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FORMATION ALGORITHMS FOR MULTIPLE MOBILE ROBOTS BASED ON VISION DETECTION

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Abstract- Unmanned operating system is applied to various fields. The disadvantages of the single unmanned system, such as its own limitations, poor flexibility, poor ability, low efficiency, cannot be overcome, as the complexity of the tasks continue to increase. As a result, the cooperative operation system of multi-unmanned platforms is gradually regarded as the main trend of the development of unmanned systems. A novel multiple mobile robots co-avoidance scheme and an improved linear formation algorithm are proposed in this paper. The basic principle and programming steps of the algorithm are described in detail. The improved linear formation algorithm is used for simulation studies. The validity and practicability of the line formation algorithm are verified.

Index terms: Multi-unmanned system; Collaboration; Vision Detection; Formation.

I. INTRODUCTION

Since ancient times, people have been interested in "change". Such as Monkey King can be seventy-two changes or modern transformers, etc. This means that the shape of the structure is changed. There is also a group of structural changes in the population. For example, in nature, geese often transform formation; fish also keeps a certain formation forward. Through this kind of phenomenon, we get the conclusion that it can also play a great role if multiple unmanned platform system in performing tasks formation is maintained, or formation is transformed [1]. The formation of multi unmanned platform system is a very meaningful work. The formation control of unmanned mobile platform can play a major role in military, aerospace, industry and other fields.

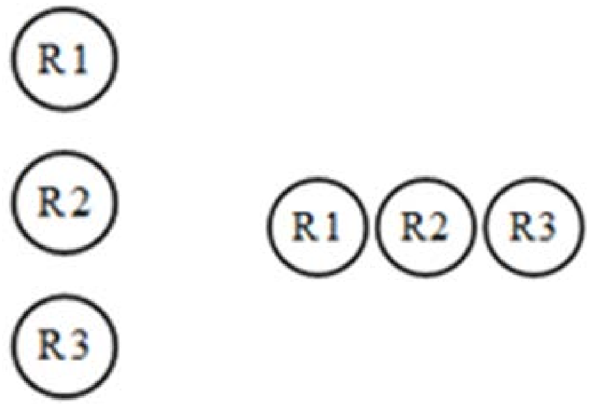
Since 1990, multi robot formation control technology has been widely used in military, production, entertainment and other fields and it has been aroused concerns in scholars. Formation control problem is studied earlier in America [2]. The formation control method based on behavior is studied by the mobile robot laboratory of Georgia Tech University through the UGV(Unmanned Ground Vehicle)Demo II; the local sensing information is used to study the formation control by the robot laboratory, University of Southern California[3]; in the support by Force Office of Scientific Research Air, the laboratory of MAGICC (Multiple A Gent Intelligent Coordination and Control) starts research on UAV formation[4]; multiple satellites are controlled by NASA, the space formation flight and space virtual detection are studied.

A considerable amount of work has been invested in research on formation control, even if the domestic researches start later. For example: Pioneer 2 intelligent robot is used as the object of study by Shanghai Jiaotong University, a distributed formation control system is described and designed, and parallel formation, triangular formation and column formation are accomplished through experiments; the formation vector is introduced into the formation control to study the robot hunting task by Harbin Institute of Technology; the formation control task is accomplished through the design of the four basic behaviors of the robot by Cao Zhiqiang and et al. from Institute of automation, Chinese Academy of Sciences; behavior based method is applied in the study of formation control problems by using of the introduction of feedback mechanism from robot research center of Beijing Institute of Technology[5].

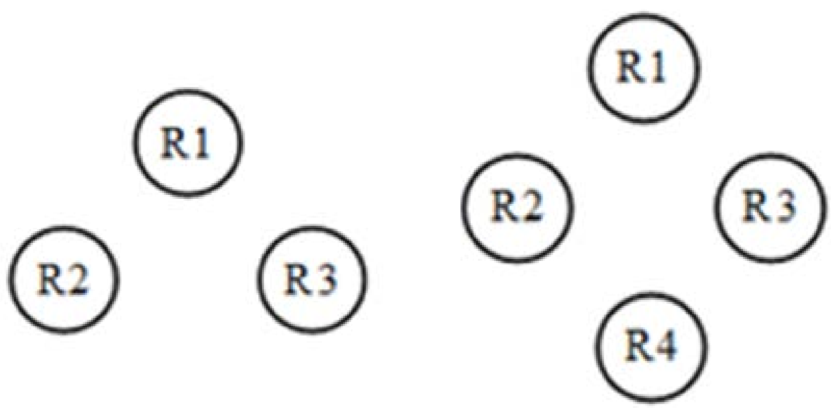
In summary, both domestic and abroad, research on the control technology of formation has become a hot and practical topic. For multiple mobile robot systems, a novel multiple mobile robots co-avoidance scheme and an improved linear formation algorithm are proposed in this paper. The validity and practicability of the line formation algorithm are verified.

II. FORMATION ALGORITHM AND IMPROVEMENT

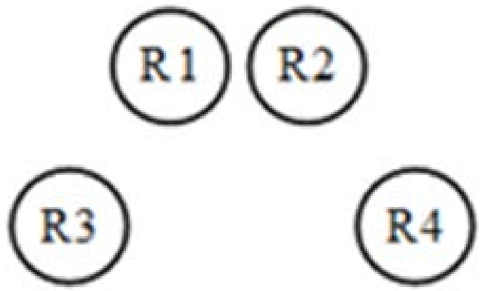
According to the characteristics and requirements of the task, the ground multi unmanned platform can be formed or protected in various shapes ___ usually in a straight line, lined up, triangular, diamond and wedge [6]. As shown in Figure 1.



(a) Column (b) Lined up



(c) Triangle (d) Diamond



(e) Wedge

Figure 1. Typical formation

Formation control includes two parts: Configuration/Reconfiguration and Formation Keeping[7]. The formation control method of unmanned mobile platform mainly includes: behavior based method[8], artificial potential field method[9], leader-follower method[10], Virtual structure method[11], Circulation method[12] and MPC method[13]. Yun Xiaoping and et al. for the distributed mobile robot formation is studied on the line and circle formation, the original formation algorithm is improved. A new method based on the least square method is proposed.

