ELEMENTS OF SYNTHESIS, ANALYSIS, DESIGN, SIMULATION OF A MOBILE TELETHESIS

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Abstract: *The paper summarizes the steps of structural analysis, kinematic analysis, structural design, and simulation of a mobile telethesis. The telethesis is made of a mobile platform, a robotic arm with 5 degrees of freedom to which an anthropomorphic mechanical hand is attached. The structural analysis and the kinematic analysis are performed with the methods used to analyze robotic structures adapted accordingly. The constructive design is performed with CATIA software, which allows operational simulation of the CAD model obtained. It also presents a virtual simulation for two specific activities that the telethesis can perform. This simulation is very important for functional testing in the telethesis workspace. Mobile teletheses can be useful as well for people without disabilities to improve the performance of activities they can undertake.*

Keywords: *mobile telethesis, structural analysis, cinematic analysis, CAD design, virtual simulation*

1. Introduction

Teletheses are complex mechatronic structures that are part of the medical robotic equipment. These devices are used to serve persons with motor disabilities who cannot move, or move with great difficulty. Depending on the area served there are fixed and mobile teletheses. Fixed teletheses are placed in a stable location (on a table, a bedside table, even on a wheelchair), where they can act in the space right next to the person served, according to the workspace of the robotic arm of the telethesis. Mobile teletheses are mobile platforms, equipped with robotic arms that can move in indoor enclosures such as an apartment and outdoors, such as a garden. Both fixed and mobile teletheses are equipped with mechanical hands-gripping systems that may have varying degrees of complexity, from variants with two brackets (two fingers), to very complex variants, anthropomorphic grippers similar to a human hand [1], [2].

The choice of the gripper depends on the functionality degree desired for the telethesis. The trend today is oriented towards a gripper sufficiently powerful, usually in the category of the anthropomorphic variants, to ensure a level of functionality suitable for the telethesis use. Since the 70s different types of teletheses [3], [4], [5] were proposed, some very complex, which unfortunately were not implemented according to the needs, even at their minimum. As concrete examples, we can mention: Spartacus[6] telethesis, achievement of the 70s; Manus[7] telethesis, EL-E[8] telethesis and PerMMA[9] telethesis, more recent achievements. Towards the late 90s and in the first decade of the 21st century, concerns in this area were reduced, but not because such equipment would not have been necessary, but because of the option of other topics of medical robotics, particularly complex equipment for tomography investigations and Da Vinci surgical robots. Currently there are materials, devices, equipment, and appropriate technical solutions to achieve a fixed or mobile telethesis sufficiently powerful and reliable, affordable too for whom they are intended, people who do not always have enough funds.

This paper summarizes the stages of structural and kinematic analysis, engineering design and functional simulation of a mobile telethesis, with emphasis on the robotic arm ones, in line with the current technique.

2. Elements of structural analysis

Structurally, a telethesis must be similar to a human arm or of lower complexity, but it must provide acceptable functionality. A similar structure to the human arm, a referential telethesis, without the palm and the fingers, must have three movements of rotation (I, II, III). It is similar to the movements of the shoulder joint, one movement of rotation (IV), similar to the movement of the elbow joint and three movements of rotation (V, VI, VII), similar to the joint of the palm (see Figure 1a)[1].

