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KINEMATIC CONTROL FUNCTIONS FOR A 2T STRUCTURE INTEGRATED ON AN ASSISTANT ROBOT

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Abstract: *The term robotic assistance used to refer to mechanical structures that helped and supported people with disabilities through physical interaction. Today, the term has taken on a much broader meaning, referring to mechanical robotic systems that support and assist human users, offering the possibility of extending human abilities beyond the area of medicine, and can be used for various daily activities. There is a lot of research in the literature on concepts, realised models or solutions for mechanised structures that disinfect hospitals, transport medicine and food to patients, provide home care to the sick or support people with locomotor problems.*
Key words: *people with disabilities, 2T serial structure, assistive robot, locomotor assistance, mathematical modeling, locomotor disability, robot assistants.*

1. INTRODUCTION

People often need support in their daily activities, and thanks to recently developed personal robots, this has become easier and more accessible.

Today's robot assistants are successfully used in various areas of medicine and provide support in operating rooms, physiotherapy and rehabilitation, cleaning and sterilization, dispensing medicines and diagnosing patients without the presence of a doctor using artificial intelligence.

If we refer to the medical system, i.e. hospitals, robot assistants will become indispensable in this field of activity. If we look into the future, the increase in robotization and development, both in the medical and social fields, will have a well-established and well-defined strategic point.

This is particularly argued by the continuing growth of the world's population, i.e. the elderly and people with disabilities. Another alarm signal that opened the need for them (robot nurses) was due to the Covid crisis, which showed the poor preparedness of the medical system, especially in Romania, and led to overcrowding of hospital wards and a major shortage of nurses.

However, the research side of the field is still ongoing and there are quite a few shortcomings until such robots can provide help in a truly safe, efficient, and fully autonomous way. Starting from these premises, the paper proposes to develop a concept of a mechanical robotic system capable of assisting people with locomotor disabilities, consisting of a mobile structure and a serial structure, 2T, as shown in figure 1.[1]

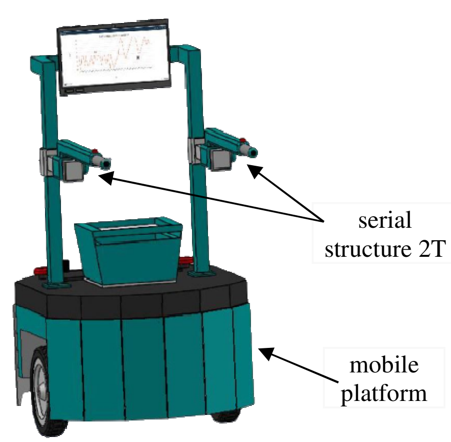

Fig. 1 The design of the assistant robot composed of mobile platform and 2T serial structure

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It should be noted that only the serial structure is treated in the paper, the development of the mobile robot is treated in another paper.

2. OVERVIEW OF THE ROBOT FOR LOCOMOTOR ASSISTANCE

In this paragraph, we will describe the serial structure of the concept proposed for development, thus presenting the functions of the robot as well as the operating mode.

The robotic structure can be reconfigured according to the user's needs, taking into account aspects such as the degree of disability, the patient's age or muscle strength.

The right arm of the robot is the one that contains tactile sensors, so it is through this that the presence of the human operator will be detected, in short, any functionality of the robot is linked to the grip of the handle.

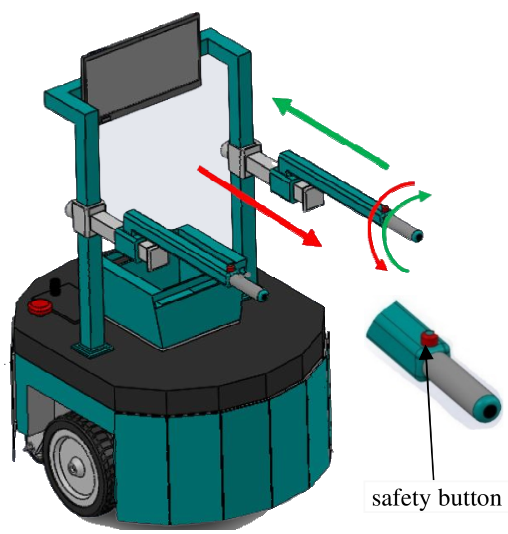

Fig. 2 Speed acceleration and deceleration control when moving the robotic structure

The operator has the possibility to set the travel speed (acceleration / deceleration), figure 2, by turning the handle clockwise or counter-clockwise, while holding down the safety button with the thumb of the right hand. If the handle is turned clockwise and the safety button is pressed, the travel speed of the robot will increase by 0.005 m/s. Counterclockwise and with the safety button pressed, the robot will reduce speed by 0.005 m/s. To keep the speed constant, the user will have to release the safety button.

