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Developing and modeling of voice control system for prosthetic robot arm in medical systems

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ABSTRACT

In parallel with the development of technology, various control methods are also developed. Voice control system is one of these control methods. In this study, an effective modelling upon mathematical models used in the literature is performed, and a voice control system is developed in order to control prosthetic robot arms. The developed control system has been applied on four-jointed RRRR robot arm. Implementation tests were performed on the designed system. As a result of the tests; it has been observed that the technique utilized in our system achieves about 11% more efficient voice recognition than currently used techniques in the literature. With the improved mathematical modelling, it has been shown that voice commands could be effectively used for controlling the prosthetic robot arm.

1. Introduction

Robotic technology and the systems that are capable of controlling the robotic technology have been affected from the development of technology (Kubik and Sugisaka, 2001; Stanton et al., 1990; Gundogdu and Yucedag, 2013; Sabto and Mutib, 2013). Various studies have been conducted in the field of robotic technology (Valente, 2016; Cambera and Feliu-Batlle, 2017; Yagimli and Varol, 2008; Gundogdu and Calhan, 2013; Rogowski, 2013; Cetinkaya, 2009). Many control systems are available such as voice control, visual inspection and control systems with brain waves (Pattnaik and Sarraf, 2016; Gundogdu and Yucedag, 2013; Jayasekara et al., 2008; Kim, 2013; Ju et al., 2007). Also, in recent years, many theoretical and practical applications have been realized by using control systems with voice (Chahuara et al., 2017; Kubik and Sugisaka, 2001; Nishimori et al., 2007; Hanser, 1988; Nolan, 1998; Reed et al., 1994).

In the literature, many studies made with voice control system such as robot arm control, door lock control, mobile vehicle systems control and control of the wheelchair are available (Ferrús and Somonte, 2016; Izumi et al., 2004; Jayasekara et al., 2009; Huang and Shi, 2012; Phelps et al., 2000; Sajkowski, 2012; Kuljic et al., 2007; Gundogdu and Calhan, 2013; Wahyudi et al., 2008; Liu et al., 2005; Shim et al., 2010; Kajikawa et al., 2003; Lv et al., 2008; Zhou et al., 1994). Many methods have been developed for voice control system and these developed methods have been used by applying the many mechanism. These methods are voice processing methods such as fuzzy logic, neural networks and Markov model (Jayasekara et al., 2009; Wahyudi et al., 2008; Majdalawieh et al., 2004; Alghamdi et al., 2008; Chatterjee et al., 2005; Phoophuangpairoj, 2011). There are many ways to implement the real environment to these obtained models. One of these ways is the modeling of voice processing on the computer (Izumi et al., 2004; Zhou et al., 1994). As well as the computer, DSPs (Digital Signal Processor) are also widely used in voice processing technology (Qadri and Ahmed, 2009). Not only a common language such as English, but also many different languages are used in the voice processing technology while giving commands (Qidwai and Shakir, 2012; Izumi et al., 2004).

In this study, a voice recognition system has been developed in order to control prosthetic robot arms. The general structure of the system is shown Fig. 1. The mathematical model of single defined

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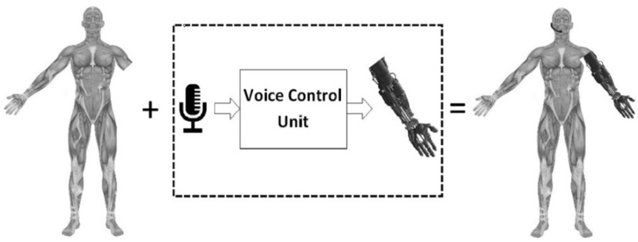

Fig. 1. General diagram of the system.

voice which is used for voice processing in the literature by Qidwai has been improved, and physical implementation of this model was implemented. In order to evaluate the interoperability of the system, a four-jointed RRRR (Rotational-Rotational-Rotational-Rotational, 4-rotary joints) robot arm model was designed, and this model was turned into a physical product. After making the necessary connections between the robot arm and the voice processing system, predefined voice commands were applied to the system. Finally, it was observed that how much of the applied voice commands was performed by the robot arm. According to the observed results; the detection rate for voice commands has increased even more owing to the developed system. The designed voice control system for the prosthetic robot arms is more efficient than the voice recognition systems used in the literature. The flowchart of the system is shown in Fig. 2.

2. Voice recognition system

Mathematical models of different types of voice recognition were obtained. The physical product was formed to be able to test these models.

2.1. Design of voice recognition model

In voice processing method, Eqs. (1) and (2) were defined by using the mathematical model that is used by Qidwai. First of all, voice that would be used was identified to the system with any sensor such as microphone. When the user says the system-defined voices, the system decides appropriate behavior thanks to the algorithm. How to obtain the model of the voice that was desired to be defined as shown in Fig. 3.

