Intelligent Vision Based Unmanned Ground Vehicle Formation Control

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Abstract

Vehicle formation control using vision plays a vital role in the design of new control laws in order to reduce the complexity of the system. In the traditional approach, in formation control, using leader follower configuration, navigation is based on the location values transmitted by the leader. Though the method has advantages of increased range, the problems are fading, multipath reflection, Line of sight communication and the increased overhead when the number of followers increases. The present paper seeks to overcome the above problems using a simple vision based framework in real time in a leader-follower configuration. In order to reduce the processing overhead and reduce the number of sensors a simple vision based system is developed using only a single. The system consists of two parroots (i) Vision system and (ii) control algorithm. The vision algorithm uses a simple color tracking mechanism .The control algorithm uses the relative distance and angular displacement between the leader and the follower. The effectiveness of the algorithms, is demonstrated for a convoy using autonomous control for the master and vision control for the follower .

Nomenclature

x,y = pixel positions

v = linear velocity

ω = angular velocity

D = relative distance

φ = pitch angle

θ = roll angle

Ψ = yaw angle

I. Introduction

In recent times there has been active research in the field of control and coordination of multiple mobile robots that allows robots to maintain a particular formation while following a specified trajectory and to perform cooperative tasks. Many researchers have focused on multiple unmanned ground vehicles and conducted research on how a team of AGVs can cooperate to perform the assigned tasks efficiently. There are several advantages of a cooperative team over a single AGV system. They can perform more complex tasks, the system is more reliable and robust because the failure of one robot would not affect the others. Finally, the design of the individual AGV is much simpler and the overall system cost can be reduced significantly. There has been various approaches for formation control in navigation which have been proposed based on combining reactive behaviors [1], [5] to those based on leader-follower graphs [4], [19] and virtual structures . Due to the increase in computing power of commercial off-the-shelf computers, it has become possible to process data from information rich sensors such as a simple web camera , for guidance and navigation of vehicles. The applications of leader-follower robots include exploring remote locations, surveillance and enclosing a target. In this paper, in the leader-follower formation control approach uses a robot, the leader, which moves along a predefined trajectory[5] while the followers, maintain a desired distance and orientation to it .The follower uses a single camera as a sensor[3] to obtain the features to track a particular target (leader robot) and follows it thereby reducing the complexity of using multiple sensors. The feature tracking is performed in the vision system using a simple blob detection using color and free man chain coding . Here multiple blob detection is used and the area of the blobs and the distance between them is used as the parameters to control the follower ROBOT.

II. Vision System

The proposed system in the paper consists of follower vehicle with a forward facing camera mounted on it. The camera is used to obtain the feature from the markers mounted on the leader vehicle. The incoming RGB frames from the camera is converted to HSV color space .This conversion is performed in order to reduce the computation complexity, where the color is identified using the single Hue plane of the converted frame rather than multiple RGB planes. A threshold is applied on the HSV converted frame for segmenting the desired color range. The segmented binary image is further processed to identify the region of the desired color .The angular displacement and the relative distance is measured based on the area of the contours obtained. Figure 1 illustrates the proposed system block diagram .Each block is explained in the forth coming sections

