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DEVELOPMENT OF THE KNRM SYSTEM BASED MOBILE ROBOT

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Abstract. *The paper develops a mobile based robot arm using KNRm system. The core of KNRm system adopts NI Single-Board RIO 9606 embedded platform, which integrates some sensors, two servomotors, four RC servomotors, a controller, and an image processing module. The developed mobile platform uses light sensors and touch sensors for line tracking and detects the initial location, and uses ultrasonic sensors to detect the obstacles. Trapezoidal acceleration and deceleration algorithm and Proportional-Integral-Derivative (PID) algorithm are used for precise motion control. Specifically, the developed motion platform takes advantages of NI LabView Vision Assistant's image processing functionalities, like color threshold, dilation, erosion, and convex hull, for distance estimation of the object. The mobile platform embeds a robot arm with four degrees of freedom. The driver of the robot arm uses RC servomotors with four joints. The robot arm can move to the assigned position, and catch the selected object using image binanzation method and Otsu algorithm by the visual system.*
Keywords: Mobile based robot arm, KNRm system, NI Single-Board RIO 9606, DC servomotors, trapezoidal acceleration and deceleration algorithm, Proportional-Integral-Derivative (PID) algorithm, Otsu algorithm

1. **Introduction.** An autonomous mobile platform usually works for a predefined task to allow a remote user to order the mobile platform doing the assigned task. Mobile robots have been widely applied in many fields, such as factory automation dangerous environment detection, office automation, hospital, entertainment, farm automation and security system. There are some successful examples, such as ASIMO, KHR, NAO, QRIO and AIBO. We have designed an intelligent mobile robot to do auto-recharging process autonomously [1,2]. In practice, a human can want the mobile platform to do something else and monitor the assigned task with the robot arm such as catching an exploder and moving a dangerous object. In the paper, we design a mobile platform to finish some assigned tasks with a robot arm. The mobile robot can help the human to work in dangerous environment.

We research path planning of mobile robots to solve the problems such that the robots can move from the start point to the target point on uneven terrain. In the past literature, many experts research stable walking on uneven terrain. Ma et al. designed a mobile platform to be called IsiSkate and is an omnidirectional mobile robot. The platform used force and inertial sensors for the evaluation of human posture for static and dynamic equilibrium analysis of a human standing on it [3].

Peng et al. designed a where/track mobile platform to search and rescue in dangerous environment. The motion modes of the mobile platform can be switched alternatively to adapt on different ground situations [4]. Bloesch et al. presented a state estimation approach for legged robots based on stochastic filtering, and designed an unscented Kalman filter and outliers rejection methodology based on a consistent formulation of the underlying tochastic model [5]. Guo et al. developed a mobile platform, based on KNR controller. The mobile robot embedded a robot arm with four degrees of freedom, and used light sensors and touch sensors for line tracking and detection of the initial location [6].

The paper is organized as follows. Section 2 describes the system architecture of the mobile robot. Section 3 explains the motion control of the mobile based robot arm. The vision system is presented in Section 4. Section 5 presents the experimental results for the mobile robot to finish assigned tasks. Section 6 presents brief concluding remarks.

2. **System Architecture.** The block diagram of the mobile based robot arm is shown in Figure 1. The system contains two parts. One is a computer and a vision system. The computer can program the motion functions using NI LabView system. The vision system recognizes the shape and color of the selected object. The monitor interface system is developed on the computer. The other is a KNR system, some sensors, some based on LEGO sensors, three DC servomotors and four RC servomotors.

