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Modelling and Identification of the Superintending Mobile Robot

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Identification of the model of the mathematical mobile superintending robot was presented in the article applying setups with fuzzy logic. The problem was solved numerical and experimentally.

Keywords: Modelling, identification, fuzzy logic, robot

1. Introduction

Fuzzy logic is serving to the description of phenomena and nations having the ambiguous and not precise character. It is possible of fuzzy logic to determine not precise and ambiguous terms formally: "high temperature", "low temperature". When modelling manipulators and robots are being made many inaccuracies. The mathematical model isn't known exactly as a rule. The correct analysis of dynamics requires identification of dynamic equalization of the movement [4,6]. The mathematical form of the description of physical phenomena was obtained applying equalization Lagrange'a II kind.

2. Modelling and identification of fuzzy logic

In designing fuzzy sets a specification of the set of reflections is most important. In case of the ambiguous term "high temperature" the other value will be considered too high, if we will accept the temperature interval [0÷10C^o] and other, if we will accept the temperature interval [0÷1000C^o]. Field called space or the set, of action, will be marked with the X letter. Remembering that he is X with nonfuzzy set. Definition of the fuzzy set [7] was formulated:

A fuzzy set in sure of non empty X space, written down as $A \subseteq X$, we are calling the set of pairs

$$A = \{(x, \mu_A(x)); x \in X\} \tag{1}$$

where:

$$\mu_A : X \to [0,1] \tag{2}$$

he is a function of affiliation of the A fuzzy set. This function for every element $x \in X$ he is assigning the mark to affiliation in the A fuzzy set, discriminate three cases: full affiliation in the A fuzzy set of the x element, when $\mu_A(x) = 1$, affiliation is lacking the x element to the A fuzzy set, when $\mu_A(x) = 0$, and partial affiliation in the A fuzzy set of the x element, when $0 < \mu_A(x) < 1$. Exist many standard forms of the function of affiliation [7] however he most often complies: gauss functions, triangular functions and trapezoidal functions [8.9].

Symbolic rules are occurring in setups with fuzzy logic "**IF–THEN**", quality characterised variables with linguistic variables and fuzzy operators "**AND**", it is possible to write the rule down:

$$\textbf{IF} \quad x_1 \quad \text{it is small } \textbf{AND} \quad x_2 \quad \text{it is large } \textbf{THEN} \quad y \quad \text{it is average} \tag{3}$$

A mathematical model was accepted (Fig. 1b) to the description of the movement of the superintending robot (Fig. 1a).

Dynamic equation of the movement was used for examinations from work [1, 2, 3, 5].