Mathematical description of the above model is given below.

$$uf_1 * nf(a-1) \rightarrow uf_1 \cdot nf(a-1) \tag{1}$$

Here, uf_1 shows the user frequency that is used by the user while saying the voice command, $nf(a-1)$ denotes the natural frequency that is combined by letters of command coming together. Also $uf_1.nf(a-1)$ denotes the frequency of command that is composed of user frequency and natural frequency defined based on the user. As an example, for "right" command, combining natural frequency that is composed of the letters of the word and the user frequency that composes while "right" command is said by the user, a user-specific "right" command has occurred. In this manner, commands which defined according to the user are modeled as shown in Fig. 4.

Mathematical expression of the above model is described below.

$$y(a) = uf_1 \cdot nf(a-1) + uf_2 \cdot nf(a-2) + \ldots + uf_n \cdot nf(a-n) \tag{2}$$

As seen from the model in Fig. 4, n words that is defined in voice of user $uf_1.nf(a-1)$, $uf_2.nf(a-2) \ldots uf_n.nf(a-n)$ are given in Eq. (2). By bringing together the voices, various y (a) commands that are defined with sentences can be created. As an example, $uf_1.nf(a-1)$ gets defined for "left" command while $uf_5.nf(a-5)$

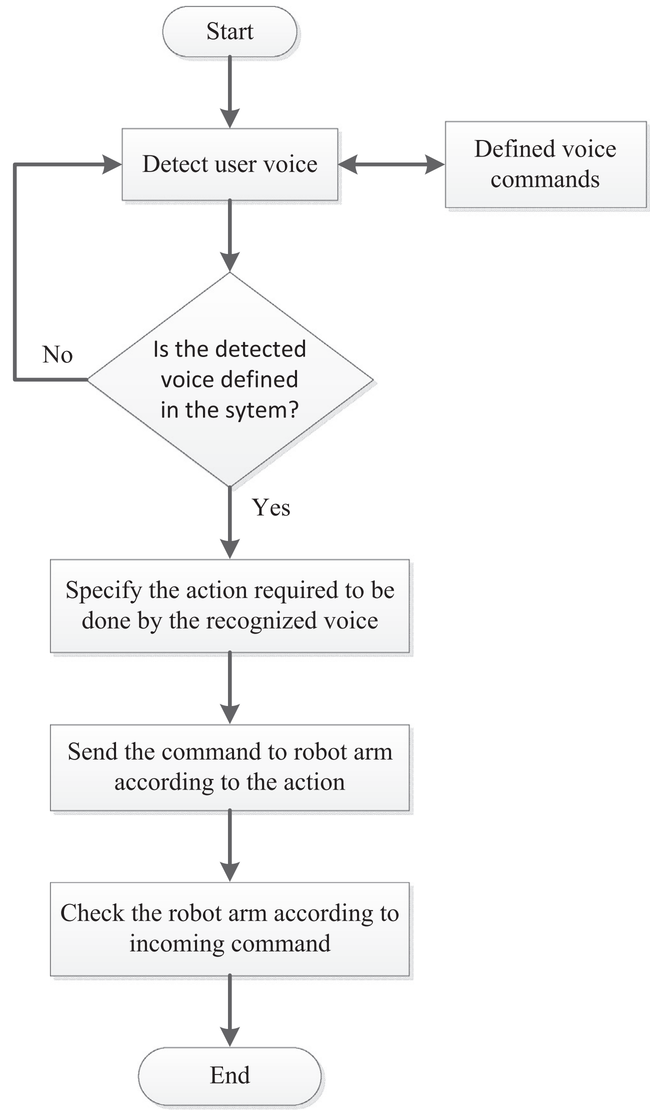

Fig. 2. The flowchart of the system.

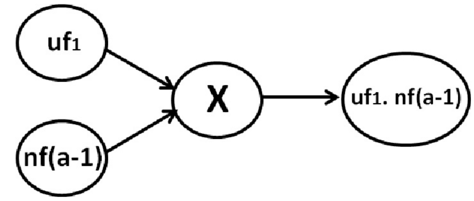

Fig. 3. Identification of voice command.

gets defined for "turn" command on the model. With the algorithms used in the model, the command "turn the left" $= y(a) = uf_1.nf(a-1) + uf_5.nf(a-5)$ is defined. For this model, an equation that is shown as below was obtained benefiting from Qidwai.

$$\underset{a}{\begin{bmatrix} y(a) \\ y(a-1) \\ \vdots \\ y(a-m) \end{bmatrix}} = \underset{b}{\begin{bmatrix} nf(a-1) & \ldots & nf(a-n) \\ \vdots & \ddots & \vdots \\ nf(a-m+1) & \ldots & nf(a-m-n) \end{bmatrix}} \underset{c}{\begin{bmatrix} uf_1 \\ \vdots \\ uf_n \end{bmatrix}} \tag{3}$$

In Eq. (3), the matrix represented by c shows “user frequency matrix”, the matrix represented by b shows “natural frequencies matrix” while the matrix represented by a shows matrix composed of user-defined commands.