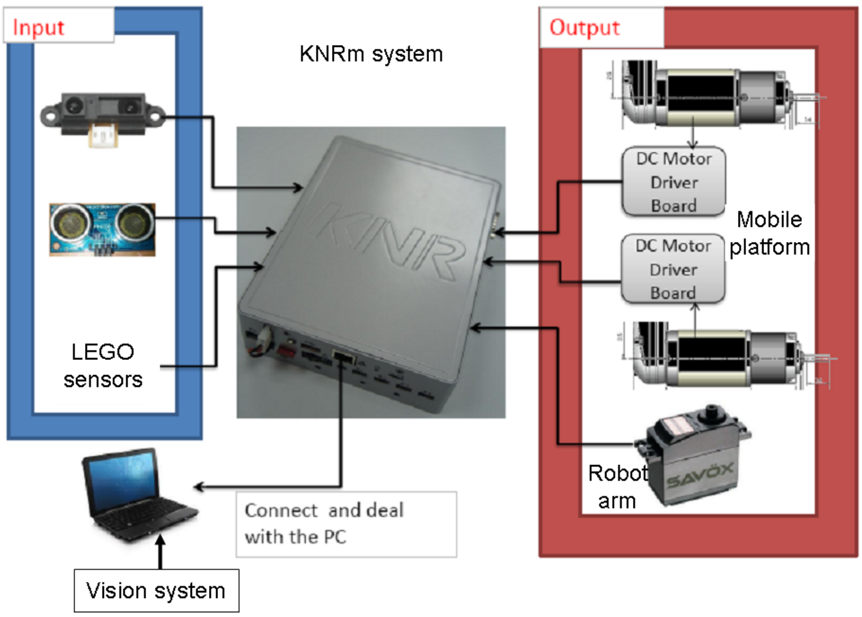


FIGURE 1. System architecture

The main controller of the mobile based robot arm is a KNRm control box. The main element of the sensor system contains some ultrasonic sensors to be fixed on the front side of the mobile platform. The ultrasonic sensors can detect the long distance from the obstacle. The mobile robot uses some IR sensors to detect the fixed distance range of the obstacle. Some LEGO based sensors are used to detect the known motion path that programs on the ground using the electrical adhesive tape. The mobile platform has two driving wheels to be embedded on the front side and uses one steer-wheel to balance the centre of gravity. The prototype of the mobile based robot arm is shown in Figure 2. The driver elements of the robot arm are four RC servomotors. The robot arm fixes on the front side of the mobile platform, and is driven by the KNRm controller. The rotation angle of each joint is shown in the left side of Figure 2.

