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### Determination of rotation angle based on invariant moment and MADALINE for HGA grasping

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#### Abstract

To proposed a new adaptive intelligent system for a robot work cell that can visually track and intercept an invariant stationary HGA feature undergoing arbitrary orientation anywhere along its predicted trajectory within the robot's workspace is presented in this paper. A combination of the seven invariant moment technique, image feature technique and the MADALINE network are used for identifying the stationary HGA at any rotation angle without overlapping and generating the predicted robot trajectory respectively. An invariant moment that has system for a scale, translation and orientation are calculated for each significant region in the input images. Inertial ellipse is determining for angle rotation that compare against to the accepted orientation that required. The result shown that, the relationship between the visual feedback image data and the control command for changing the axis motion shows deviation of robot placing less than 2% by the MADALINE network for intercepting stationary HGA at any rotation angle. The location and image features of these HGAs need not be preprogrammed, marked and known before, and any change in a task is possible without changing the robot program. Finally, this novel method can improve the hard disk drive (HDD) assembly process productivity.

**Keywords :** HGA, Invariant moment, Orientation angle, MADALINE

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### 1. Introduction

The head gimbal assembly (HGA) is the essential component in hard disk drive that rely on the drive quality. In process of mounting the HGA to the actuator arm is considered. The HGA orientation is subjected to achieve in good rotation prior mount to the actuator arm. Apart from the traditional alignment method, machine vision is developed [1] along with seven invariant moments that apply to assist the HGA pick and place activity. These two consolidations will deploy to reduce the variation of drive yield due to the assembly complexity.

Transportation of the HGA to the swaging process of the head stack assembly (HSA) is carried by the shipping tray. The orientation angle is an essential to make the head alignment in row.

Traditional picking up process as illustrated in Figure 1 the pick and place robot hand gripper does not perform the orientation angle on each HGA in the shipping tray. As described in swaging process, the HGA is now done in row of head alignment on the actuator arm as illustrated in Figure 2. In this traditional situation, all HGAs are picked up by robot hand gripper regardless of checking the orientation angle from the shipping tray. Otherwise, to align the HGA on the alignment nest is objected to improper seated in tooling pin and lower clamp. These symptoms may cause damaged to HGA by end effector hit to the HGA structural regardless of checking out the orientation angle as illustrated in Figure 3.

