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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Controlling of Five Axis Manipulator with Turkish Voice Commands Using Microcontrollers

Mikrodenetleyicileri Kullanarak Türkçe Sesli Komutlarla Beş Eksenli Manipülatör Kontrolü

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Abstract

The interaction between human beings and machines has been increasing in conjunction with the development of computer technology. Controlling a system with voice-based commands is one of the most popular applications in this area. In this study, the main goal is to build a system, which is able to control a robotic arm comprised of five controllable axes with certain voice commands.

The robotic arm controlling process starts with the matching of sounds taken from the user. Then sounds processed in voice recognition card. After the command recognized by voice recognition card, then index number is sent to a microcontroller. Consequently, this operation provides a communication between voice recognition module and servo motor drive card. Finally, the microcontroller calculates the required angles by using the data provided by the previous process and sends this data to the servo motor drive card in order to realize the robotic arm action.

Keywords: Speech Recognition, Robot Control.

Öz

Bilgisayar teknolojisi gelişimiyle birlikte, insanlar ile makineler arasındaki etkileşim artmaktadır. Ses tabanlı komutlarla bir sistemi kontrol etmek bu alandaki en popüler uygulamalardan biridir. Bu çalışmada ana hedef, belirli sesli komutlarla beş kontrol edilebilir eksenden oluşan robot kolunu kontrol edebilen bir sistem oluşturmaktır. Robot kolunu kontrol etme işlemi, kullanıcıdan alınan seslerin ve ses tanıma kartında işlenmiş ve ses tanıma kartı tarafından tanımlanan seslerin eşleştirilmesi ile başlar. Ardından pozitif bir eşleme varsa, sistem tarafından ses tanıma modülü ve servo motor sürücü kartı arasında bir iletişim sağlayan bir mikrodenetleyiciye veri gönderilir. Son olarak, mikrodenetleyici, önceki işlem tarafından sağlanan verileri kullanarak gerekli açıları hesaplar ve robotik kol hareketini gerçekleştirmek için bu verileri servo motor sürücü kartına gönderir.

Anahtar Kelimeler: Konuşma tanıma, robot kontrol

I. Introduction

A large part of the research in robot technology that provides new opportunities and makes human life easier is about developing intelligent machines that can move on their own. The use of image and audio processing algorithms taking part in this research area, in conjunction with intelligent machines such as robots, has an important place in today's technological advances, in order to facilitate a better way for human life.

Speech is the most important form of communication. Thus, speech-recognition systems aim to achieve human-machine communication by fast and efficient means. For this purpose, various studies have been carried out in recent years to improve speech-recognition technology [1]. Speech-recognition systems could be used the human-computer communication that

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provides for browsing of the web pages, typing a text without touching the keyboard, enabling the programs, control the wheelchair by people with disabilities [2, 3, 4, 5]. Speech-recognition technology consisted of different disciplines, such as AI, machine learning, mathematics, statistics, cognition and linguistics, has profited significantly both from these disciplines and advances in electronics (microphone, sound-card technologies, processor speeds, etc.) [6, 7, 8, 9].

In the literature, there are some works similar to ours. Peter has developed a system to control a mobile robot using voice-commands. He used the Hidden Markov Model (HMM) as a speech-recognition method. A robotic control unit has been developed under an interface provided by the robot manufacturer [10]. Özdemircan carried out robot control by voice-command. Voice-commands features were extracted using Mel Frequency Cepstral Coefficients (MFCC) and were recognized by using Artificial Neural Networks. [11].

