Klinik Uygulamalarda Kullanılması için 3B Sanallaştırıcı Entegreli Robotik Kol

Design of 3D Digitization Integrated Robotic Arm to Help Clinical Applications

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***Özetçe*—Gelişen teknoloji sayesinde robotlar hayatın birçok bölümüne entegre olmuştur. Robotlar programlanabilir, çok fonksiyonlu, işten ve zamandan tasarruf sağlayan cihazlar olarak adlandırılır. Bu çalışmada robotik bir kola üç boyutlu sayısallaştırıcı özelliği eklenerek, bir nesnenin sanal ortama aktarılması için bu robotik kolun yeni bir araç haline getirilmesi hedeflenmiştir. Robotik kolun mekanik tasarımı Autodesk Fusion 360 yazılımı ile geliştirilmiş ve üç boyutlu yazıcılarda PLA malzemesi ile robotik kol fiziksel prototipi gerçekleştirilmiştir. Robotik kolun hareketlerini yapacak olan step motorların kontrolü için motor sürücülerinin monte edildiği Arduino Mega 2560 modeli genel amaçlı bir mikrodenetleyici kartı kullanılmıştır. Nesnenin uzaydaki X-Y-Z koordinatlarını hesaplayabilmek için üç boyutlu sayısallaştırıcıda kullanılan enkoderler Arduino'nun dijital pinlerine bağlanmıştır. Python ile geliştirilen ara yüz programı kullanılarak geliştirilen sistem kontrol edilmiştir. Sonuç olarak, özellikle klinik uygulamalarda kullanılabilecek bir cihaz biyomekanik laboratuvarına kazandırılmıştır.**

Anahtar Kelimeler: Robotik Kol, 3B Sayısallaştırıcı, Klinik Uygulamalar

***Abstract*—Thanks to developing technology, robots have been integrated into many parts of daily life. Robots are called programmable, multifunctional, work, and time-saving devices. In this study, it is aimed to enhance a robotic arm to become a new tool for transferring an object to the virtual environment by integrating a three-dimensional digitizing property to the robotic arm. The robotic arm is developed using the software of Autodesk Fusion 360 and its physical prototype is implemented using PLA filament in three dimensional printers. A general-purpose microcontroller board of Arduino Mega 2560 model connected to motor drivers is used to control stepper motors that conduct robotic arm actions. Encoders used in the three-dimensional digitizer are connected to digital pins of the Arduino board to calculate the X-Y-Z coordinates of the object in the space. The proposed system is controlled via the interface program, which is developed in Python programming language. As a result, a device to use in clinical applications is available in our biomechanics laboratuary, now.**

Keywords: Robotic Arm, 3D Digitizer, Clinical Applications

I. INTRODUCTION

A. DEFINITION OF ROBOT

Robots are taking a major part in our lives currently. According to the Robot Institute of America, the robot is defined as a reprogrammable and multifunctional device which performs desired tasks according to specific commands [1]. Therefore, robots are the electronic devices that able to carry out human tasks faster, stronger, more precisely, and more accurate than the human. According to rapid development in technology, robots have already taken their parts in our lives. Medicine and health care, entertainment, education, agriculture, transportation, cybernetics, and gastronomy are a few example fields that robots are being used. Depending on the efficient results of the tests with robots in those fields, the increment of the robot usage in the fields is easily predictable.

As biomedical engineers, we focused on robot applications in the field of medicine. Medical robots utilize therapeutic applications due to their precise working principle [2]. Besides, if we thought diagnostic devices such as magnetic resonance imaging (MRI), X-ray imaging, ultrasound imaging as medical robots, we can easily see that the prevalence of them in medicine.

To improve the patient's trust in hospitals and doctors, robot usage in medicine is extremely important.