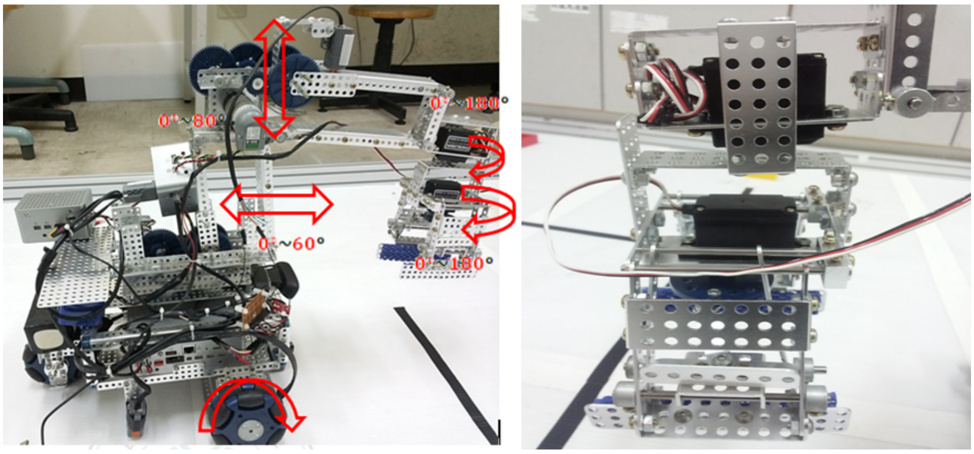


FIGURE 2. Mobile based robot arm

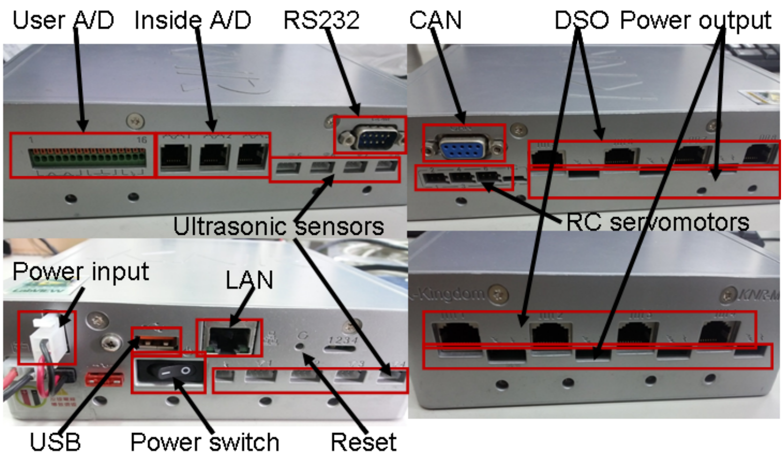


FIGURE 3. The KNRm controller

In order to achieve the purpose of accurate positioning, the control core of the mobile platform uses the KNRm controller. The structure of the mobile platform uses Matrix element. The hardware device of the KNRm control box is shown in Figure 3. The length, width and height are about 20cm, 20cm and 5cm respectively. The control box displays the function of each connective pin. Users can select the needed element to connect with the control box for the assigned task.

3. **Mobile Based Robot Arm.** The mobile based robot arm can use two DC servomotors moving on the programmed motion paths. The KNRm system controls each DC servomotor using the module based driver device, and plans the rotation range according to the feedback signal of the encoder sensor. The controller of the KNRm system uses PID control law and trapezoidal acceleration and deceleration algorithm to control each DC servomotor, and tune the mobile platform to follow the programmed trajectories. The mobile based robot arm uses three spring elements to decrease the vibration of the motion platform.

The controller of the KNRm system computes each compensator signals (P, I and D) according to the error signals as the following:

$$e = SP - PV \tag{1}$$

$$u(t) = K_c \left[e + \frac{1}{T_i} \int_0^t e dt + T_d \frac{de}{dt} \right] \tag{2}$$

SP is desired value, and PV is measured value. K_c is the proportional constant, T_i is integral time constant, and T_d is derivative time constant. In the motion control algorithm of the mobile based robot arm uses trapezoidal acceleration and deceleration algorithm to get the precious position in movement process. The curve of the trapezoidal acceleration and deceleration algorithm is shown in Figure 4. We can compute the displacement of DC servomotor using the velocity value. The formula can be written as the following:

$$\Delta X = \frac{1}{2}a\Delta T_1^2 + V\Delta T_2 + \frac{1}{2}a\Delta T_3^2 \tag{3}$$

where a is acceleration; V is velocity and ΔX is displacement. Then we can rewrite the formula as the following:

$$S = V_0\frac{V_0}{a} - \frac{1}{2}a\left(\frac{V_0}{a}\right)^2 = \frac{1}{2}\frac{V_0^2}{a} \tag{4}$$

where V_0 is the initial velocity.

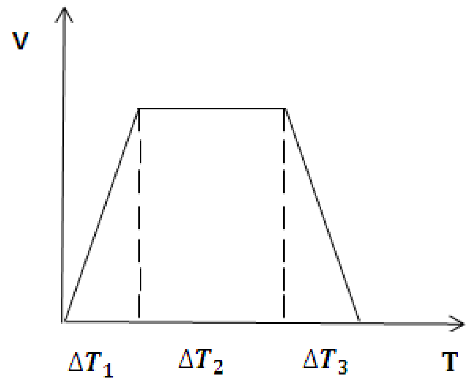


FIGURE 4. Trapezoidal acceleration and deceleration algorithm

4. **Visual System.** We use image binanzation method and Otsu algorithm to classify color and shape of the sphere using image recognition system, and define the pixels of a given picture to be represented L in gray levels $[1, 2, \ldots, L]$. The number of each pixel at level i is denoted by n_i, and the total number of pixels is $N = n_1 + n_2 + \cdots + n_L$. In order to simplify the discussion, we can rewrite the gray level histogram to be normalized and regarded as a probability distribution:

