Development of a Robot Manipulator Design for Brain Surgery

Beyin Cerrahisi için bir Robot Manipülatör Tasarımının Geliştirilmesi

Didem Güzin[1], Erkin Gezgin[2]
[1]Department of Mechanical Engineering, İzmir Katip Celebi University, İzmir, Turkey
didem.guzin@gmail.com
[2]Department of Mechatronics Engineering, İzmir Katip Celebi University, İzmir, Turkey
erkin.gezgin@ikcu.edu.tr

***Özetçe*— Günümüzde beyin cerrahisi alanında gerçekleştirilen operasyonlar, ağırlıklı olarak klasik cerrahi yöntemler ve ekipmanlarla yapılmaktadır. Her ne kadar ilgili literatürde, hızla gelişen teknolojik ilerlemeler sayesinde beyin cerrahi sistemlerinin robotizasyonu ile ilgili çalışmalara rastlansa da, bu uygulamalarda yapıları esas olarak endüstriyel otomasyon için tasarlanmış konvansiyonel seri robot manipülatörlerin operasyonlara entegre edilmesi üzerine yoğunlaşılmıştır. Bu nedenle ilgili literatür içerisinde, kinematik yapısı robotik beyin cerrahisi operasyonları için özelleşmiş, kafatası çalışma uzayına uygun, gerekli operasyon hassasiyetine sahip robot manipülatör tasarımlarının eksikliği göze çarpmaktadır. Bu noktadan yola çıkarak çalışma kapsamında, kinematik yapısı beyin biyopsi operasyonlarında konumlandırma için özel olarak oluşturulmuş bir küresel paralel robot manipülatörün ön prototip performansının değerlendirilerek, operasyon verimliliği, sistem güvenilirliği, çalışma hacmi kısıtları ve üretim kolaylığı kapsamında tasarımının geliştirilmesi ve iyileştirilmesi hedeflenmiştir.**

Anahtar Kelimeler—Medikal Robotik, Beyin Cerrahi, Küresel Paralel Manipülatör

***Abstract*— Nowadays, most of the brain surgery operations are carried out by utilizing classical surgery methodologies and equipment. Although related literature includes studies on the robotization of brain surgery systems by the help of technological advancements, these applications mostly focused on the integration of robot manipulators that are designed for industrial automation into the medical area. Thus it can be clearly seen that, there exist lack of robot manipulators that are specifically designed for brain surgery applications, have necessary precision requirements and workspace constraints. In light of this, evaluating its pre-prototype performance, current study focuses on the improvement of a spherical parallel manipulator structure that was designed for positioning in robotic brain biopsy by taking operation efficiency, system reliability, workspace constraints and ease of manufacturing into consideration.**

Keywords—Medical Robotics, Brain Surgery, Spherical Parallel Manipulator

I. INTRODUCTION

Utilization rate of robotic systems in medical field has been increased day by day, by the help of advanced robot technologies. Today, robot assisted surgeries have been frequently preferred to traditional operations due to advantages such high operational precision, enhanced dexterity, reduced complication risks and operation durations. During the last decade, various medical robotic systems have been proposed and implemented in various medical areas in order to transform traditional operations into robot-assisted surgeries. Due to the fact that related operations require delicacy and increased precision thanks to brains anatomical complexity, neurosurgery becomes one of the challenging areas for robotization.

During the last periods of 1980's, concept of robotic surgery in brain operations was emerged starting with an application. Being the first robotic brain surgery operation, it was performed by Kwoh et al. [1] by utilizing a standard industrial robotic arm (Puma 560) in order to position brain biopsy needle. Following this research, many serial and parallel robot manipulators have been modified to perform minimally invasive brain surgeries by various research groups in related literature throughout the years [2-4]. By the help of new studies in medical and robotic field, robot manipulators that take into account specific operational constraints and needs have also started to be emerged. Essomba et al. [5] proposed the mechanical design of a typical robot manipulator for craniotomy application considering its kinematic and force transmission ability. Similarly, a parallel remote center of motion mechanism was designed for the same operation during the studies of Dehghani et al. [6].