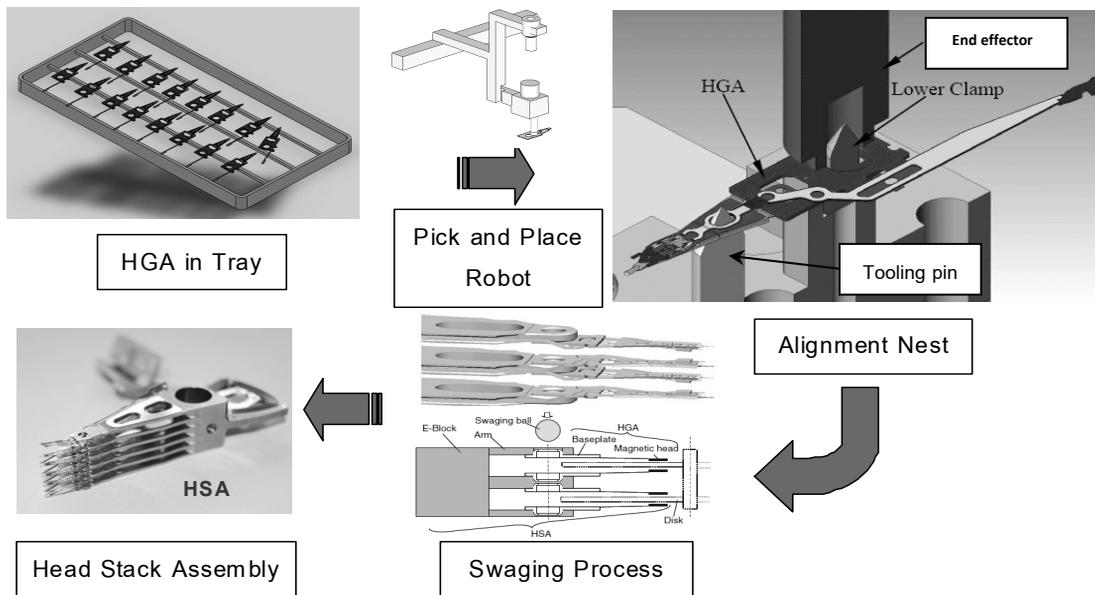


Figure 1 HGA picking up process to head stack assembly

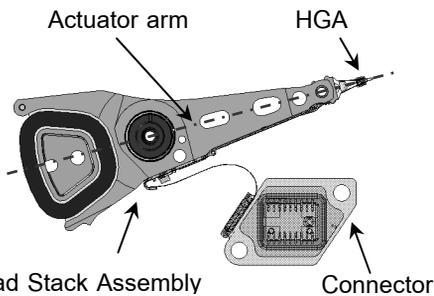


Figure 2 The HGA aligned in row of head stack assembly



Figure 3 The illustration of HGA damaged

Figure 2 The HGA aligned in row of head stack assembly

Another orientation issues due to the tolerance deviation of the shipping tray or shaking during transportation from engineered design case. To ensure the quality of such components, machine vision is essential to perform the inspection. Machine vision is one of the most versatile in quality assurance of many hard disk drive industries.

There are several approaches for applying the machine vision that involve with image processing were proposed. Machine vision to assist the component assembly was proposed [1] that can be reduced human error. The developed automatic visual inspection [2] was reduced noise from component image using Gaussian filter. Image processing is a fundamental of machine vision that deals with the algorithm to extract the characteristic of the image. Recently, edge detection is mainly basis of image segmentation, image representation and image recognition [3]. Morphological image processing is widely using for image segmentation that performs as a nonlinear filtering method. Many researches are introduced invariant moment in image representation and recognition [3-5]. These have been widely applied to image pattern recognition due to its invariant features on translation, scaling and rotation. To determine the orientation of angle rotation that considered, the shape representation [9] which is widely used to extract reliable information of the object outline is proposed. Inertial ellipse is applied corresponding to locate the target of its hole centroid and equivalent ellipses around HGA body orientation is implicit to HGA orientation be determined. However, to address this research problem, result of invariant moment analysis correspond to the orientation is presented. In additional, comparison between good orientation and not good orientation is determined.

In this paper, we developed an enhancement technique for HGA orientation feature extraction. Seven invariant moments of rotations are represented for shape recognition. Inertial ellipse as feature attraction is used to determine the orientation rotation of HGA. The image processing toolbox of MATLAB is encouraged. This novel method can improve the HDD assembly process, especially in HGA pick and place. Finally, this development can reduce the HDD yield loss and improve productivity.

## 2. Experiment

This research objective is to find the rotation angle which corresponded to the good orientation that considered. In this experiment, zero degree is indicated in good orientation. The output is consists of a rotation angle that supposed to HGA orientation angle and predicted robot trajectory for robotic manipulator applications. Figure 4 is the experiment setup of this research.

### 2.1 Image acquisition

HGA images were taken by web camera. These images are corresponding with the real object where factory built. Three modal orientations are determined. Figure 5 (a) original image illustrates the three modal orientations for experiment setup.

### 2.2 Image processing

Gaussian filter [2] is considered for pre-processing the HGA images prior segment process. The benefit of the Gaussian filtering can be used as a noise removal and is the only filter that has no ripple and hence no ringing effect.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}} \quad (1)$$

where  $G(x,y)$  is the Gaussian function which spread about the center in 2-D function at the intensity value on the position  $(x,y)$  component and  $\sigma$  is the standard distribution of the spread factor.