$$p_i = n_i/N, \;\; p_i \geq 0, \;\; \sum_{i=1}^{L} p_i = 1 \tag{5}$$

Now suppose that we dichotomize the pixels into two classes C_0 and C_1 (background and objects) by a threshold at level k; C_0 denotes pixels with levels $[1, 2, \ldots, k]$, and C_1 denotes pixels with levels $[k+1, k+2, \ldots, L]$. Then the probabilities of class occurrence and the class mean levels, respectively, are given by

$$\omega_0 = \Pr(C_0) = \sum_{i=1}^{k} p_i = \omega(k), \quad \omega_1 = \Pr(C_1) = \sum_{i=k+1}^{L} p_i = 1 - \omega(k) \tag{6}$$

$$\omega(k) = \sum_{i=1}^{k} p_i, \quad \mu(k) = \sum_{i=1}^{k} ip_i, \quad \mu_G = \mu(L) = \sum_{i=1}^{L} ip_i \tag{7}$$

In order to evaluate the optimal threshold value (at level k), the following discriminant criterion measures are used in the discriminant analysis [7]:

$$\lambda = \sigma_B^2/\sigma_W^2, \quad \kappa = \sigma_G^2/\sigma_W^2, \quad \eta = \sigma_B^2/\sigma_G^2 \tag{8}$$

$$\sigma_W^2 = \omega_0\sigma_0^2 + \omega_1\sigma_1^2, \quad \sigma_B^2 = \omega_0\omega_1(\mu_1 - \mu_0)^2, \quad \sigma_G^2 = \sum_{i=1}^{L}(i - \mu_G)^2 p_i \tag{9}$$

The optimal threshold is to maximize η value. The image recognition method of the sphere is shown in Figure 5. The method calculates the radius of each sphere on the ground. The vision system is fixed on the gripper of the robot arm, and catches the distance from the robot arm to the selected object according to the radius value of the sphere. The main controller of the mobile platform catches the image signal from the vision system (Open-CV), and searches the assigned sphere on each flame, and controls the robot arm approach to the selected sphere. The mobile platform tunes the moving direction according to the position of the detected sphere. The size of the detected sphere is shown in Figure 6. The mobile robot turns catch the selected sphere in the centre of the flame, and open the gripper to catch the selected sphere. Then the robot arm moves down to catch the selected sphere until the threshold distance of the sphere radius.