The influence of the robot physical size is not considered by the original linear formation algorithm. Robots are considered to be a point that can move to any direction with a perfect distance sensor. By considering the actual physical condition as shown in Figure 2, the steps of the mobile robot with the improved algorithm for linear formations as follows:

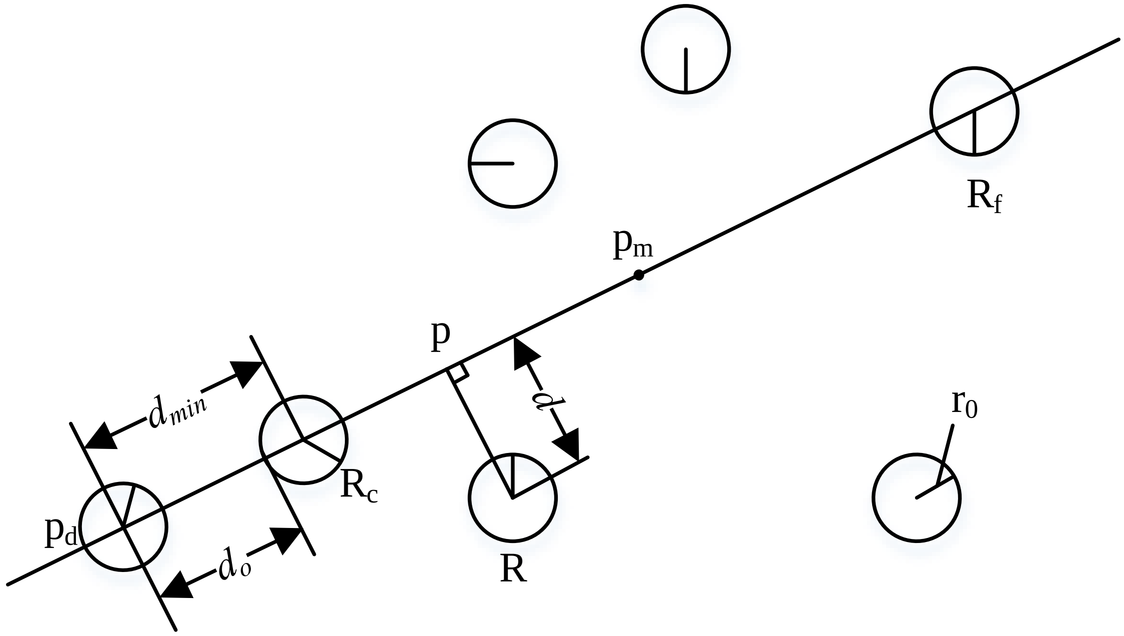


Figure 2. Schematic diagram of linear formation algorithm

1) The nearest robot R_c and the farthest robotic R_f, are determined based on the R's distance sensor,
2) R_s and R_f are connected through a line l, and to determine whether there is the R_0 to the line l of pedal p between R_c and R_f;
3) If it is, to determine whether there is enough space between R_c and R_f to accommodate R_0. If there is enough space, then the R_0 moves to the midpoint P_m of the R_c and R_f;
4) If the pedal p is not between R_c and R_f, or distance between R_c and R_f is not enough to accommodate R. Then the R moves to position P_d on the l where the distance from R_c is d_{min}, and in the opposite direction with R_f,

The potential field method is used to avoid robot collision. If the cutoff point of the potential field algorithm is represented by d_0, then the object (or robot) that is less than d_0, will give the robot a repulsive force. If there is enough space between R_c and R_f, that is:

$$\left|R_c R_f\right| \geq 2d_0 \quad (1)$$

d_{min} can be used to get the next in the Step 4:

$$d_{min} = r_0 + d_0 \quad (2)$$

In the formula, R_0 is the radius of the robot.

The improved algorithm and the least squares fitting algorithm can eventually form a straight line formation, but the straight line is unknown. In many practical applications, the formation of a specific line is required. In this paper, a new method of multi robot formation is proposed based on the above algorithm. The specific steps as follows:

(1) All robots share a coordinate system, and determine the robot to the specified pedal position coordinates $P_i=(x_i, y_i)$;

(2) All the distance between pedals coordinate is calculated, and to find out the maximum distance of pedals between the robot R_1 and R_2. The distance between the two robots is calculated to determine whether there is sufficient space to accommodate all the robots. That is $L_{max}=\sqrt{(x_2-x_1)^2+(y_2-y_1)^2} \geq n*d_{min}$;

(3) If the space is enough, the R_2 target position is set to the current position to the line L of pedal $P_2=(X_2, Y_2)$ position, and go to step 5, otherwise go to step 4;

(4) If space is insufficient, the target location of the R_2 is set to the position of $n*d_{min}$ to R_1;

(5) The target position of robot R_i which is the nearest robot R_2 is set to the location of the R_2 robot for the d_{min};

(6) The target position of robot which is the nearest robot R_{i+1} is set to the location of the R_i robot for the d_{min}. Looping to execute this step until all robots are traversed completely.

(7) The target location of the R_1 is set to the position of $n*d_{min}$ to R_2;

(8) If there are no other robots in the target location of the R_i, R_i moves to the target location. Loop to execute this step until all the robots move to the target location except for the R_1. Finally R_1 moves to the target location.

III. VISUAL DETECTION ALGORITHM

The visual inspection is made of light from a source (such as an incandescent light, the sun, etc.) to a ray of light and then through the space to some objects. Most of the light on the object is absorbed by the object's surface. Only a small portion of the light that is not absorbed is perceived by us, and the color of light is formed. The computer or video device is used to replace the human’s eye to do measurement and judgment, which is called the visual inspection. Computer vision products are used to convert the object to image signal and send to the dedicated image processing system. According to the pixel distribution and brightness, color and other information image signal is transformed into digital signal. The image system is used to extract the features of these signals. And the scenes of the device action through the results are judged.

The simplest camera model is the pinhole model. In the pinhole model only the perspective projection transformation and the rigid body transformation are included. It does not include camera distortion but the distortion factor is the basis of other models. The pinhole model is shown in Figure 3. Among them, f is the focal length of the camera, Z is the distance between the camera and the object, X is the length of the object, x is the height of the object in the image plane. If the camera's focal length is known, the height of the object in the plane and the distance between the center of the pinhole and the object are known. Then the actual height of the object can be obtained by using the similar triangle theorem. The calculation formula is shown as 3.