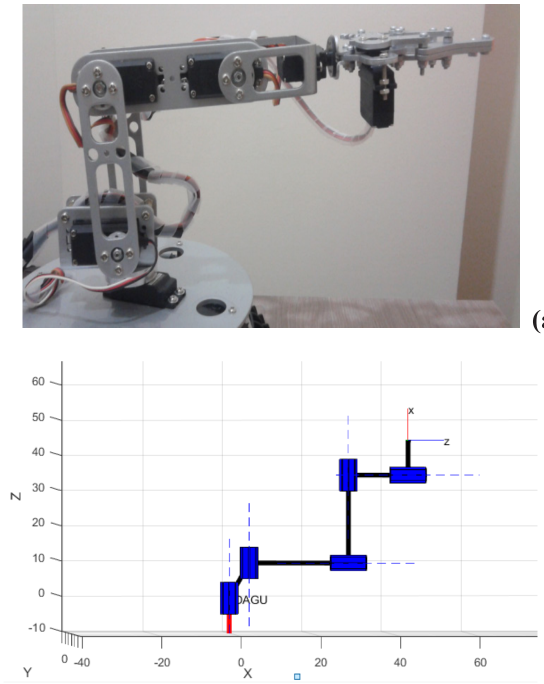
Nishimori has developed a voice-controlled wheelchair in order to help people with physical disabilities [12]. Ishikawa has developed a robot that moves by voice-command and can avoid obstacles. A feature extraction of Levinson Durbin's algorithm and the LPC coefficients were used [13]. Kelebekler has completed a real-time application of a speaker-independent, speech-recognition system. The utterances of ten male and ten female speakers have been used to create the database [14].

Unlike the studies above, special speech recognition module is used in this work. Additionally, all the control issues are performed by using MSP430 type microcontrollers with the RC servo motor control driver.

This paper is organized as follows: Section 2 provides the kinematics and control information of manipulator. Section 3 presents speech-recognition model, realized voice-recognition and control systems are presented in Section 4. Experimental results are described in section 5 then conclusions are presented in section 6.

II. KINEMATICS AND CONTROL OF MANIPULATOR

A robotic manipulator is a type of mechanical arm which is usually programmable. The manipulator may be the sum of the mechanism or may be part of a more complex robot. The links of such a manipulator are connected by joints which allow either rotational motion or translational displacement. The links of the manipulator can be considered to form a kinematic chain. Five Degree of Freedom [DOF] robot manipulator with the gripper is used in this study. Figure and reference model of the robot which was used in this study are given in Figure 1a and 1b respectively.



(a)

(b)

Figure 1. a) Robot arm b) Robot arm reference model.

2.1. Forward Kinematics of Manipulator

To find out the forward kinematic model of the robotic manipulator, Denavit–Hartenberg (DH) parameters are determined according to the reference model, which are given in Table 1 [15].

Table 1. D-H parameter of the manipulator.

	$\alpha_{(i)}$	$a_{(i)}$	d_i	θ_i
1	90	0	d_1 (32.5 mm)	θ_1
2	0	a_2 (77 mm)	0	θ_2
3	0	a_3 (75.9 mm)	0	θ_3
4	-90	0	0	θ_4
5	0	0	d_5 (140 mm)	θ_5

The forward kinematic equations of the robotic arm obtained using Pieper-Roth transformation matrix method (Eq. 1):

$$ {}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i * \cos a_i & \sin\theta_i * \sin a_i & a_i * \cos\theta_i \\ \sin\theta_i & \cos\theta_i * \cos a_i & -\cos\theta_i & a_i * \sin\theta_i \\ 0 & \sin a_i & \cos a_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

where i is joint of the robot.

The robotic arm complete forward kinematic model is achieved by multiplying each joint transformation matrix to each other respectively as given below (Equation 2);

$$ {}^0_5T = {}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T\,{}^4_5T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^0_1T = \begin{bmatrix} cos\theta_1 & 0 & sin\theta_1 & 0 \\ sin\theta_1 & 0 & -cos\theta_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

$$ {}^1_2T = \begin{bmatrix} cos\theta_2 & -sin\theta_2 & 0 & a_2 * cos\theta_2 \\ sin\theta_2 & cos\theta_2 & 0 & a_2 * sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^2_3T = \begin{bmatrix} cos\theta_3 & -sin\theta_3 & 0 & a_3 * cos\theta_3 \\ sin\theta_3 & cos\theta_3 & 0 & a_3 * sin\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^3_4T = \begin{bmatrix} cos\theta_4 & 0 & -sin\theta_4 & a_4 * cos\theta_4 \\ sin\theta_4 & 0 & cos\theta_4 & a_4 * sin\theta_4 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^4_5T = \begin{bmatrix} cos\theta_5 & -sin\theta_5 & 0 & 0 \\ sin\theta_5 & cos\theta_5 & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Finally, complete forward kinematic model is obtained as follows (Eq. 3):