As seen in brief literature summary, although there exist studies on the field to increase operational efficiency and precision by implementing robot manipulators to the field, considering limited literature and specialized systems being scarce, it can easily be seen that robotic brain surgery is a vast scientific field that is still in development. In light of this, current paper focuses on improvement of the two degrees of freedom spherical parallel robot manipulator that was designed for positioning in robotic brain biopsy and firstly presented by the research group including the same authors [7]. During the study, early prototype of the proposed system was evaluated first. Afterwards the structure of the manipulator was improved by considering its precision, reliability, workspace constraints and ease of manufacturing.

II. STRUCTURAL DESIGN AND CRITERIA

Brain is one of the most complex organs that control all functions of the body and it is protected within the skull. During the lifetime of a human being, several complications might occur inside the brain volume such as abnormal growth tissue formations (tumors), aneurysm, and neurodegenerative diseases that affect quality of life of an individual. In order to support surgeons in case of these kinds of scenarios during diagnosis and/or treatment periods, there exist varios kind of manual stereotactic frames that guides surgical tools to the target inside the closed workspace environment (Figure 1).

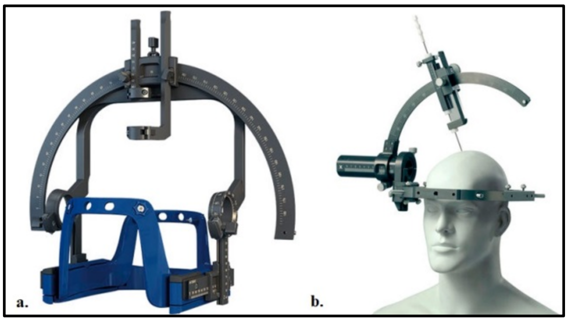

Figure 1. Stereotactic frames (a.Elekta, b.BRAMSYS)

Considering the kinematic structures of these stereotactic frames, their spherical nature allows them to adapt skull shape easily during operations.

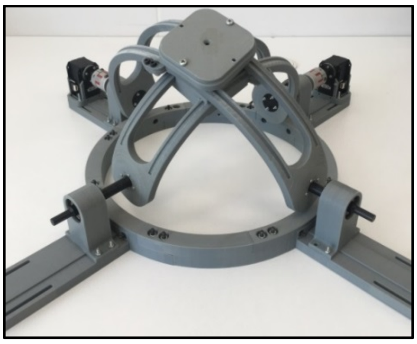

Figure 2. Two degrees of freedom spherical parallel robot manipulator for brain biopsy

Thus earlier study [7] proposed two degrees of freedom spherical parallel robot manipulator that was designed for robotic guidance to replace manual stereotactic frames (Figure 2). Although the precision of proposed spherical manipulator's first prototype was introduced to be sufficient in that study, it was investigated that manipulator's structural integrity mostly relies on the rapid prototyping. Thus further enhancements on precision cannot be attained easily unless a different version of a rapid prototype system with an improved print quality is utilized. The reason behind this lies on the fact that input links of the manipulator have a unibody structure with a form of a spherical surface (Figure 3).

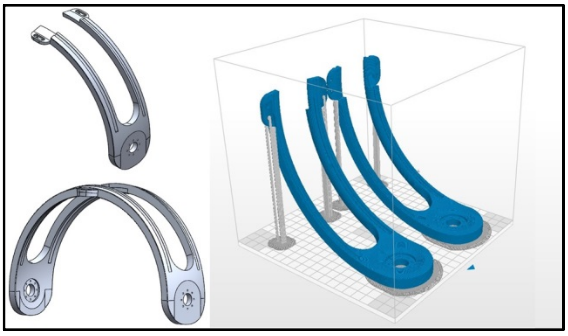

Figure 3. Unibody design of the input links

As a result it is not cost efficient to manufacture these links by conventional methods. Also in case of a failure or necessity for replacement, it would be harder to reproduce spare parts effectively and that decreases the fault tolerance of the structure. Considering these facts, preserving kinematic representation of the manipulator (Figure 4),