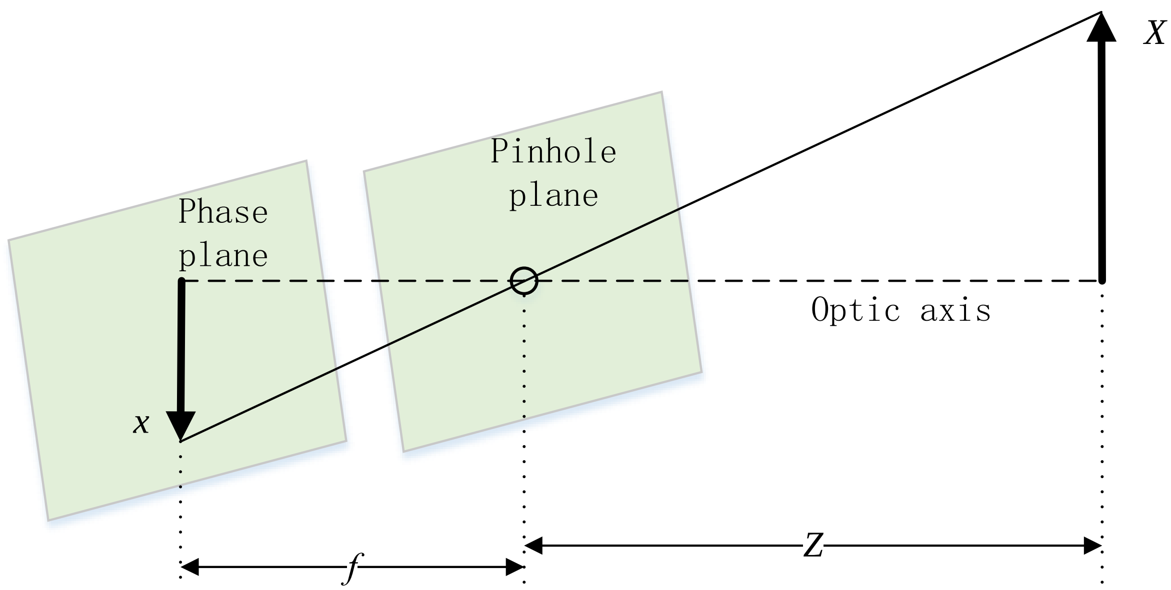


Figure 3. Pinhole camera model

$$-x = f\frac{X}{Z} \quad (3)$$

The object is no longer inverted in the image plane if it is switched on the pinhole plane and the image plane in Figure 3. The minus sign in the formula 3 can be removed. As shown in Figure 4. The point *Q(X, Y, Z)* is projected onto the image plane by the projection center. The position of the image plane is represented by *q(x, y, f).*

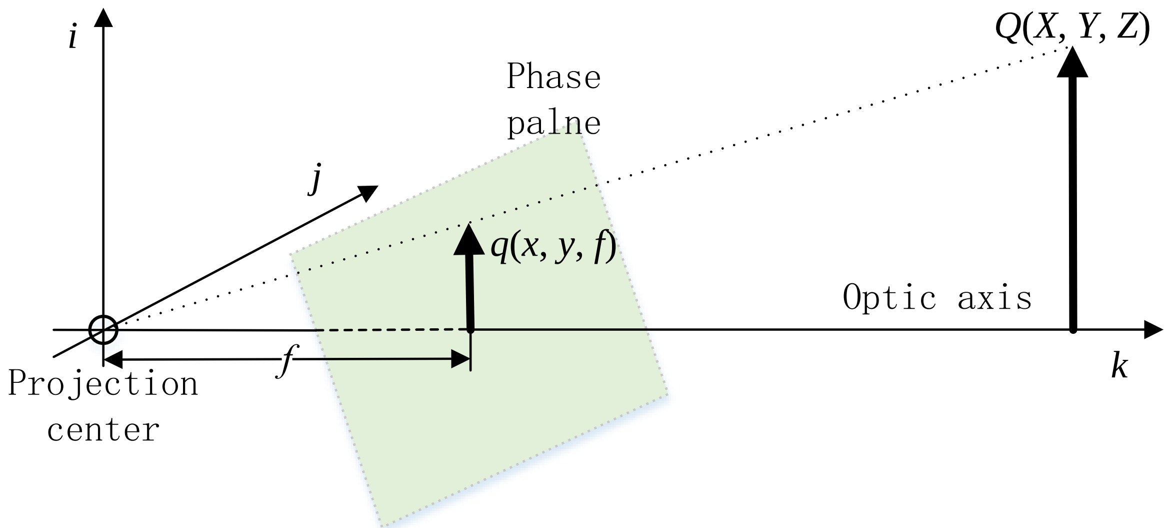


Figure 4. Projection transformation

If the distortion of the camera is considered, some new parameters are introduced, namely f_x, f_y, c_x and c_y. Among them, c_x and c_y are the optical axis of the imaging plane center offset; f_x and f_y are two different focal lengths. Due to the single pixel in the low cost imaging apparatus is not square. So the point in the ideal world is projected into a point on the image plane in some way, which can be represented by 4.

$$x_{screen} = f_x(\frac{X}{Z}) + c_x, y_{screen} = f_y(\frac{Y}{Z}) + c_y \quad (4)$$

If the camera's various parameters are known, the size of the object in the image plane is known and the distance between the projection center and the actual object is known. Then the actual size of the object can be obtained by the formula 5.