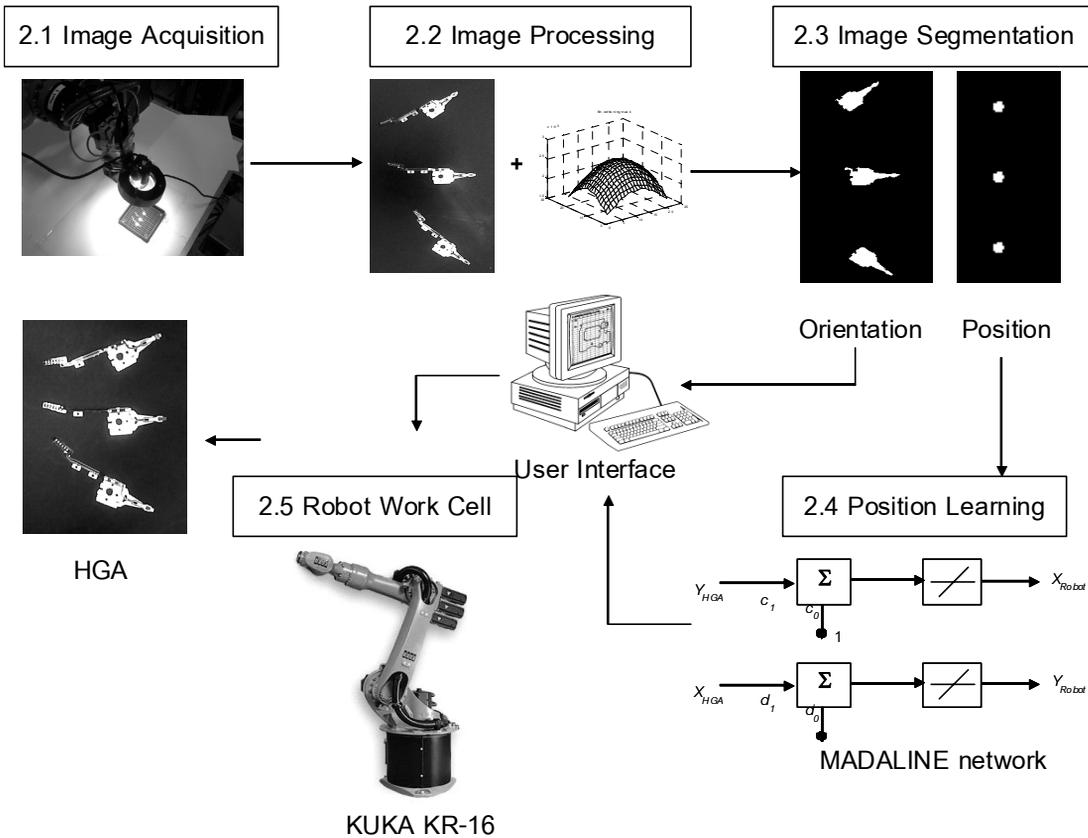


Figure 4 The experiment setup

2.3 Image segmentation

2.3.1 Morphological

Morphological image process [2,3], in general, mathematical morphology is a nonlinear filtering method. Fundamental is based on set theory and idea to use a structuring element (SE) to extract the corresponding shape of the HGA image for image analysis and recognition. In tradition edge detection, the morphological segmentation is using for segmented by thresholding the gray scale image and then the image is determined to convert into binary image.

On this section, the target area, holes in image, are determined as illustrated in Figure 6. The target bodies are also determined as a region of orientation. The basic operations of mathematical morphology are erosion, dilation, opening and closing, which deal with original image and SE that performed by mathematics set operation.

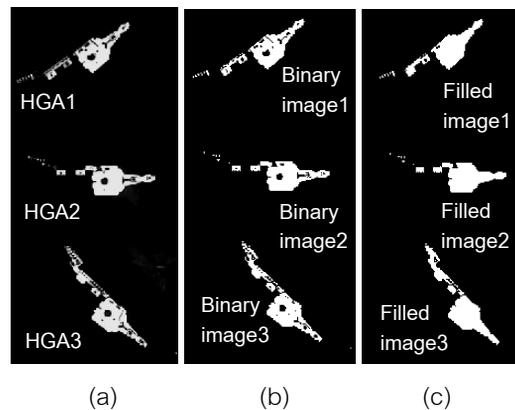
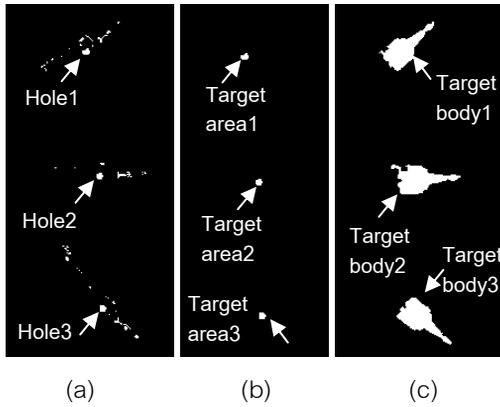


Figure 5 The HGA images in process of pre-processing, HGA1, HGA2 and HGA3 are shows (a) original image, (b) binary image and (c) filled image



**Figure 6** The HGA images in process of morphological, (a) hole in image, (b) target area and (c) target body

2.3.2 Invariant moment

In this work, invariant moment analysis for HGA orientation is described [5, 6]. Pattern recognition in angle of rotation is also determined. Statistical contribution in invariant moment analysis can be taken in account.