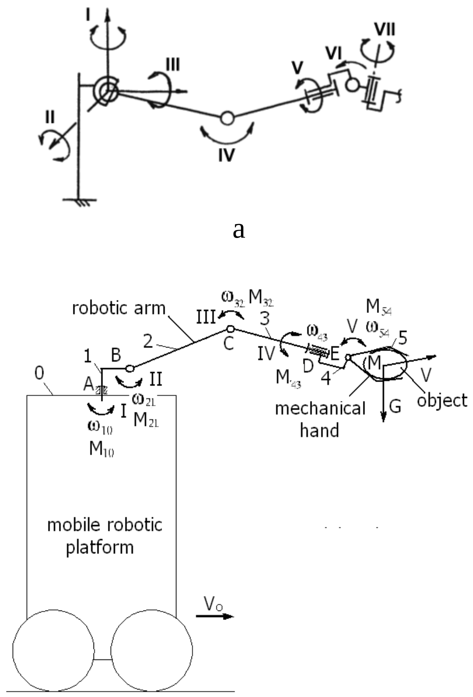


Figure 1: Structural scheme of the telethesis

Compared to the structure of the reference telethesis, we propose the structural scheme in Figure 1b for the telethesis arm. It is mounted on a mobile robotic platform, enabling the movement of the telethesis around the specific workspace. This paper will not go into construction details of the platform, which should ensure movement forward, backward and left - right on a flat surface such as an apartment. The platform enables the robotic arm mounting at standard height of objects that are currently used of about 800 mm (see Figure 2). The structural diagram of the arm is obtained by a 5-torque series: 3 (A, B, C) for positioning and 2 (D, E) for guidance, according to Figure 1. The positioning structure is a simplified variant of the human arm structure, obtained by removing two turns of the spherical coupling corresponding to the shoulder, similar to the robotic arm joints (characterized by angular coordinates). In this analysis, the mechanical hand is not taken into account in terms of its structure (it is considered only as the fifth linear element).

After the structural analysis, we have: the degree of mobility M = 3 (I, II, III) +2 (IV, V) = 5 [10]. The number of external connections of the robotic arm mechanism is L = 6 (ω_{10}, M_{10};ω_{21}, M_{21}; ω_{32}, M_{32}; ω_{43}, M_{43}; ω_{54} ,M_{54}; V, G). Kinematic and static interpretation of the parameters M and L - M is:

M = 5 (5 independent movements: ω_{10}, ω_{21}, ω_{32}, ω_{43}, ω_{54} and 5 dependent momentums : M_{10}, M_{21}, M_{32}, M_{43}, M_{54}), L-M = 6-5 = 1 (a dependent movement: V=V(ω_{10}, ω_{21}, ω_{32}, ω_{43}, ω_{54}) and an independent force : G = mg, m- mass of the object) [10].

3. Kinematics analysis

In Figure 2 the general kinematic scheme of the telethesis indicating linear(in mm) and angular dimensions of the elements is illustrated.

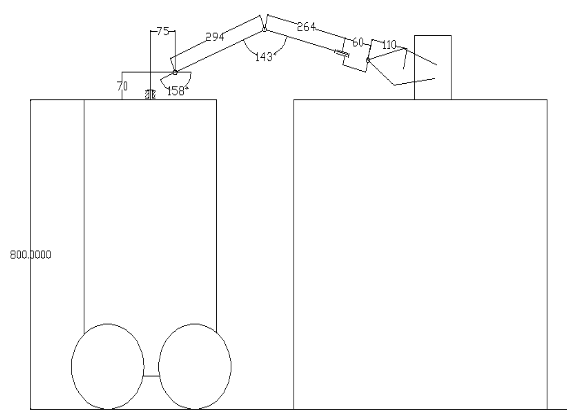


Figure 2: General kinematic scheme of the telethesis

The dimensions of the robot arm are adopted through similarity with the human arm dimensions, in an approximate ratio of 1:1, to ensure coverage of working space similar to the one it accesses. Corresponding to the three-mobile joint of the shoulder, the simplified solution is adopted using two torques of rotation, and to increase handling, the two torques' axes are lagged, even if this solution is different from the natural one in which rotation axes are concurrent. According to Figures

2 and 3, the linear dimensions are: $d_{11}=70\ mm$; $d_{12}=75\ mm$; $d_2=294\ mm$ $d_3=264\ mm$; $d_4=60\ mm$ $d_5=110\ mm$.

The kinematic analysis is performed through homogeneous operators' method [11]. It consists in attaching to each joint of a local reference system and the use of a mobile reference system to cover all power train (Figure 3).