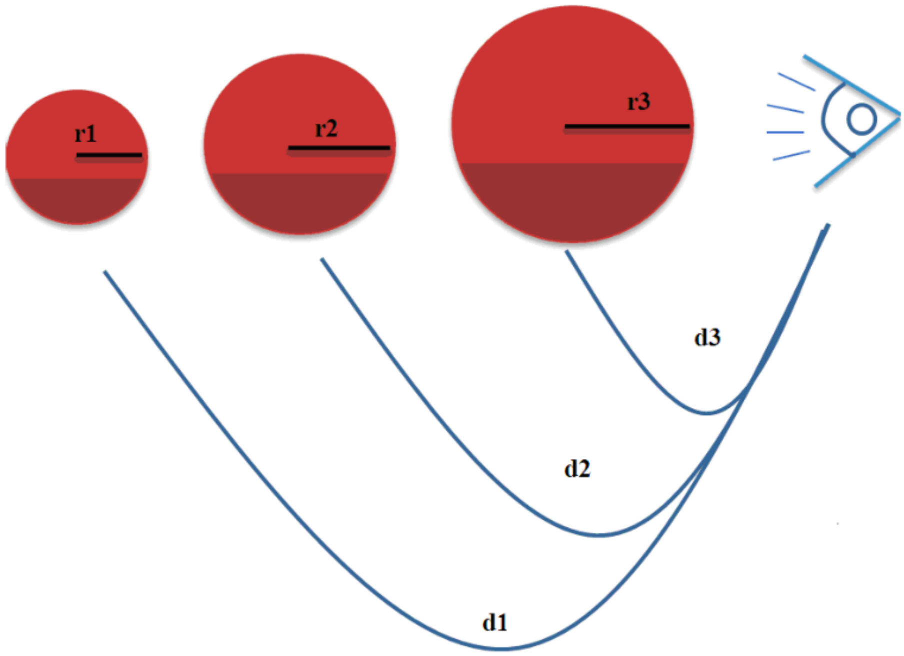
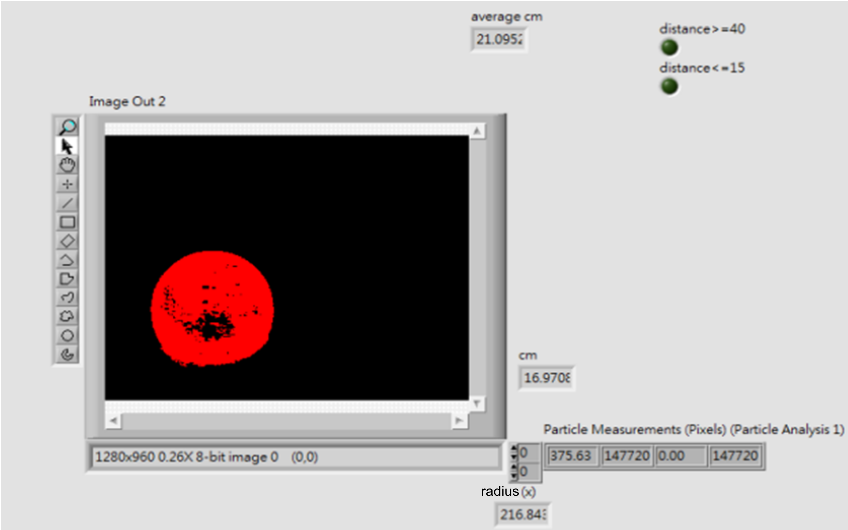


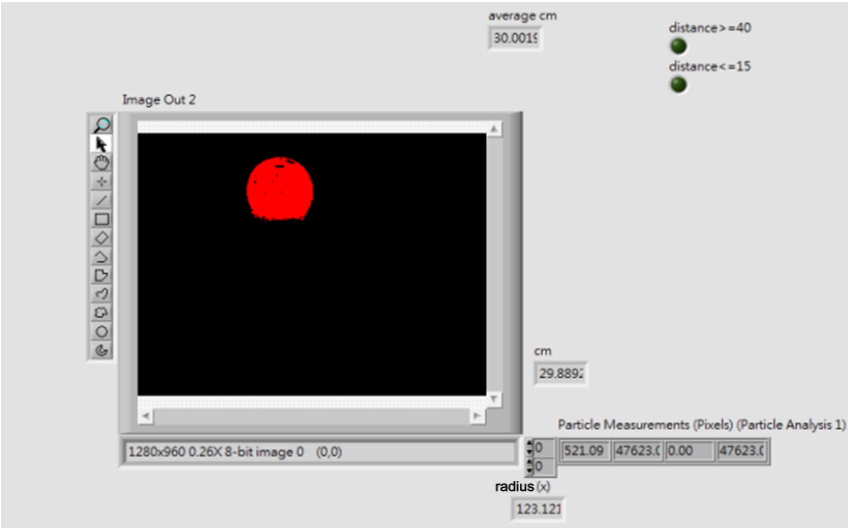
Figure 5. Detection method of visual system

5. **Experimental Results.** We implement the experimental scenarios for the mobile platform moving in the region (length 4m and width 2m). The mobile platform searches and moves the position of spheres, and uses the vision system to focus on the assigned sphere. The vision system is fixed on the gripper of the robot arm. The pre-processing of the vision system is shown in Figure 7 using LabView software. The processing of image recognition includes four steps, namely, open objects, remove small objects, convex hull and particle analysis. The program of LabView is shown in Figure 8 for pre-processing of the vision system.