We can investigate the medical robots in two parts. Robots indirect diagnosis and imaging processes, and the robots serve as assistants to doctors. Robots are being used epidemically in the departments of neurology, orthopedics, general laparoscopy, percutaneous, guiding catheter, radiosurgery, and rehabilitation [3,4,5,6,7]. To give a more specific example, the most popular surgical system Da Vinci can be discussed. First, the Da Vinci is produced in the intention of the perform surgical operations of the astronauts. However, it is now being used only in short-distance laparoscopy operations [8]. Da Vinci is consisting of two main units. The first one is the control unit which the doctors can control the arms of the robots. The second one is the system that processes the information and creates a connection between the control unit and the robot arms. The information coming from the control unit is transferred by this unit and the precise movement of the arms is being generated.

B. DEFINITION OF 3D DIGITIZER

Nowadays, data processing and data acquisition processes of the computer systems have gathered speed thanks to the developing processor and memory units. For instance, while it takes minutes to addition with the first computer produced, it does not even take seconds with the computer we are using. In this way, it is realized that outputs can be obtained very quickly from the incoming data. The processing of a 3D image of a material or part of its great importance for manufacturers. Thus, accuracy and precision measurements can be made in millimetric measurements in the product. Therefore, the use of a 3D digitizer is rapidly increasing in the industry. Computer-aided design (CAD) is usually used for the design and drawing of technical projects [9]. The use of CAD has great importance for the design, analysis, manufacture, and planning of the products. Increased use of 3D digitizers leads to the rapid development of CAD, reverse engineering, medicine, and inspection of applications [10]. Reverse engineering applications in the industry aim to produce an object more smoothly with 3D data. The term 3D digitizer means the digital transfer of an object's 3D image to the computer [11]. These transmitted digital data can be conveniently used in many different areas on the computer such as product accuracy and sharpness, durability tests, and production line tests.

3D digitizers are available in two different types [9]; contact probe 3D digitizer and non-contact laser 3D scanners. Contact probe 3D digitizers are touched too many different points of the object with the material which is called probes in the device and the measurements are taken as the location of these points in space. Then, the distance between these points and the reference point is measured by the encoders. Finally, collected data combined with computer software and 3D image of the object is created [12].

Another type of the 3D digitizer is non-contact 3D laser scanners. In this device, the laser beams forward to the and reflected beams collected by the detectors of the device. These detectors find the distance of the object from the reference point of the device by using reflected beams. These dots are combined with the software on the computer to create a 3D digital image of the object.

C. PURPOSE AND AIM OF THE PROJECT

Our project includes both robotic arms and encoders integrated into the robotic arm. These encoders will enable the robotic arm to be used as a 3D digitizer. In this way, these devices, which are available only as a robotic arm or as a 3D digitizer, will be combined in a single compact device. In the previous sections, we mentioned the features of robotic systems and 3D digitizers. These systems are used very actively in clinical applications and scientific researches. This compact device is intended for use in clinical applications such as tattoo removal, hair removal, dental prothesis organization, and total knee arthroplasty organization. In tattoo removal and hair removal procedures, the robotic arm can be forward laser beams to the automated point with 3D digitizers. In this way, errors can be caused by human factors that can be prevented. In dental prosthesis and total knee arthroplasty procedures, the device can be used for personalized treatment.

II. METHODS

1) Electronic Parts Assembly

- First, we investigated the properties of the parts specified in the electronic parts section from the datasheets such as Arduino Mega 2560 [13], stepper motor [14], and encoders [15]. For instance, operating voltages, maximum current limits, pinout information, and data transfer protocols.
- According to these informations, we generated a circuit diagram and a board by using Autodesk Eagle (Figure 1).

2) Physical Parts Assembly

- First, we determined the necessary additional materails such as screws, threaded inserts, bearings, straps, and GT2 pulleys.
- Then we assembled the printed body parts, stepper motors and encoders of each section of the robotic arm.
- Lastly, we assembled all section in each other, and connected the stepper motors and encoder with our electronic controller circuit (Figure 2).

