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Determining the arm's motion angle using inverse kinematics models and adaptive neuro-fuzzy interface system

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Abstract

Robotics technology is known as a great technology demand to be developed continuesly. One of the important things that need to be considered is the control of the motion of the robot. Movement predictions can be modeled in mathematical equations. Prediction based on learning logic is also very supportive of motion control systems, especially arm motion. In this study, the authors combined the two methods as the main study. The working principle of the arm is to take colored objects detected by the camera. In this study, we made arm four DOFs (Degree of Freedom), but only one DOF is controlled by ANFIS because the other three DOFs only move at two fixed angles. Two methods of determining the arm angle of motion used are inverse kinematics and ANFIS methods. The angle of motion and the position of the red object can be observed in real-time on the monitor with the interface in the MATLAB GUI. The angular output that appears in the MATLAB GUI is sent to Arduino in the form of characters, then, Arduino translates it into servo motion to the coordinates of the object detected by the camera. The results showed that the ANFIS method was more effective than the inverse kinematics model.

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INTRODUCTION

Globalization's impact on the Era of the Industrial Revolution 4.0, requires all people in the world to know technological developments. Until today, technology is still a primary need for humans. The strong reason for implementing technology in every activity is improving work effectiveness and productivity [1]. However, it should be underlined that the role of technology is only limited to helping humans, not as an absolute substitute for human work. One of the technologies in question is robotic technology [2]

Robots are one of the most popular fields of automation techniques [3] and artificial intelligence [4]. This is also a development in manufacturing technology [5]. Mobile robot technology is a combination of sensing technology, information processing technology, engine processing technology, electronic technology, computer technology, and any other technologies [6].

Recently, the development of technology in robotics is a very serious concern, especially in the role of robots in dangerous environments such as space exploration [6], [7], firefighting [8], or industrial robots [9],

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[10]. One robot that is widely used is a mobile manipulator robot [11] specifically designed to take and move objects from one place to another [12]–[15]. In this case, kinematic motion analysis needs to be studied so that the arm moves on target, precisely, and accurately. Based on these cases, the authors are interested in conducting research that combines intelligent navigation control systems based on fuzzy logic and ANFIS-based arm 2 DOF motion control systems. The application to merge these two systems will form an intelligent mobile manipulator.

METHOD

The research methods that will be used in this study are:

Materials

The main components in this study are mobile robots, Arduino Uno, HC-SR04 ultrasonic sensors, Xtech Camera 5 Mp webcam, and servo motors.

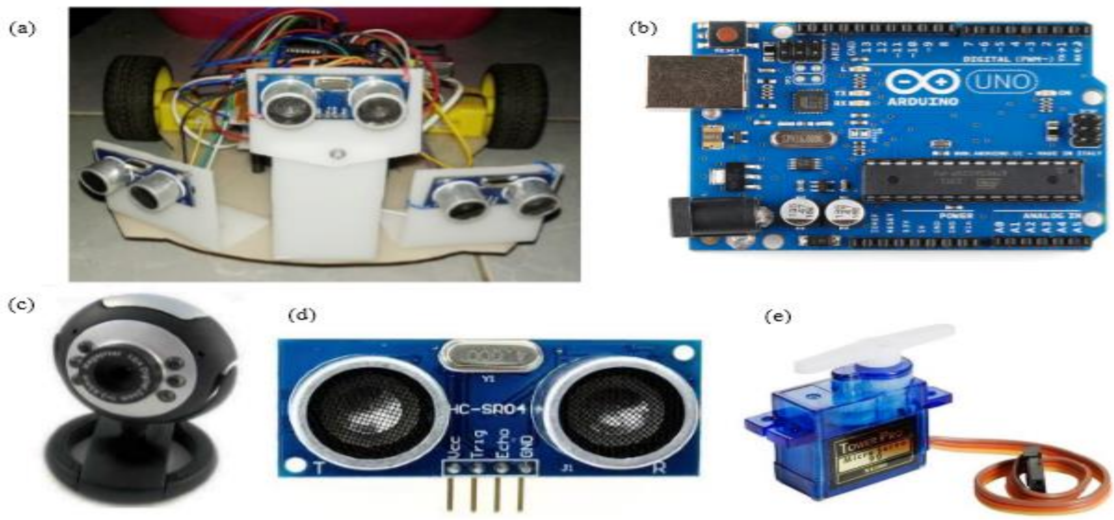

Figure 1. The Main Components to Make Arm Robot

Research Procedure

General research procedures can be seen in the following flowchart on Figure 2. The newest location of this intelligent mobile manipulator is using Arduino Uno as a microcontroller, a robot mobile navigation control in the form of three HC-SR04 sensors accompanied by a fuzzy logic intelligence system, and arm one DOF motion control accompanied by ANFIS intelligence system where object detectors use Webcam Xtech Camera 5 Mp.