2.2. Identification of voice commands by developing the generated system

A new model was developed utilizing the obtained model benefiting from the literature. Whilst voice recognition was made once in the first model, in the new model voice recognition was made twice. When experimental results are examined, it is easy seen that our twice defined system was better than once defined system. Because, it was clearly observed that higher voice detection rate is acquired by using our developed model. The new model obtained is shown in Fig. 5.

Here, in the Fig. 5, uf_1 and uf_2 denote user frequencies which are used by users while saying the desired same command. $nf(a-1)$ denotes the natural frequency that is formed by the combination of letters of the command whilst $uf_1.nf(a-1)$ and $uf_2.nf(a-2)$ denote the command frequencies which are utilized for the same command defined according to user that are composed by user frequency and natural frequency of command.

In the system, number of user frequency can be 1, 2, 4, and 8. However, when the system is applied to the robot arm, it is observed that the other voice recognitions rates are less efficient than two. Therefore, we preferred to use 2 user frequencies in this system. As an example, two separate different voice identification were made for “right” command. As seen from the equation, $uf_1 * nf(a-1) \rightarrow uf_1.nf(a-1)$, the voice defined for user was modeled twice as seen in $(right)_1 = uf_{1/1}.nf(a-1)$ and $(right)_2 = uf_{1/2}.nf(a-1)$. In this way, user- defined specific commands are shown in Fig. 6.

As seen from the model in Fig. 6, the same voice was modeled twice as $uf_{1/1}.nf(a-1)$ and $uf_{1/2}.nf(a-1)$. Firstly, the system decides whether the given command is registered command in the system according to the command which is given to the sensor by user and then performs required accordingly command. In the model voice defined twice, the voice recognition rate increases further because of a word defined twice. The following equation is

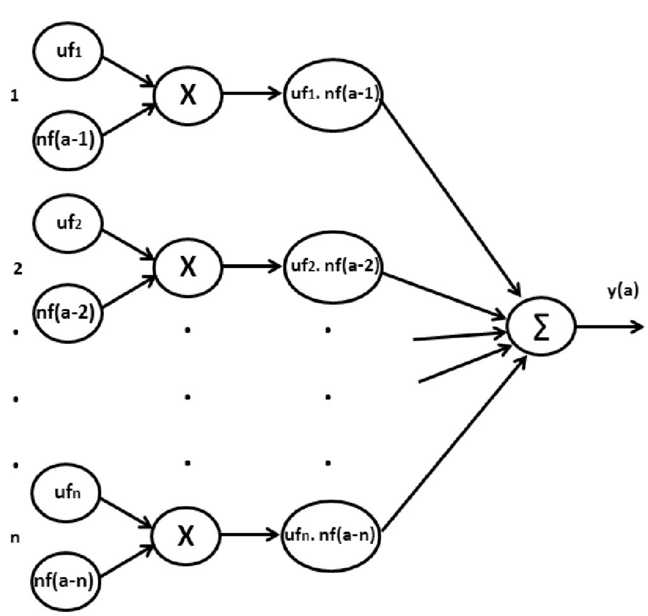

Fig. 4. Voice commands defined according to the user.

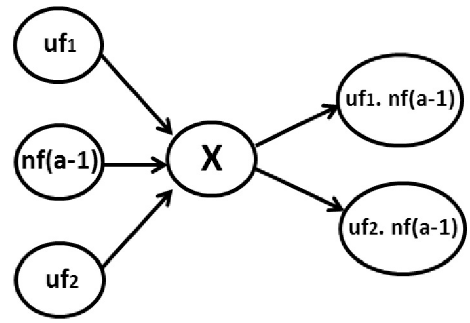

Fig. 5. Twice defining of the same voice command.

obtained utilizing the model in Eq. (3) that is obtained benefiting from Qidwai (Qidwai and Shakir, 2012).