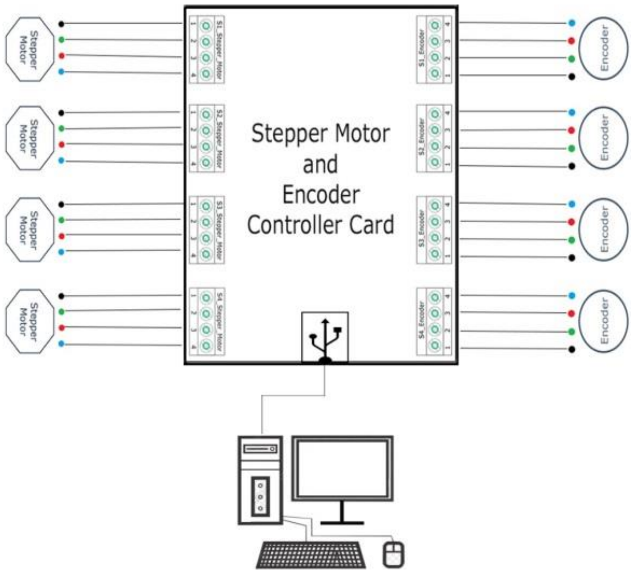

Figure 1. Schematics of the circuit.

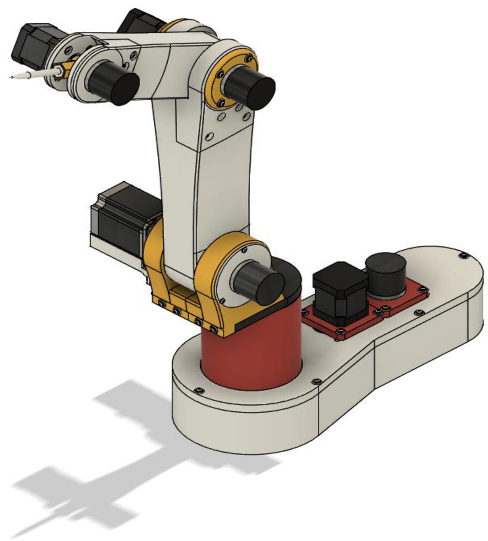

Figure 2. Fusion 360 drawing.

III. RESULTS

The main purpose of the study is to add a new feature to the use of robots in the medical field as biomedical engineers. Our primary goal is to use this design in clinical applications such as laser hair removal, laser tattoo removal, dental prosthesis, total knee arthroplasty. Produced for this purpose, this device contains both a robotic arm that will provide motion functions and a 3D digitizer that will perform the digitization process. In this way, the 3D image of the desired object is transferred to the digital environment. While existing 3D scanners scan an object with the help of a laser, in some cases it is insufficient. For example, when it is desired to scan an object that reflects light, mistakes occur in the 3D image during the transfer to digital, or the shadows formed during the scanning of irregular structures cause errors in the 3D image. The 3D digitizer we used to solve this problem includes a contact probe. Thanks to this probe, the coordinates are obtained by touching the excess point of the object to be scanned as much as possible. By combining these coordinates in a digital environment, a 3D image of the object is obtained.

In the project, we printed the physical parts in the materials section one by one with a 3D printer in our laboratory. Then, we assembled all of these printed parts as mentioned in the method section. After this part, we placed the electronic components in the required parts of the 3D digitizer integrated robotic arm. We used the kinematic analysis method for the robotic arm and its electronic parts to function properly. Kinematic analysis is the examination of time and speed parameters of movements. In this way, the robotic arm was provided to work correctly and as desired. Then, by transferring data between Python and Arduino Mega 2560, we added certain functions to the robotic arm. We also designed an interface that controls the operation of the robotic arm (Figure 3).

The application is designed to control the functions of the robotic arm. The movement of the robotic arm is ensured by the "run" command recorded data. In the "manual control" section, the movement of the robot arm can be provided manually with the data we have given instantly. In the "Current arm position" section, the position of the robot's extreme probe in space is shown as X-Y-Z coordinates. Also, the angle between each joint is shown in "joint boxes". Any desired location can be saved manually in the "saved motion" section with the "Add" button and can be used for future functions.