DC motors are used to drive the robot. This type of motor offers several advantages such as small size, fast drive and response, low torque for speed, low fluctuations and smooth operation.

For the proposed structure, a DC servo motor is used, with a voltage of 48V that can develop a power of up to 0.8 Kw.[2]

Touch sensors are now known as tactile sensors. These sensors are sensitive to touch, pressure and force and are used for a wide range of applications, including some in robotics to protect the robot in the event of a collision or for the actual handling of the robot.

As shown in figure 3, the robot can be easily rotated if the right hand drive is moved horizontally to the left or right, depending on the direction of travel required by the operator.

If the user wishes to move the robotic system backwards (backwards travel), the user must gently lift the right handle, but without holding down the safety button.

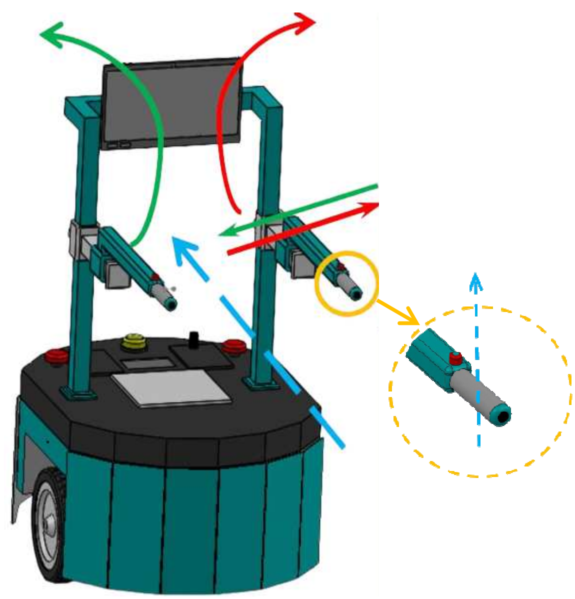

Fig. 3 Movements required for orientation of the robotic structure

To access the robot's arm movements, the operator has to hold down the safety button on the left handle. For upward movement, the left handle must be turned clockwise, and for downward movement, the left handle must be turned anticlockwise, as shown in figure 4.

The speed for this type of movement is also 0.005 m/s, for either type of movement (up/down).

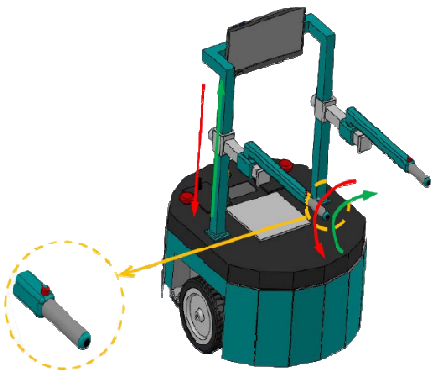

Fig. 4 Up/down movement for sliding structure arms

It is important to point out that the robot is equipped with safety systems to prevent any accident during the use of the robot. In order to extend the arms of the robot system, the user will have to hold down the safety button of the left handle and move it horizontally to the left or to the right, as shown in the figure 5. By this action, the arms will slide forward or backward at a speed of 0.001 m/s for length adjustment.

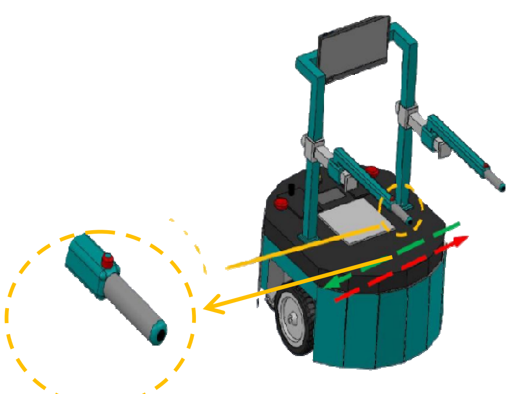

Fig. 5 Extension/retraction by sliding the arms (forwards/backwards)

A particularly important aspect is the real-time monitoring of the operator's vital status, especially since we are talking about people with locomotor disabilities, for whom in the event of an accident or any type of health problem requiring timely travel to a medical facility or a location where they can receive specialized assistance is a difficult or even impossible task. In particular, it is about monitoring vital parameters such as: heart cycle rate, respiratory cycle rate, blood oxygen saturation.

