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Identification of automatic guided vehicle (agv) based on magnetic guided sensor for industrial material transfer

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Abstract. Automatic Guided Vehicle (AGV) is a material transfer tool that is now widely used in the industry. One of the advantages is that it can transfer material automatically without the need for an operator who has to drive it. AGV using a magnetic guided sensor is one of the most widely used types. So that the tool can run according to the planned trajectory, it is necessary to design a controller that matches its characteristics. The design of the controller is needed identification of the model of the plant to know the characteristics of the plant. Identification with the Extended Least Square method is a form of parameter estimation recursively through a quadratic error gradient formulation with a criterion function involving all errors. The structural approach model used linearly uses Auto-Regressive eXogenous (ARX) and Auto-Regressive Moving Average eXogenous (ARMAX). The validation process of the model uses the Means Square Error (MSE) criteria and the FIT percentage. Based on the results obtained by the best plant with ARMAX model structure with MSE values 82.14 and percentage of FIT value 89.98%.

1. Introduction

Automatic Guided Vehicle (AGV) is a device that has experienced rapid development in recent years. AGV is widely used for material transfer in industries such as automotive, medicine, cigarettes, etc. In the process of transferring materials usually use vehicles operated by humans such as the Forklip. The use of AGV allows it to transfer material automatically without using human operators. So that it can improve efficiency in production and can reduce errors by humans in carrying out work that has a high degree of saturation [1–3] The latest technology allows AGV movements to be monitored online, as well as to calculate the amount of material that has been moved.

The mechanism of guidance on AGV to work automatically varies including RFID, Magnetic Sensor, and Laser [4, 5]. The mechanism most often used is using a magnetic sensor. One of the advantages of the track installation process using magnetic tape is that it is easier to apply and has a low cost [6, 7]. There are several types of AGV models among the most frequently used for material transfer applications, i.e. the tow or tugger type [4]. The drive and steering control mechanism for movement of the AGV there are several types including the skid drive, which consists of two driving motors as well as steering control.

For AGV to run well following the planned track, reliable control strategies are needed. Before designing the controller, the identification of the AGV plant is needed. The identification process aims to find out the characteristics of the plant. In case know the characteristics of the plant, it will easily determine the strategy and control method that will be used [8, 9]. In AGV with the skid drive

mechanism is a type of Multiple Input Single Output (MISO) system. Therefore, a structural model approach to MISO is needed to obtain a system model that is close to the nature of the actual characteristics.

The structural approach models of ARX (Auto-Regressive eXogenous) and ARMAX (Auto-Regressive Moving Average eXogenous) can be used for modelling MISO systems [10]. The parameter estimation method can be used using the Extended Least Square. This method is also often used for Single Input Single Output (SISO) systems [11]. As a validation of the identification process, the Mean Square Error (MSE) and the best FIT criteria can be used. The MSE criterion allows the value of the estimated error obtained to be as small as possible. While the best FIT criteria allow a model that can resemble the real plant [12].

In this study, the plant identification process will be carried out on the AGV that has the characteristics of the MISO system using the extended least square method. The structure of the approaching model that is designed using ARX and ARMAX will be compared. As a validation of the model that has been obtained, MSE and FIT criteria are used to determine the best model obtained.

2. Automatic Guided Vehicle (AGV)

AGV has been very widely used in the industrial world, especially to carry out the task of transferring materials in warehouses, assemblies, etc. This use cannot be separated from the development of mobile robot technology which is the initial idea of making this tool [1] .Guiding methods to be able to walk according to the track are also diverse. In this study, the method used to guide using magnetic sensors. This selection is because it is easier for the track installation process simply by using magnetic tape which tends not to disturb the density of the industrial environment [6]. Figure 1 shows the AGV design used.

Figure 1. Automatic Guided Vehicle

The AGV of the drive and steering control mechanism to get through the planned trajectory is the most important thing. The control depends on the type and mechanism used. In the design that is made using a type of tow or tugger relative to the medium load class maximum of 200 kg. For the drive and steering mechanism that is used to use the skid drive. This mechanism allows two motors are used as a drive as well as for steering. So that this mechanism is included in the Multiple Input Single Output (MISO) system. Where there are two inputs are control signals from the Brushless motor driver and one output is the position of the AGV deviation.

