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Realization of a Bionic Hand Controlled via Bluetooth Communication Utilizing a Microcontroller

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Abstract: The ability of people without limbs to do their own work and their adaptation to life can be achieved with bionic hands. The aim of this study is to realize the design and application of bionic hand that can be controlled by mobile application for handicapped individuals. The aerobic designs necessary to solve this problem were made and a prototype was produced and controlled with Arduino Mega 2560 microcontroller. For the five fingers of the bionic hand designed with the work carried out, the independent movement of the five fingers from the fingertip to all the other joints has been successfully performed using five SG90 model mini servomotors. The movement of the servomotors is provided by the software developed with the MIT AI2 Companion program on the mobile phone. The software algorithm has been fulfilled separately for each finger and each joint. Microcontroller and mobile phone communication is done with HC-06 Bluetooth module. Servomotor fin connections are made with fishing line with the tip of each finger. The two joints of the thumb and three joints of the other four fingers are controlled by winding the fishing line, which is connected to the servomotor, according to the determined rotation angle. Thus, the control of the fingers on the hand was realized through the mobile application. Ultimately, the effective use of the bionic hand will have an impact on every individual's participation in society. Every individual who is brought into the society has the potential to be an individual who enters the business life at the same time. For this reason, this will allow for an increase in employment and working power. It is also more sustainable because it raises people's living standards.

Keywords: Bionic hand, SG90 mini servomotor, Microcontroller, Mobile application, HC-06 Bluetooth module.

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1. INTRODUCTION

Many of the disabled individuals living in our society cannot do many jobs due to their disabilities, and therefore their quality of life is seriously reduced. There are people in our lives who are born without a limb, who have lost their hands by accident or by amputation. They have difficulty in living their lives. In addition, they tend to keep themselves in the background psychologically in their work and social environments. Because this situation is not only organ loss for individuals, but also organ loss; means loss in function, body image, work and relationships (Özsoy & Okyayuz, 2016).

The ability of people without limbs to do their own work and to adapt to life can be solved with bionic hands. The bionic hand allows the individual to continue their daily lives like other healthy individuals by completing the missing hand limb. In order to solve this problem, necessary aerobic designs must be made, formulas must be drawn up, and a prototype must be produced and controlled by controllers.

When a literature review is conducted, it is seen that various studies have been carried out on this subject from the past to the present. Karaçizmeli et al. (2014) carried out the control of the mechatronic-based robotic hand with the position information obtained from the human hand with the help of flexibility sensors mounted on the glove. They performed hand control with data from sensors connected to the glove in the other hand. However, they also stated that there is a disadvantage that hand control is not provided independently of the other hand. Şenli (2011) fulfilled a bioelectrical database of the activity of hand muscles and made interaction network and interface work between human and prosthetic hand using this database. In addition, he subjected the recorded bioelectrical signals to a series of preprocessing, established the relationships between the electromyogram (EMG) signals and hand and finger movements, and provided the control of the bionic hand with a microcontroller. Aydın (2020) conducted high precision bio-electronic hand design work in his master's thesis. He filtered the EMG signals received from the forearm muscles and transmitted them to the microcontroller and provided the movements of the servomotors with this microcontroller. In another study, Paaßen et al. (2018) proposed an expectation maximization transfer learning that minimizes data classification that may occur in the bionic hand. With the algorithm they developed, data loss during transfer is minimized. Klug et al. (2005) designed a robot arm inspired by biological principles for industrial applications. They stated that one of the shortcomings in their studies was that they could not perform the sprains on their systems. Deng et al. (2016) carried out a study that takes into account the force applied while grasping soft and hard objects by the bionic hand. They improved the bionic hand grasp of objects with the polyvinylidene fluoride sensor they used. Lastly, Andrecioli and Engeberg (2013) developed an adaptive sliding mode prosthetic hand controller with a variable slope manifold. Considering all these studies, it can be predicted that bionic hand studies will continue without slowing down.

