheme is mostly easy to use in any scenario but the only flaw is that it generates crisp output and the time response (settling time $t_s$) is comparatively slow. Nowadays, systems are equipped with fuzzy based controllers that regulate the output variables rather than producing Boolean output logics [10].

Moreover, the trend of implementing hybrid control algorithms is also popular i.e. F-PID, control algorithm [11]. Keeping the latest trends this paper also focuses same hybrid scheme named as F-PID where the gains for all three velocities are tuned through three fuzzy logic tuners [12] as illustrated in the Fig. 3 hence in this way the dynamic plant (hovercraft in our case) can be controlled more accurately rather than using the crisp gains of PID. The scheme used within fuzzy is Mamdani controller because it generates regulated output as needed in our case. To understand the whole scheme in a better way Fig. 4 and Fig. 5 are provided below:

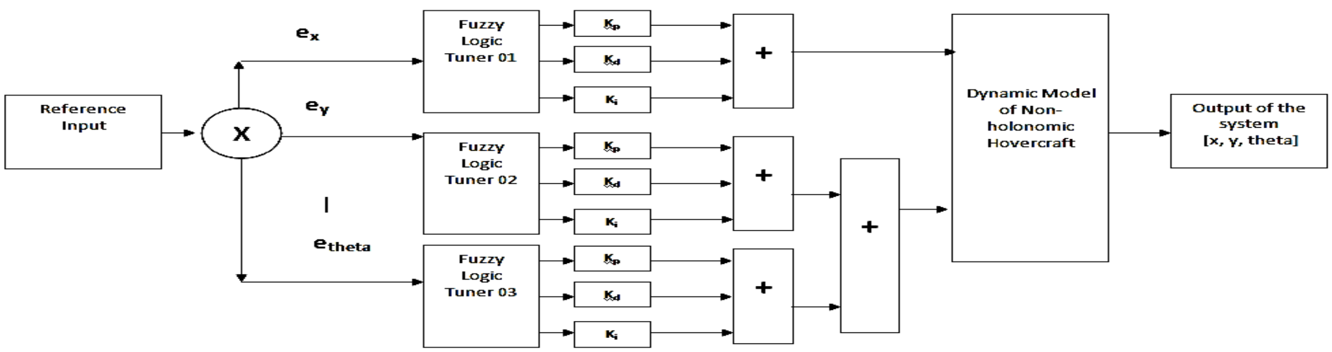
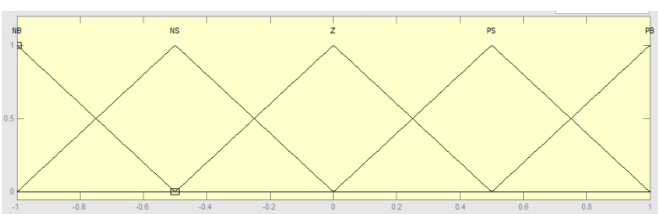
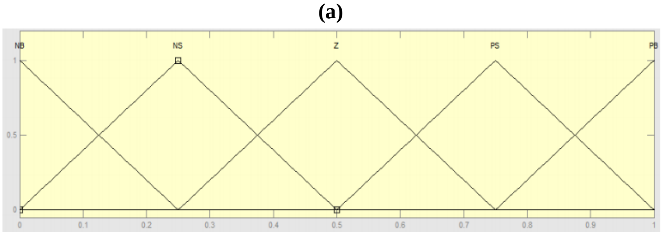