$$ {}^0_5T = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ A_{21} & A_{22} & A_{23} & A_{24} \\ A_{31} & A_{32} & A_{33} & A_{44} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

where;

$$ A_{11}=C_1(C_{234}C_5C_6-S_{234}S_6)-S_1S_5C_6 $$

$$ A_{12}=C_1(-C_{234}C_5C_6-S_{234}C_6)+S_1S_5S_6 $$

$$ A_{13} = C_1(C_{234}S_5)+S_1C_5 $$

$$ A_{14} = C_1(C_{234}a_4+C_{23}a_3+C_2a_2) $$

$$ A_{21} = S_1(C_{234}C_5C_6-S_{234}S_6)-C_1S_5C_6 $$

$$ A_{22} = S_1(-C_{234}C_5C_6-S_{234}C_6)-C_1S_5S_6 $$

$$ A_{23} = S_1(C_{234}S_5)-C_1C_5 $$

$$ A_{24} = S_1(C_{234}a_4+C_{23}a_3+C_2a_2) $$

$$ A_{31} = S_{234}C_5C_6-C_{234}C_6 $$

$$ A_{32} = -S_{234}C_5C_6-C_{234}C_6 $$

$$ A_{33} = S_{234}S_5 $$

$$ A_{34} = S_{234}a_4+S_{23}a_3+S_2a_2 $$

and

$$ C_1 = Cos\,\theta_1 $$

$$ C_{12} = C_1C_2 - S_1S_2 $$

$$ C_{12} = C_1C_2 - S_1S_2 $$

$$ S_{12} = S_1C_2 - C_1S_2 $$

$$ C_{234} = C_2(C_3C_4 - S_3S_4) - S_2(S_3C_4 + C_3S_4) $$

$$ S_{234} = S_2(C_3C_4 - S_3S_4) + C_2(S_3C_4 + C_3S_4) $$

2.2. RC Servo Motor Control

PWM signal is used to control the positions of six RC servo motors on the robot arm. RC servo motor positions related to PWM signals are given Figure 2 [16].

The appropriate PWM signal is sent to the voice commands (COK = 100, AZ = 50, BİRAZ = 10) received from the RC servomotors on each robot axis.

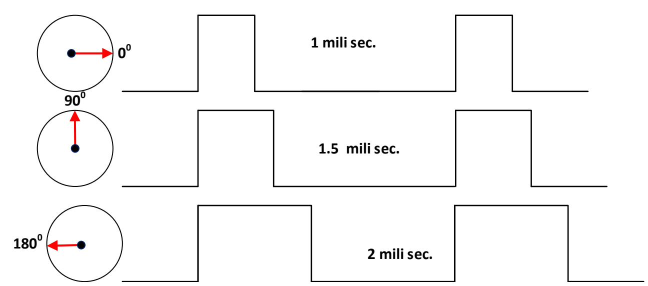


Figure 2. Shaft angle values and PWM signals.

III. SPEECH RECOGNITION MODEL

The speech recognition systems vary according to the characteristics of the targeted language. Turkish is an agglutinative language and many suffixes can be added to the end of a Turkish word. For this reason, it is difficult to develop a word-based speech recognition system for Turkish Language [17, 18].

The working of voice-recognition systems is based on the principle of the artificial realization of functions, as performed by an audience in the process of vocal communication between people. If we want to make a voice-recognition system, the human hearing, linguistic coding and understanding systems must be replaced by recording and processing the voice, linguistic coding and pairing respectively. A speech-recognition model is given in Figure 3.