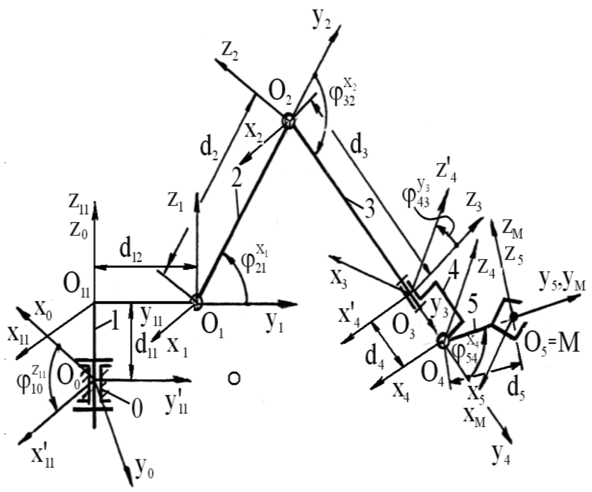


Figure 3: Kinematic scheme of the telethesis

The position of the characteristic point M in the reference system $O_o x_o y_o z_o$ is: $A_{0M} = A_{0\text{-}11}\, A_{11\text{-}1}\, A_{12}\, A_{23}\, A_{34}\, A_{45=M}$, where:

$$A_{0-11} = R^z_{0-11} \cdot T^z_{0-11};\ A_{11-1} = T^y_{11-1};$$

$$A_{12} = R^x_{12} \cdot T^y_{12};\ A_{23} = R^x_{23} \cdot T^y_{23};\ A_{34} = R^y_{34} \cdot T^y_{34};$$

$$A_{45=M} = R^x_{45=M} \cdot T^y_{45=M}.$$

These matrices are:

$$R^z_{0-11} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C_{10} & -S_{10} & 0 \\ 0 & S_{10} & C_{10} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$T^z_{1-11} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ d_{11} & 0 & 0 & 1 \end{bmatrix}$$

$$;T^y_{11-1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ d_{12} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$R^x_{12} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & C_{21} & -S_{21} \\ 0 & 0 & S_{21} & C_{21} \end{bmatrix};$$

$$T^y_{12} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ d_2 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$R^x_{23} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & C_{32} & -S_{32} \\ 0 & 0 & S_{32} & C_{32} \end{bmatrix}; \qquad (1)$$

$$T^y_{23} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ d_3 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$R^y_{34} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C_{43} & 0 & S_{43} \\ 0 & 0 & 1 & 0 \\ 0 & -S_{43} & 0 & C_{43} \end{bmatrix};$$

$$T^y_{34} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ d_4 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$R^x_{45=M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & C_{54} & -S_{54} \\ 0 & 0 & S_{54} & C_{54} \end{bmatrix};$$

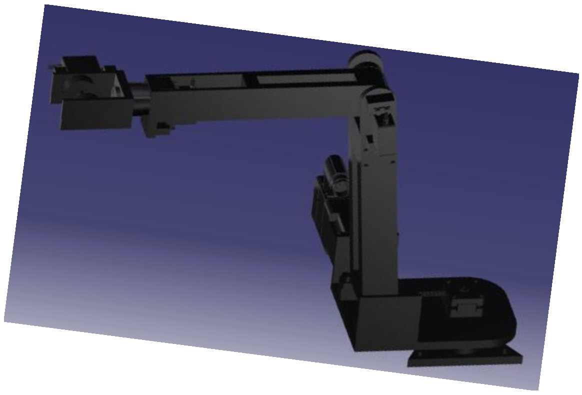
$$T^{y}_{45=M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ d_5 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

In these matrices : $C_{10} = \cos\varphi^{z}_{10}$; $S_{10} = \sin\varphi^{z}_{10}$; $d_{11} = \overline{O_0O_{11}}$; $d_{12} = \overline{O_{11}O_1}$ $C_{21} = \cos\varphi^{x}_{21}$; $S_{21} = \sin\varphi^{x}_{21}$; $d_2 = \overline{O_1O_2}$; $C_{32} = \cos\varphi^{x}_{32}$; $S_{32} = \sin\varphi^{x}_{32}$; $d_3 = \overline{O_2O_3}$; $C_{43} = \cos\varphi^{y}_{43}$; $S_{43} = \sin\varphi^{y}_{43}$; $d_4 = \overline{O_3O_4}$; $C_{54} = \cos\varphi^{x}_{54}$; $S_{54} = \sin\varphi^{x}_{54}$; $d_5 = \overline{O_4O_{5=M}}$ $(O_5 \equiv O_M)$; i = 0,1,2,3,4,5=M; the angles φ^{k}_{ij} are the angles between the reference systems i and j and d_i are the distances between the reference systems with parallel axes.