There are some considerations to consider in the design and realization of a bionic hand. One of them is to determine the hand limb design that is suitable for the individual. After that, the calculation of the power values of the motors suitable for this hand limb is made according to the designed limb. In addition, it is necessary for the preliminary design to determine the number of inputs and outputs in the control system to be used and to calculate the power switches for the system. Then, what needs to be done is to create the flow diagram of a hand limb and embed it in the microcontroller determined according to the system requirements. In the study carried out, a bionic hand study was designed and applied to facilitate people with no limbs. A microcontroller is included in the control of this bionic hand. The control signals of the microcontroller were sent from a mobile device using Bluetooth communication. System movements were realized by adjusting the angles of the servomotors. In the presentation of this study, after a short introduction given above, "Materials and Methods" are expressed in the second part. After showing the “Results and Discussion” obtained in the third part, “Conclusions” is given at the end of the paper.

2. MATERIAL AND METHOD

In this study, five fingers of the bionic hand were controlled by a mobile application. The movements of three joints in four fingers and two joints in the thumb from the fingertip to the root joints are controlled by signals sent from the mobile software. In this way, the movement and gripping feature of the desired finger(s) is realized.

Arduino MEGA 2560 microcontroller is used to control the whole system. It is also preferred for power sharing with Arduino UNO. Among the reasons why this microcontroller finds many applications today; programming with an integrated development environment (IDE) and coding with commands similar to the C programming language. Arduino microcontrollers have at least one 5 V regulated integrated circuit (IC) and one 16 MHz crystal oscillator (Hidayanti et al., 2020). An external programmer is not needed for programming Arduino microcontrollers, because a bootloader program is already written to the microcontroller. Arduino Mega 2560 can be powered by an external power supply in the range of 6-20 V. However, when a supply under 7 V is made, the 5 V pin may output less than its value, and therefore the board may start to work unstable. When the board is supplied with a voltage greater than 12 V, the regulator may overheat. This may cause damage to the card. Considering all these, it is recommended to limit the supply voltage of the recommended microcontroller to the range of 7-12 V (Allahverdi et al., 2019).

HC-06 Bluetooth module is used in the communication of the microcontroller used with the mobile device. The Bluetooth module has been developed for short distance communications, and this communication protocol uses the 2.4-2.48 GHz industrial, scientific and medical (ISM) band. Communication can be provided up to 10 m, provided that there is no obstacle between devices. HC-06 Bluetooth module works at 2.4 GHz communication frequency. The sensitivity of the module is less than -80 dBm and the output power is less than 4 dBm. Asynchronous communication speed is 2.1 MBps/160 KBps, synchronous communication speed is 1 MBps/1 MBps. The operating voltage is in the range of 1.8-3.6 V. HC-06 Bluetooth module supports Bluetooth 2.0.

In the implemented system, RC (Radio Control) Tower Pro SG90 DC type mini servomotor, which provides position control at small powers, is used. Servomotors are closed-loop motors that can minimize position errors that may occur in the system, receive continuous feedback and are highly preferred in position control. They are divided into three according to their working angles; 120-140°, 0-180° and 0-360° servomotors. Servomotors with 0-180° and operating voltage of 5 V DC were preferred in the study. Their structures are small and their strain torques are high (Süzen et al., 2017). 20 ms period signals are sent for position control of servomotors. If there is a duty value of 2 ms within 20 ms, the position of the servomotor becomes 180°. If the duty value is 1 ms within 20 ms, the position of the servomotor becomes 0°. Angle values in other intervals are obtained by giving values between the duty value and 1-2 ms. The dimensions of these servomotors are 22.2 × 11.8 × 31 mm, their weight is 9 g, and their speed is 0.1/60° (VanHuy et al., 2017).

In the study, two methods were applied to obtain and compare the determined angle values of each finger and knuckles. The first one is obtained by making the relationship between the arc length and the angle with the method of finding the central angle in the circle. The second method is obtained by measuring the rotation time of the servomotor, that is, by the relationship established between the position of the servomotor and the pulse width.

The first method is related to the length of the servomotor fin and the length of the finger from the root to the knuckle. Therefore, the rotation angle of the servomotor blade was calculated based on the formula for calculating the center angle in the circle. In Figure 1, the relation shape of servomotor blade rotation angle and finger joint length is given.