Also of major importance is the provision of real-time geo-location and a real-time travel history.

So one option for sampling and monitoring parameters, but also for data transmission, is to use an IoT (Internet of Things) platform. Wireless communication technology is a key element in continuous monitoring. [3],[4].

3. MATHEMATICAL MODELLING OF THE 2T STRUCTURE

In this chapter, geometrical equations for the 2T mechanical structure of the robot will established using consecrated algorithms.

The application of the algorithms gives a detailed analysis in both graphical and numerical form of the kinematics and geometry of the structure. For the geometric modelling, the algorithm of the location matrices will be used, according to [5].

Considering the mechanical configuration, according to the design dimensions, for the application of the mathematical modelling equations, the input data are given in the following nominal geometry matrix, as shown in table 1.

Table 1

Matrix of nominal geometry

i=1→2	**Joint type**	$\left(\bar{p}_{i,i-1}^{(0)}\right)^T = \bar{p}_i^{(0)} - \bar{p}_{i-1}^{(0)}$			$\bar{k}_i^{(0)T}$		
		$p_{x\,i,i-1}^{(0)}$	$p_{y\,i,i-1}^{(0)}$	$p_{z\,i,i-1}^{(0)}$	$k_{ix}^{(0)}$	$k_{iy}^{(0)}$	$k_{iz}^{(0)}$
1.	T	l_1	0	l_2	0	0	1
2.	T	0	l_3	0	0	1	0

Based on the table the geometrical features are highlighted:

$$\left(i=1;\bar{k}_1 \equiv \bar{z}_1;\Delta_1=0\right);\left(i=2;\bar{k}_2 \equiv \bar{y}_2;\Delta_2=0\right) \qquad (1)$$

Thus, inconsistent with [5], [6], the column vector of the operational coordinates is of the form:

$$^{0}\bar{X} = \begin{bmatrix} \bar{p} \\ \dots\dots \\ \bar{\psi} \end{bmatrix} = \begin{bmatrix} \left(p_x \quad p_y \quad p_z\right)^T \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ \left(\alpha_z \quad \beta_y \quad \gamma_z\right)^T \end{bmatrix} = \left\{ \begin{array}{c} \begin{bmatrix} l_1 \\ l_3+q_2 \\ l_2+q_1 \end{bmatrix} \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ [0 \quad 0 \quad 0]^T \end{array} \right\} \qquad (2)$$

The above expressions characterize the direct geometric modeling of the 2T robot under analysis. They are also known as direct geometry equations or direct geometric model equations, which express the orientation and position of the characteristic point with respect to the fixed reference system O attached to the robot base.

4. KINEMATIC MODEL OF THE 2T STRUCTURE

In the kinematic analysis, two aspects are taken into account - the position and orientation of each joint, necessary to describe the location of the end effector in the workspace. According to the literature [5] the iterative algorithm will be applied and in the first stage of the algorithm application the linear and angular accelerations and velocities corresponding to the fixed base of the robot will be considered to be:

$$^{0}\bar{\omega}_0 = \underset{(3x1)}{[0]},\ ^{0}\dot{\bar{\omega}}_0 = \underset{(3x1)}{[0]},\ ^{0}\bar{v}_0 = \underset{(3x1)}{[0]},\ ^{0}\dot{\bar{v}}_0 = \underset{(3x1)}{[0]} \qquad (3)$$

For $i=1 \rightarrow n$, determine the velocities, respectively the angular and linear accelerations defining the absolute motion of each driven joint, using the following expressions:

$$^{0}\bar{\omega}_i = {}^{0}\bar{\omega}_{i-1} + \Delta_i \cdot \dot{q}_i \cdot {}^{0}\bar{k}_i = {}^{0}\bar{\omega}_{i-1} + \Delta_i \cdot {}^{0}_{i}[R] \cdot \dot{q}_i \cdot {}^{i}\bar{k}_i \qquad (4)$$

$$^{0}\bar{v}_i = \left({}^{0}\bar{v}_{i-1} + {}^{0}\bar{\omega}_{i-1} \times \bar{p}_{ii-1} \right) + (1-\Delta_i) \cdot \qquad (5)$$