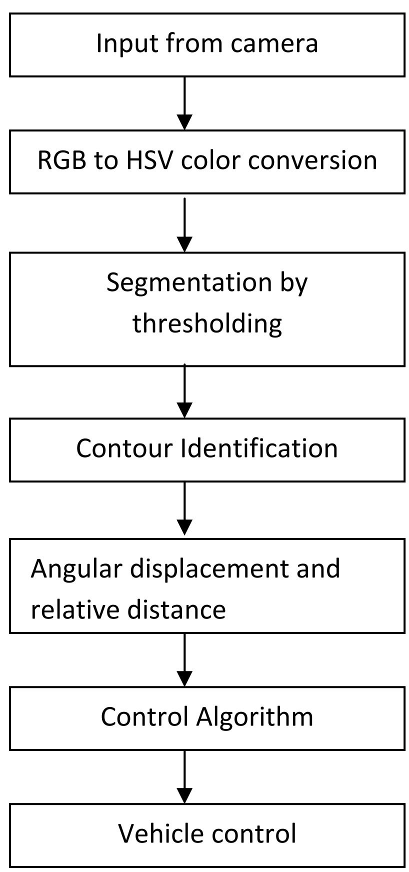

Figure 1:Overall proposed system flow diagram

III. RGB To HSV Color Conversion

The conversion from RGB color space to HSV color space can be performed using equation (1).Where red (r) ,green (g),blue (b) ∈[0,1] be the coordinates of the RGB color space and max and min is the greatest and least of r, g and b correspondingly .In order to find the Hue angle h∈[0,360] for HSV color space .The computation can be performed as shown below.

$$h = \begin{cases} 0, & \text{if } \max = \min \\ \left(60^0 \times \frac{g-b}{\max - \min} + 360^0\right) \bmod 360^0, & \text{if } \max = r\ , \\ 60^0 \times \frac{b-r}{\max - \min} + 120^0, & \text{if } \max = g \\ 60^0 \times \frac{r-g}{\max - \min} + 240^0, & \text{if } \max = b, \end{cases} \quad (1)$$

The value h is normalized to lie between 0 and 180^0 to fit into an 8 bit gray scale image(0-255),and h= 0 is used when max=min, though the hue has no geometric meaning for gray. The s and v values for HSV color space are defined as follows :

$$s = \begin{cases} 0, & if\ max = 0 \\ \frac{max - min}{max} = 1 - \frac{min}{max}, & otherwise \end{cases}$$

$$v = max$$

The v, or value channel represents the gray scale portion of the image .

A threshold for the Hue value of the image is set based on the mounted marker color. Using the threshold value, segmentation between the desired color information and other colors is performed. The resulting image is a binary image with white indicating the desired color region ad black assumed to be the noisy region. The contour of desired region is obtained as described in the section below.

IV. Contour Detection

Freeman chain code method is used for Finding contours ,which is based on 8 connectivity of 3X3 windows of Freeman chain code. Two factors determine the success of the algorithm: The first factor is the direction of traverses either clockwise or anticlockwise. The other is the start location of the 3X3 window traverse. Chain code scheme is a representation that consists of series of numbers which represent the direction of the next pixel that can be used to represent shape of the objects. Chain code is a list of codes ranging from 0 to 7 in clockwise direction representing the direction of the next pixel connected in 3X3 windows as shown in Table1 The coordinate of the next pixel is calculated based on the addition and subtraction of columns and rows by 1, depending on the value of the chain code. This representation is based on work by Freeman chain code.

Table 1:Chain code representation

5	6	7
4	X,Y	0
3	2	1

In the above table, the numbers 0 to 7 are the chain codes for different positions in which the next pixel might occur. Corresponding to the codes in the table1, the next pixel position can be obtained by referring to table2. Table2 contains the 07 codes and also gives the corresponding pixel positions in terms of x and y coordinates as follows:

Table 2:Chain code for next pixel position

Current pixel position x,y		
Code	Next row	Next column
0	X	y+1
1	x-1	y+1
2	x-1	Y
3	x-1	y-1
4	X	y-1
5	x+1	y-1
6	x+1	Y
7	x+1	y+1

At each pixel we determine the position of the next pixel and so on the outline of the whole object can be obtained. Hence, given a binary image, the boundaries of the objects in the image can be determined efficiently.