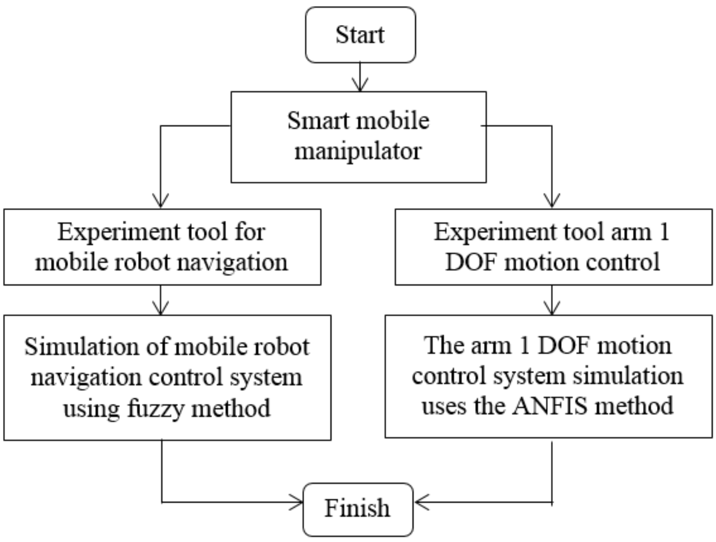

Figure 2. Flow of Intelligent Mobile Manipulator Research

In mobile robot navigation control system, the physical aspects reviewed are left motor speed and right motor speed. Robot mobile is designed to move automatically using fuzzy logic and can avoid obstacles. Distance data from the HC-SR04 ultrasonic sensor installed on the mobile robot becomes input data which will be processed. Meanwhile, the output is in the form of a direct mobile robot movement response.

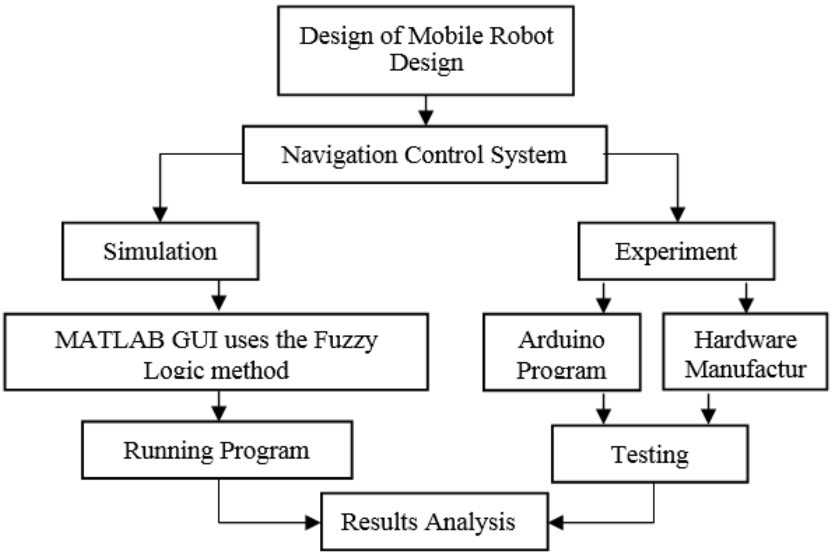

Figure 3. Flow of Research in Making Mobile Robots

The procedure for research on mobile robots starts with conducting a 4th order numerical Runge-Kutta simulation that produces a description of the mobile robot's trajectory. Then the distance data processing is carried out from ultrasonic sensors as input for fuzzy motion logic which is then processed by MATLAB. This process produces an output speed of the motor wherefrom that speed we can find out the mobile robot navigation. The research scheme for making mobile robots can be seen in the flowchart of Figure 3.

Designing Hardware

The robot was made by integrating mobile avoider robots, cameras, and arms, also using four servo motors. Servo 1 and 2 drive the support of the arm, while servo 3 and 4 move the clamp. In the servo, there are three pins. Each of it is approved with a ground, Vcc, and input on the Arduino board. Pin inputs are selected for servo input 1, servo input 2, and servo input 3, and servo input 4 respectively pins 4, 7, 8, and 13 on the Arduino board Figure 4.