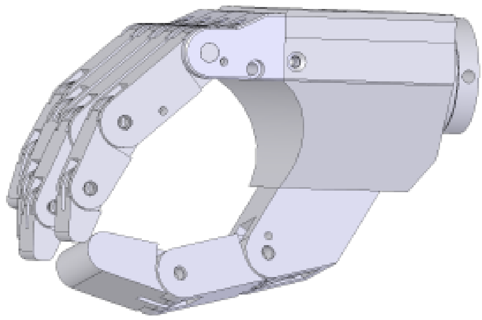
4. Constructive design and CAD model

The constructive design was based on the kinematic scheme, under the premise that the serviceable weight that can be handled by the telethesis is 1.5 kg (a bottle, a book, any object). The constructive form of the telethesis arm is represented in Figure 4a (the CAD model), and in Figure 4b, the mechanical hand that is designed to be mounted on the telethesis is illustrated. In this paper, we do not provide constructive details for the mobile platform or for the mechanical hand. For these components, see my papers [12], [13].

On constructive peculiarities of the robotics, there are the following comments: the component parts have been calculated according to the forces acting on joints by the serviceable weight and the forces caused by the weight of the elements and outer forces that appear when the telethesis moves. The accuracy class for the design of the pieces is of fine mechanics, materials used must have high mechanical and physical performance but low density, for low mass respectively weight of parts and on the whole of the telethesis arm [2]. Couplings of the telethesis robotic arm are driven by electric motors and the mechanical hand is an anthropomorphic gripper with five fingers, each finger actuated by a pneumatic motor. The technical project conducted in CATIA software allows functional simulation of the telethesis, to identify any malfunctions.



a



b

Figure 4: Robotic arm of the telethesis(a) and the mecahanical hand of the telethesis(b)

5. Elements of virtual simulation

Virtual simulation is very useful for testing the possible use of the telethesis [14]. As an example, the telethesis is located in an apartment that is furnished in a common manner (Figure 5) and two activities are simulated: transfer of books from a bookshelf on a table near the person aided by the telethesis (Figure 6). Simulation in virtual environment is important from at least two points of view, namely: setting the main possibilities of use and practicing the telethesis use by the beneficiary. To set the use possibilities it is important that the virtual environment should be furnished almost like in reality. The possibility to change the type of furniture is important too, the same as its arrangement in space. Both aspects are easy to solve in an adequately conceived virtual environment. As far as the practice of possibilities of use is concerned, it must be done to get dexterity so that the degree of failure of a goal or of a phase in a more complex action to be minimized.

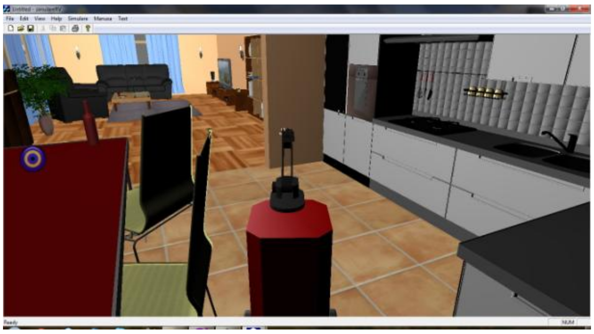


Figure 5: Space where the telethesis will be active

Figure 6: Example of activities: book transfer

6. Elements of command subsystem

The remote operation of the telethesis is achieved by means of auxiliary equipment such as: a camera, a console, a controller, a TCM2 and of sonar equipment. The diagram shown in Figure 7 represents the relationship man-telethesis-auxiliary equipment.

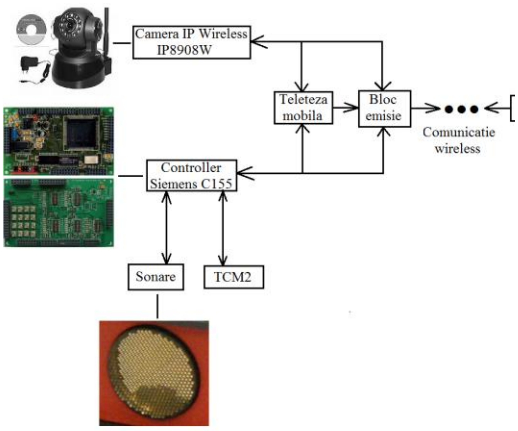
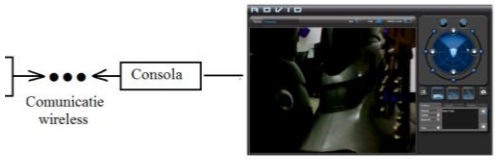


Figure 7: Command equipment scheme



7. Results and future research

After implementing the virtual scene and incorporating the mobile telethesis, more problems appeared which in part have been solved, and in part will be addressed in research to be carried further.