3. Identification

3.1. Extended Least Square

The plant parameter identification method is performed by measuring the input and output of data online and offline. The input signal measurement data u (k) is obtained by dynamically giving the signal to the system. Then the results of the response from the system in the form of output data y(k) will be recorded along with the input signal. In the identification process carried out in this study using data offline. The approach taken considers the plant is a black box with no known parameters. Plant modeling is used in the form of a stochastic system model with a linear structured model approach. The identification method used is using the Extended Least Square. This method is a recursive method through the quadratic error gradient formulation with the criteria function involving all errors. The basic model of a system is represented in equation (1) below

$$y(k) = \varphi^T(k-1)\theta \tag{1}$$

where,

$$\varphi^T(k-1) = \begin{bmatrix} -y(k-1) \\ -y(k-1) \\ u(k-1) \\ u(k-2) \end{bmatrix} \quad \theta = \begin{bmatrix} a_1 \\ a_2 \\ b_0 \\ b_1 \end{bmatrix} \tag{2}$$

where, $\varphi^T(k-1)$ is measurement of input-output data and θ is parameters plant

The plant parameter values will continue to be calculated until the error meets the minimum criteria as shown in equation (3). The estimation is then performed to obtain the parameter value that satisfies equation (4).

$$J_{min} = \frac{1}{2}e^2 \tag{3}$$

$$\hat{\theta}(k) = \theta(k-1) + F(k)\{y(k) - \varphi^T\theta(k-1)\}\varphi(k-1) \tag{4}$$

3.2. Structure Model of MISO System

MISO system is a system that has more than one input and only one output. In this AGV system, the input consists of two pieces, and the input consists of one input. The system structure model in the discrete domain can be represented in equation (5) and can be shown in Figure 2.
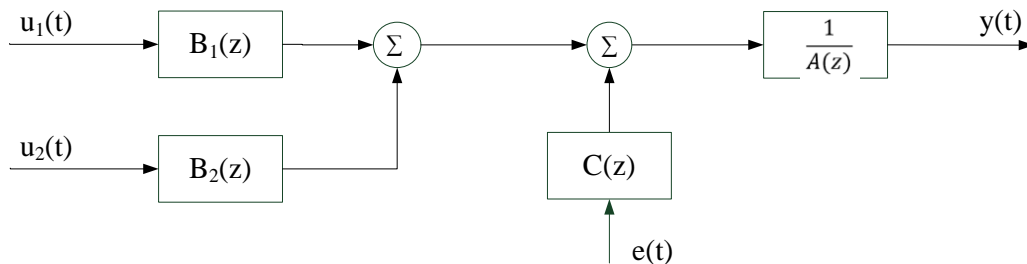

Figure 2. Structure MISO System

$$A(z)y(t) = B_1(z)u_1(t) + B_2(z)u_2(t) + C(z)e(t) \tag{5}$$

The structural model that can be used in this system can be selected by the ARX structure model approach. The structure of this model is a form of stochastic system which considers external factors

such as noise or interference in the input and output bookkeeping process [8]. The equation of the structure of this model is represented in equation (6) below

$$A(z)y(t) = B_1(z)u_1(t) + B_2(z)u_2(t) + C(z)e(t) \qquad (6)$$

In addition to the structure of this model, there is also a model structure. The most fundamental difference with the ARX structure is that there is a dynamic disturbance found in the system [10]. The equations of the structure of this model are represented in equation (7) below

$$A(z)y(t) = B_1(z)u_1(t) + B_2(z)u_2(t) + C(z)e(t) \qquad (7)$$

3.3. Validation
In order to know the equation of the model that is close to the real condition with the real plant, each model that has been obtained needs to be carried out a validation process. Validations that are often used in the modeling process include the MSE (Mean Square Error) criteria and the percentage of fit [12]. MSE is a criterion that shows how much the error deviation is from zero. Mathematically shown in equation (8).

$$\mathbf{MSE} = \sqrt{\frac{\sum_i^n (y_i - \hat{y}_i)^2}{n}} \qquad (8)$$

where, y_i is output measurement data, $\hat{y}_i$ is output estimation data and *n* is number of data.

The percentage of fit criteria is a criterion that shows the compatibility of the system of identification results with the actual plant. Mathematically shown in equation (9).

$$\mathbf{Best\ Fit} = \mathbf{100} \left[\mathbf{1} - \frac{\mathbf{norm}(\hat{y}_i - y_i)}{\mathbf{norm}(y_i - \bar{y})} \right] \% \qquad (9)$$

where, y_i is output measurement data, $\hat{y}_i$ is output estimation data and $\bar{y}$ is mean value data.