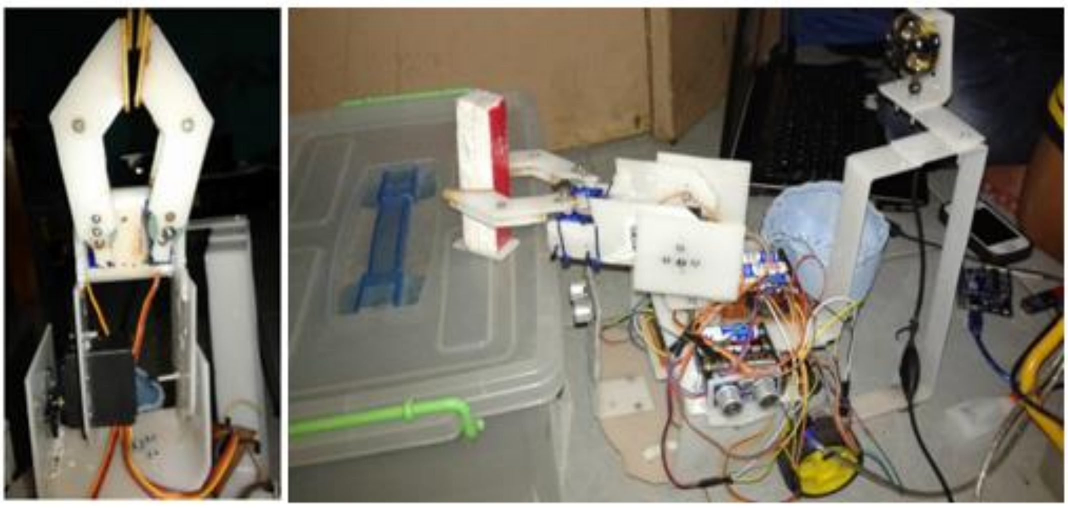

Figure 4. Arm Robot Design

Detecting The Red Objects

Red spectrum was detected in real-time using the MATLAB program with input from the Xtech Camera 5 Mp. The logic of this program is a webcam that discusses the surrounding area, then MATLAB distributed the desired object, here uses image processing and RGB analysis, the next object with a predetermined character (in this study is a red object) which can be seen in the computer using GUI MATLAB. The detection results of real-time objects can be seen in Figure 5. In the example of color detection above, it can be seen that the red object matches the coordinates (155, 331).

Figure 5. Detected The Red Object with The Field Coordinates (155, 331)

Determining the Motion Angle of the Arm using the Inverse Kinematics Model

This research used arm 4 DOF type, which will be controlled with ANFIS only 1 DOF, so the kinematics that needs to be reviewed is arm 1 DOF kinematics (Fig. 6).

$$x = l\cos(\theta)(1)$$

$$y = l\sin(\theta)(2)$$

If x and y are known, θ can be calculated by the equation 3

$$\theta = \arctan\left(\frac{y}{x}\right) or\ \theta = tan^{-1}\left(\frac{y}{x}\right)(3)$$

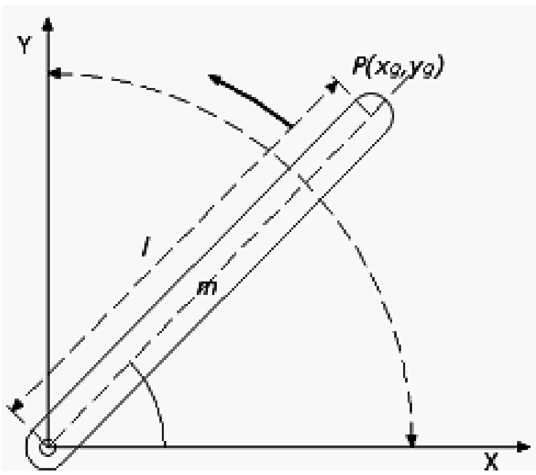

Figure 6. Arm 1 DOF kinematics [16]

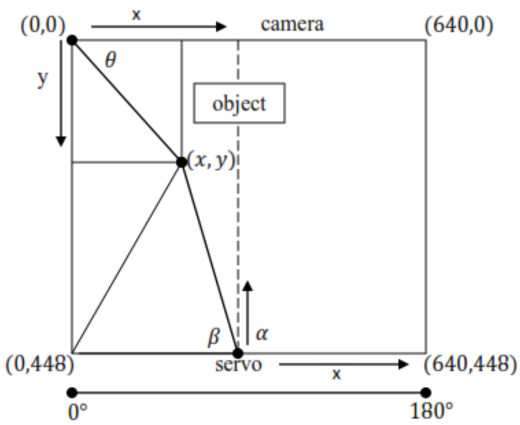

Figure 7. The inverse kinematics model of the arm 1 DOF [17]