IV. DISCUSSION

The first thing to pay attention to in robotic arm projects is to think correctly about the loads on the stepper motor. Because stepper motors both lift the arms that will do the work and also carry other loads to get on these arms. Therefore, we had problems with the movement of the arm because we did not pay attention to this in the first design we made. We planned to solve this problem by redrawing the project and increasing the torque of the stepper motors by using a gearbox. Besides, one of the biggest limitations of the project is that its section 4 part is constantly changed according to the operations. This reduces the robot’s mobilization. Also, the robot will need to be calibrated each time section 4 is changed. We also plan to use the project to map the mouth for dental prosthesis procedures. But the pen we draw on the 3D digitizer part is such that it will complicate the process.

Rearranging the design using a laser or other tools will make this process even easier.

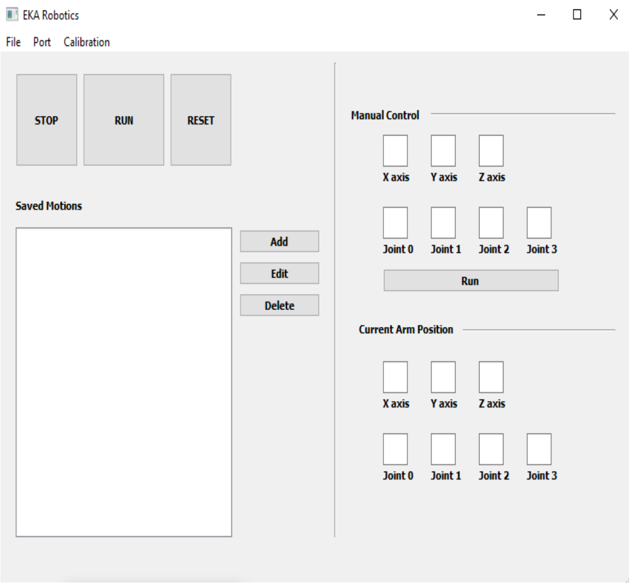

Figure 3. EKA Robotics Application.

We used a 3D printer to print the parts of the robot. Therefore, we encountered problems such as cracking during the assembly of the printed parts. Because PLA filament which is then used material for printing is a brittle material. Printing and assembling the project with more durable parts will solve this problem. Besides, the Nema 17 stepper motor driver cards are insufficient from the cooling way. Therefore, in the high currents for the operations caused to burn in the driver cards. So, we had to impose current limitations while using it. This caused a decrease in the performance of the stepper motors.

In the project, we used a belt to transfer the stepper motor rotation to the robotic arm at the base. We had to put this belt inside the sole because of the design. This required us to disassemble the base each time to fix any problems that might arise from the strap. Therefore, more mobile solution tools can be considered by re-evaluating the design of the robot.

For the control of the 3D digitizing integrated robotic arm, we used a control card which contains Arduino Mega 2560 and the stepper motor driver cards. The drawing of this circuit is in the above sections. When starting to project, our first goal was to print this control card with PCB printing. In this way, we were reducing the cable density to be used. However, since the Covid-19 affected international cargo distributions, we had to waive this idea. In other words, the robot's future improvement options include the proper design and printing of this control card.

Our initial goal was to produce a robot that assists the doctor during surgery by listening to the doctor's commands. But since we were insufficient in the software part, we had to evaluate this voice command process in the next projects. However, with the development of the software with the 3D digitizing integrated robotic arm that we have produced, the voice command feature can be added very easily. In this way, a study can be carried out to facilitate the work of the doctor during the operation by selecting the surgical materials with the command of the doctor and give the surgical material according to the doctor's commands. Also, like biomedical engineering, we were not able to add any debugging system to the robot, as we are weaker in the software design. The development of the software will help solve many problems.

3D digitizers are used in many areas on the market. Our aim in this project is to add a new branch to the use of thesedigitizers in the medical field. Producing of the arms with bigger measures can help use this device in other areas. For instance, the robot can be used in industrial areas such as quality control. Also, the voice command feature we mentioned earlier can help use the device in areas such as industry.

As a result, with software and design improvements, this robot can take its place among the robots being used in the market.

REFERENCES

[1] R. A. Beasley, "Medical Robots: Current Systems and Research Directions," J. Robot., vol. 2012, pp. 1–14, 2012 DOI: 10.1155/2012/401613.