$$\underbrace{\begin{bmatrix} y(a)^1 & y(a)^2 \\ y(a-1)^1 & y(a-1)^2 \\ \vdots & \vdots \\ y(a-m)^1 & y(a-m)^2 \end{bmatrix}}_{a} = \underbrace{\begin{bmatrix} nf(a-1) & \dots & nf(a-n) \\ \vdots & \ddots & \vdots \\ nf(a-m+1) & \dots & nf(a-m-n) \end{bmatrix}}_{b} \underbrace{\begin{bmatrix} uf_{\frac{1}{1}} & uf_{\frac{1}{2}} \\ \vdots & \vdots \\ uf_{\frac{n}{1}} & uf_{\frac{n}{2}} \end{bmatrix}}_{c} \quad (4)$$

In Eq. (4), the matrix represented by “c” shows “user frequency matrix”, the matrix represented by “b” shows “natural frequencies matrix” while the matrix represented by “a” shows matrix composed of user-defined commands.

2.3. Implementation of voice recognition system

In our work, firstly voice recognition system was designed. Then, printed circuit boards were made in order to make physical implementation of the system. The developed system in Fig. 7 consists of microcontroller and voice detection card.

First of all, the voices detected by the sensor were evaluated in the voice recognition unit and the processed information was sent to the microcontroller. In this way, it is provided that the information is stored in the microcontroller according to the model designed. When prompted by the system user to perform a command, the user tells the command to the microphone and the system transmits the voice to microcontroller. Finally, microcontroller decides whether to apply or to not apply the command by making the required comparisons according to the designed model.

3. Designing of four-jointed RRRR robot arm

A robot arm model was designed and implemented in order to make real-environment analysis of the obtained voice recognition model.

3.1. Modelling of robot arm

While obtaining the mathematical model of the robot arm shown in Figs. (8a and 8b), firstly, kinematic modeling was obtained by using Denavit-Hartenberg (D-H) method. Afterwards, forward kinematic equations were applied into this obtained model (Ozgur and Mezouar, 2016; Kucuk and Bingul, 2004). Finally, results in Table 1 were obtained as a result of the determination of variables with D-H method.

If D-H parameters shown in Table 1 are placed instead on the general matrix for the forward kinematics, obtains the matrix equation shown below (Kucuk and Bingul, 2004).

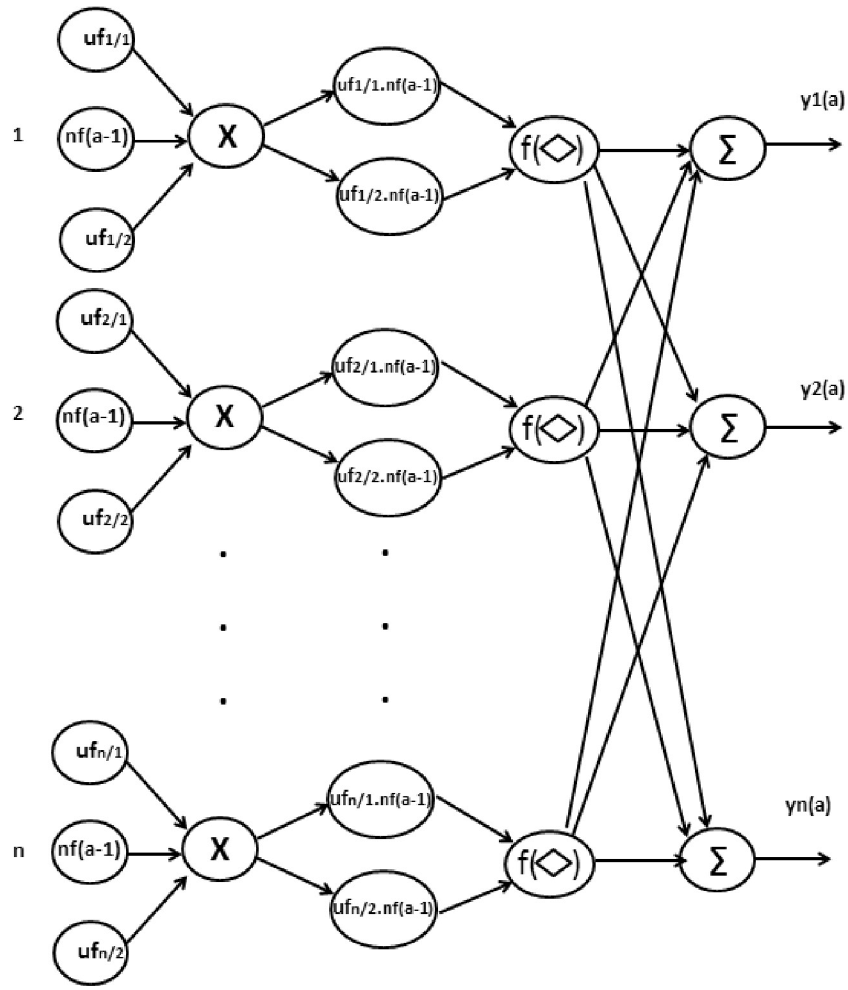

Fig. 6. Twice defined voice commands according to the user.