Fig. 7 is the inverse kinematics model of the arm 1 DOF motion control system. This model transforms the pixel coordinates into the field Cartesian coordinates. This is important because the position of 0 points on the camera is different from the position of 0 points in the coordinates of the field. Robots have a camera in the centerline. The camera's coordinates are (640,448), it can be assumed that the servo is placed at position x = 320 so that it can be accessed by the motion angle on the coordinates of the object to retrieve the object. If $x < 320$, then

$$\beta = tan^{-1}\left(\frac{y}{x}\right)(4)$$

when $y = 448 - y$, and $x = 320 - x$, so we could obtain:

$$\alpha = 180° - \beta (5)$$

if $x > 320$, then

$$\alpha = tan^{-1}\left(\frac{y}{x}\right) (6)$$

when $x = x - 320$, and $y = y - 448$, so we obtained:

$$\alpha = 90° - \beta (7)$$

Determining the Angle of Arm Motion Using the Anfis Method

Determining the angle of motion using the ANFIS method consists of two sides. They are making training data and processing training data [18]. The training data processing used motion angle as input on Arduino programming to drive servo. Numbers randomly arranged to the arms move precisely at the coordinates of the red object.

In determining arm movements using the ANFIS method, the neuron structure describes the data flow processing from input to produce output. The leftmost part of the image consisting of two black circles is the input connected by six inputs consisting of white circles which are categories of inputs. From these six input categories, it is then processed to produce nine motion logics consisting of nine blue spheres which are outputs developed by nine white spheres, one DOF arm movements on cellular manipulators (Figure 8).

Table 1. The Training Data Motion Angle as Input on Arduino

Coordinates x	Coordinates y	angle (°)
571	342	120
422	341	125
345	337	130
293	347	135
240	346	140
217	345	145
154	341	150
51	338	155
27	335	160
9	328	165