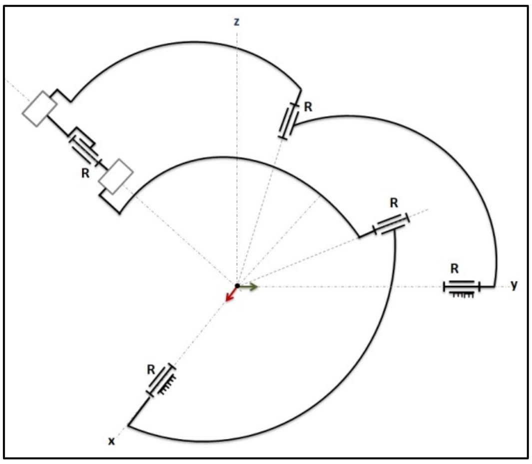

Figure 4. Kinematic representation of spherical manipulator

structure of the manipulator was improved by implementing modular design strategy. Instead of unibody design of the first prototype, all of the links were redesigned in the form of individual component assemblies (Figure 5).

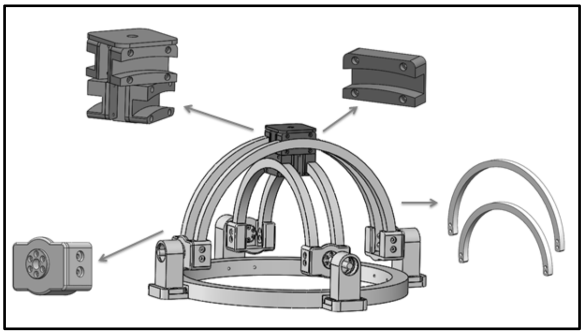

Figure 5. Improved structure of the manipulator

This change allowed the utilization of common manufacturing techniques in order to reduce joint gaps further inside the system and enhance overall precision. Input link geometries were also simplified to have cylindrical surfaces instead of spherical surfaces to achieve ease of manufacturing (Figure 6).

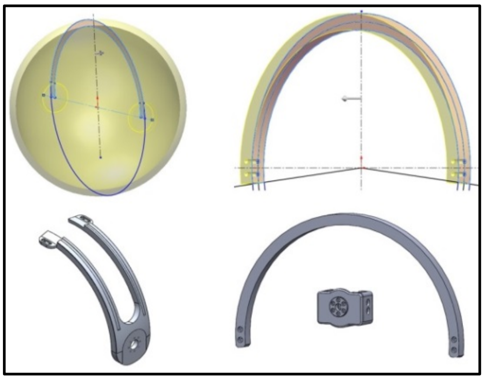

Figure 6. Comparison of input link geometries

After the structural modification, workspace of the manipulator was also decided to be improved due to the achieved modularity that easily permits to improve workspace characteristics without affecting overall manipulator footprint. Thus human brain anatomy was examined to identify the percentages of tumor locations inside human brain. In light of this using tumor location data found on the study of Gould et al. [8] (Figure 7),

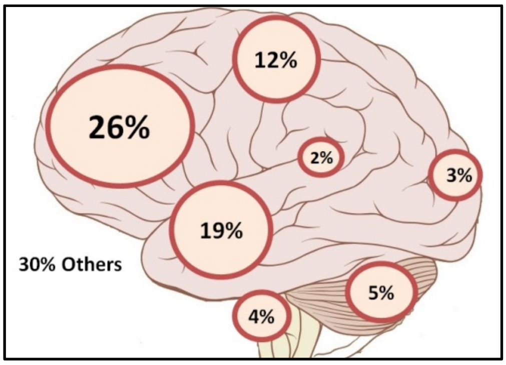

Figure 7. Percentage of tumor formations inside human brain (human brain illustration:[9])

radius of the big arc and guide limits of the input links were increased to expand circular travels of individual manipulator platforms. As seen in workspace comparisons between the early prototype and modified structure in figure 8, 54% increase in workspace was achieved.