The computed of the centroid,  $m_{pq}$  of image  $f(x,y)$  whose center has been shift to centroid of image. Therefore, the central moments are invariant to image translation based on Hu [4] introduced the seven invariant moments. In this case, the simple method is using the orientation of the inertial ellipse as closed regions [6]. This meant that the inertial ellipse is based on the second order area moments of the object. To normalize the translation by the centroid,

$$m_{10} = m_{01} = 0 \tag{2}$$

and normalize the rotation by the constraint  $m_{11} = 0$  and get the angle  $\theta$ ;

$$\tan 2\theta = \frac{2m_{11}}{m_{20} - m_{02}} \tag{3}$$

This is the widely principle of the axes transformation of the inertial ellipse. The angle may be corresponded to either the major axis length or the minor axis length.

2.3.3 Orientation angle

Figure 7 illustrated the orientation angle transformation of the principle of axes from the three modal of orientations. Major axis length and minor axis length are computed the rotation angle. These three modal of orientations supposed as the pick position of the robot hand gripper. The ninety degree indicated the target orientation angle where the robot hand gripper is done for the trajectory at the place position. Orientation angle adjustment is also done by the KUKA robot manipulator protocol.



**Figure 7** The orientation angle transformation of the principle of axes

2.4 Position learning

2.4.1 MADALINE network

The MADALINE network [7,9] is applied to map the visual information to position and orientation of the end effector in the real time operation of the robot work cell system. The network is used to compute the robot trajectory. Its structure has only a hidden single layer which uses a linear transfer function to determine the input-output relationship. An output vectors representing the image coordinate pairs as illustrated in Figure 8.

An appropriate initial weight  $c_1, d_1$  and biases  $c_0, d_0$  are weighted to each external input and the sum of them is sent to the hidden layer which has the linear transfer function. The weight can be determined by training the MADALINE network using

the least mean squares error rule (LMS) with a small learning rate value. The LMS algorithm tries to iterate the weights and biases values until they converge. The convergence means this supervised learning rule is used to adjust the weights and biases of the network in order to move the network outputs closer to the targets or a small error goal. The linear transfer function calculates the neuron's output vector 'a' by simply returning the value passed to it as following:

$$\mathbf{a} = \text{purelin}(\mathbf{n}) = \text{purelin}(\mathbf{Wp} + \mathbf{b}) = \mathbf{Wp} + \mathbf{b} \quad (4)$$

This network has to be trained before using. For this experiment, 24 target positions ( $X_{HGA}, Y_{HGA}$ ) and end effector coordinate pairs data ( $X_{Robot}, Y_{Robot}$ ) are used for object position learning. The input layer, hidden layer and output layer are 24-24-24 nodes respectively. The number of learning repetition times (epochs) that using in this algorithm is about 10.

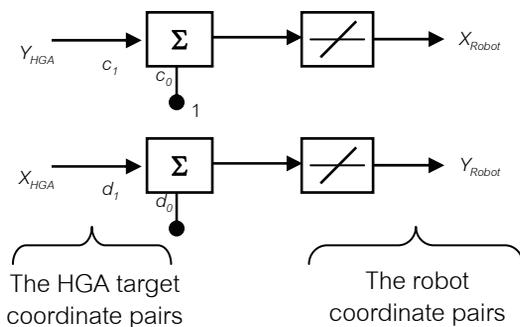


Figure 8 MADALINE network for rotational HGA grasping task

### 2.5 Robot work cell

To determine the robot coordinate pairs in robot work cell that achieved from the computed centroid in Figure 4 & 6 where indicated the target area. Total 24 coordinates of target area are manipulated into the neural network [8,9].

## 3. Result

### 3.1 Invariant moment

The invariant moment results for HGA1, HGA2 and HGA3 which tested from the target bodies of HGA from Figure 6 (c) are shown in Table 1. The values of the Hu seven invariant moments described in 2.3.2 that indicated as  $m_1$  to  $m_7$  to describe the rotation moments in each seven orders. The results shown that there are no significant different on each HGA of any rotations on each order. This means that each HGA has the same characteristic and has the same order moments. Thus, the method can be used for the orientation angle determination of the HGA closed region for robot interpolation.