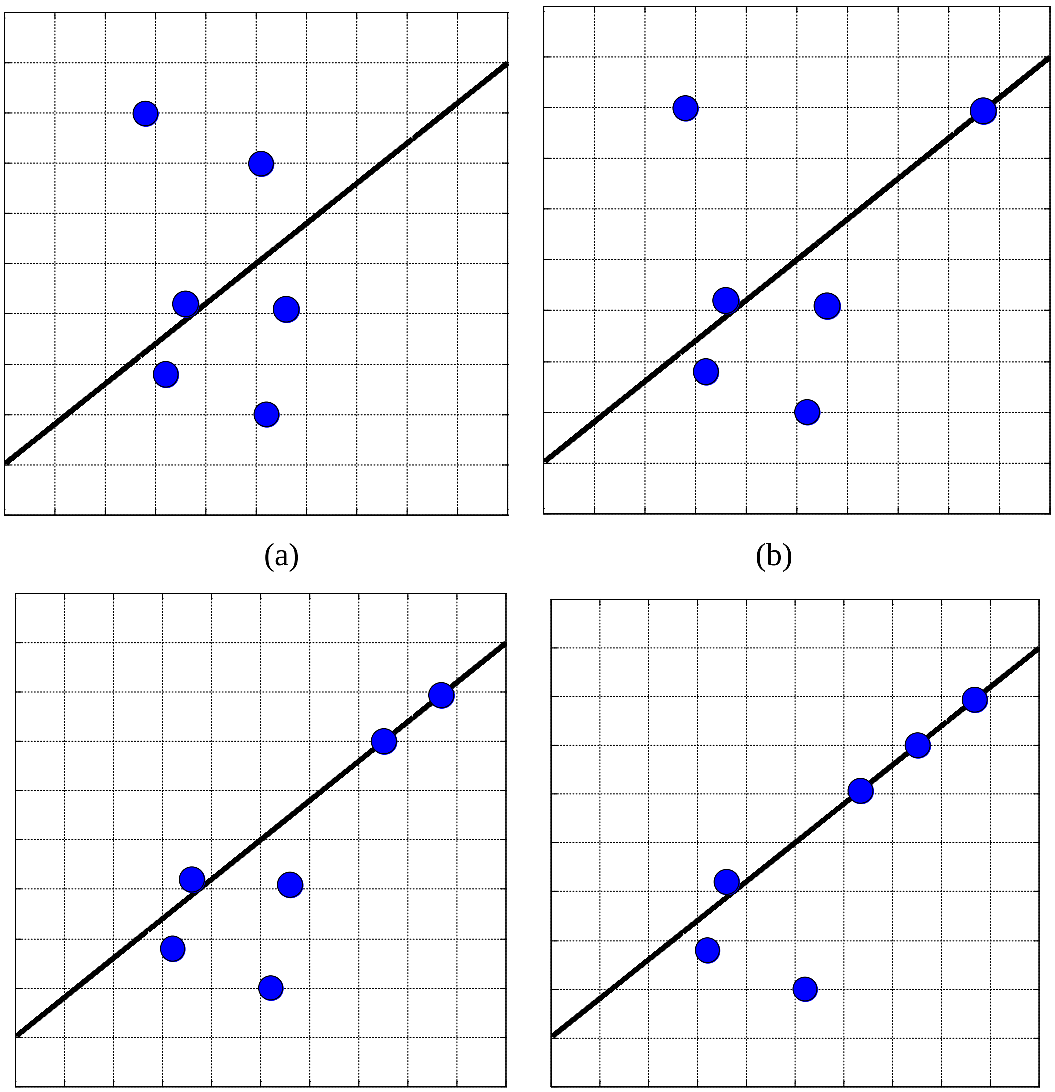
$$X = \frac{Z(x_{screen} - c_x)}{f_x}, Y = \frac{Z(y_{screen} - c_y)}{f_y} \quad (5)$$

IV. Results and analysis of cooperative formation obstacle avoidance

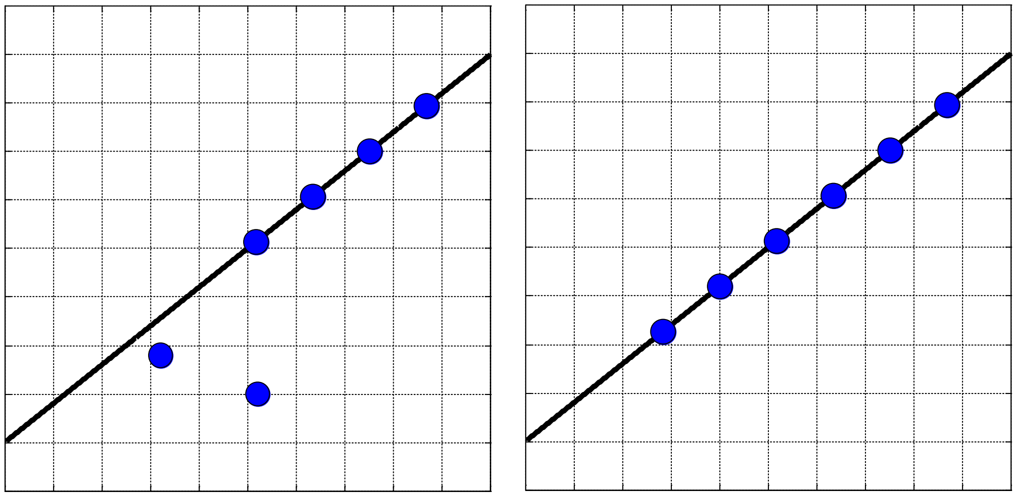
a. Improved formation algorithm simulation

In the above steps, n is represented the number of mobile robots, d_{min} is set to the minimum safe distance between mobile robots. In order to verify the two steps involved in the process, the simulation experiments are carried out. Experimental results are shown in Figure 5 and Figure 6 respectively. The target line is $y = 0.8x + 100$.

A situation is not considered by the above that The connection of multiple robots and the line that is to be formed are perpendicular to each other. A relatively simple solution is to move the robot first that near the target position.

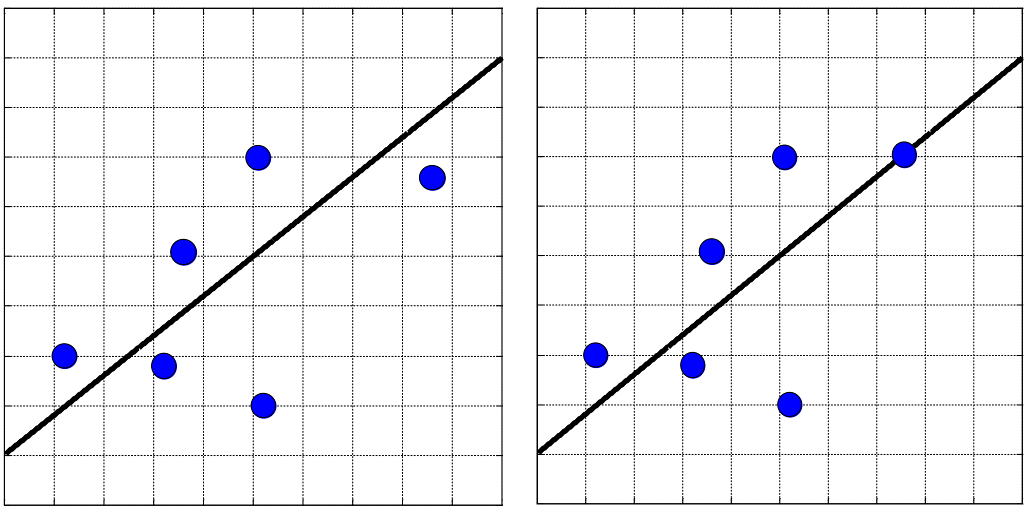


(a) (b) (c) (d)