**Fig. 3: Fuzzy based PID Block Diagram**

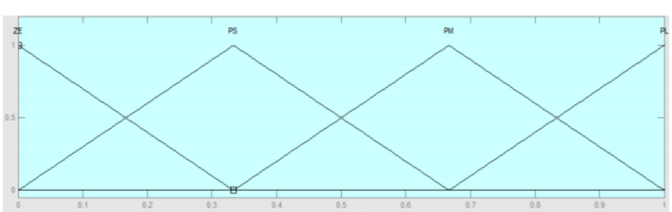


**(a)**



**(b)**

**Fig. 4: Input Membership Functions for (a) Error e and (b) Delta Error (de/dt)**



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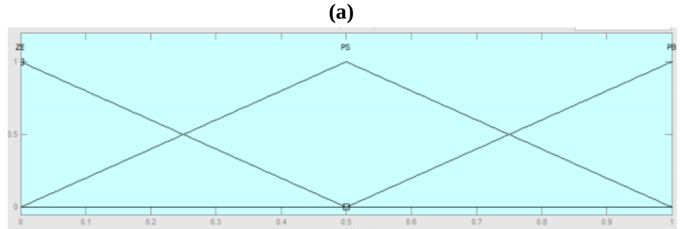

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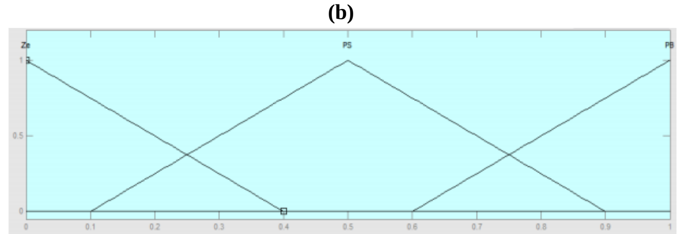


**(c)**

**Fig. 5: Output Membership Function for (a) Kp (b) Ki (c) Kd**

The proposed control scheme of F-PID also performs trajectory tracking hence in this regard the Simulink is used to generate the tracking simulation results as illustrated in Fig. 6. Moreover, this shows the trajectory comparison between the F-PID controller and the conventional fuzzy logic controller in the presence of external noise as shown below:

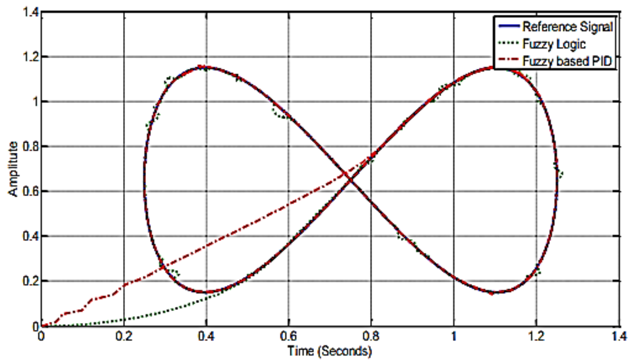



**Fig. 6: Trajectory Tracking using F-PID and Fuzzy Tuner**

## IV. HARDWARE AND SOFTWARE COMPONENTS

This suggests that the hardware comprises of non-holonomic structure having two brushless DC motors which are duly controlled through Electronic Speed Controller (ESC). The values are sent to ESC via Raspberry Pi controller which h is the main proposed processor. Moreover a servomechanism is also compensated inside this hovercraft in order to maneuver it towards right and left direction. In addition to this there are some configurable sensors such as:

- Ultrasonic sensors for obstacle detection,
- DHT11 for sensing temperature and humidity of the environment,
- MQ5 sensor for detecting the availability of hazardous gases in the environment,
- BMP-180 for sharing the actual altitude with respect to sea surface at which the hovercraft is hovering and
- Last but not the least GPS Neo sensor is also interfaced in order to acquire the exact location of hovercraft.

These all values are sensed by sensors and received by Pi and later on these parameters will be monitored using specific internet protocol. One can see the camera being deployed on hovercraft in order to correlate the runtime captured pictures with feed pictures on regular basis to let user know whether the hovercraft is hovering in familiar or strange environment.