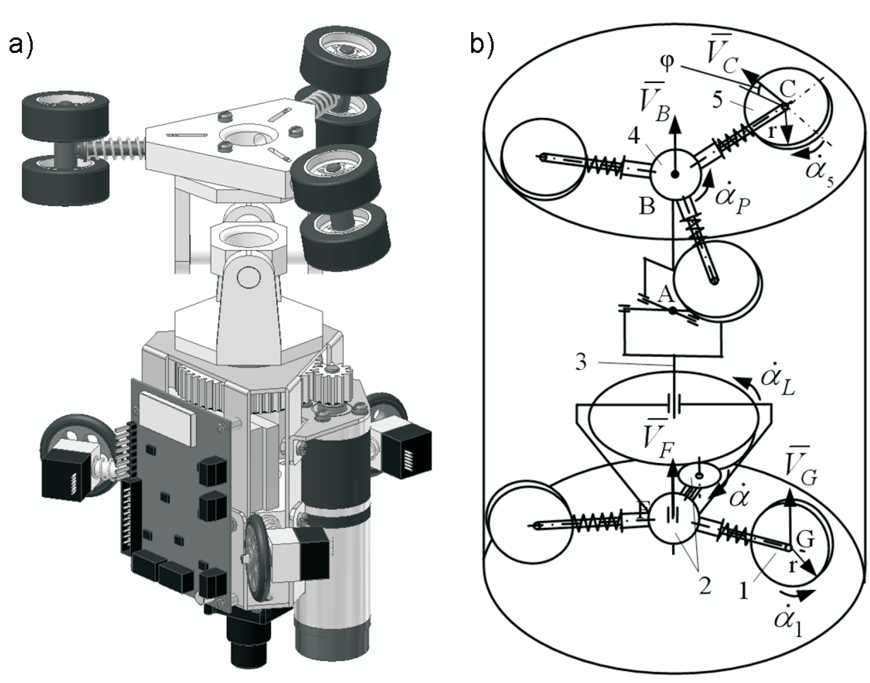

Figure 1 a) Inspection robot, b) Model of the robot

Dynamic equation of the movement presented in the form

$$
\begin{aligned}
&\left(\frac{3600\left(l_4+r\right)^2 z_s^2 tg\left(\varphi\right)^2\left(3m_1+m_2+m_3\right)}{z_k^2\pi^2}+\frac{10800 I_{Gx}\left(l_4+r\right)^2 z_s^2 tg\left(\varphi\right)^2}{z_k^2\pi^2 r^2}\right)\ddot{\alpha}\\
&+\left(\frac{I_{Fy}z_s^2}{z_k^2}+\frac{3600 m_4\left(l_4+r\right)^2 z_s^2 tg\left(\varphi\right)^2}{z_k^2\pi^2\cos\left(\delta\right)^2}+\frac{I_{By}z_s^2}{z_k^2\cos\left(\delta\right)^2}+\frac{3m_5 z_s^2 l_4^2\cos\left(\varphi\right)^2}{z_k^2\cos\left(\delta\right)^2}\right)\ddot{\alpha}\\
&+\left(\frac{3I_{Cy}z_s^2 l_4^2\cos\left(\varphi\right)^2}{z_k^2 r^2\cos\left(\delta\right)^2}\right)\ddot{\alpha}+\left(\frac{60 m_1 l_4\left(l_4+r\right)z_s tg\left(\varphi\right)\left(1-2\sin\left(\psi\right)\right)}{z_k\pi}\right)\ddot{\beta}\\
&+\frac{180 z_s tg\left(\varphi\right)N_1 f_1\left(l_4+r\right)}{z_k\pi r}+\frac{180 z_s tg\left(\varphi\right)G_1\sin\left(\beta\right)\left(l_4+r\right)}{z_k\pi}\\
&+\frac{60G_2\sin\left(\beta\right)z_s tg\left(\varphi\right)\left(l_4+r\right)}{z_k\pi}+\frac{60G_3\sin\left(\beta\right)z_s tg\left(\varphi\right)\left(l_4+r\right)}{z_k\pi}\\
&+\frac{60G_4\sin\left(\gamma\right)z_s tg\left(\varphi\right)\left(l_4+r\right)}{z_k\pi\cos\left(\delta\right)}+\frac{3\cos\left(\varphi\right)\pi z_s l_4\left(G_5 r\sin\left(\gamma\right)+N_2 f_2\right)}{z_k\pi r\cos\left(\delta\right)}\\
&=\frac{\cos\left(\varphi\right)^2}{\cos\left(\delta\right)}M
\end{aligned}
\tag{4}
$$

were transformed and were written down in space state

$$\dot{\alpha}=A\alpha+B\left[f\left(\alpha,\beta,\gamma\right)+G\left(\alpha,\beta,\gamma\right)u(t)\right] \tag{5}$$

or in the form in a vector manner matrix

$$\begin{bmatrix}\dot{\alpha}_1\\ \dot{\alpha}_2\end{bmatrix}=\begin{bmatrix}0&1\\0&0\end{bmatrix}\begin{bmatrix}\alpha_1\\ \alpha_2\end{bmatrix}+\begin{bmatrix}0\\1\end{bmatrix}\left[-\frac{1}{s_1}\left(s_2\ddot{\beta}+s_3\right)+\frac{s_4}{s_1}u(t)\right] \tag{6}$$

where:

$$
\begin{aligned}
s_1 \;=\;& \frac{3600\left(l_4+r\right)^2 z_s^2 tg\left(\varphi\right)^2\left(3m_1+m_2+m_3\right)}{z_k^2\pi^2}+\frac{10800 I_{Gx}\left(l_4+r\right)^2 z_s^2 tg\left(\varphi\right)^2}{z_k^2\pi^2 r^2}\\
&+\frac{I_{Fy}z_s^2}{z_k^2}+\frac{3600 m_4\left(l_4+r\right)^2 z_s^2 tg\left(\varphi\right)^2}{z_k^2\pi^2\cos\left(\delta\right)^2}+\frac{I_{By}z_s^2}{z_k^2\cos\left(\delta\right)^2}\\
&+\frac{3m_5 z_s^2 l_4^2\cos\left(\varphi\right)^2}{z_k^2\cos\left(\delta\right)^2}+\frac{3I_{Cy}z_s^2 l_4^2\cos\left(\varphi\right)^2}{z_k^2 r^2\cos\left(\delta\right)^2}
\end{aligned}
\tag{7}
$$