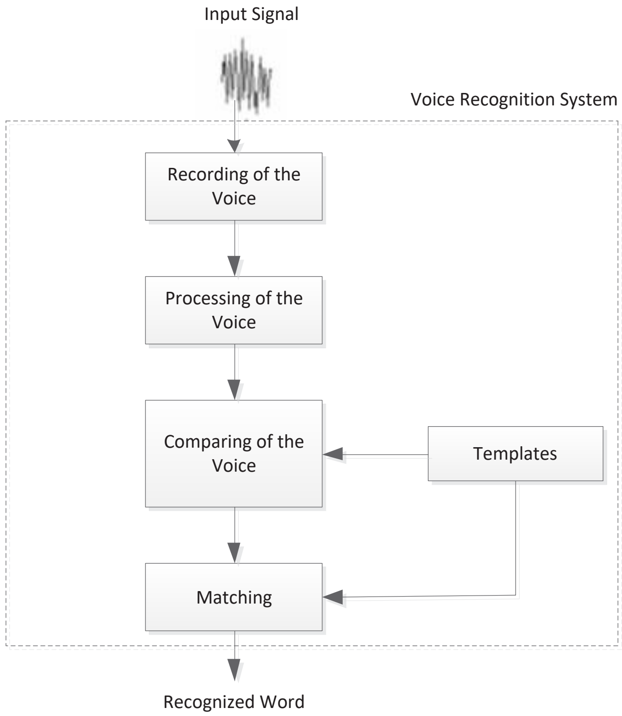


Figure 3. Speech recognition model.

IV. REALIZED VOICE-RECOGNITION AND CONTROL SYSTEMS

The sound is sensed with a microphone and then it is checked with a speech-recognition kit. If a sensed-voice is a predefined sound, this sound is checked and the result is sent to the microcontroller. According to this information, the microcontroller sends the angle information necessary for the movement of the robot arm to the motor driver board. As a result of this operation, the robot arm is controlled by the sound.

Voice-recognition applications consist of complex algorithms that require high processing power. It's hardly possible to carry out with general-purpose controllers. Due to the EasyVr voice recognition module, the voice-control feature can easily be added to microcontroller applications.

The EasyVr module [18] has twenty-six speaker-independent (SI) and thirty-two speaker-definition (SD) voice commands. Each command lasts for a maximum of five seconds. SI command sets can be used for the English, German, Italian and Japanese languages. User-defined commands can be defined in the desired language. Figure 4 shows the EasyVr voice-recognition module. After commands are defined for the module with the computer interface, it can operate independently of the PC by being connected to any microcontroller.

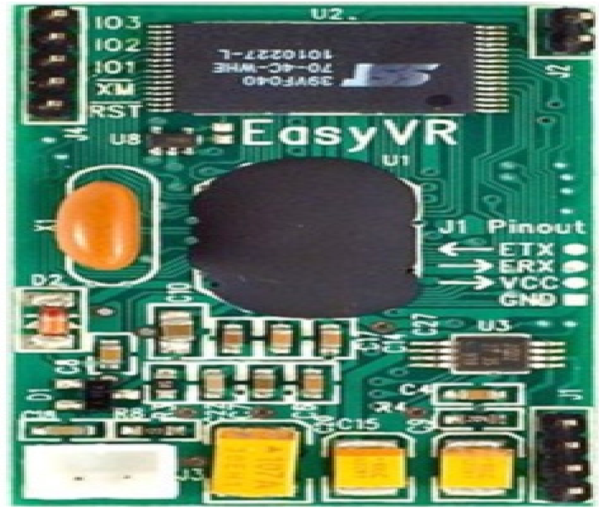


Figure 4. EasyVr voice-recognition module.

Firstly, it is necessary to select a serial port connecting to the module in section. Connecting is realized after the selection of the port name. The commands which are desired to be defined are entered in the part for group numbers. When a connection is established between the EasyVr module and the microcontroller, it must be denoted as a communicating number of the group.

The MSP430 microcontroller converts the information obtained from a voice-recognition kit to the knowledge of the angle which is required for the movement of the robot arm and sends this, with the angle of the axis, to the motor-drive-board. Figure 5 shows a block diagram MSP430 microcontroller communicating with other units. There is bi-directional communication between the MSP430 microcontroller and the EasyVr voice-recognition module. The ID of the recognized voice on the voice-recognition card is sent to the G2231 microcontroller. Incoming ID information is sent to the G2553 microcontroller. The G2553 microcontroller calculates the angle and sends it to the motor-driver card. The motor-driver card converts the angle information to the electrical signal required for the servo-motor and sends it to the robotic arm.