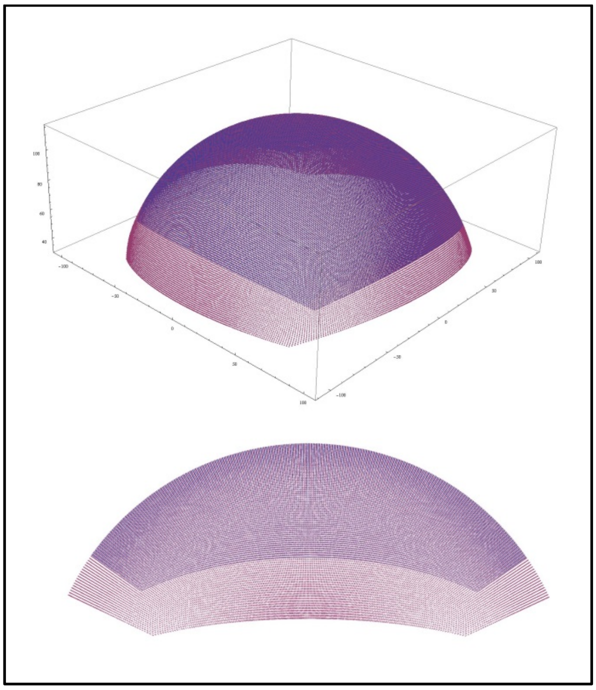

Figure 8. Workspace comparisons between the early prototype and modified structure

III. CONCLUSION

When the most of exist studies on robotic neurosurgery in medical field is considered, they reflect that the specialized robotic systems are based on the usage of industrial robots equipped with adapted surgical tools. Within this study, pre-prototype performance of a spherical parallel robot manipulator which was designed for robotic brain biopsy has been evaluated and its structure has been improved in terms of operation efficiency, system reliability, workspace constraints and ease of manufacturing. From this point of view, the unibody links design of the early prototype has evolved in order to have ease of production. In addition, with the utilization of conventional manufacturing techniques, the joint gaps inside the system has been reduced and its overall precision has enhanced. The system design has became modular owing to all structural modification and 54% increase in its workspace has observed.

AUTHOR CONTRIBUTIONS

Both authors contributed equally to this manuscript.

ACKNOWLEDGEMENT

This study was funded by Izmir Katip Celebi University BAP 2018-ÖDL-MÜMF-0017

REFERENCES

[1] Y.S. Kwoh, I.S. Reed, J.Y. Chen, H. Shao, T.K. Truong, and E.A. Jonckheere, “A new computerized tomographic aided robotic stereotactic system.”, Robot. Age vol. 7, 1985, pp. 17-21.

[2] H.J. Marcus, V.N. Vakharia, S. Ourselin, J. Duncan, M. Tisdall, and K. Aquilina, “Robot-assisted stereotactic brain biopsy: systematic review and bibliometric analysis.”, Child's Nervous System vol. 34(7), 2018, pp. 1299-1309.

[3] A. Carai, A. Mastronuzzi, A. De Benedictis, R. Messina, A. Cacchione, E. Miele and A. Savioli, “Robot-assisted stereotactic biopsy of diffuse intrinsic pontine glioma: a single-center experience.”, World neurosurgery vol. 101, 2017, pp. 584-588.

[4] K. Hongo, S. Kobayashi, Y. Kakizawa, J.I. Koyama, T. Goto, H. Okudera and K. Takakura, “NeuRobot: telecontrolled micromanipulator system for minimally invasive microneurosurgery-preliminary results.”, Neurosurgery vol. 51(4), 2002, pp. 985-988.

[5] T. Essomba, C. T. Wu, S. T. Lee and C. H. Kuo, “Mechanical design of a craniotomy robotic manipulator based on optimal kinematic and force performance.”, In Robotics and Mechatronics Springer Cham., 2016, pp. 191-198.

[6] M. Dehghani, M. M. Moghadam and P. Torabi, “Analysis, optimization and prototyping of a parallel RCM mechanism of a surgical robot for craniotomy surgery.”, Industrial Robot: An International Journal, 2018.

[7] E. Gezgin, S. Özbek, D. Güzin, O.E. Ağbaş and E.B. Gezer, “Structural design of a positioning spherical parallel manipulator to be utilized in brain biopsy.”, The International Journal of Medical Robotics and Computer Assisted Surgery 15(5) e2011, 2019.

[8] J. Gould, “Breaking down the epidemiology of brain cancer.”, Nature 561(7724), 2018, pp. 40-41.

[9] Patrick J. Lynch, medical illustrator; C. Carl Jaffe, MD, cardiologist. https ://creativecommons.org/licenses/by/2.5/