4. Result and Discussion

The AGV identification process is carried out using three input and output measurement data with varying amounts of data. Input or reference signals are given in the form of analog brushless motor driver analog signals totaling 2 channels. The form of the input and output signals as shown in Figure 3.The output signal is in the form of a deviation from the AGV movement to the magnetic tape where the deviation is measured by a magnetic sensor. For the sampling time used in the process of taking both data every 0.01 second.
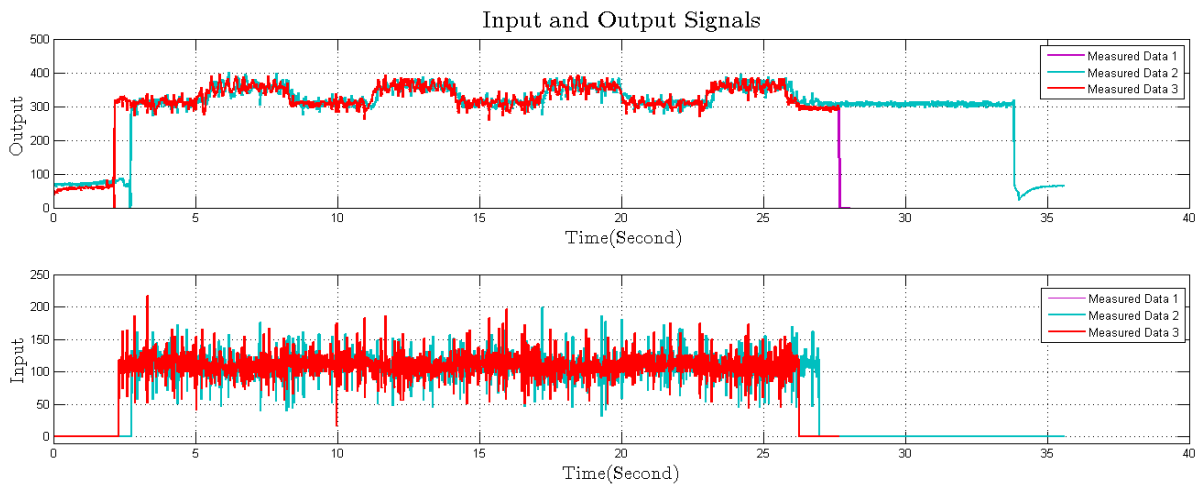

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Figure 3. Input-Output Measurement Data

The desired model structure in this identification will be selected with the ARX and ARMAX models. In the ARX structure, the desired system model has the number of pole 4, the number of zero 4, and the dead time 1. Whereas for the ARMAX structure model the desired system model has the number of pole 4, the number of zero 3, and dead time 1. The process of identifying the plant model is done offline using measurement data input and output through the process of estimating the parameters of the Extended Least Square method. After the plant model is obtained, a validation process will be carried out using the Means Square Error (MSE) criteria and fit ratio presentation (FIT). The plant model to be chosen must have the smallest MSE value. The FIT percentage criteria must have the largest value close to 100 %.

In the identification process using the first variation of data with the number of data 2768. Based on the identification process, the ARX structure the MSE value is 81.39 and the percentage value of FIT is 88.41 %. For the ARMAX structure, the MSE value is 81.42 and the percentage value of FIT is 88.41 %. Then, using the second data variation with the number of data 2560. Based on the identification process, the ARX structure the MSE value is 83.19 and the percentage value of FIT is 89.92 %. For the ARMAX structure, the MSE value is 82.14 and the FIT percentage value is 89.98 %. Then, identification process using the third variation of data with the number of data 2805. Based on the identification process, the ARX structure the MSE value is 83.19 and the percentage value of FIT is 89.92 %. For the ARMAX structure, the MSE value is 82.14 and the FIT percentage value is 89.98 %. Figure 4 shows the results of the model estimation for all measurement data. The overall results of the identification process using variations in data changes and the structural model approach can be presented more fully in Table 1.
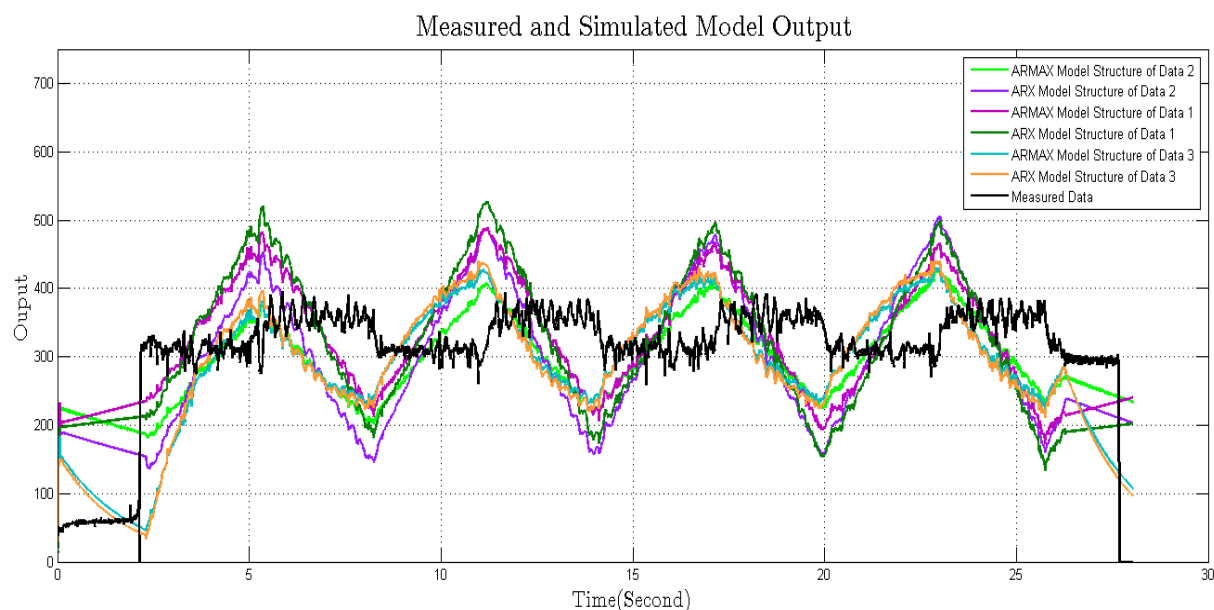