$$s_2 = \frac{60 m_1 l_4\left(l_4+r\right)z_s tg\left(\varphi\right)\left(1-2\sin\left(\psi\right)\right)}{z_k\pi} \tag{8}$$

$$
\begin{aligned}
s_3 \;=\;& \frac{180 z_s tg\left(\varphi\right)N_1 f_1\left(l_4+r\right)}{z_k\pi r}+\frac{180 z_s tg\left(\varphi\right)G_1\sin\left(\beta\right)\left(l_4+r\right)}{z_k\pi}\\
&+\frac{60G_2\sin\left(\beta\right)z_s tg\left(\varphi\right)\left(l_4+r\right)}{z_k\pi}+\frac{60G_3\sin\left(\beta\right)z_s tg\left(\varphi\right)\left(l_4+r\right)}{z_k\pi}\\
&+\frac{60G_4\sin\left(\gamma\right)z_s tg\left(\varphi\right)\left(l_4+r\right)}{z_k\pi\cos\left(\delta\right)}+\frac{3\cos\left(\varphi\right)\pi z_s l_4\left(G_5 r\sin\left(\gamma\right)+N_2 f_2\right)}{z_k\pi r\cos\left(\delta\right)}
\end{aligned}
\tag{9}
$$

$$s_4 = \frac{\cos\left(\varphi\right)^2}{\cos\left(\delta\right)} \tag{10}$$

In dependence (7–10) non–linear parameters are occurring: β, γ, δ the pipes dependent on the profile. Elements $f(\alpha,\beta,\gamma)$ and $G(\alpha,\beta,\gamma)$ in dependence (5) these are non–linear functions

$$f(\alpha,\beta,\gamma) = -\frac{1}{s_1}\left(s_2\ddot{\beta}+s_3\right) \quad (11)$$

$$G(\alpha,\beta,\gamma) = \frac{s_4}{s_1} \quad (12)$$

approximated by setups of fuzzy logic.

Because dependence $f(\alpha,\beta,\gamma)$ and $G(\alpha,\beta,\gamma)$ they don't have the linear form with regard to parameters (7–10), they are applying to modelling for inaccuracies in this dependence. The setup of identification was accepted in the form:

$$\dot{\hat{\alpha}} = A\hat{\alpha} + B\left[\hat{f}\left(\alpha,\hat{\beta},\hat{\gamma}\right) + \hat{G}\left(\alpha,\hat{\beta},\hat{\gamma}\right)u\right] + K\tilde{\alpha} \quad (13)$$

where vector $\hat{\alpha}$ he is estimation of state vector α, $\hat{f}\left(\alpha,\hat{\beta},\hat{\gamma}\right)$, $\hat{G}\left(\alpha,\hat{\beta},\hat{\gamma}\right)$ it estimations of non-linear functions in equation (5). Accepting the error of the estimation of the state vector in the form

$$\tilde{\alpha} = \alpha - \hat{\alpha} \quad (14)$$

and subtraction equation (13) from equation (5) a description was presented to identification in space of errors

$$\dot{\tilde{\alpha}} = A_H\tilde{\alpha} + B\left[\tilde{f}\left(\alpha,\beta,\gamma,\hat{\beta},\hat{\gamma}\right) + \tilde{G}\left(\alpha,\beta,\gamma,\hat{\beta},\hat{\gamma}\right)u\right] \quad (15)$$

where: $A_H = A - K$, and matrix K she is so matching so that characteristic equalization of the A_H matrix is stable strictly.

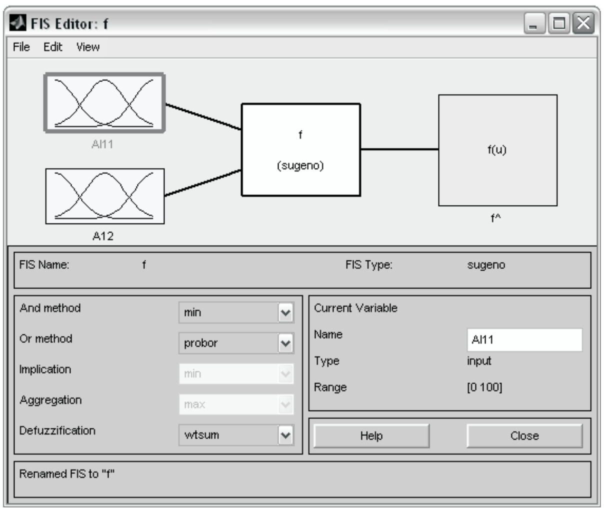

Figure 2 Model of fuzzy logic approximated non–linear functions

3. Simulation of identification with fuzzy logic

To assigning to the function $\hat{f}\left(\alpha, \hat{\beta}, \hat{\gamma}\right)$, $\hat{G}\left(\alpha, \hat{\beta}, \hat{\gamma}\right)$ setups executed with fuzzy logic were applied to the application Matlab^{TM} (Fig. 2), who is making it possible to create models of fuzzy logic (*fuzzy logic toolbox)* [10,11].