Whereas proposed software to implement this Air Cushion Vehicle (ACV) is Raspbian. Discussing the block diagram, this autonomous hovercraft will stimuli whenever any input coordinates are provided using TCP IP connect application and this stimulation will enable specific procedure followed in below mentioned steps:

- Mapping and Localization
- Path Planning and Avoiding obstacles
- Sharing attitude of environment while hovering

Firstly, the hovercraft is at rest and on providing input coordinates i.e. (x, y), it will produce a distance variable having some numeric value. This value will then be sent to Raspberry Pi, where F-PID algorithm will be executed and this will generate regulated values for Kp, Ki and Kd which will later on, drive the hovering process. Furthermore, the SD card of Pi has been stored with images of particular area (EDC lab in our case) and this hovercraft will refresh this data and make it ready for further correlation while hovering towards its destination. The hovering will not take place until one of the two DC brushless motors at plenum side manages to maintain the desired RPM then the second DC brushless motor will start up and in this way the hovercraft will start its journey autonomously to reach at its destination. The second step is to enable the HC SR04 ultrasonic sensors that will monitor the hurdle or obstacle that comes around the hovercraft and in case of obstacle the signal will be feedback to Raspberry Pi and proposed controller will use compass capability in order to re-plan the path as illustrated beneath the heading of results. While hovering the sensors attached to it will submit the values to Pi and through built in Wi-Fi shield these all parameters will be shared on a single IP. The whole procedure can be visualized from Fig. 7.

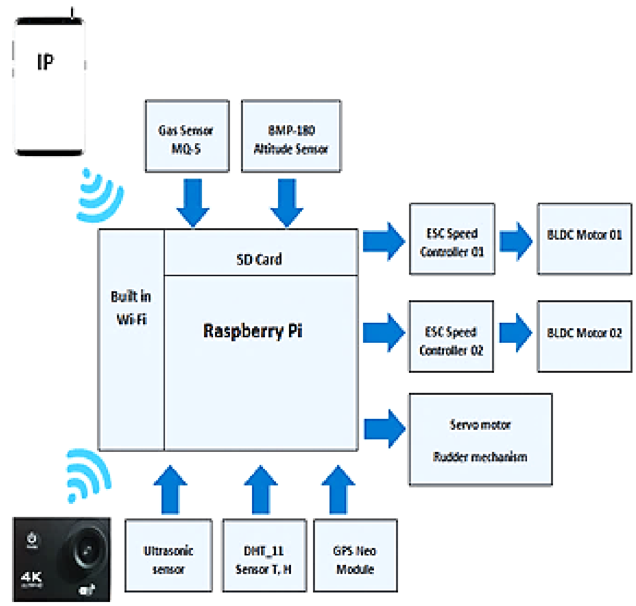
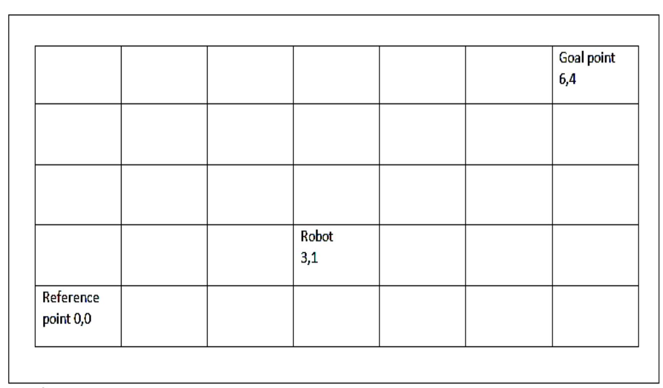



**Fig. 7: The Block Diagram of Proposed Prototype**

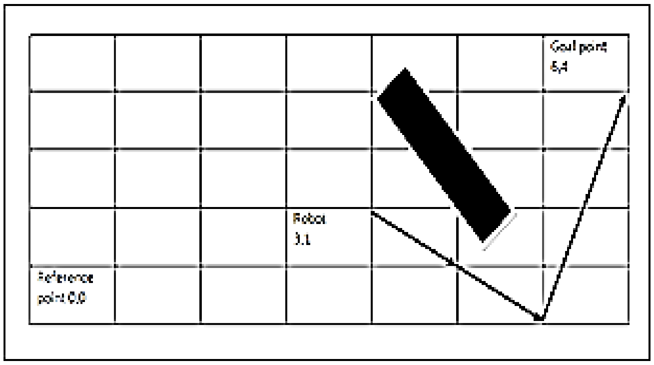
## V. RESULTS

User input in the form of coordinates will be communicated through IoT to Pi controller and then distance will be computed by the hybrid algorithm. The main equation for computation of distance can be understood from Fig. 8 and is given here under:

$$d^{2} = ((X_{goal2} - X_{goal1})^{2} + (Ygoal_{2} - Ygoal_{1})^{2} \qquad (11)$$