V. Vehicle Kinematics

Vehicle kinematics for the leader follower configuration are described using the following equations:

$$x = v\cos\phi$$

$$y = v\sin\phi$$

$$\phi = \omega$$

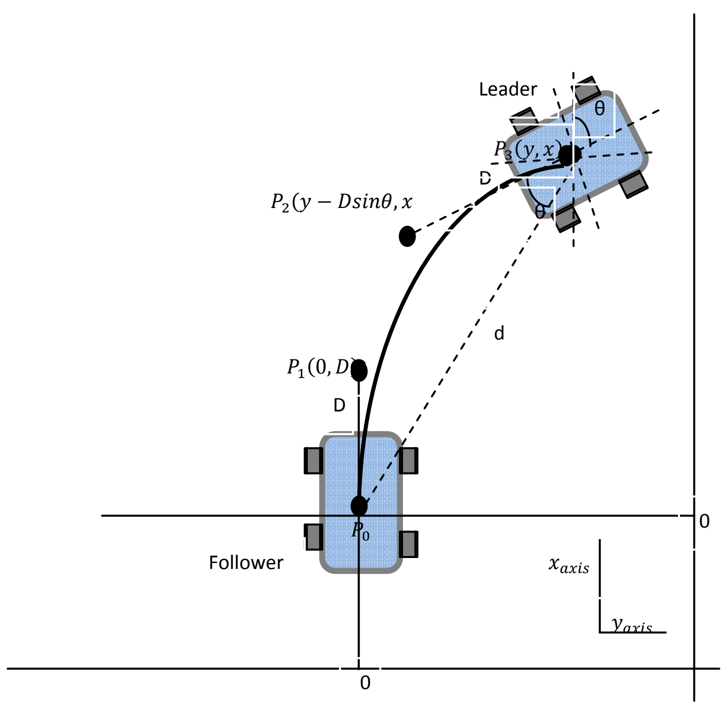

Figure 2: Relative distance and angular displacement estimation in leader follower configuration .

The position of the leader vehicle with respect to the world coordinates in Cartesian form is described as (x,y), ϕ is the leader's orientation angle, and v and ω are its linear and angular velocities ω and denote linear speeds of the left and the right wheels, respectively.

For a predefined trajectory the leader vehicle with a constant velocity v ,is set in motion. The follower robot has to take into account these changes in velocities by keeping track of the length of the trajectory followed. The controller is proportional in nature, increasing the followers speed if the relative distance is more than the desired threshold and decreasing speed or reversing the vehicle motion if the relative distance is less than the desired threshold distance. The change in linear velocity Δv is given by equation (2):

$$\Delta v \; \alpha \; (s - s_0) \qquad (2)$$

where *s0* is the desired relative distance between the vehicles.

Also, the follower robots need to vary their angular velocity, ω, which is computed as follows, to keep up with the leader robot. The angle of orientation of the follower vehicle is controlled by the relative speed of the right and left wheel (motors) of the vehicle which is described using equation (3).

$$\omega = \left(\frac{v}{R}\right) = vK \qquad (3)$$

where R and K are the radius and curvature of the trajectory, respectively. The curvature of any parametric curve is as shown in equation (4):

$$K = \frac{\dot{x}\ddot{y} - \dot{y}\ddot{x}}{\sqrt{\dot{x}^2 + \dot{y}^2}} \qquad (4)$$

so that the curvature at this point is:

$$k = \frac{\ddot{y}}{\dot{x}^2} = \frac{2(y - D\sin\theta)}{3d^2} \quad (5)$$

Where D is distance and the desired angular velocity is computed as ω. Individual wheel velocities are then calculated from Eqn. (3) and Eqn. (5).

VI. Measurements of the target posture using the visual system

The objective of the follower robot is to follow a target robot evolving with unknown motion on the working area. The follower vehicle is equipped with a forward facing camera mounted on it. The camera is used to obtain the feature from the markers mounted on the leader vehicle .In order to ease the calculation, and without losing generality the horizontal median of the square shown in Figure 7is made to coincide with the camera center. The positions of the pattern's marks on the image are expressed in pixels as (x_i, y_i) with i=A,B,C and D. These variables are considered as image features.