$$^{0}\dot{\bar{\omega}}_i = {}^{0}\dot{\bar{\omega}}_{i-1} + \Delta_i \cdot \left({}^{0}\bar{\omega}_{i-1} \times \dot{q}_i \cdot {}^{0}_{i}[R] \cdot {}^{i}\bar{k}_i + \ddot{q}_i \cdot {}^{0}_{i}[R] \cdot {}^{i}\bar{k}_i \right) \qquad (6)$$

$$^{0}\dot{\bar{v}}_i = \left({}^{0}\dot{\bar{v}}_{i-1} + {}^{0}\dot{\bar{\omega}}_{i-1} \times \bar{p}_{ii-1} + {}^{0}\bar{\omega}_{i-1} \times {}^{0}\bar{\omega}_{i-1} \times \bar{p} \right. \\ \left. + (1-\Delta_i) \cdot \left(2 \cdot {}^{0}\bar{\omega}_i \times \dot{q}_i \cdot {}^{0}\bar{k}_i + \ddot{q}_i \cdot {}^{0}\bar{k}_i \right) \right. \qquad (7)$$

In the last step of the iterative algorithm for $i = n$, the absolute motion of the characteristic point of the serial structure is defined, taking into account the absolute linear and angular velocities and accelerations (operational velocities and accelerations).

$$^{0}\dot{\bar{X}} = \begin{bmatrix} {}^{0}\bar{v}_n^T & {}^{0}\bar{\omega}_n^T \end{bmatrix}^T \qquad (8)$$

$$^{0}\ddot{\bar{X}} = \begin{bmatrix} {}^{0}\dot{\bar{v}}_n^T & {}^{0}\dot{\bar{\omega}}_n^T \end{bmatrix}^T \qquad (9)$$

Thus, according to (4)-(7), for the first joint of the 2T structure, $i=1$, is determined [7]:

$$^{0}\bar{\omega}_1 = {}^{0}\bar{\omega}_0 + \Delta_1 \cdot {}^{0}_{1}[R] \cdot \dot{q}_1 \cdot {}^{1}\bar{k}_1 = \underset{(3x1)}{[0]} \qquad (10)$$

$$^{0}\bar{v}_1 = \left({}^{0}\bar{v}_0 + {}^{0}\bar{\omega}_0 \times \bar{p}_{10} \right) + (1-\Delta_1) \cdot \dot{q}_1 \qquad (11)$$

$$^{0}\dot{\bar{\omega}}_1 = {}^{0}\dot{\bar{\omega}}_0 + \Delta_1 \cdot \left({}^{0}\bar{\omega}_0 \times \dot{q}_1 \cdot {}^{0}_{1}[R] \cdot {}^{1}\bar{k}_1 + \right. \\ \left. + \ddot{q}_1 \cdot {}^{0}_{1}[R] \cdot {}^{1}\bar{k}_1 \right) = \underset{(3x1)}{[0]} \qquad (12)$$

$$ {}^0\dot{\bar v}_1 = \left({}^0\dot{\bar v}_0 + {}^0\dot{\bar\omega}_0 \times \bar p_{10} + {}^0\bar\omega_0 \times {}^0\bar\omega_0 \times \bar p_{10} \right) + $$

$$ +(1-\Delta_1)\cdot \begin{pmatrix} 2\cdot {}^0\bar\omega_1 \times \dot q_1 \cdot {}^0_1[R]\cdot {}^1\bar k_1 + \\ + \ddot q_1 \cdot {}^0_1[R]\cdot {}^1\bar k_1 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \ddot q_1 \end{pmatrix} \qquad (13) $$

where,

$$ {}^1\bar k_1 = {}^0\bar k_1 = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}; $$

$$ {}^0\bar\omega_0 = {}^0\bar v_0 = {}^0\dot{\bar\omega}_0 = {}^0\dot{\bar v}_0 = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \qquad (14) $$

$$ \left\{ {}^0\bar\omega_1 \times \right\} = \underset{(3x1)}{[0]}\ ; \quad \bar p_{10} = \begin{pmatrix} l_1 \\ 0 \\ l_2 + q_1 \end{pmatrix} $$