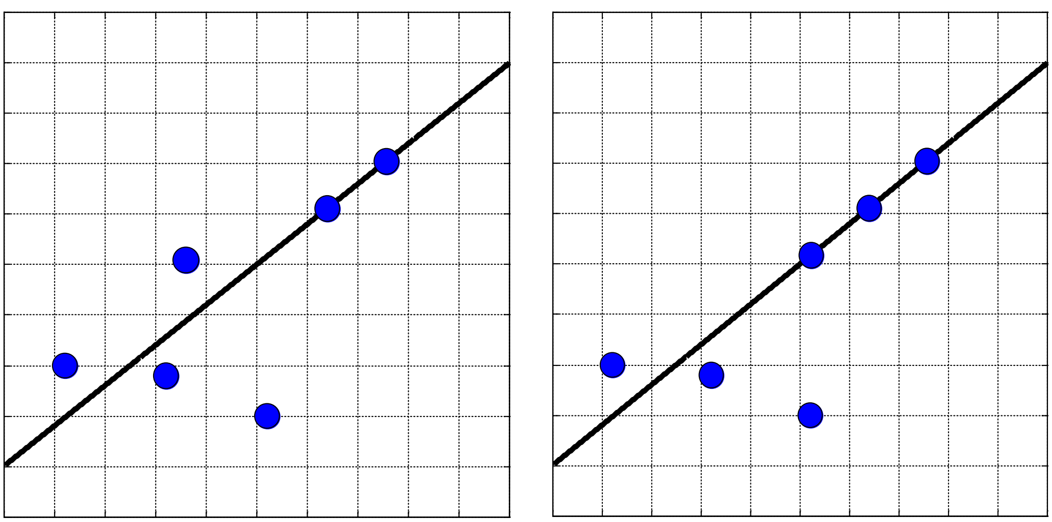


(e) (f)

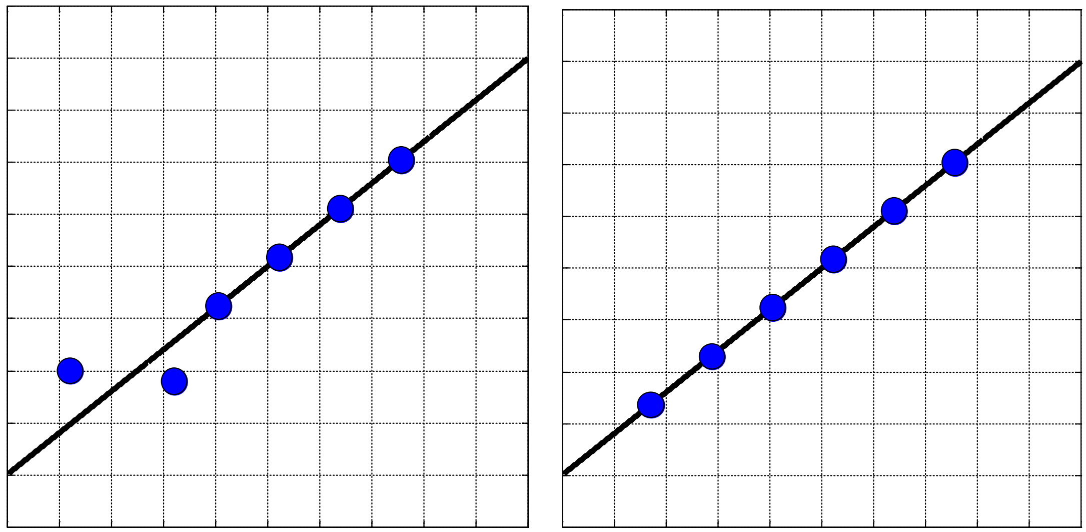
Figure.5 The space between R_1 and R_2 is insufficient



(a) (b)



(c) (d)



(e) (f)

Figure.6 The space between R_1 and R_2 is sufficient

b. Simulation of cooperative obstacle avoidance algorithm based on vision

The test scenario is shown in Figure 7. The ground unmanned mobile platform is not able to determine its location information. Location information of adjacent mobile platforms and obstacles cannot be perceived. The ground unmanned mobile platform can only turn, forward and backward. The image information of the test environment can be acquired by the four rotor UAV. And the image information is transmitted to the PC by wireless. The height information of the flight can be obtained by the ultrasonic sensor with the four rotor unmanned platform. The focal length of the camera is fixed and the parameters of the camera are known. Combining with the theory of visual detection the position information of the ground unmanned mobile platform and the obstacle can be determined by the processing of the image. The straight line formation of unmanned platform is realized through the cooperation of four rotor UAV to avoid hitting the obstacle from A region to B region.