$$
{}^{0}{}_{1}T = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & h \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^{1}{}_{2}T = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s\theta_2 & c\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$
$$
{}^{2}{}_{3}T = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & l_1 \\ s\theta_3 & c\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^{3}{}_{4}T = \begin{bmatrix} c\theta_4 & -s\theta_4 & 0 & l_2 \\ s\theta_4 & c\theta_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}
$$
$$
{}^{4}{}_{5}T = \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

Joint matrixes of robot arm are shown in Eq. (5). Mathematical model of the forward kinematics of the robot arm was obtained as shown below when the operation ${}^{0}{}_{5}T = {}^{0}{}_{1}T.{}^{1}{}_{2}T.{}^{2}{}_{3}T.{}^{3}{}_{4}T.{}^{4}{}_{5}T$ was applied to the joint matrices according to forward kinematic method.

$$
{}^{0}{}_{5}T = \begin{bmatrix} c\theta_1.c\theta_{234} & -c\theta_1.s\theta_{234} & s\theta_1 & c\theta_1.c\theta_{234}.l_3 + c\theta_1.c\theta_{23}.l_2 + c\theta_1.c\theta_2.l_1 \\ s\theta_1.c\theta_{234} & -s\theta_1.s\theta_{234} & -s\theta_1 & s\theta_1.c\theta_{234}.l_3 + s\theta_1.c\theta_{23}.l_2 + s\theta_1.c\theta_2.l_1 \\ s\theta_{234} & c\theta_{234} & 0 & s\theta_{234}.l_3 + s\theta_{23}.l_2 + s\theta_3.l_1 + h \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}
$$

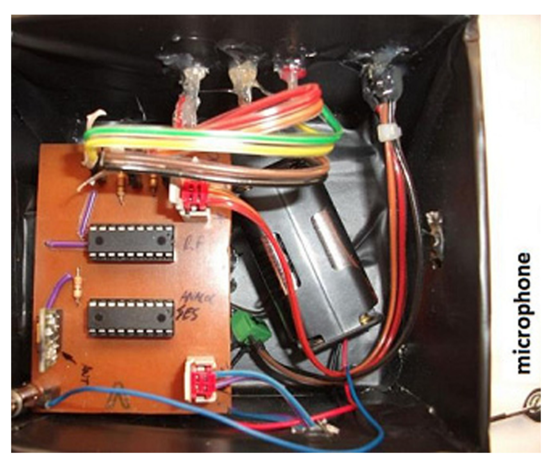

Fig. 7. Microcontroller and voice detection card.

In Eq. (6), $c\theta_{234} = c\theta_{23}.c\theta_4 - s\theta_{23}.s\theta_4$, $s\theta_{234} = c\theta_{23}.s\theta_4 + s\theta_{23}.c\theta_4$,, $c\theta_{23} = c\theta_2.c\theta_3 - s\theta_2.s\theta_3$ and $s\theta_{23} = c\theta_2.s\theta_3 + s\theta_2.c\theta_3$ is expressed.

4. Implementation of robot arm

In order to apply the model of robot arm designed in the real environment, six standard RC servo motors, 3 mm thick aluminum

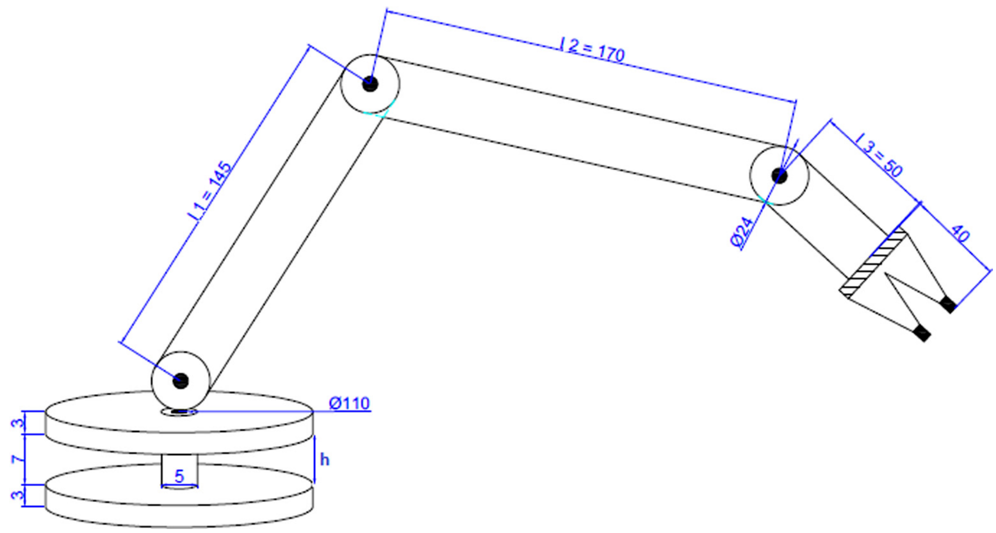

Fig. 8(a). Robot arm and joint variables Default Position.