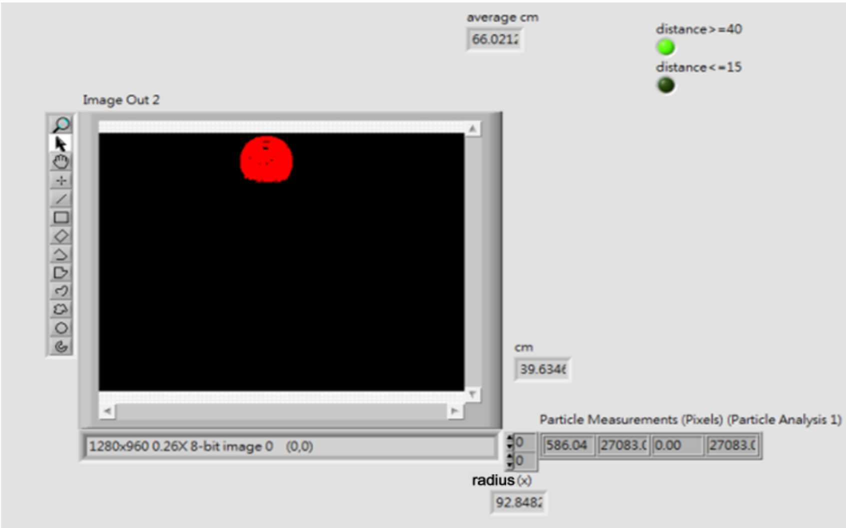
The vision system sets the parameters using the vision acquisition module and vision assistant module of the LabView software, and catches the sphere in the centre of each flame, and computes the average value of the measured signals using add array element function shown in Figure 9. Finally the mobile platform searches and moves to the position of the sphere shown in Figure 10(a), and tune the direction of the robot arm to catch the image of the sphere in the centre of the flame shown in Figure 10(b). The control box of the mobile platform uses LabView software to recognize the color of the sphere to be right shown in Figure 10(c).