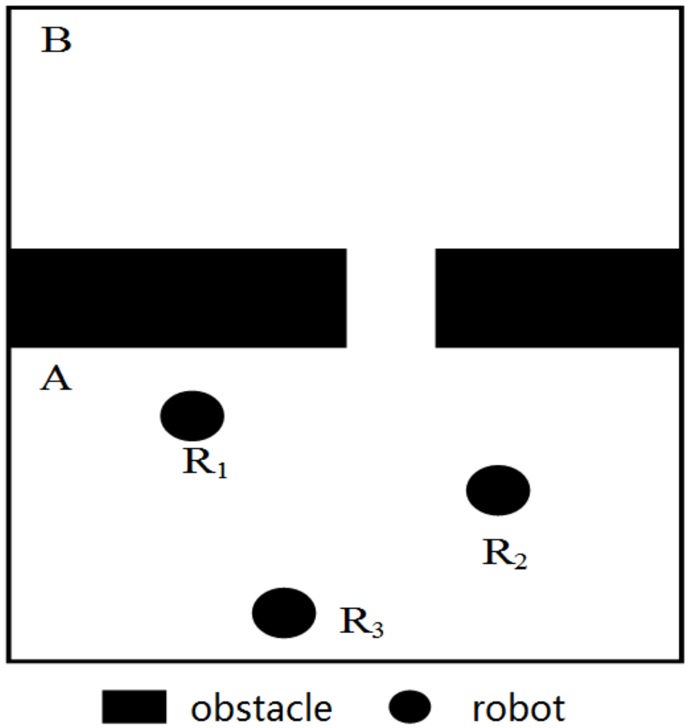


Figure.7 Cooperative formation obstacle avoidance test scenario

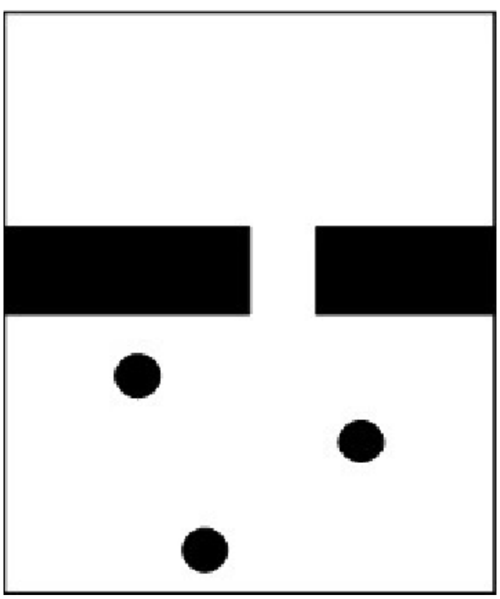
The image processing described in this paper is essentially a digital image processing. The continuous three-dimensional random signal is projected onto the two-dimensional plane of the sensor in the real world. The two-dimensional data matrix is obtained after sampling and quantization. Digital image processing is the processing of the two-dimensional data matrix. The main task of this section is to get the position information which is required by the processing of two-dimensional images. The process of digital image processing include: gray scale, binarization, morphological operation, active region extraction and image marking.

The maximum value method, the average value method and the proportional method can be used to deal with color images into gray scale. The RGB component value of each pixel is calculated by each pixel value of the image that obtained, called the maximum value method(*R_Value*, *G_Value*, *B_Value*). The maximum value of the three components is set to the value of the pixel. The average value of the three component is set to the value of the pixel is called the average value method. The three component of the current pixel are set to *R_Value*, *G_Value*, *B_Value*. The pixel value is calculated by the formula calculation: $0.30 \times R\_Value + 0.59 \times G\_Value + 0.11 \times B\_Value$, called the proportional method.

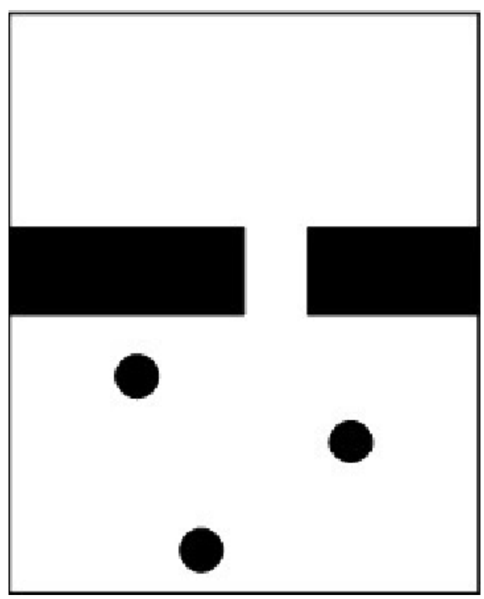
The gray value of each pixel in the digital image is set to be 0 or 255, which is called the binarization. The entire image will show a clear black and white. Binarization image is very important in the digital image processing. Complex images are simple, the amount of data is reduced, and the contour of the target area is highlighted.

The beginning of the mathematical morphology is used in the study of petrography. It has been widely used in digital image processing and machine vision at present. Morphological operations have been developed as an effective digital image analysis method and theory. In general, the morphological processing of the image can be expressed as a kind of neighborhood operation. A special definition of the neighborhood is called "structural element". The factors that determine the effect of morphological operation are the size, content and method of logical operation. Erosion and Dilation are often used in morphological operations.

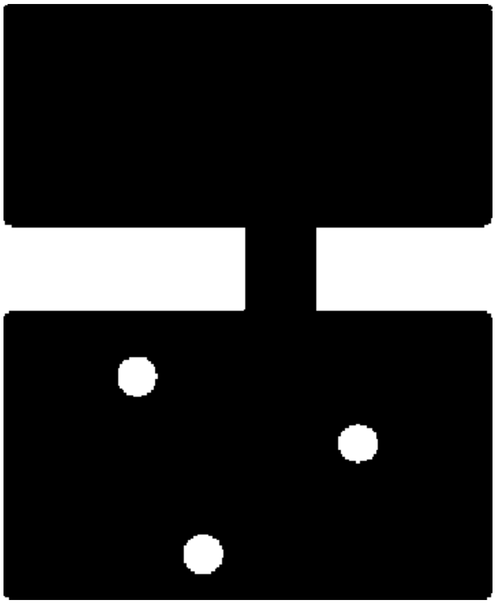
The process of image processing for multi unmanned platforms is shown in Figure 8 (a) - (f). The black rectangle in the picture indicates the obstacles and the black circle represents the ground unmanned platform. The location of the ground unmanned platform and obstacles are shown in Figure 8 (f). Detailed information on the location information and the number of pixels in the image of an unmanned mobile platform and obstacles are shown in Table 1.