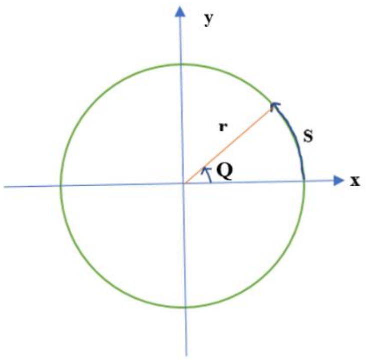


Figure 1. Relation of servomotor blade rotation angle and knuckle length

Here, Q represents the rotation angle of the servomotor vane, r the servomotor vane length, and S the length from finger root to knuckle. The ratio of arc length to radius gives the angle of rotation. The angle of rotation and the length of the arc of the circle are described as follows:

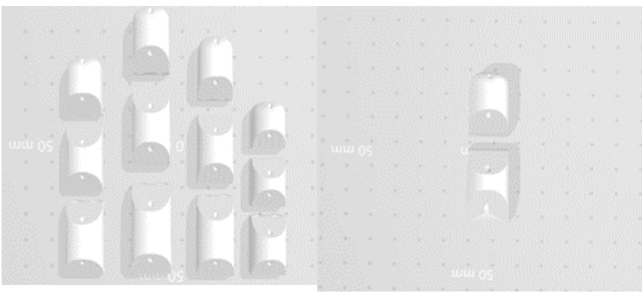
$$Q = S/r \tag{1}$$

$$|S| = (Q \times 2 \times \pi \times r)/360 \tag{2}$$

From here, the angle of rotation is again found in detail as follows:

$$Q = [(360/2) \times S]/(2 \times \pi \times r) \tag{3}$$

The fin length of the servomotors used in the realized bionic hand design is taken as $r = 1.5$ cm and the π value is taken as 3.14. Since the servomotor blade can provide a maximum of 180° rotation, the calculation was made over the semicircle and 360 / 2 was written in the formula in **(3)**. Finger knuckle lengths are shown in Figure 2.

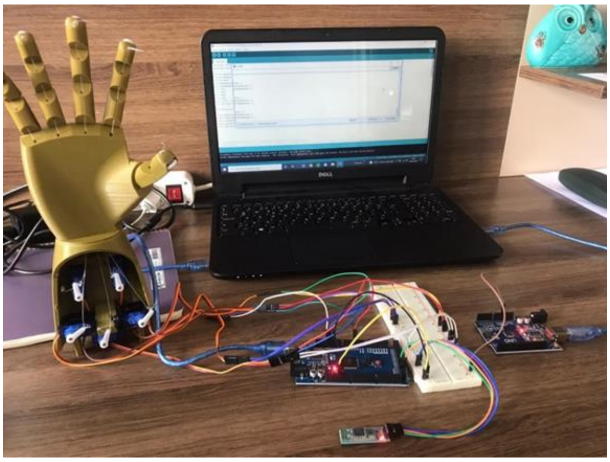


(a) **(b)**

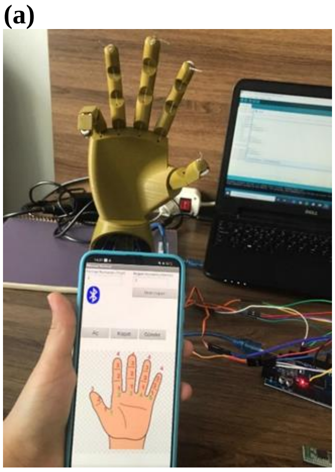
Figure 2. Finger knuckle lengths

The second method is the measurement of the servomotor rotation time, that is, the relationship between the servomotor position and the pulse width. After the electronic circuit connections were made with the bionic hand prototype, the code written in the Arduino IDE program was uploaded to the microcontroller board and Bluetooth connection was provided in the mobile application. Afterwards, 180° angle was entered for five fingers and the rotation of the servomotor blade was ensured and the time was kept. As a result of this process, the time was stopped during the full closing movements of all nodes and noted. By using the relationship between servomotor position and pulse width, the duration obtained as a result of the experiment, the estimated realistic servomotor blade rotation angles were obtained by using the ratio/proportional method. The time taken for a rotation angle of 1° is $0.5/90 = 0.0056$ ms.

It was made in 3D printer for mechanical design and green polylactic acid (PLA) filament was used as material. The realized bionic hand design and electronic setup are presented in detail in Figure 3. The extra material in the servomotor bed was cleaned by melting it with solder. Support percentage rate must be entered to the printer when printing on the 3D printer. Normally, this rate can be between 10% and 15%. Since this rate is entered as 20% while printing, a filament layer has been created on the printer for extra support on the prototype. The extra support layer was removed with a side cutter and pliers. Thus, the unnecessary filament layer is eliminated. After cleaning the parts of the hand prototype, joint connections for each finger were made with fishing line and parachute rubber, and its connection to the hand body was ensured.