He is a task of setups with fuzzy logic assigning to the function $\hat{f}\left(\alpha, \hat{\beta}, \hat{\gamma}\right)$, $\hat{G}\left(\alpha, \hat{\beta}, \hat{\gamma}\right)$ in such a way, in order to error $\tilde{\alpha}$ between the state vector α of the computing model, and with state vector $\hat{\alpha}$ estimator he was like smallest. Were admitted to designing in the phase model of the type Takagi–Sugeno [7, 10, 11]. The fuzzy block is transforming space of inputs into form $X = [\dot{\alpha}_{1a}, \dot{\alpha}_{1b}] \times [\dot{\alpha}_{2a}, \dot{\alpha}_{2b}] \subset R^n$ in fuzzy set $A \in X$ characterized with function $\mu_A(x) : X \to [0,\,1]$, that is is assigning the mark of affiliation in fuzzy sets. On (Fig. 3) accepted functions were presented to affiliation in the form of Gauss' function (gaussmf) to input with intervals of variability $\dot{\alpha}_1 \in [0, 100], \dot{\alpha}_2 \in [0,\ 10]$.

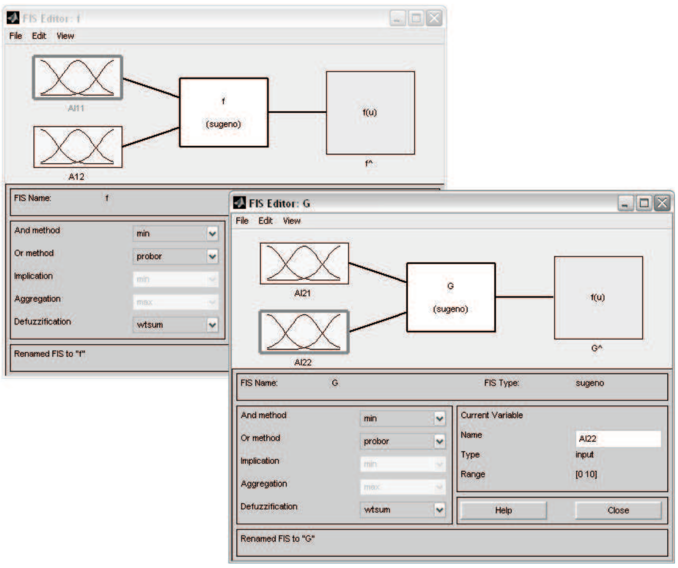

Figure 3 Functions of affiliation and intervals of variability

In accordance to assumptions (Fig. 2) a model was accepted, whom space of input is two–dimensional in, because two input quantity is available. The base of rules was accepted for the characterised model how on (Fig. 4). 3 functions of affiliation were accepted for inputs of the fuzzy setup and 9 rules were created of inferring. They laid down a principle every rule from one input with every rule of the other input, since information about each outputs from fuzzy setups is missing.

A set was accepted on the input A from T–norm [8] of type minimum

$$\mu_{A_1^j \times \ldots \times A_n^j}(x) = \min\left[\mu_{A_1^j}, \ldots, \mu_{A_n^j}\right] \tag{16}$$