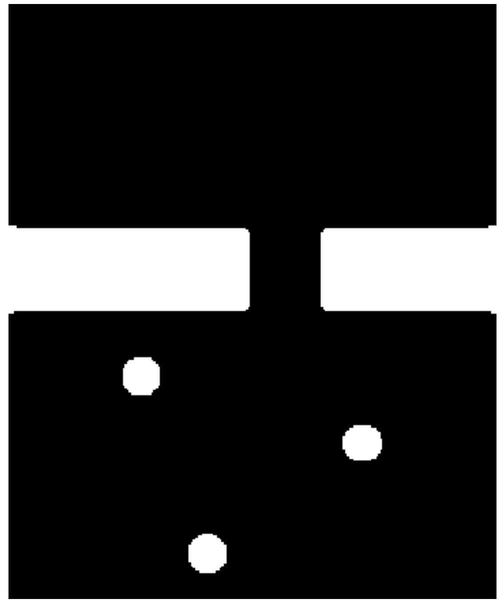
(a) Original image



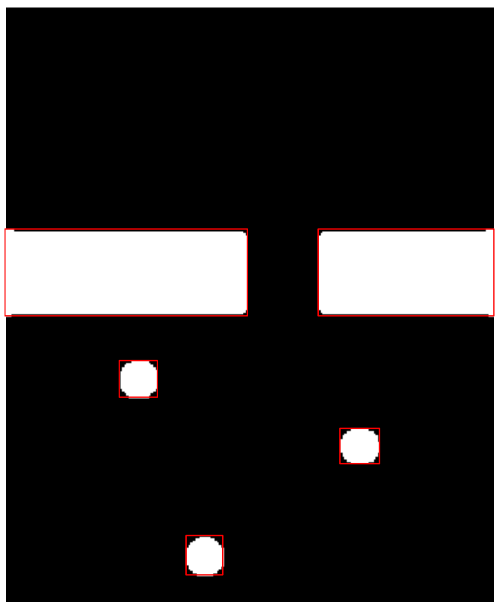
(b) Original gray image



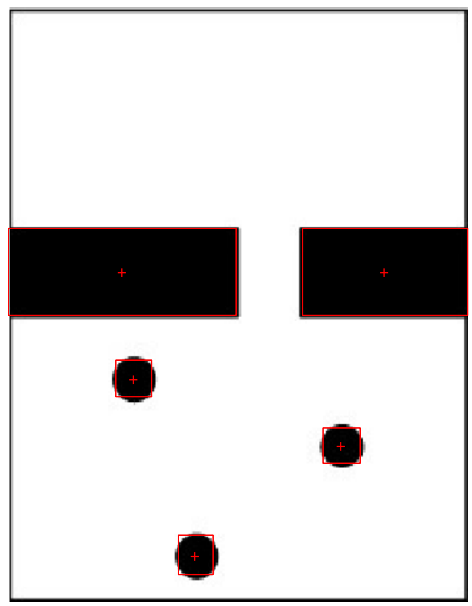
(c) binarization



(d) Morphological operation



(e) Effective region extraction



(f) Labeled image

Figure.8 Image processing

Table 1: Image processing results

Parameters / **S**	***x***	***y***	**Area**	**L**	**W**
S_1	55.3332	121.4953	4181	110	40
S_2	61.0486	170.0486	247	17	17
S_3	91.0319	250.7410	251	17	18
S_4	182.6652	121.4936	3041	80	40
S_5	161.4644	200.5105	239	18	16

That can be analyzed by the data in Table 1, the number of pixels of S1 and S4 for more. The S_1 and S_4 are labeled as the obstacles according to the actual situation. The S_2, S_3 and S_5 are labeled as the ground unmanned platform as the number of pixels are similar. And it can be concluded that the radius is about 17. The information on the middle channel of the two obstacles can be obtained by processing the image, which is not listed in the table. The length and width of the two obstacles are 110, 40, 40 and 80. The center position of the channel can be obtained as (126.4992 121.4765).

The formation simulation experiment can be carried out with the combination of the formation algorithm and the image processing algorithm. Since the origin of the coordinate system used in the image processing is the upper left corner of the image this method is also used in this way. The location of obstacles can plan the route information of the safe passage. It can be concluded that the formation of the linear equation is about x = 126.4992. That is perpendicular to the X axis. The position coordinates of R_1, R_2 and R_3 are (61.0486 170.0486)、(91.0319 250.7410) and (161.4644 200.5105). The safe spacing is set to 35 pixels. The 80.6924 is the distance between R_1 and R_2 pedal in a straight line. R_3 can be accommodated. Unmanned ground platform from the random state formation to the line formation the simulation processes are shown in Figure 9. The process of avoiding obstacles in a straight line formation is shown in Figure 10. Only a few moments of the state are displayed.