(a)



(b)

Figure 3. The performed bionic hand design and electronic setup

The free end of the fishing line is removed from the hand body to the wrist, which is the servomotor bearing. The rotations of the five servomotor blades are fixed to the servomotor bed with the help of a silicone gun so that they do not interfere with each other. The fishing line, which is free on the wrist, is connected to the corresponding servomotor blades so that each of the five fingers is connected to a servomotor separately. Thus, when the servomotor blade rotates according to the adjusted angle value, the movement of the fingers will be realized depending on the rotation angle. Then, the finger joints, hand body and servomotor bearing connection of the hand prototype were made. Servomotors are fixed to the wrist and fingertip servomotor blade connection is made. The mechanical part has been completed and thus the stage of providing the electronic equipment has started.

In the electronic circuit design, each servomotor is connected to the PWM pins of the Arduino Mega 2560 microcontroller. The servomotor to which the thumb is connected is connected to the 13th pin, the servomotor to which the index finger is connected to the 12th pin, the servomotor to the 11th pin to which the middle finger is connected, the servomotor to the 2nd pin to which the ring finger is connected and the servomotor to the 3rd pin to which the pinky finger is connected. The 5 V terminals of the servomotors are connected to the 5 V pin of the microcontroller, and the ground terminals are connected to the GND pin of the microcontroller. However, after the Arduino Mega 2560 microcontroller was connected to the computer and the project was run. It was observed that only the Arduino Mega 2560 microcontroller was not enough to meet the power drawn by the servomotors, so a second microcontroller was added to the circuit to support and share power. By connecting the 5 V and ground ends of three servomotors to the power pins of the Arduino UNO microcontroller and two servomotors and the HC-06 Bluetooth module to the power pins of the Arduino Mega 2560 microcontroller, the desired operation of the servomotors has been achieved with two power connections. In addition, the RX end of the HC-06 Bluetooth module is connected to pin 50 of the microcontroller, the TX end to pin 51 of the microcontroller, the 5 V end to the 5 V pin of the microcontroller, and the GND end to the GND pin of the microcontroller, and the electronic circuit design has been completed.

The flow showing the operation of the system is given in Figure 4. Thanks to the codes uploaded to the microcontroller card of the bionic hand and the mobile application connected to the microcontroller card with the Bluetooth module, the desired finger and joint movements can be performed with the commands given. When the power connection is provided to the microcontroller card, the information entered through the buttons in the mobile application is transmitted to the microcontroller. Then, the servomotor movements were performed according to the situations given below.

First, the system was asked the question "Have the finger number and knuckle number been entered?" in the mobile application. If the answer is “Yes”, the next step is taken, if the answer is “No”, the initial state is returned. When the answer is “Yes”, the next step, the finger information, is read. Thumb, index finger, middle finger, ring finger and little finger were defined from 1 to 5, respectively, and it was determined which finger and which joint would move according to the finger and knuckle number read. Two conditions, namely the middle and root joints defined in the thumb, respectively, and three conditions were defined in the other fingers, namely the tip, middle and root joints. For example, if the entered finger number is 1 and the node number is 2, the loop containing the commands of the part up to the 2nd node of the 1st finger is executed. In the next step, according to the finger and knuckle number selected for each finger separately, the information about which joint will be moved starting from the end joint was sent, and thus all fingers were independently controlled.

The "Open" button to open all fingers and the "Close" button to close all fingers were added to the mobile application design. In addition, a number is defined for each finger that allows the fingers to be opened separately. The finger and knuckle number information entered in the mobile application is transmitted to the microcontroller and the rotation angles of the servomotors are determined according to the situations defined in the codes. The movement of the desired joints of the determined finger is provided by the rotations of the servomotor blades. The desired finger has the ability to open fully independently from other fingers, and it is also designed to have the ability to fully close and fully open all fingers at the same time.