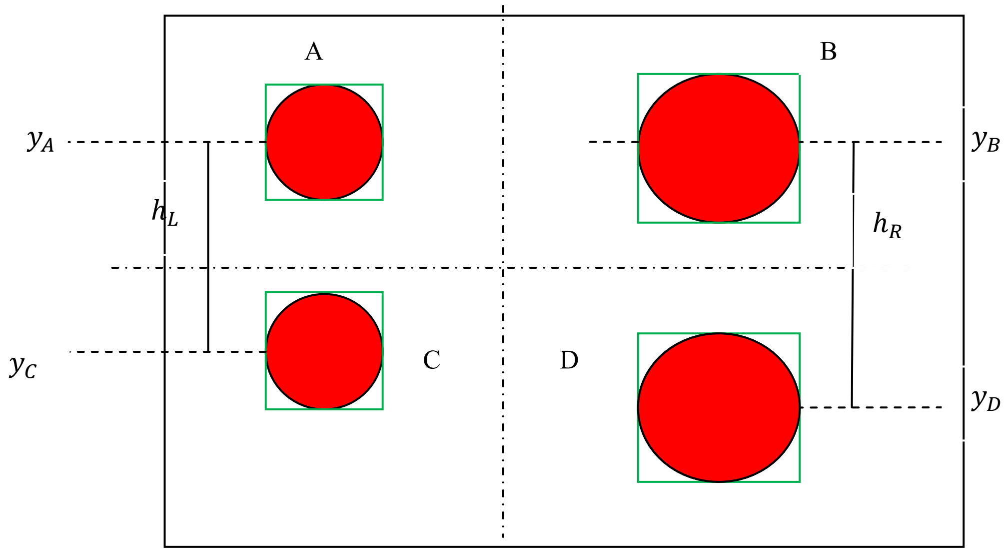

Figure 3:Target vehicle pattern

From the image features measured by the vision system it is possible to compute posture of the target vehicle(x_T, z_T, φ_T), measured on a coordinate system associated to the camera(X_C, Z_C).The vision system 's horizontal projection and the posture of the target vehicle on the camera's coordinate system is illustrated in Figure from which the following expressions are obtained:

$$x_T = \frac{x_R + x_L}{2}, z_T = \frac{z_R + z_L}{2}, \varphi_T = \cos^{-1}\frac{x_R - x_L}{E} \qquad (6)$$

where E is the length of the sides of the square. Using inverse perspective projection the measurement equations can be formulated as :

$$x_L = \frac{z_L - f}{f}x_A, x_R = \frac{z_R - f}{f}x_B$$

$$(7)$$

$$z_L = f\left\{\frac{E}{h_L} + 1\right\}, z_R = f\left\{\frac{E}{h_R} + 1\right\}$$