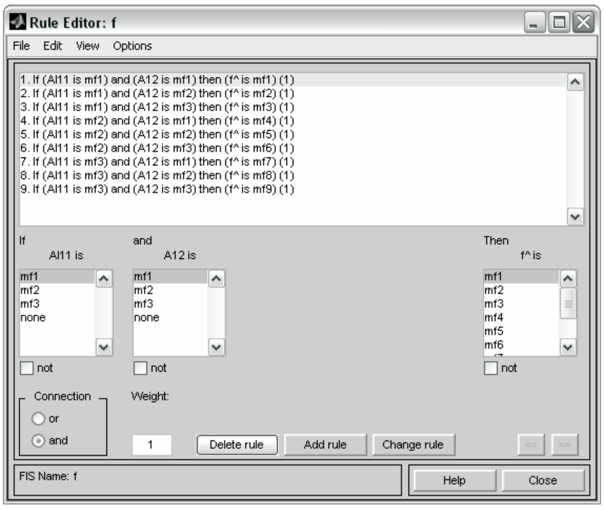

Figure 4 Base of rules for the accepted set

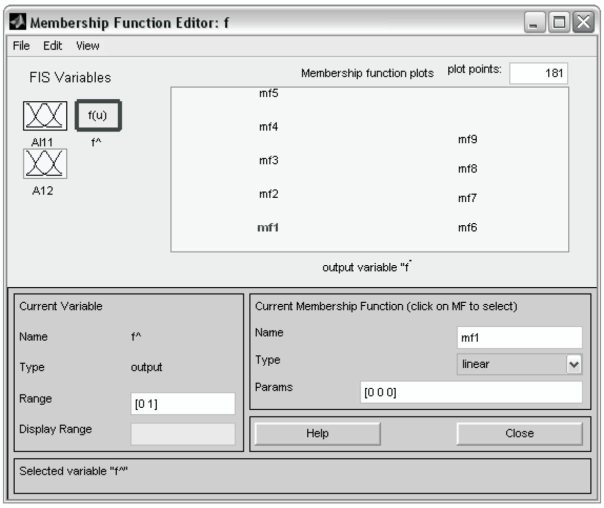

Figure 5 Exit of the setup fuzzy logic

On the exit of the model Takagi–Sugeno, presented on (Fig. 5) an equal signal was received

$$y\left(x\right)=\frac{\sum\limits_{j=1}^{M}\bar{y}_j\tau_j}{\sum\limits_{j=1}^{M}\tau_j} \tag{17}$$

where:

$$\tau_j = \prod_{i=1}^{n} \mu_{A_i^j}(x_i) \tag{18}$$

he is a level of the ignitron j rules.

Available interface in the application Matlab^{TM} he is making it possible to create arbitrary setups with fuzzy logic. Applied setups were utilized for approximation of non–linear functions with fuzzy logic (11), (12), and they were being modelled in the form (Fig. 6).

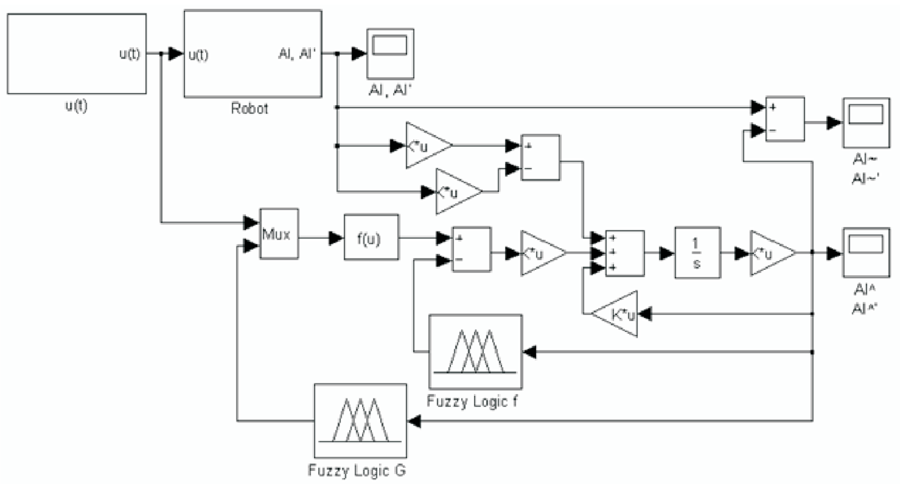

Figure 6 Structure of identification

Fuzzy Logic f and *Fuzzy Logic G* these are fuzzy setups, of whom approximation is a task non–linear in (11), (12). Numeric information binding signals to the unambiguous method is utilizing all fuzzy sets of input and output. Solved in order proposed checking, a verification was carried out.

4. Verification

Simulation examinations were verified at the beginning with experimental studies (Fig. 7.).

The next stage: identification of parameters of the superintending robot according to the structure (Fig. 6) in the application Matlab^{TM}–Simulink accepting for input function $u(t)$ driving moment of the motor (Fig. 7b – Fig. 8.a). Accepting as input function moment on the shaft motor from measurements (Fig. 7b – Fig. 8a) were taken according to the point 3 identification of parameters of the superintending robot. Parameters estimator these are the angle of rotation and angle velocity (Fig. 8c) on the shaft driving motor, were compared to parameters obtained during measurements (Fig. 8b).