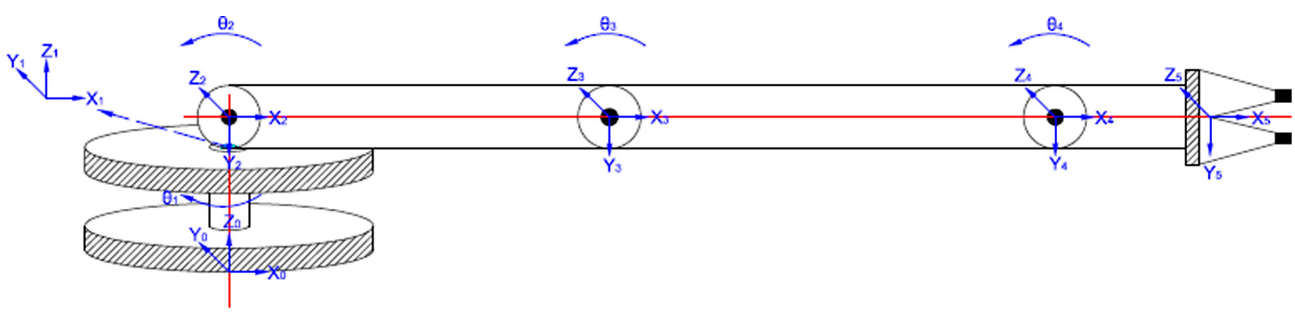

Fig. 8(b). Robot arm and joint variables Initial Position.

Table 1
Determination of D-H parameters.

Axis no.	D-H parameters				i. joint variable
i	α_{i-1}	a_{i-1}	d_i	θ_i	d_i or θ_i
1	0	0	h	θ_1	θ_1
2	90	0	0	θ_2	θ_2
3	0	L_1	0	θ_3	θ_3
4	0	L_2	0	θ_4	θ_4
5	0	L_3	0	0	0

sheet, 3 mm thick Plexiglass material and screws in various sizes were used. Plexiglass material was cut as length of L_1 = 145 mm, length of L_2 = 170 mm and width of 24 mm. Third length of the robot arm was formed by cutting aluminum sheet as length of L_3 = 50 mm. Moreover, finger part of the robot arm was formed by cutting aluminum sheet as end functionalist of the robot arm. Mechanism which makes the robot arm move right and left was formed by cutting a part having diameter of Φ = 110 mm and a length of h = 7 mm. The robot arm shown in Fig. 9 was made by combining the materials that were cut according to sizes in Fig. 8(a).

Robot arm has a control card and a system connected to the control board. Robot arm shown in Fig. 9 and voice recognition system transmit the data to each other by serial communication path. Through serial communication the transmission of commands detected in the voice recognition card are provided to the robot arm. Block diagram of the designed system is shown in Fig. 10.

The voice recognition card shown in Fig. 10 consists of voice processing board (Gundogdu and Calhan, 2013) and 2 PIC microcontrollers. The first microcontroller controls the sound processing board which converts incoming voice signals to digital. It is also responsible for storing these voices digitally and applying

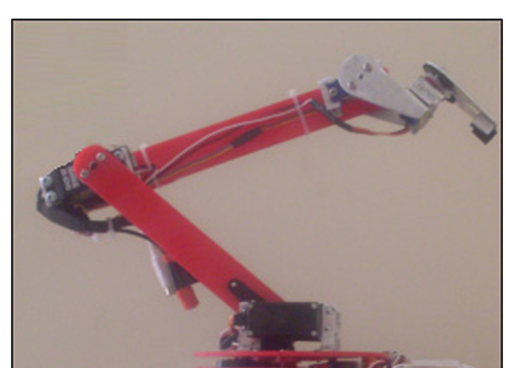

Fig. 9. Robot arm.