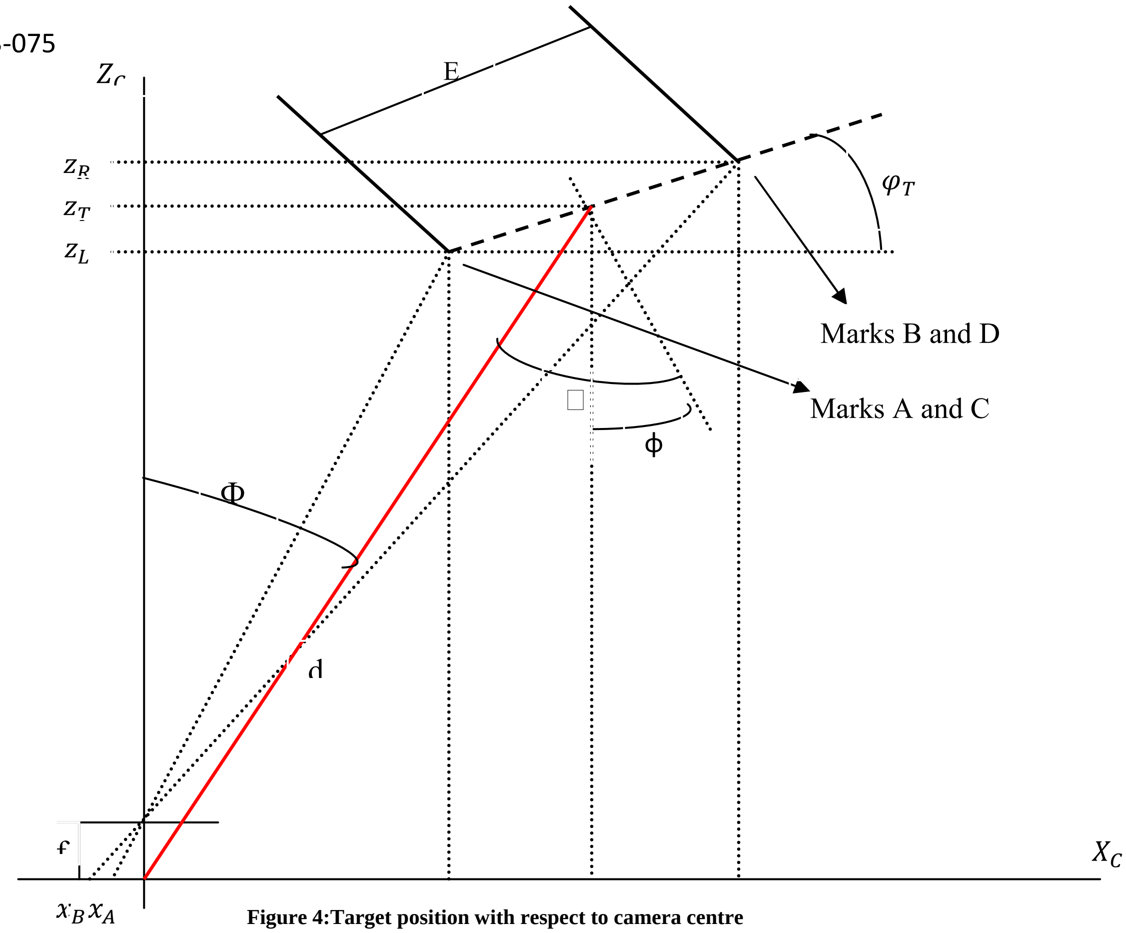

Figure 4:Target position with respect to camera centre

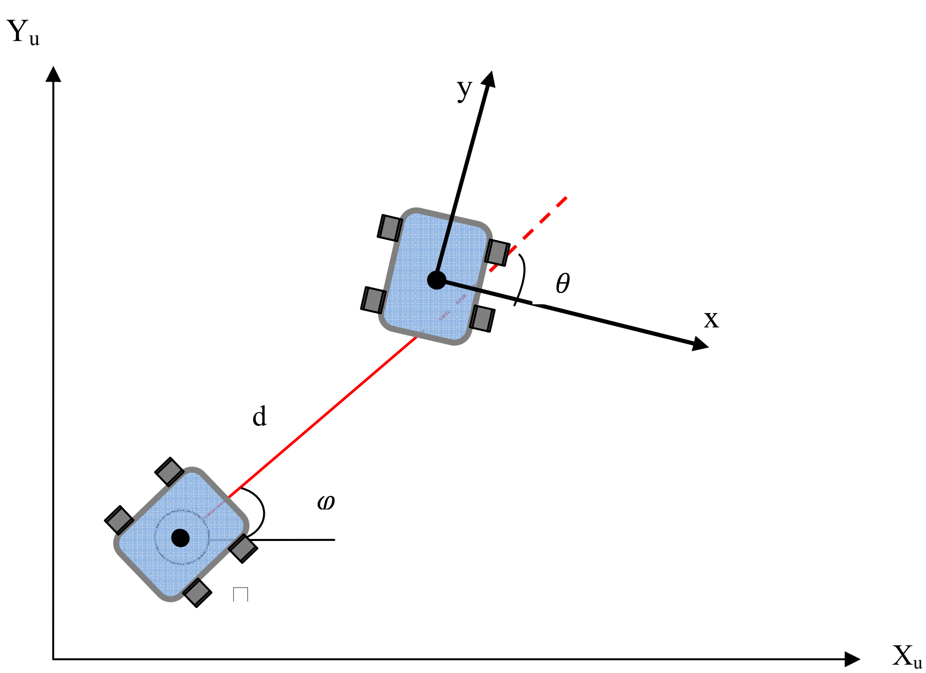

Figure 5:Relative distance and angular displacement of target vehicle with respect to follower