(a) 15cm

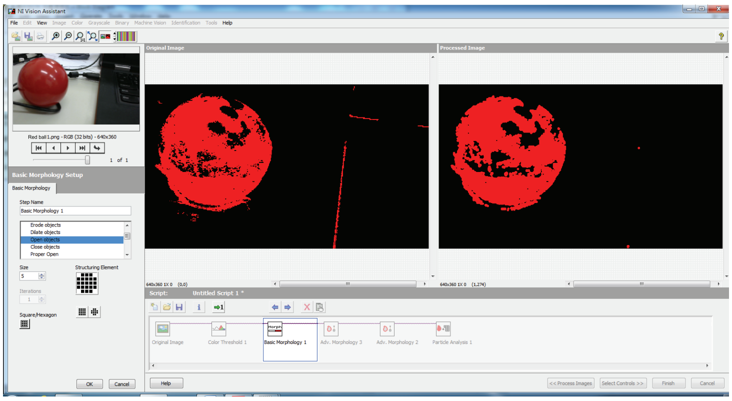


(b) 30cm

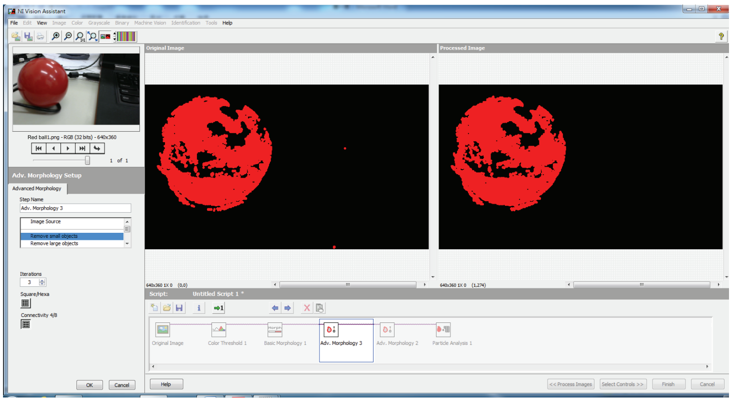


(c) 40cm

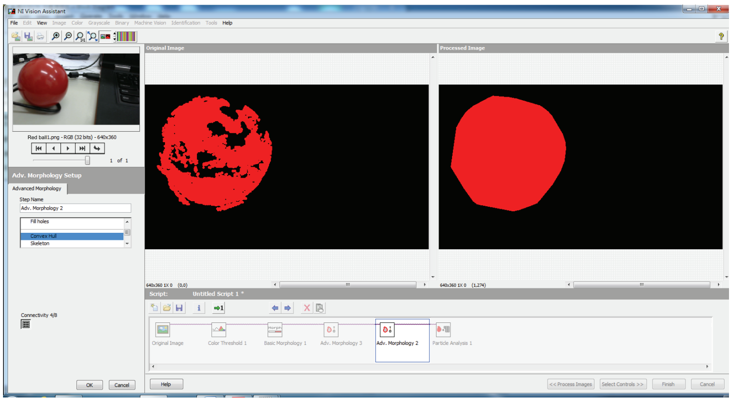
Figure 6. The radius of the sphere for visual system