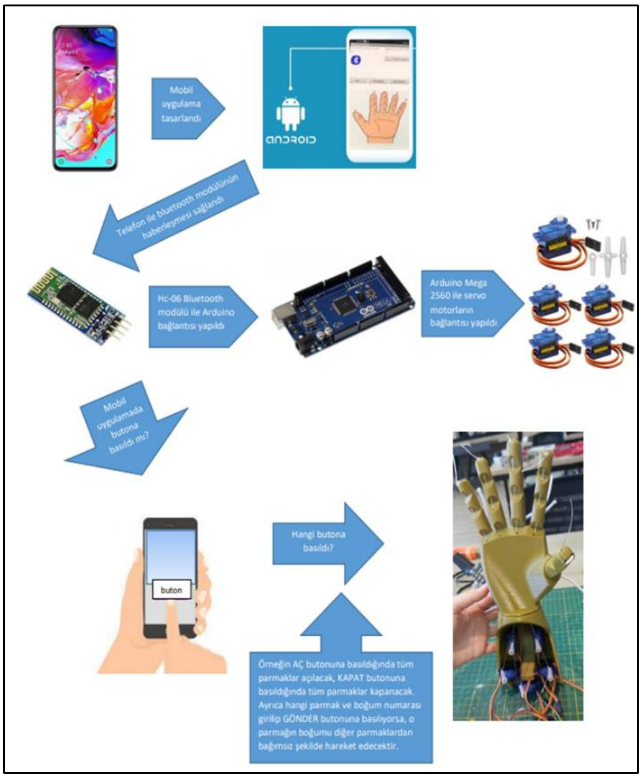


Figure 4. Flow showing the operation of the system

3. RESULTS AND DISCUSSION

(3) is used in the first method for the servomotor blade rotation calculation. In the second method, the PWM signal-servomotor position relationship is considered. In the program calculated using these two methods, the servomotor blade rotation angles determined by the experimental practice-observation method are given in Table 1.

Table 1. Center angle calculation, rotation angle values found with PWM signal-servomotor position relationship and used in the program.

Finger name	Knuckle number	Length to finger knuckle, S (cm)	Servomotor blade length, r (cm)	Servomotor blade rotation angle found from equation (3) with center angle calculation, Q (°)	Full closing time of finger knuckle (ms)	Rotation angle of servomotor blade found with PWM signal and servomotor position relationship, Q (°)	Rotation angle values used in the program, Q (°)
Thumb	First knuckle	2	1.5	38.216	0.594	106	112
	Second knuckle	3	1.5	95.541	0.924	165	170
Index Finger	First knuckle	2	1.5	38.216	0.235	42	50
	Second knuckle	2.4	1.5	84.076	0.532	95	100
	Third knuckle	3	1.5	141.401	0.918	164	170
Middle finger	First knuckle	2	1.5	38.216	0.202	36	40
	Second knuckle	2.5	1.5	71.656	0.375	67	80
	Third knuckle	3.5	1.5	152.866	0.941	168	179
Ring Finger	First knuckle	2	1.5	38.216	0.336	60	63
	Second knuckle	2	1.5	76.433	0.610	109	115
	Third knuckle	3	1.5	133.758	0.969	173	179
Little finger	First knuckle	1.5	1.5	28.663	0.459	82	91
	Second knuckle	1.75	1.5	62.102	0.717	128	135
	Third knuckle	2.5	1.5	109.873	0.958	171	179

In the second method, when the PWM signal and servomotor position relationship is calculated using the ratio proportional method, since the time taken for a 90° rotation angle of the servomotor blade is 0.5 ms, the time taken for a 1° rotation angle is 0, It is calculated that $5/90 = 0.0056$ ms. The exact closure times of the knuckles of each finger were found by timing with a stopwatch. Servomotor blade rotation angles were calculated for each finger and knuckle using the found times rotation angle/rotation time ratio.

For the rotation angles of the servomotor blade given above, when the angles resulting from the two methods were compared, the closing times of the knuckles for each finger were determined by the second method, the observation method, and it was observed that the corresponding servomotor rotation angle gave the most realistic and most reliable results. Because when the angle values obtained in the calculation of the center angle and rotation angle calculation, which is the first method, are entered into the system, it has been determined that the targeted healthy finger movements have not been achieved. The second method was compared with the first method and it was observed that the second method gave values close to the true angle values. In order to obtain exact values, the values in the second method were optimized by experimental observations. When the angle values calculated as a result of the first method are compared with the angle values selected in the application, it is seen that there are serious deviations. For this reason, angle values were selected based on the second method, which has the closest angle values to reality. Afterwards, since the servomotor rotation angles were aimed to be sensitive, the healthiest angle values were obtained by increasing-decreasing and observing the calculated angles. Thus, precisely precise turning angles were determined.