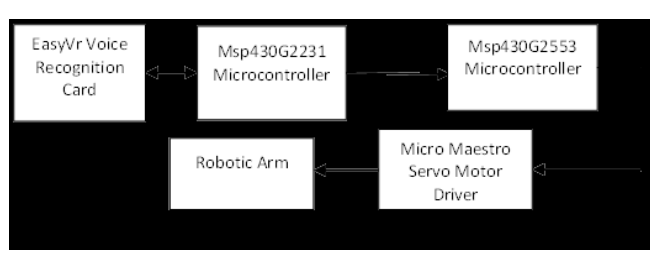


Figure 5. Connections between hardware modules.

The MSP430 is an ultra-low-power-consumption microcontroller manufactured by Texas Instruments. It has a 16-bit RISC architecture. It contains many modules like I2C, SPI, USART and ADC classic modules. IAR Embedded Workbench or Code Composer Studio could be used for programming MSP430 microcontrollers. The MSP430G2231 and the MSP430G2553 microcontrollers are an entry-level microcontroller that fulfills many functions and has two input-output ports (P1 and P2). The P1 port has eight input-output ports and P2 has six input-output ports. The LaunchPad used in both microcontrollers is given in Figure 6 [19].

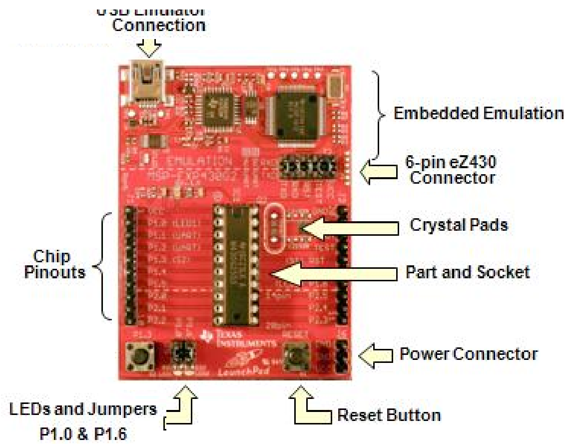


Figure 6. MSP 430 LauncPad.

The six-channel Micro Maestro motor-driver card is used to control the servo-motor. The Micro Maestro is an extremely small, versatile, servo-controller and general-purpose I/O card. It supports three different control methods; USB for direct connection to a computer, TTL serial for use in embedded systems and the built-in scripting for applications that can run without a host computer. Micro Maestro motor-driver card connection diagram is given Figure 7.

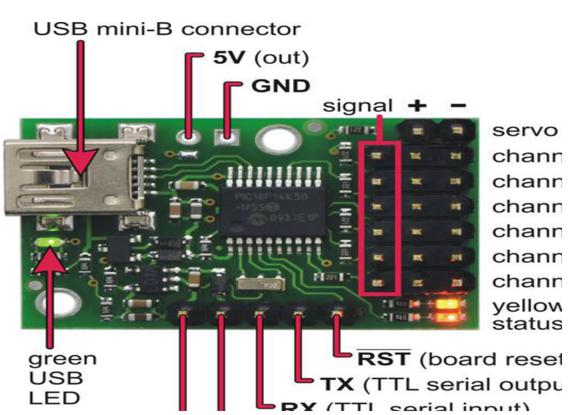


Figure 7. Micro Maestro motor-driver card.

Movement of the robot arm was achieved with the angle information sent from MSP430G2553 microcontroller to the motor driver board using serial communication. The package structure sent by the microcontroller to the motor-driver board is shown in Table 2.

Table 2. The package structure of the motor-driver board.

Byte	1	2	3	4
Package Structure	0x84	channel number	target low bits	target high bits

The first byte 0x84 is the default for protocol type. The second byte shows the motor channel number. The motor driver board has six servo-motors driver. The lower 7 bits of the third data byte represents bits 0–6 of the target (the lower 7 bits), while the lower 7 bits of the fourth data byte represents bits 7–13 of the target. If the channel is configured as a servo, then the target represents the pulse width to transmit in units of quarter-microseconds. A target value of 0 tells the Maestro to stop sending pulses to the servo. For example, if channel 2 is configured as a servo and you want to set its target to 1500 µs (1500×4 = 6000), you could send the following byte sequence: in hex: 0x84, 0x02, 0x70, 0x17 [20].