Figure 4. Result of Model Estimation

Table 1. Result of Identification

Data	Structure	Model (Discrit)	MSE	FIT
1	ARX	$A(z) = 1 - 1.063\,z^{-1} - 0.874\,z^{-2} + 0.7864\,z^{-3} + 0.5684\,z^{-4}$ $B_1(z) = 0.2828\,z^{-1} + 0.6702\,z^{-2} + 0.2171\,z^{-3} + 0.04413\,z^{-4}$ $B_2(z) = -0.09782\,z^{-1} - 0.09849\,z^{-2} + 0.00356\,z^{-3} + 0.04413\,z^{-4}$	101.2	73.97 %
	ARMAX	$A(z) = 1 - 1.031\,z^{-1} - 0.7249\,z^{-2} + 0.7626\,z^{-3} + 0.4436\,z^{-4}$ $B_1(z) = 0.6926\,z^{-1} + 0.8358\,z^{-2} + 0.3849\,z^{-3}$ $B_2(z) = -0.2217\,z^{-1} - 0.3289\,z^{-2} - 0.1013\,z^{-3}$ $C(z) = 1 + 1.152\,z^{-1} + 0.5499\,z^{-2} + 0.2711\,z^{-3}$	73.53	77.81 %
2	ARX	$A(z) = 1 - 0.9727\,z^{-1} - 0.1838\,z^{-2} + 0.1225\,z^{-3} + 0.03377\,z^{-4}$ $B_1(z) = 0.09846\,z^{-1} + 0.09513\,z^{-2} - 0.07827\,z^{-3} + 0.0007531\,z^{-4}$ $B_2(z) = -0.1018\,z^{-1} - 0.008699z^{-2} + 0.03157\,z^{-3} + 0.03328\,z^{-4}$	81.39	88.41 %
	ARMAX	$A(z) = 1 - 1.613\,z^{-1} + 0.8417\,z^{-2} - 0.1637\,z^{-3} - 0.06511\,z^{-4}$ $B_1(z) = 0.1131\,z^{-1} + 0.004832\,z^{-2} - 0.04377\,z^{-3}$ $B_2(z) = -0.09184\,z^{-1} + 0.007001\,z^{-2} + 0.01459\,z^{-3}$ $C(z) = 1 - 0.6346\,z^{-1} + 0.4406\,z^{-2} - 0.07688\,z^{-3}$	81.42	88.41 %
3	ARX	$A(z) = 1 - 0.7164\,z^{-1} - 0.407\,z^{-2} - 0.05785\,z^{-3} + 0.1822\,z^{-4}$ $B_1(z) = 0.002861\,z^{-1} + 0.0876\,z^{-2} + 0.04482\,z^{-3} + 0.0001309\,z^{-4}$ $B_2(z) = -0.07994\,z^{-1} - 0.02877\,z^{-2} - 0.03347\,z^{-3} + 0.01933\,z^{-4}$	83.19	89.92 %
	ARMAX	$A(z) = 1 + 0.4929\,z^{-1} - 0.5375\,z^{-2} + 0.977\,z^{-3} + 0.02437\,z^{-4}$ $B_1(z) = 0.06146\,z^{-1} + 0.1127\,z^{-2} + 0.09943\,z^{-3}$ $B_2(z) = -0.07767\,z^{-1} - 0.1098\,z^{-2} - 0.0583\,z^{-3}$ $C(z) = 1 + 1.314\,z^{-1} + 0.7272\,z^{-2} - 0.13761\,z^{-3}$	82.14	89.98 %

5. Conclusions
Based on the identification process that has been carried out through the parameter estimation and validation stages, the system that approaches the plant has the smallest MSE and the largest percentage of fit value. So that the structural model derived from the third data with the ARMAX structural

approach with the number of pole 4 and zero 3 is the best plant model. Where has a validation value of MSE 82.14 and FIT 89.98 %.

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