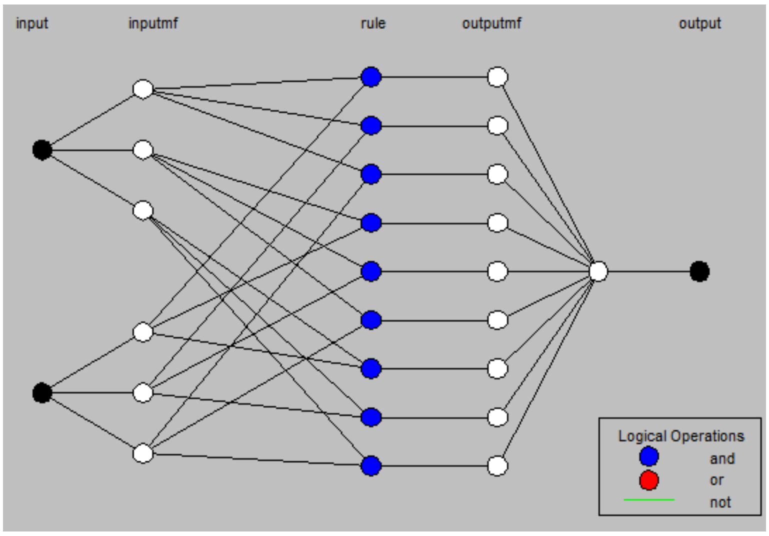

Figure 8. ANFIS Structure Neuron of Input-Process-Output

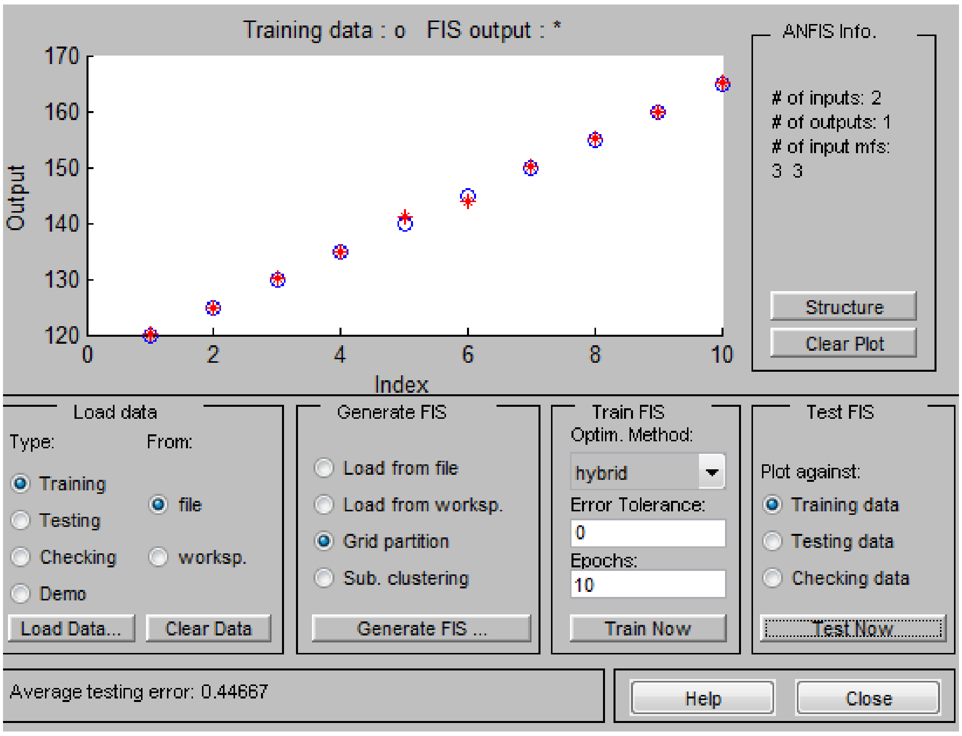

Figure 9. Training Data

Figure 7 shows an evaluation of the programming ability of training data that estimates the coordination of arm angle. ANFIS general learning data can be used in the next session, which is processing training data. After logically solved by the ANFIS method, then it is used as a range for each input and output of Sugeno's fuzzy model [17]. To receive robotic motion in real-time, an interface is needed which in this study used the MATLAB GUI. The design of the GUI that was made involves the input and output components that are made the following display design.

RESULTS AND DISCUSSION

By using COM3 on the monitor port, connecting the Arduino port to the camera port, it will make the camera automatically protect the red object complete with the coordinates of the object's added value. Then, by applying the ANFIS method, the coordinate data is used as input, processed with training data to produce output in the form of angular motion that appears automatically in the output column. In this experiment, it was obtained for x and y coordinates of [321.2358, 368.6205] obtained by the motion angle of 151,808°.

Table 2. Training Data vs ANFIS Data of Motion Angle of Arm Robot

Training data			ANFIS data
x	y	θ	θ
571	342	120	120.0293
422	341	125	124.9314
345	337	130	130.0262
293	347	135	134.7939
240	346	140	141.0128
217	345	145	144.0297
154	341	150	150.2021
51	338	155	155.0351
27	335	160	159.9186
9	328	165	165.0199

Table 3. Training Data vs Inverse Kinematics Models of Motion Angles of Arm Robot

Training data			Inverse kinematics			
x	***y***	***θ***	***x'***	***y'***	***β***	***α***
571	342	120	22	123	10.14	79.86
422	341	125	26	21	38.92	51.08
345	337	130	103	17	9.372	80.62
293	347	135	27	101	75	104.966
240	346	140	80	102	51.89	128.107
217	345	145	103	103	1	135
154	341	150	166	107	32.8	147.195
51	338	155	269	110	22.24	157.759
27	335	160	293	113	21.089	158.910
9	328	165	311	120	21.099	158.900

Table 2 shows that the data result of angle with ANFIS has a very close resemblance, whereas in Table 3 it can be seen that the angle of the training data does not have a close resemblance to the inverse kinematics yield angle. The difference in the results of inverse kinematics with training data is influenced by the servo geometry of the camera which is not parallel so it is difficult to make mathematical models that can accurately describe the geometry [14]. From the arm manipulator-making process, it can be concluded that one DOF which has varied angular motion can be ascertained its movement towards the coordinates of the object described by two methods: ANFIS method and inverse kinematics method. The inverse kinematics method is performed to determine the coordinates of pixel conversion in the Cartesian plane. While the ANFIS method is done by manually searching the angle and arm settings right at the coordinates of the object, for example, if the camera changes an object with coordinates (571, 342), then the arm will move at an angle 120°. Based on the research conducted, it can be obtained the results of the ANFIS method that is more effective. Prediction of motion angle can be seen in Figure 10.

Figure 10. Interfacing Motion Angles of Arm Robot Using ANFIS Model

CONCLUSION

An arm robot was made with one DOF has a motion control system using ANFIS. Prediction of arm angle movement on ANFIS is very suitable with the training data provided. The motion control prediction is also calculated using the inverse kinematics model. Based on the training data obtained, the ANFIS method is more precise than the inverse kinematics model.

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