By applying the study, the joint movements of the five fingers of a targeted hand were provided by servomotors. The designed application is mobilized with the Bluetooth module.

4. CONCLUSIONS

In this study, a bionic hand and its control were successfully carried out with the mobile application, which is the target of the project. The project was designed and implemented as closely as possible to the normal human hand size, based on joint control of the fingers attached to a hand body prototype. In the applications made, it has been observed that the PWM method, which adjusts the angle of the servomotor in the control of the servomotor blade rotation angles, gives more successful results. Achieving precise grip angles of the fingers has not been fully realized due to tolerances in mechanical designs. In order to adjust this sensitivity, the angle values were improved with the experimental apply observation method.

In the following periods, it is possible to provide project development with research and development studies by making use of the development of technology. However, one of the next aims of this project is to develop the project not only with a hand prototype, but also to imitate all the structures and movements of the human hand. There is also the development of the bionic hand for different purposes. For example, in the next stages, it is aimed to detect the image of the object that the bionic hand has grasped with the image processing method and to determine which substance it consists of depending on the color-shape-tissue structure and to provide the gripping movement by applying the appropriate pressure to the object that the bionic hand has grasped. Providing the movements of the bionic hand with sound or brain signals can be counted among other work that can be done. The demand for bionic hands is increasing both in the health sector and in companies that design medical products. With the advancement of technology, the project is open to improvements in line with demand. Ultimately, the project has sustainability and has the potential to be turned into a product.

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Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Allahverdi, Ç., Şahan, A., Özdemir, M. Y. (2019, July). Mühendislik ve temel bilim projelerinde Arduino kullanımı. In International Congress on Human Computer Interaction, Optimization and Robotic Applications, (pp. 70–74). https://doi.org/10.36287/setsci.4.5.016

Andrecioli, R., Engeberg, E. D. (2013). Adaptive sliding manifold slope via grasped object stiffness detection with a prosthetic hand. Mechatronics, 23(8), 1171-1179. https://doi.org/10.1016/j.mechatronics.2013.10.006

Aydın, E. (2020). Yüksek hassasiyetli biyo-elektronik el tasarımı (Master's thesis, Maltepe Üniversitesi, Lisansüstü Eğitim Enstitüsü).

Deng, H., Zhong, G., Li, X., Nie, W. (2016). Slippage and deformation preventive control of bionic prosthetic hands. IEEE/ASME Transactions On Mechatronics, 22(2), 888-897. https://doi.org/10.1109/TMECH.2016.2639553

Hidayanti, F., Rahmah, F., Wiryawan, A. (2020). Design of motorcycle security system with fingerprint sensor using arduino uno microcontroller. International Journal of Advanced Science and Technology, 29(05), 4374-4391.

Karaçizmeli, C., Çakır, G., Tükel, D. (2014, April). Robotic hand project. In 2014 22nd Signal Processing and Communications Applications Conference (SIU) (pp. 473-476). IEEE. https://doi.org/10.1109/SIU.2014.6830268

Klug, S., Möhl, B., Von Stryk, O., Barth, O. (2005). Design and application of a 3 DOF bionic robot arm. regulation, 11, 12.

Özsoy, İ., Okyayuz, Ü. H. (2016). Amputasyon geçirmiş kişilerin baş etme becerileri. Olgu sunumu. Klinik Psikiyatri Dergisi, 19(1), 45-51. https://doi.org/10.5505/kpd.2016.30074

Paaßen, B., Schulz, A., Hahne, J., Hammer, B. (2018). Expectation maximization transfer learning and its application for bionic hand prostheses. Neurocomputing, 298, 122-133. https://doi.org/10.1016/j.neucom.2017.11.072

Süzen, A. A., Ceylan, O., Çetin, A., Ulusoy, A. (2017). Arduino kontrollü çizim robotu. Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 8(Özel (Special) 1), 79-87.

Şenli, K. (2011). EMG (Elektromiyografi) Kontrollü Protez Kol Tasarımı (Doctoral Dissertation, DEÜ Fen Bilimleri Enstitüsü).

VanHuy, T., Minh, D. T., Kien, N. P., Vu, T. A. (2017). Simple robotic hand in motion using arduino controlled servos. International Journal of Science and Research (IJSR), 6(3), 972-975. https://doi.org/10.21275/ART20171455