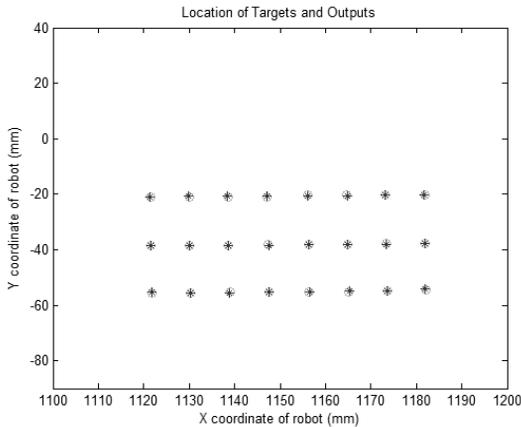
### 3.2 Orientation angle

Figure 7 presents the orientation angle transformation of the principle of axes from the three modal of orientations. Major axis length and minor axis length are computed the rotation angle. Table 1 is the result of the orientation angles in degree at the pick position before orientation angle adjustment and place position after orientation angle adjustment is done by robot interpolation.

### 3.3 Position learning

The results of the hybrid vision system based on the combination of the model-based object recognition technique and artificial neural network. These features are varied in position and orientation. Different in location of HGA features were placed on the stationary tray at random locations. The HGAs were grabbed by the camera and the desired HGA can be identified by features.

- = HGA target coordinate
- + = Robot target coordinate



**Figure 9** Relationship between the robot and target HGA coordinates

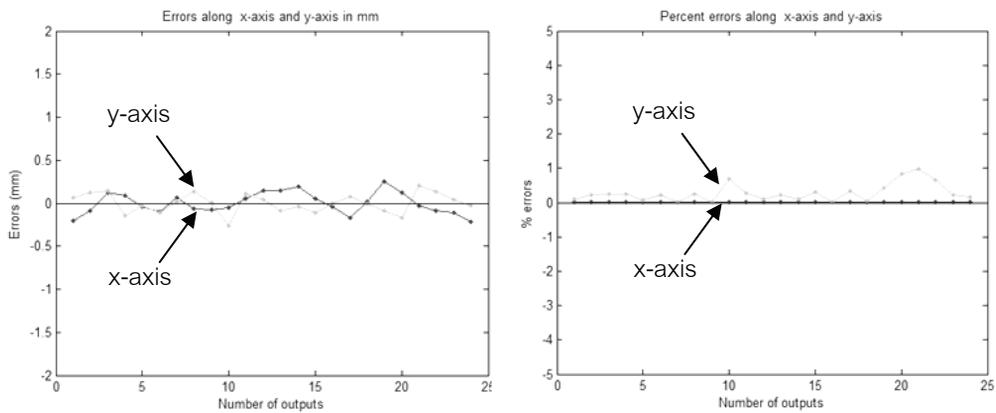
The relationship between the robot target coordinate and HGA target coordinate illustrated as Figure 9 was first determined by using the computer simulation for the off-line study. In case of HGA grasping with an artificial neural network experiment, the relationship between the robot and HGA target coordinate can be trained and learned by using MADALINE. That is, 24 coordinates of target area were used for object position learning. After training this network, it can recognize the predicted robot trajectory that used for grasping task.

The results from the computer simulation will be also presented for experimental validation of the off-line algorithm in the on-line study. The robot protocol received the target location data and sent to the robot manipulator to pick and place the desired HGA on the tray.

**4. Conclusion**

A new adaptive linear robot control system for a robot work cell can visually track and intercept stationary objects undergoing arbitrary orientation anywhere along its predicted trajectory within the robot’s workspace is presented in this paper.

To test the effectiveness of the relation between the robot target coordinate and HGA target coordinate, simulations where the robot target and HGA target are performed. The error in millimeter and percentage along x-axis and y-axis are illustrated in Figure 10 that shown the repetition performance that robot trajectory can used for grasping task within tolerance acceptance. The best performance is achieved on x-axis but also y-axis is also done the same performance.