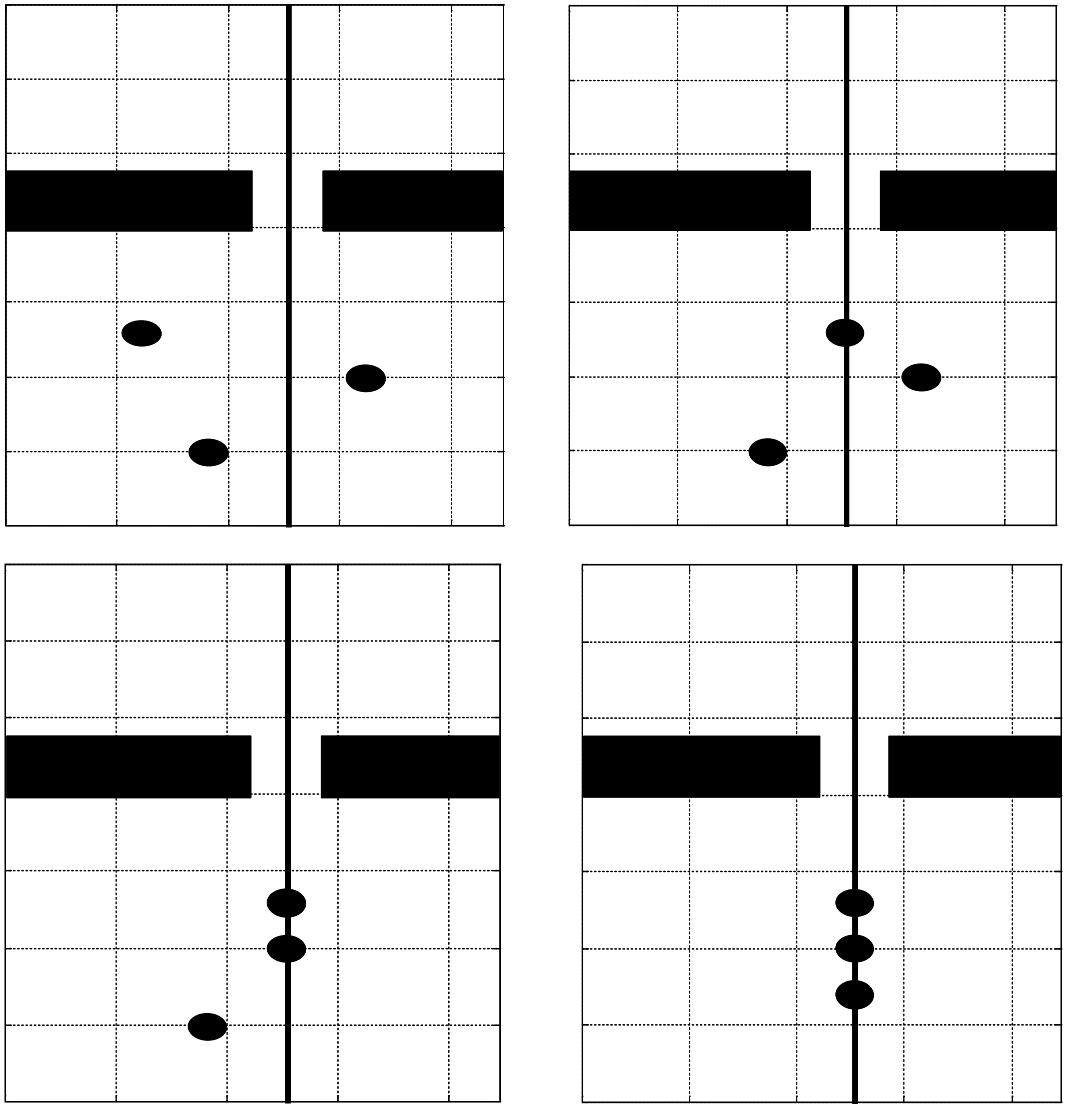
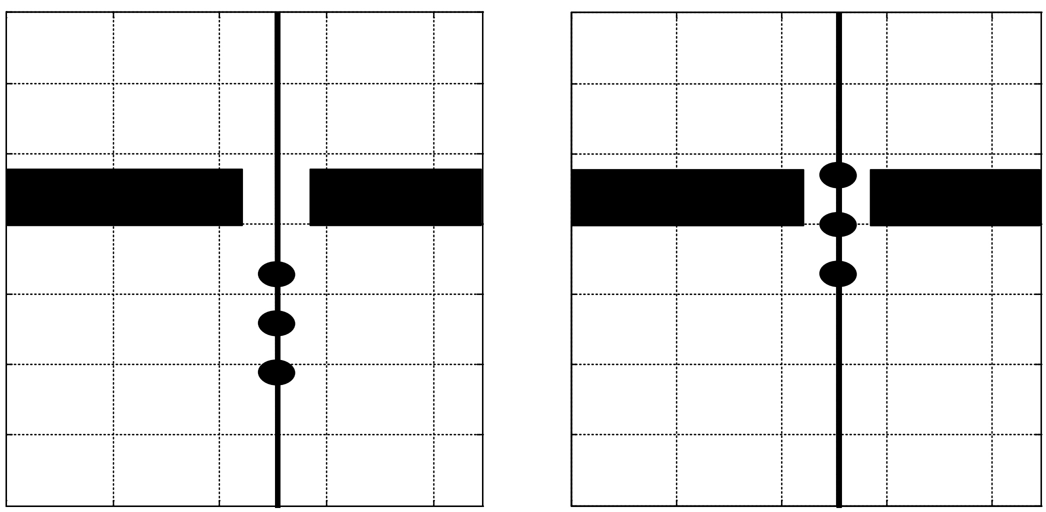


Figure.9 The formation of linear



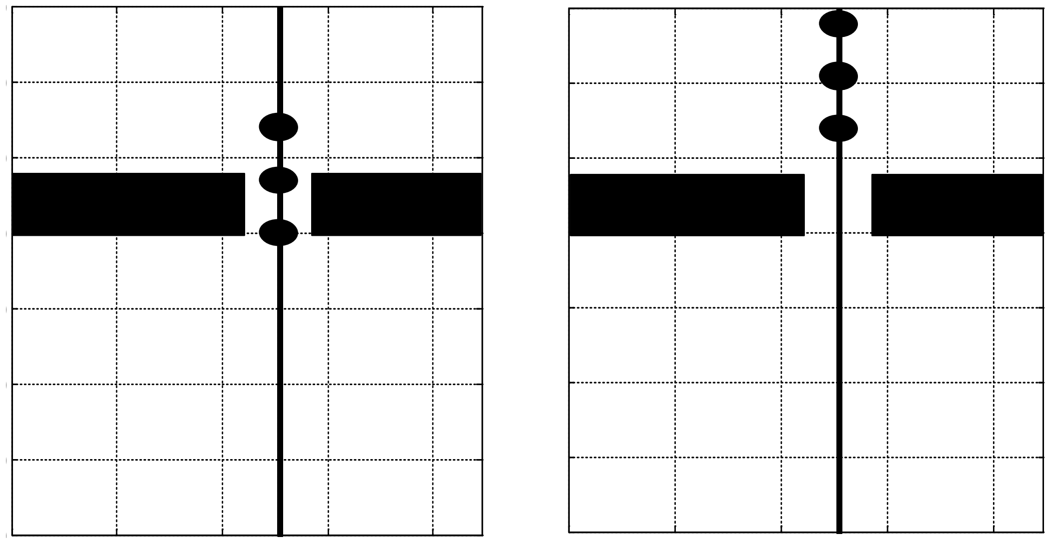


Figure.10 Straight forward formation

VI. CONCLUSIONS

In this paper, a novel cooperative obstacle avoidance scheme and an improved linear formation algorithm for multiple mobile robots are proposed. The simulation experiments are carried out on the formation of the line. The validity and the performance of the linear formation algorithm are verified. Experiment is carried out on the cooperative obstacle avoidance. The cooperative obstacle avoidance scheme is a powerful support to the cooperative work of multi unmanned platform. However, the ground multi mobile robot used in this paper cannot be able to achieve precise control. The structure needs to be improved, such as the use of the steering gear to control the vehicle to get better results. In addition, the transmission rate is not satisfied with the requirement of the real time transmission image because of the serial connection of PC of 2.4G. The WIFI transmission will be used to solve the problem in the future.

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