Given the same expressions for *i=2*, the following kinematic parameters as obtained:

$$ {}^0\bar\omega_2 = {}^0\bar\omega_1 + \Delta_2 \cdot \dot q_2 \cdot {}^0\bar k_2 = {}^0\bar\omega_2 + $$

$$ +\Delta_2 \cdot {}^0_2[R]\cdot \dot q_2 \cdot {}^2\bar k_2 = \underset{(3x1)}{[0]} \qquad (15) $$

$$ {}^0\bar v_2 = \left({}^0\bar v_1 + {}^0\bar\omega_1 \times \bar p_{21} \right) + (1-\Delta_2)\cdot \dot q_2 \qquad (16) $$

$$ {}^0\dot{\bar\omega}_2 = {}^0\dot{\bar\omega}_1 + \Delta_2 \cdot ({}^0\bar\omega_1 \times \dot q_2 \cdot {}^0_2[R]\cdot {}^2\bar k_2 + $$

$$ + \ddot q_2 \cdot {}^0_2[R]\cdot {}^2\bar k_2 = \underset{(3x1)}{[0]} \qquad (16) $$

$$ {}^0\dot{\bar v}_2 = \left({}^0\dot{\bar v}_1 + {}^0\dot{\bar\omega}_1 \times \bar p_{21} + {}^0\bar\omega_1 \times {}^0\bar\omega_1 \times \bar p_{21} \right) + (1-\Delta_2)\cdot $$

$$ \cdot\left(2\cdot {}^0\bar\omega_2 \times \dot q_2 \cdot {}^0_2[R]\cdot {}^2\bar k_2 + \ddot q_2 \cdot {}^0_2[R]\cdot {}^2\bar k_2 \right) = \begin{pmatrix} 0 \\ \ddot q_2 \\ \ddot q_1 \end{pmatrix} \qquad (17) $$

where,

$$ {}^0\bar k_2 = {}^2\bar k_2 = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}; \quad \bar p_{21} = \begin{pmatrix} 0 \\ l_3 + q_2 \\ 0 \end{pmatrix} \qquad (18) $$

$$ \left\{ {}^0\bar\omega_2 \times \right\} = \underset{(3x1)}{[0]}\ ; \quad \left\{ {}^0\dot{\omega}_1 \times \right\} = \underset{(3x1)}{[0]} $$

In keeping with (8), there are obtained the relations:

$$ {}^0\dot{X} = \begin{bmatrix} {}^0 v_2 \\ {}^0\omega_2 \end{bmatrix} = \begin{bmatrix} (0 & \dot q_2 & \dot q_1)^T \\ (0 & 0 & 0)^T \end{bmatrix} \qquad (19) $$

$$ {}^0\ddot{X} = \begin{bmatrix} {}^0\dot v_2 \\ {}^0\dot\omega_2 \end{bmatrix} = \begin{bmatrix} (0 & \ddot q_2 & \ddot q_1)^T \\ (0 & 0 & 0)^T \end{bmatrix} \qquad (20) $$

The expressions determined above represent the equations of direct kinematics, which characterize the absolute motion of the characteristic point .

5. CONCLUSION

The paper proposes a constructive solution of a robotic system capable of helping people with locomotor problems, figure 6. It is important to mention that only the serial structure has been treated in the paper, the mobile robot being the subject of another paper.

Thus, in the first part of the paper the operation of the concept was described in detail. The second part is dedicated to the mathematical modeling, so the direct geometric model was presented, which regardless of the algorithm used aims to determine the equations of the direct geometry that will be used to establish the direct kinematic model. In the study of geometry, no mechanical characteristics were taken into account and no kinematic or dynamic restrictions were imposed. Also, in the work the operational kinematic parameters expressing the motion of the serial structure, fixed on the mobile structure in Cartesian space, were established. The iterative method was used to define these parameters. With this method the kinematic parameters were defined with respect to the fixed *O* system.

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FUNCTIILE DE COMANDĂ ŞI CINEMATICĂ PENTRU O STRUCTURA 2T INTEGRATĂ PE UN ROBOT ASISTENT

Rezumat: *Termenul de asistență robotizată se referea în trecut la structuri mecanice care ajutau și susțineau persoanele cu dizabilități prin intermediul interacțiunii fizice. Astăzi, termenul a căpătat un sens mult mai larg, referindu-se la sisteme mecanice robotizate care sprijină și vin în ajutorul utilizatorilor umani, oferind posibilitatea extinderii abilităților omenești și în afara ariei de medicină, ei putând fi destinați diferitelor activități zilnice. În literatură există numeroase cercetări cu privire la concepte, modele realizate sau soluții de structuri mecanizate care dezinfectează spitalele, care transportă medicamente și hrană pacienților, care oferă bolnavilor îngrijire la domiciliu sau care să vină în sprijinul persoanelor cu probleme locomotorii.*

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