It was resolved:

- proper furnishing of the virtual scene with objects of various configuration-shapes and sizes, allowing their rearrangement;
- giving the objects in the virtual scene minimum of physical properties, of which the most important, for the present application, are: color and contact resistance;
- directing the mobile telethesis through remote operation by a console with display tracing of the image taken by the camera mounted on the telethesis body.

In future research we will seek first, the telethesis routing optimization in virtual environment and data transfer to the real telethesis to allow it to perform in a similar manner, more accurate, the task.

Ultimately we intend to make operational real-time control of the telethesis, through a multifunctional interface (first vocally and then manually), the telethesis movement being tracked on a display based on images transmitted by two cameras: one mounted on the telethesis body and the second on the robotic arm of the telethesis.

Also a standard procedure will be set for efficient use practice of the mobile telethesis in the virtual scene.

8. Acknowledgment

We express our gratitude to the Company Cloos Germany and its Romanian representative Robcon which partly sustained these works. Their know how and support offered us the possibility to present in this Conference the results of our programming and research activities.

9. Conclusions

Based on those presented in this paper we can draw the following conclusions:

- mobile teletheses are complex robotic equipment which consists of three main parts: the mobile platform, the robotic arm and the mechanical hand;
- the structural and kinematic analysis can be performed with methods specific for robot kinematics and structure analysis;
- structure design through advanced software such as CATIA, allows obtaining advanced constructive variants and functional simulation;
- virtual simulation allows testing of activities achievable by the telethesis.

References

[1] Straetu, I., *Elements of Medical Robotics and Prostheses/Elemente de robotica medicala si protezare*, Brasov, Lux Libris Press, 2004.

[2] Staretu, I., a.a., *Mechanical Hand. Anthropomorphic Gripping Mechanism for Prostheses and Robots/Maini mecanice. Mecanisme antropomorfe de prehensiune pentru protezare si roboti*, Lux Libris Press, Brasov, Romania, 2001.

[3] Coiffet, Ph., *La Robotique/Robotics*, Paris, Hermes Press, 1993.

[4] Guittet I., *La Robotique medicale/Medical Robotics*, Paris, Hermes Press, 1988.

[5] HillmanI, M., Rehabilitation Robotics from Past to Present - a Historical Perspective, Proceedings of the ICORR 2003.

[6] Guittet, J., Kwee, H. H.,The Spartacus Telethesis : Manipulator Control Studies ,1979.

[7] rissen, B. J. F. et al., Collaborative Control of the Manus Manipulator, 8 November 2005.

[8] Jain, A., Kemp, C. C., EL-E: an assistive Mobile Manipulator that autonomously fetches Objects from Flat Surfaces, 18 September 2009.

[9] Cooper, R., Wheeled Mobility and Manipulation Technologies, The Bridge, Vol. 39, No. 1, Spring 2009, USA.

[10]Staretu, I., Daj, I., *Mechanisms and Machine Elements/Mecanisme si organe de masini*, Lux Libris, Brasov, Romania, 2000.

[11] Dudita, Fl.,a.a., *Linkage Mechanisms*, Bucharest. Tehnica Press, 1987.

[12] Staretu,I., *Sisteme de prehensiune/Gripping Systems*-second edition, Lux Libris, Braşov, 2010.

[13]Staretu,I.,*Gripping Systems*, Derc Publishing House, Tewksbury, Massachusetts,U.S.A., 2011.

[14]Staretu, I., Constructive Optimization and Virtual Simulation of the Mechatronical Modular Structures Usable as Prostheses and Teletheses for the Human Hand, National Romanian Grant 894, 2007-2008.