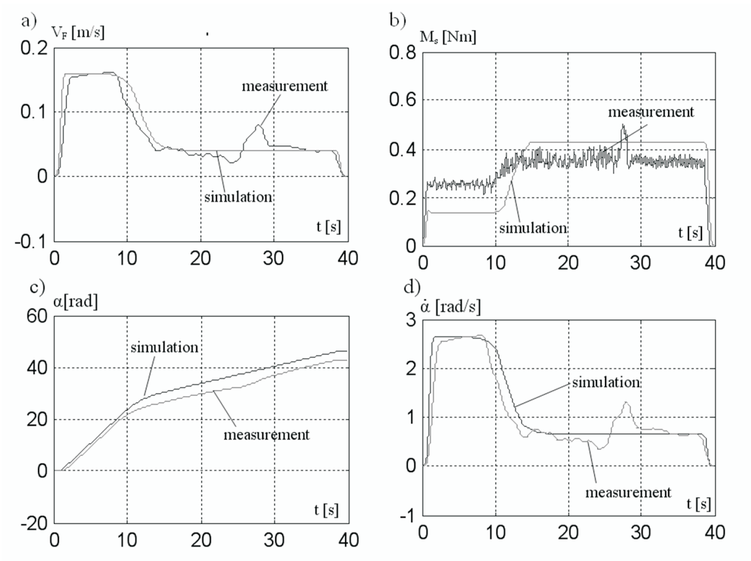

Figure 7 Diagrams from the simulation and measurements. a) velocities of the F point robot, b) driving moments of the motor, c,d) kinematics parameters

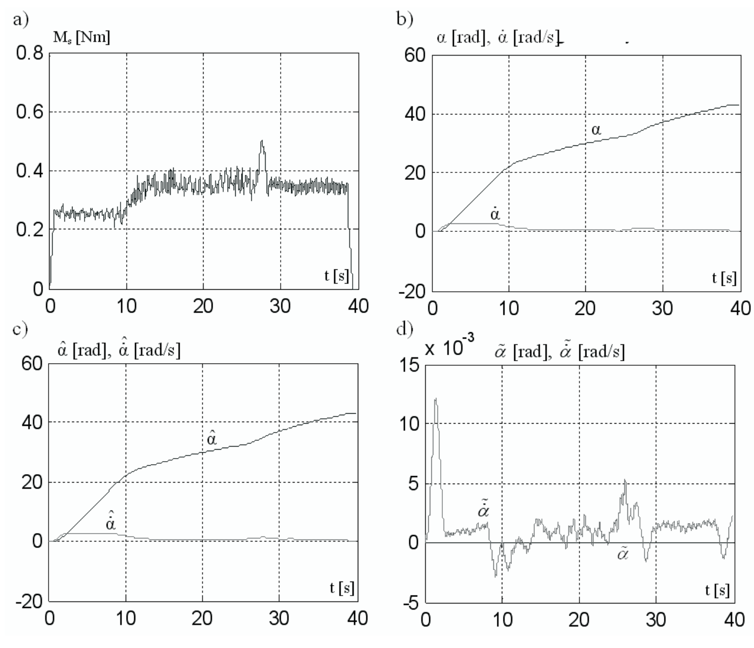

Figure 8 Results of identification. a) imput signal, b) angle of rotation and angular velocity on the shaft driving motor, c) parameters estimator, d) errors estimator

Taking them away an error defined on the shaft motor of the estimation of the angle of rotation and the angle velocity was obtained as (14) (Fig. 8d). Were received zero (Fig. 8d) error of the estimation of the angle of rotation on the shaft motor, and small error of the estimation of the angle velocity $\dot{\tilde{\alpha}}$. Obtained solutions to identification fuzzy logic are limited, and the proposed procedure is enabling identification of non–linear setups to apply setups to the process with fuzzy logic.

5. Summary

The verification and identification with fuzzy logic were carried out after start of the prototype of the superintending robot. Diagrams was compared during the verification from measurements and the simulation. Diagrams is differing from simulation diagrams hardly anything from measurements on the real robot, what confirms the need for designing and the simulation. Visible differences are an effect of how many reasons during the simulation (inaccuracies of the estimation of parameters model, a description of physical phenomena is missing "incomplete modelling") how and of measurements (parametric interferences – change of the diameter of the pipeline). It is possible with fuzzy logic to apply setups to identification of dynamic equations movement, of real parameters, and to monitoring dynamic loads and fault finding.

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