Using variables of equation 3 and 4 ,and assuming the robot centre and camera centre coincide, the relative position and angular displacement with respect to the target vehicle (φ,□,D) can be calculated using the following equations.

$$\varphi = \tan^{-1}\left(\frac{x_T}{z_T}\right)$$

$$\Phi = \tan^{-1}\left(\frac{z_R - z_L}{x_R - x_L}\right) \qquad (8)$$

$$\theta = \varphi + \Phi$$

$$D = \sqrt{(x_T^2 + z_T^2)}$$

VII. Experimental Setup and Results

In order to show the effectiveness of the algorithms, experiments were performed on a ground based set up consisting of two ground vehicles in a convoy formation using autonomous control for the master and vision control for the slave robot which uses a low cost vision sensor(camera) as the only sensor to obtain the location information. The robot vehicle frame and chassis is a model manufactured by Robokit. It has a differential 4-wheeled robot base with two wheels at the front and the two wheels are at the back. The vehicle uses four DC motors(geared) for

Figure 6:Experimental setup

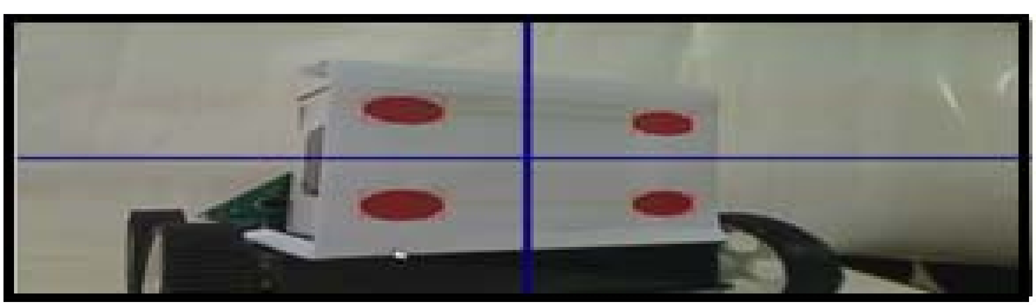

Figure 7:Detected target markers using the camera

driving the four wheels independently .The DC motors are controlled by a microcontroller . Visual tracking the most important block of the system gives the information about the leader vehicle , its relative distance and angular displacement. For the vision algorithm the coding was performed in python language with OpenCV library modules imported to python block. Figure 6 illustrates the experimental setup of the proposed system .The visually detected markers from the camera is shown in Figure 7. Figure 8 to 10 illustrates the detection of the target at various positions ,left at 15 degree, straight , and 30 degree right respectively. Table 3 illustrates the desired and estimated results for the relative distance estimation between the target and the follower. Table 4 illustrates the desired and estimated results for the angular displacement estimation of the target from the follower.

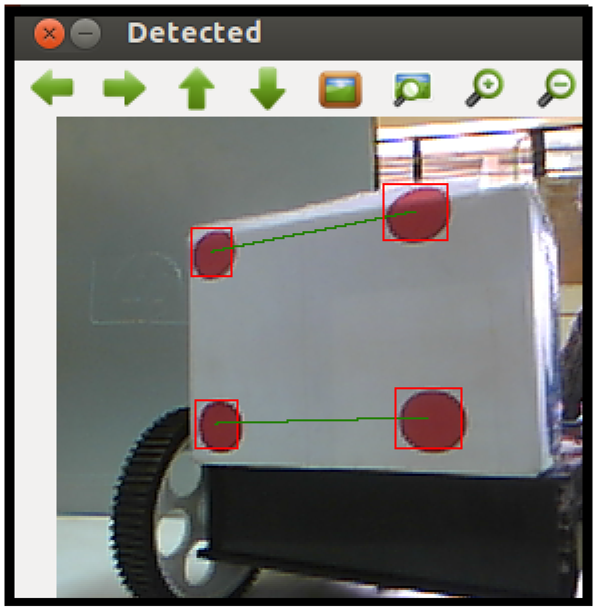

Figure 8:Leader vehicle at 30 degree right turn.