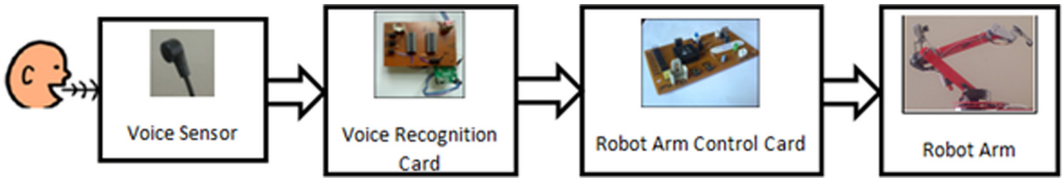

Fig. 10. Block diagram of the designed system.

Table 2
Voice commands and actions carried out by robot arm.

Voice commands	Actions carried out by robot arm	θ_1 (i + 1)	θ_2 (i + 1)	θ_3 (i + 1)	θ_4 (i + 1)
Turn the right	Robot arm returns 90 degrees to the right	θ_1(i) + 90	θ_2 (i)	θ_3(i)	θ_4(i)
Turn the left	Robot arm returns 90 degrees to the left	θ_1(i) − 90	θ_2(i)	θ_3(i)	θ_4(i)
Default position	Robot arm comes to the position in Fig. 8(a)	0	140	−120	−60
Initial position	Robot arm comes to the position in Fig. 8(b)	0	0	0	0
Open	Robot arm open its fingers	θ_1(i)	θ_2(i)	θ_3(i)	θ_4(i)
Close	Robot arm closes its fingers	θ_1(i)	θ_2(i)	θ_3(i)	θ_4(i)

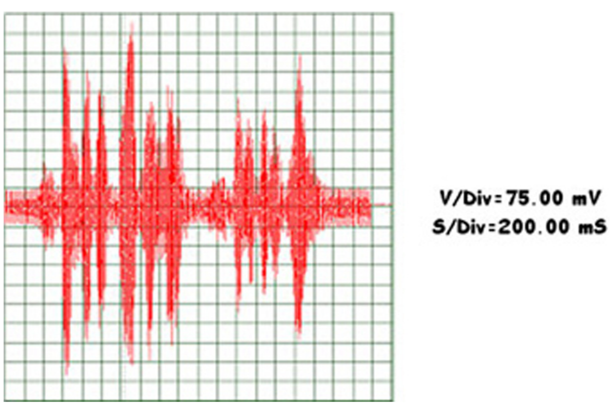

Fig. 11. Block diagram of the wave form of the "Default Position" command.

mathematical model on the system. Besides, in our system, a physical noise canceller is used to prevent the noise of the voice signal from the microphone. (Gundogdu and Calhan, 2013). According to the Nyquist theorem, the minimum rate of speech should be 8000 samples/s since human speech is less than 4000 Hz (Qidwai and Shakir, 2012). We used our sampling rate as 32,000 samples per second and all voice recordings were sampled for 5 s. The second microcontroller on the voice recognition card arranges data exchange with the robot arm control card. The robot arm control card shown in Fig. 10 consists of 8051 microcontroller. The 8051 microcontroller receives the data from the voice recognition card and moves the robot arm to the desired position by generating the PWM (Pulse-Width Modulation) outputs required by this data.

5. Results and discussion

The robot arm was produced according to the mathematical model shown in Fig. 9. Voice recognition system and control card, shown in Fig. 10, were integrated to the robot arm. The robot arm was used for observing how efficient of the system that was designed for voice commands works. Various voice commands were defined with the purpose of testing the system. The commands and their operations performed by robot arm were shown in Table 2. Waveform of default position was shown in Fig. 11.