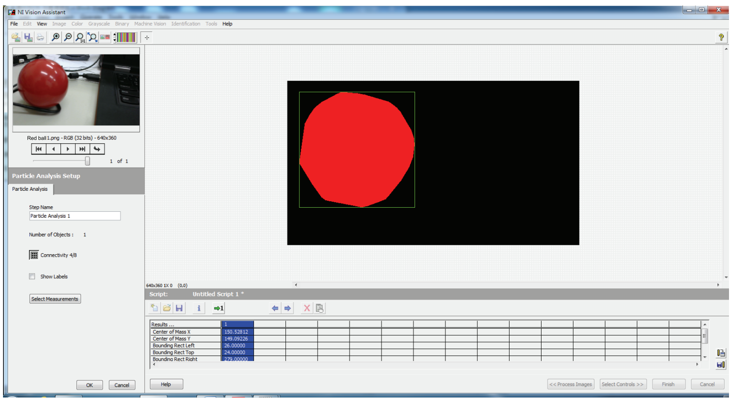
(a) Open objects



(b) Remove small objects



(c) Convex hull



(d) Particle analysis

Figure 7. Image processing of the sphere

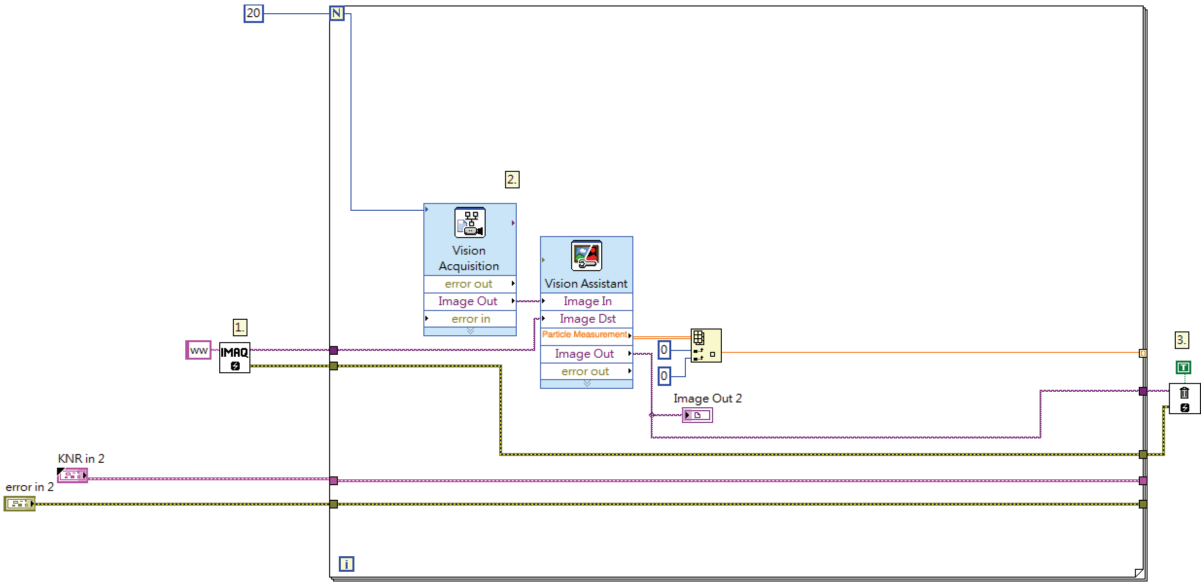


FIGURE 8. The program of image pre-processing

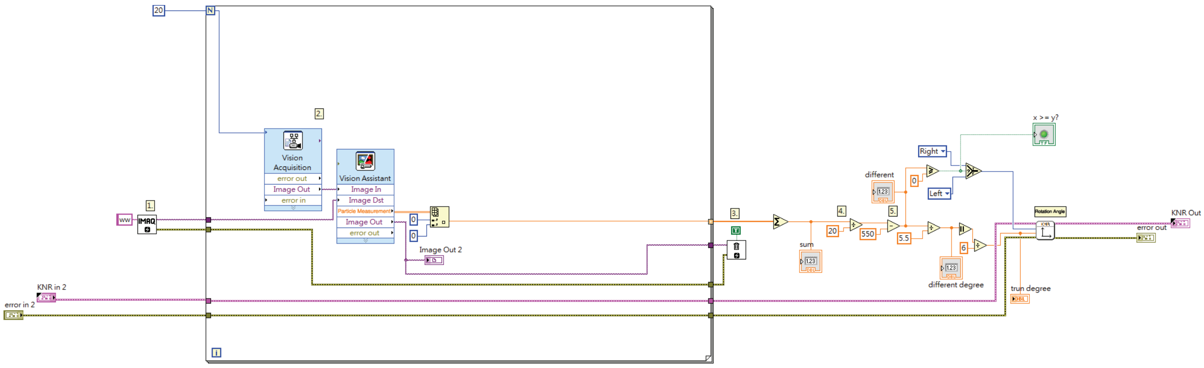
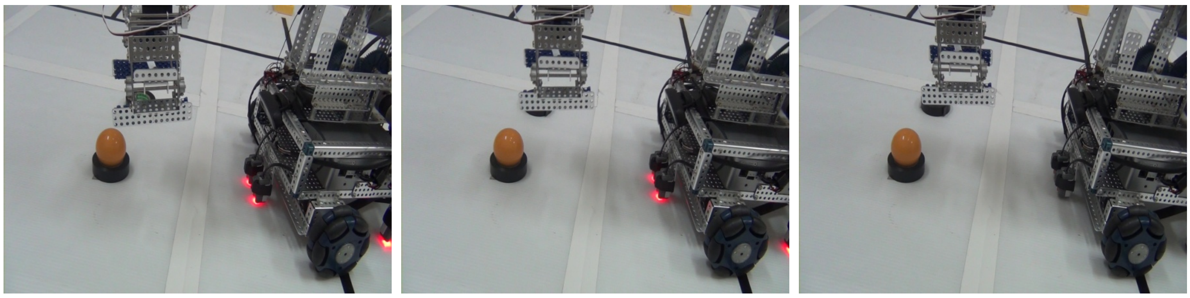


FIGURE 9. Final program of the sphere recognition



(a) (b) (c)

FIGURE 10. The experimental result

6. **Conclusion.** We design a mobile platform with a robot arm using KNRm system. The mobile platform uses trapezoidal acceleration and deceleration algorithm and Proportional-Integral-Derivative (PID) algorithm to control each DC servomotor, and moves to the assigned location. The control box of the mobile platform can use image binanzation method and Otsu algorithm to classify color and shape of the sphere using image recognition system. The controller of the KNRm system can establish the control command to the module-based driver device and control the mobile platform to move along the programmed trajectory. In the future, we want to improve the proposed method and

modify the driver system to increase the motion speed and decrease recognition time of the vision system for the mobile based robot arm.

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