[2] S. Avgousti et al., "Medical telerobotic systems: Current status and future trends," Biomed. Eng. Online, vol. 15, no. 1, pp. 1–44, 2016, DOI: 10.1186/s12938-016-0217-7.

[3] C. Ding, C. B. Saw, and R. D. Timmerman, "Cyberknife stereotactic radiosurgery and radiation therapy treatment planning system," Med. Dosim., vol. 43, no. 2, pp. 129–140, 2018, DOI: 10.1016/j.meddos.2018.02.006.

[4] M. J. G. Blyth, I. Anthony, P. Rowe, M. S. Banger, A. MacLean, and B. Jones, "Robotic arm-assisted versus conventional unicompartmental knee arthroplasty: Exploratory secondary analysis of a randomized controlled trial," Bone Jt. Res., vol. 6, no. 11, pp. 631–639, 2017, DOI: 10.1302/2046-3758.611.BJR-2017-0060.R1.

[5] F. Cardinale et al., "A new tool for touch-free patient registration for robot-assisted intracranial surgery: Application accuracy from a phantom study and a retrospective surgical series," Neurosurg. Focus, vol. 42, no. 5, pp. 1–7, 2017, DOI: 10.3171/2017.2.FOCUS16539.

[6] N. J. Brandmeir, S. Savaliya, P. Rohatgi, and M. Sather, "The comparative accuracy of the ROSA stereotactic robot across a wide range of clinical applications and registration techniques," J. Robot. Surg.,

vol. 12, no. 1, pp. 157–163, 2018, DOI: 10.1007/s11701-017-0712-2.

[7] H. Shui Liu, S. jun Duan, S. Dong Liu, F. Shuang Jia, L. Ming Zhu, and M. cen Liu, “Robot-assisted percutaneous screw placement combined with pelvic internal fixator for minimally invasive treatment of unstable pelvic ring fractures,” Int. J. Med. Robot. Comput. Assist. Surg., vol. 14, no. 5, pp. 1–8, 2018, DOI: 10.1002/rcs.1927.

[8] L. Prokhorenko, D. Klimov, D. Mishchenkov, and Y. Poduraev, “Surgeon–robot interface development framework,” Comput. Biol. Med., vol. 120, no. November 2019, 2020, DOI: 10.1016/j.compbiomed.2020.103717.

[9] J. R. Mahan, Computer-Aided Design, and Manufacturing Wiley-ASME Press Series.

[10] S. Gauthier, W. Puech, R. Bénière, and G. Subsol, “Analysis of digitized 3D mesh curvature histograms for reverse engineering,” Comput. Ind., vol. 92–93, pp. 67–83, 2017, DOI: 10.1016/j.compind.2017.06.008.

[11] A. Mathys, J. Brecko, and P. Semal, “Comparing 3D digitizing technologies: What are the differences?,” Proc. Digit. 2013 - Fed. 19th Int’l VSMM, 10th Eurographics GCH, 2nd UNESCO Mem. World Conf. Plus Spec. Sess. from CAA, Arqueol. 2.0 al., vol. 1, no. Table 1, pp. 201–204, 2013, DOI: 10.1109/DigitalHeritage.2013.6743733.

[12] M. Pieraccini, G. Guidi, and C. Atzeni, “3D digitizing of cultural heritage,” J. Cult. Herit., vol. 2, no. 1, pp. 63–70, 2001, doi: 10.1016/S1296-2074(01)01108-6.

[13] ArduinoMega 2560 datasheet, “Arduino Mega 2560 Datasheet,” in Power, 2015, p. 3.

[14] L. Allegro MicroSystems, “DMOS Microstepping Driver with Translator And Overcurrent Protection,” 2017, pp. 1–22.

[15] T. A. Khan, T. A. Taj, and I. Ijaz, “Hybrid stepper motor and its controlling techniques a survey,” Proc. 2014 IEEE North West Russ. Young Res. Electr. Electron. Eng. Conf. ElConRusNW 2014, pp. 79–83, 2014, DOI: 10.1109/ElConRusNW.2014.6839207.