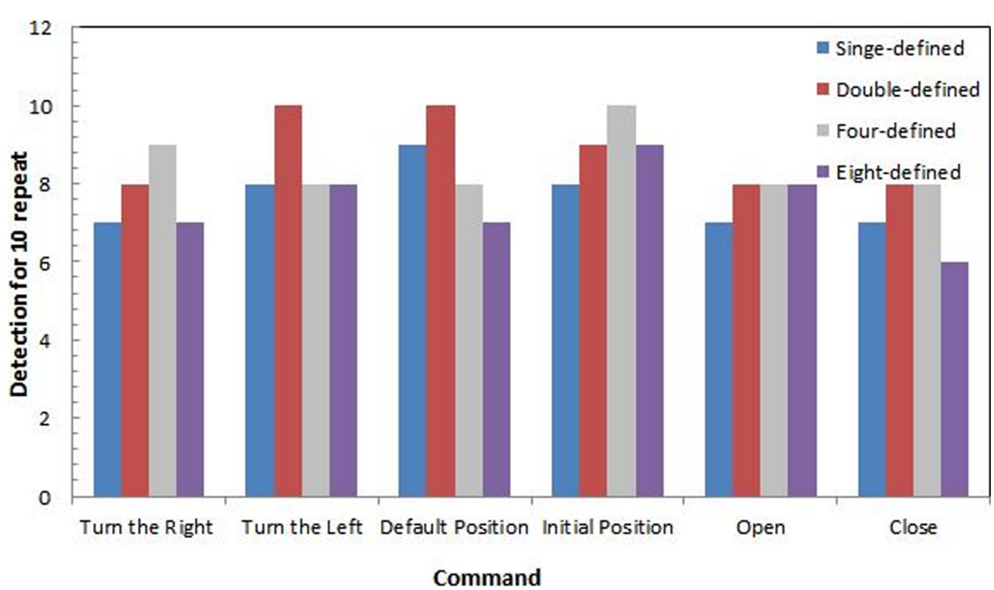

Fig. 12. Test results of the system in real environment.

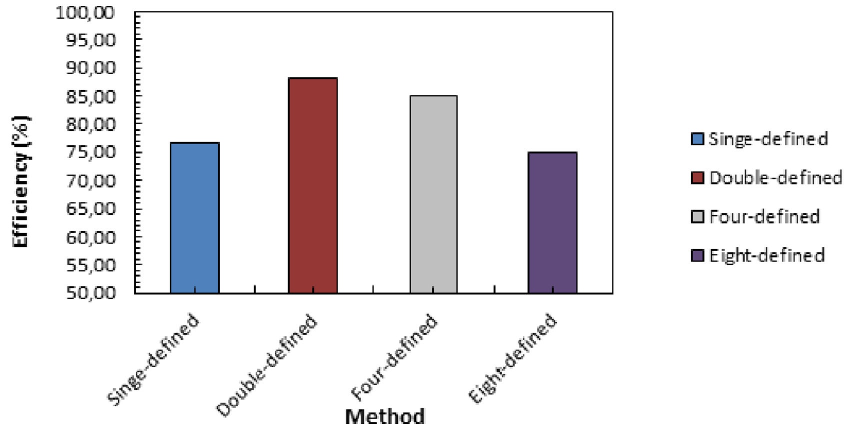

Fig. 13. Comparison of systems productivities.

Firstly, mathematical models of defined voice command were obtained according to the single-defined system in Eq. (3) and double-defined system in Eq. (4). Then, tests were performed by loading these models to voice recognition card in sequence. In addition, in order to better understand the system efficiency, behaviors of voice commands are observed using four and eight-defined systems. Each command was repeated 10 times. These commands were applied to 1, 2, 4, and 8 defined systems. The results are shown in Fig. 12. For instance; "default position" is applied to 1, 2, 4, and 8 defined voices for ten repetitions. Observation results of perception rates for our system are as follows; for one defined command 9/10, for two defined system 10/10, for four defined system 8/10, and for eight defined system 7/10.

In Fig. 13, in order to obtain the system efficiency, average number of detected commands for each system is acquired and defined as percentage. For example; average of the commands is 0.7667 for once defined voices that are 76.67% as percentage.

6. Conclusions

In this study, the voice control system was developed to control the prosthetic robot arms. The developed voice control system was applied on our own-designed, four-jointed RRRR robot arm. From the obtained results, it was observed that the developed voice recognition system for the prosthetic robot arms is more efficient than the currently used voice recognition systems in the literature.

The results of the tests showed that speed of the used processor is very important to store and recall of data. According to the obtained mathematical model, the data processing and storing as matrix causes a workload on the processor. For this reason, the speed of the processor should be selected as high as possible and accordingly the cache should be selected as large as possible.

Major contribution of this paper; as seen from the test results, mathematical model of twice-defined user frequency in Eq. (4) is more efficient than other models. The double-defined system specified in the mathematical model is about 11% more efficient than single-defined system, 3% more efficient than four-defined system, and 13% more efficient than eight-defined system. It is clearly seen from the results that the system which has twice-defined voice recognition rate of long words and sentences consisting of more than one word is more efficient. Because number of sample which was taken during comparisons was very much, efficient results were obtained.

Designed and implemented system could be used effectively in many areas of biomedical and other industries. Exemplarily:

Medical systems;

- controlling prosthetic robot arm effectively,
- controlling position of medical patient beds for bedridden patients who cannot use his hands,
- using power based wheel chairs with the voice commands for patients of paralyzed from the neck down,
- utilizing for meeting the requirements of bedridden patients who cannot use his hands with the help of robot arm which can be attached to the bed, for instance when a bedridden patient tells the command "bring me water" to the robot arm, the robot arm can make the bedridden patient drink the water which is on the table.

Industries;

- working non-arm patients in service sector such as patient who has no arm can observe the system which should be monitored and if necessary he/she can stop the system with the "stop the system" command.

Compliance with Ethical standards

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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