**Figure 10** Error in millimeter along x-axis and y-axis of relationship between the robot and target HGA coordinates and percent error along x-axis and y-axis of relationship between the robot and target HGA coordinates

**Table 1** Invariant moment, orientation angle result of HGA1, HGA2 and HGA3

Item	HGA1		HGA2		HGA3	
	Pick position	Place position	Pick position	Place position	Pick position	Place position
Rotation angle (Degree)	110	89	96	92	70	93
Moment						
$m_1$	$2.1 \times 10^8$	$1.9 \times 10^8$	$2.2 \times 10^8$	$2.1 \times 10^8$	$2.0 \times 10^8$	$2.1 \times 10^8$
$m_2$	$1.8 \times 10^{16}$	$6.7 \times 10^{15}$	$2.0 \times 10^{16}$	$1.0 \times 10^{16}$	$1.6 \times 10^{16}$	$1.0 \times 10^{16}$
$m_3$	$1.3 \times 10^{19}$	$2.8 \times 10^{18}$	$1.6 \times 10^{19}$	$6.9 \times 10^{18}$	$1.2 \times 10^{19}$	$5.0 \times 10^{18}$
$m_4$	$5.6 \times 10^{18}$	$4.8 \times 10^{17}$	$5.7 \times 10^{18}$	$1.5 \times 10^{18}$	$5.0 \times 10^{18}$	$1.2 \times 10^{18}$
$m_5$	$6.3 \times 10^{37}$	$7.0 \times 10^{35}$	$4.0 \times 10^{37}$	$4.3 \times 10^{36}$	$4.0 \times 10^{37}$	$3.0 \times 10^{36}$
$m_6$	$7.5 \times 10^{26}$	$3.6 \times 10^{25}$	$7.9 \times 10^{26}$	$1.4 \times 10^{26}$	$7.0 \times 10^{26}$	$1.1 \times 10^{26}$
$m_7$	$-8.7 \times 10^{35}$	$-2.6 \times 10^{35}$	$-6.5 \times 10^{36}$	$-1.0 \times 10^{36}$	$7.0 \times 10^{34}$	$-9.0 \times 10^{35}$

A combination of the seven invariant moments technique, image feature technique and the MADALINE network are used for identifying the stationary HGA without overlapping and generating the predicted robot trajectory based on visual servoing respectively. The necessity of determining the model of the robot, camera, all the stationary HGAs, and the environment will be eliminated. The locations and image features of these HGAs need not be preprogrammed, marked and known before, and any change in a task is possible without changing the robot program.

For the off-line algorithm, the proposed intelligent system has possible to track and determine an invariant stationary HGA feature recognition and predict robotic interception for stationary HGA. From the computer simulation, the relationship between the visual feedback image data and the control command for changing the axis motion shows deviation of robot placing less than

2% by the MADALINE network for intercepting stationary HGA at any rotation or orientation.

For the further research, the results from the computer simulation will be presented for experimental validation of the off-line algorithm in the on-line study. However, the performance is influenced by the limitations of the light and computer architecture. Light intensity is the most importance factor, which is sensitive to the reflection on the specimen. Thresholding is the main parameter used in image processing in order to obtain the image information of the tracked target. To further improve the system, the light intensity in the environment should be kept a constant.

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## 6. References

- [1] Chang J Y, Shen J Y. "Machine Vision Assistance for Flex Cable-Actuator Comb Manufacturing in Hard Disk Drives," in *Mechatronics and Machine Vision in Practice*, 15<sup>th</sup> International Conference , 2008:195-200.
- [2] Gonzalez R C, Woods R E. *Digital Image Processing*, 3<sup>rd</sup> Edition, New Jersey, Prentice Hall, 2010.
- [3] Salih N D, Ngo D C L. "An Efficient Boundary-Based Approach for Shape Representation," in *Information and Communication Technologies*, 2<sup>nd</sup>, 2006:1504-1509.
- [4] Ming-Kuei H. "Visual pattern recognition by moment invariants," *Information Theory, IRE Transactions* , 1962(8): 179-187.
- [5] Flusser J, Suk T. "Rotation Moment Invariants for Recognition of Symmetric Objects," *Image Processing, IEEE Transactions*, 2006(15): 3784-3790.
- [6] Suesse H, Ditrich F. "Robust determination of rotation-angles for Image Processing, IEEE International Conference, 2005:337-40.
- [7] Hagan M T, Demuth H B, Beale M. *Neural network design*, PWS Publishing company, USA, 1995.
- [8] Corke P, *Robotics, Vision and Control: Fundamental Algorithms in MATLAB*. Verlag Berlin Heidelberg: Springer; 2011.
- [9] Guo H W, Fa L S, Gui-Wu H. Blur identification using an adaptive ADALINE network, in *Machine Learning and Cybernetics. Proceedings of International Conference*, 2005:5314-5317.