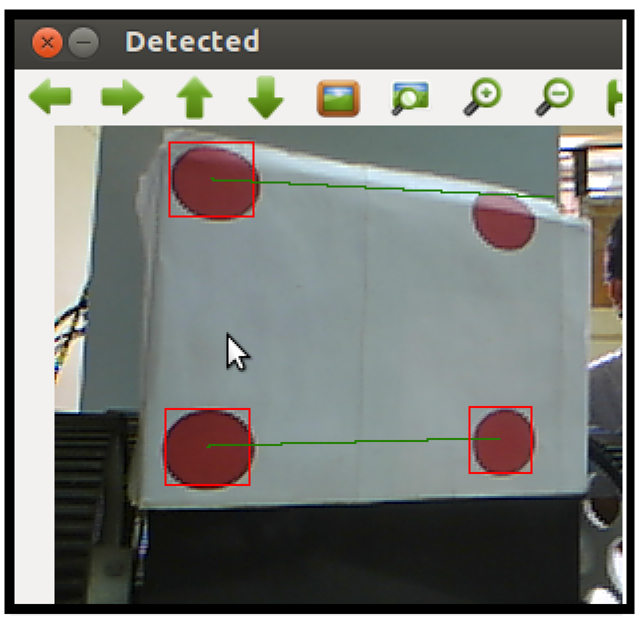

Figure 9:Leader vehicle 15 degree left turn

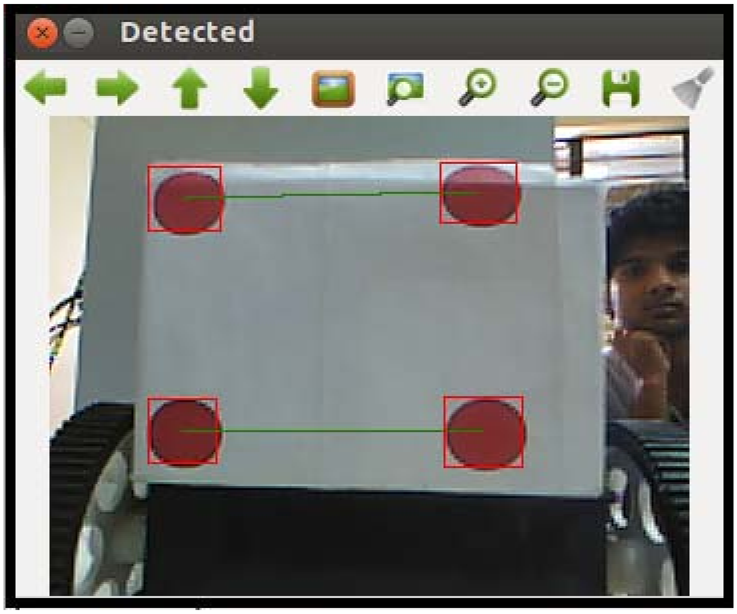

Figure 10:Leader vehicle moving straight

Table 3: Relative distance measurement table

Desired relative displacement	Obtained measurements
5cm	5.4cm
10cm	11cm
20cm	22cm
25cm	24cm
30cm	30cm
40cm	41cm
50cm	56cm

Table 4: Angular displacement measurement table

Desired angular displacement	Obtained measurements
-30	-34.48
-15	-12.67
-10	-10.4
0	0.63
10	13.34
15	17.23
30	34.13

Table 3 and 4 concludes that the measurement comparison with the desired and obtained values proves that the proposed system is suitable for outdoor maneuvering in constant lightening condition.

VIII. Conclusion

Design of a an Intelligent unmanned system for a leader-follower framework was performed and tested in a real time environment. The objective of the proposed method was to perform formation control using vision only follower .The proposed system on testing in real time environment proved to to be accurate for outdoor environment condition under constant lightning condition. The scope of the proposed system can be extended for various lightning condition and varying velocities of the target.

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