To control the robotic arm with a voice, the degrees and direction of each axis must be spoken. The EasyVr voice-recognition interface is used to describe these commands. The list of commands is shown in Figure 8.

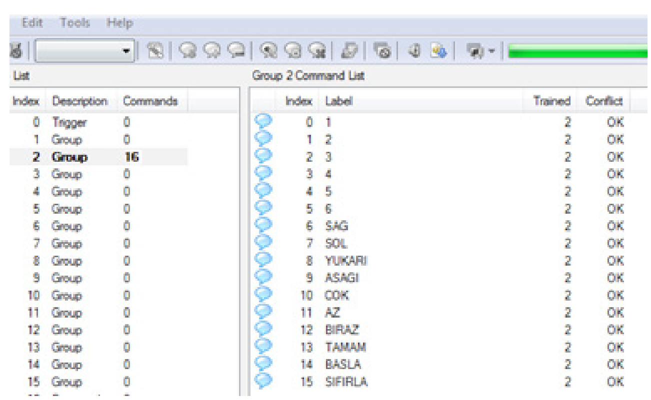


Figure 8. List of commands described in the interface program of EasyVr.

Command sequences to control the robot arm can be seen in Figure 9. Firstly, the desired axis number, then the direction, then the amount of movement and, finally, OK commands are given. This procedure is repeated separately for all axes. A start command is given for the realization of the desired movement and the movement of the axes is carried.

Commands									
Axis 1	Direction	Amount	TAMAM	Axis 2	Direction	Amount	TAMAM	....	BAŞLA

Figure 9. Pronunciation sequence of commands on robot arm control by voice.

The following steps must be realized to control the robot manipulator by voice:

1. Say the axis number (BİR "one", İKİ "two", ÜÇ" three", DÖRT "four", BEŞ "five, ALTI "six").
2. Say the direction (SAĞ "right", SOL "left, YUKARI "up", AŞAĞI "down"),
3. Say the amount degree (ÇOK "very, AZ "little", BİRAZ "slightly") to move the axis,
4. After having spoken 1 and 2 commands, say the (TAMAM "okay") command.
5. After saying the first three steps of the entire required axis, say the (BAŞLA "start") command.

For example, if you want to move manipulator axis 1 is slightly left, axis 2 is slightly down and axis 3 is very down then you have to speak "BİR SOL BİRAZ TAMAM İKİ AŞAĞI BİRAZ TAMAM ÜÇ AŞAĞI ÇOK TAMAM BASLA".

As shown in Figure 1, it is important to note that the 1st and 5th axes can only move left and right, 2nd, 3rd, 4th axes only up and down.

V. Experiments

In experimental studies, commands were tried on more than one robot arm. Various tests were undertaken to see the movement of the robotic arm. Every command defined on the robot arm has been tested thirty times. An 85.4% success rate was obtained as a result of this test.

The rates of recognition accuracy of the voice-commands used to control the robot arm are listed in Table 3. For example, the "YUKARI – up" commands were tested thirty times and twenty-four of them were correctly applied

.**Table 3.** Results of the test.

Command	Correct Detection
BİR	29
İKİ	28
ÜÇ	25
DÖRT	28
BEŞ	25
ALTI	29
SAĞ	24
SOL	27
YUKARI	24
AŞAĞI	26
ÇOK	20
AZ	27
BİRAZ	25
TAMAM	21
BAŞLA	24
SIFIRLA	28

VI. CONCLUSIONS

In this study, control of the robotic manipulator with Turkish voice-commands was successfully carried out with the help of a microcontroller-based system, without the use of a computer.

In this system, the EasyVr voice-recognition module was used to recognize the voice-commands and a micro-maestro servo-motor-driver board was used to move the axes of the robot arm. MSP430 microcontrollers were used to provide communication between the EasyVr voice-recognition module and the micro-maestro servo-motor-driver card.

Because of a computer is not used, it can be easily used in many environments as portable. At the same time, the installation, operation and cost of the system are greatly reduced.

Incorrect identification of the commands in the testing-phase environmental conditions has a major impact. Noise from the external environment of a voice-command can cause incorrect recognition of the command. Because the commands used in this study were user-dependent, the controlling of the manipulator with a voice was only possible by just one person.

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