**(a)**



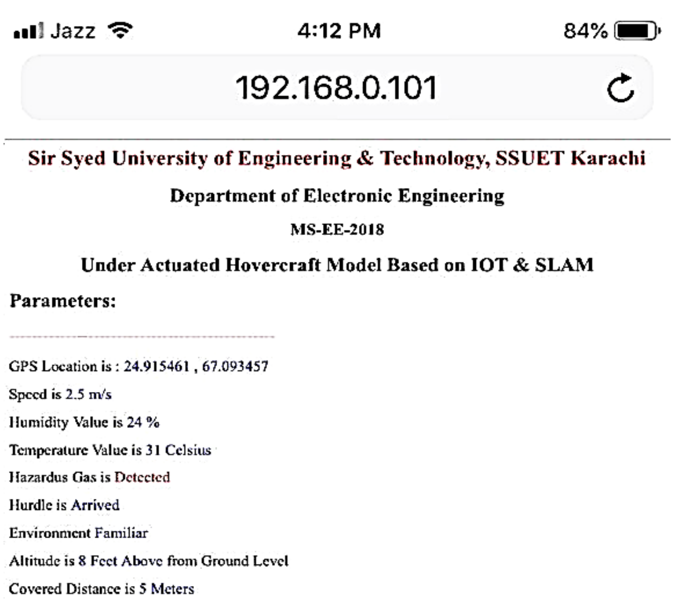

(b)

**Fig. 8: (a) The Basic Distance Value Computation with Reference Point (b) The Computation of Distance in Case of Obstacle**

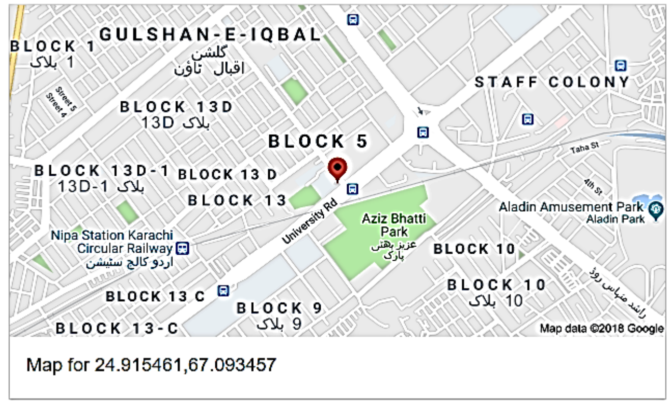
While travelling towards its specific coordinates the particular UGV will keep its camera on, to capture several pictures and get correlated again and again to conclude whether it is in familiar or in strange region as illustrated in below Fig. 9.


**Fig. 9: Localization and Mapping using Pi Controller**

In parallel to travelling and correlating pictures, our proposed prototype will acquire the data from its deployed sensors sent to Wi-Fi shield hence this data will also be shared on single internet protocol (IP) dully assigned by router, as illustrated in Fig. 10.




(a)




(b)

**Fig. 10: (a) Attitude of the Environment where ACV Hovers (b) Exact Pin Location where ACV Hovers**

## VI. CONCLUSION

The paper suggests the proper technical procedure for prototyping non-holonomic control system from deriving mathematical modeling to implementation of control algorithm. Moreover, the addition of SLAM makes this hovercraft autonomous to chase any location easily without any human intervention and last but not the least is the surveillance of surrounding using IoT feature makes this hovercraft different from others, and one of its kinds.

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