ANKLE REHABILITATION ROBOTIC PLATFORM. PART B: POSSIBLE CONSTRUCTIVE SOLUTIONS

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Abstract: Traditional rehabilitation therapies use simple devices such as elastic bands and foam rollers. They also require the constant presence of a therapist. Rehabilitation exercises are long-lasting, repetitive and require effort from both the patient and the therapist. To counteract these disadvantages, high-performance robotic systems can be used for a complete recovery of the joint. However, the implementation of therapy assisted by robotic systems at the level of recuperative institutions is difficult, due to their high costs. Hence, the need to carry out research, in order to develop platforms with low cost, but with high functionality, which allow a complete recovery of the ankle joint, but also the monitoring of the patient's progress. Although the current literature notes a multitude of systems used in medical recovery, it can be said that at the moment there is no system that fully satisfies the patient's need for recovery and that does not face the previously mentioned technical problems. Consequently, the conception, development and implementation of rehabilitation platforms, adaptable to the patient's needs, are justified and will be the object of study of this work. In this paper, authors presented their work on the design of different constructive solutions of ankle rehabilitation platforms with two basis kinematics.
Keywords: rehabilitation robot, ankle rehabilitation, constructive solutions.

1. Introduction

Based on the study of the existing literature [1-19], presented in the first part of the work, it can be said that the use of robotic systems, as a modern alternative to classical medical recovery, is very useful. However, the use of rehabilitation systems in recovery clinics is limited by certain problems and shortcomings, such as:

- The interaction between the patient and the recovery system may be poor;
- Additional control measures are necessary for patient safety during recovery exercises;
- Impossibility for the patient to repeat some recovery sessions at home;
- The impossibility of adjusting forces and moments in real time;
- Complicated command and operation interfaces;
- Aspects related to the shape, dimensions, which make it difficult to handle the systems.

In order to solve these difficulties faced by medical recovery systems, it is necessary to use special control methods that guarantee medical recovery and maintain safety throughout the period in which the patient is using the system. The purpose of the control algorithms is to monitor the robotic platforms intended for rehabilitation exercises, so that the exercises performed by the patient develop motor plasticity and therefore improve the recovery of motor functions.

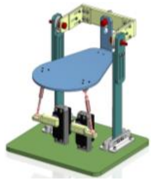
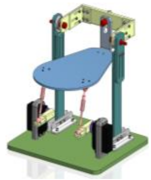
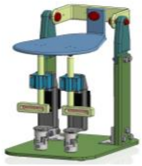
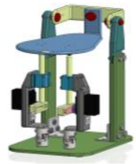
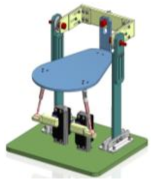
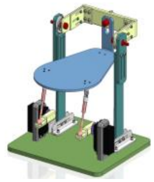
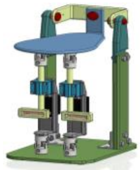
In this paper, authors presented their work on the solution selection of the rehabilitation platform, based on some criteria design imposed to different possible constructive solutions of ankle rehabilitation platforms with two basis kinematics.

2. Possible Constructive Solutions

For the robotic platforms based on mechanisms with two d.o.f., discussed above, some constructive variants have been designed, with collinear or parallel rotational axes of the two actuators. Also, the two rotational axes of driven link (the plate on which the sole of the foot rests) can be coaxial with the rotational axes of the ankle joint (the ideal case) or they can be parallel to them, being located in another plane, parallel to the one which contains the rotational axes of the ankle joint. Under these conditions, for each kinematic solution, presented in the first part of the work, four constructive variants will result. The 3D CAD models for all the 16 constructive variants are summarized in Tab. 1.

To choose the solutions that present the most advantages in use, Tab. 2, several criteria have been taken into account:

Tab. 1. Constructive solutions of robotic rehabilitation platforms with two d.o.f.

	Spatial four-bar mechanism		**Scotch-Yoke mechanism**	
	Actuators location			
	Actuators with parallel rotational axes	**Actuators with collinear rotational axes**	**Actuators with parallel rotational axes**	**Actuators with collinear rotational axes**
The rotational axes of the driven link coincide with the rotational axes of the ankle joint	CS-1 	CS-3 	CS-9 	CS-11 
	CS-2 	CS-4 	CS-10 	CS-12 
The rotational axes of the driven link are parallel with the rotational axes of the ankle joint	CS-5 	CS-7 	CS-13 	CS-15 
	CS-6 	CS-8 	CS-14 	CS-16 

Tab. 2. Selection of the adopted constructive variant.

	CS-1	**CS-2**	**CS-3**	**CS-4**	**CS- 5**	**CS-6**	**CS-7**	**CS-8**	**CS-9**	**CS-10**	**CS-11**	**CS-12**	**CS-13**	**CS-14**	**CS-15**	**CS-16**
C1	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3
C2	3	3	3	3	3	3	3	3	5	5	5	5	5	5	5	5
C3	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3
C4	5	5	4	4	5	5	4	4	5	5	4	4	5	5	4	4
C5	4	5	4	4	5	5	4	4	4	4	3	3	4	4	3	3
C6	4	5	4	5	5	4	4	4	4	5	4	4	4	5	4	4
Total	24	26	23	24	26	25	23	23	24	25	22	22	24	25	22	22

- Easy maintenance (C1) – this criterion takes into account the actuator type, as well as the kinematics of the platform mechanism (joints number and type);
- Simplicity in use (C2) – criterion that refers to the possibility of programming and using by the end user;
- Low cost (C3) - the manufacturing costs of the parts of the rehabilitation system are taken into account;
- The overall dimensions (C4) play an important role in the choice of the rehabilitation platform solution, considering both the overall dimensions of the system and its mass;
- The minimum probability of blocking is given by the joints type in the mechanisms (C5);

The angular strokes of the driven link (C6), but also the ease of reaching their maximum values.

Also, all the solutions are taking into account the safety of the patient, as well as the possibility of reaching the range of movements necessary for a complete recovery of the ankle joint. Points from 0 to 5 were awarded for each constructive variant, where 0 represents the inability of the respective variant to adapt to the requirement, and 5 represents the fulfillment of the requirement at maximum performance.

Among the discussed constructive solutions, four of them stand out that meet the most requirements, two solutions based on the spatial four-bar mechanism, solutions CS-2 (Fig. 1) and CS-5 (Fig. 2) and two based on the Scotch-Yoke mechanism, solutions CS-10 and CS-14. In order to choose the final constructive solutions that will be practically realized, dimensional synthesis, mathematical modeling and their simulation are necessary. In the first phase, only solutions CS-2 and CS-5 have been analized and discussed, and solution CS-5 has been practically realized.

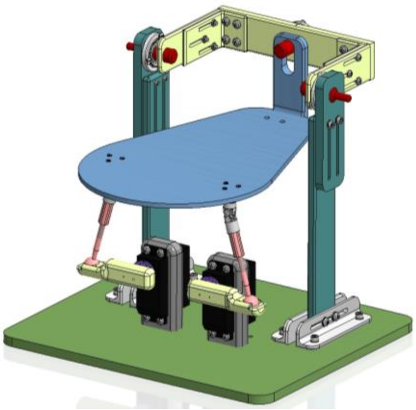


Fig. 1. Constructive solution CS-2.

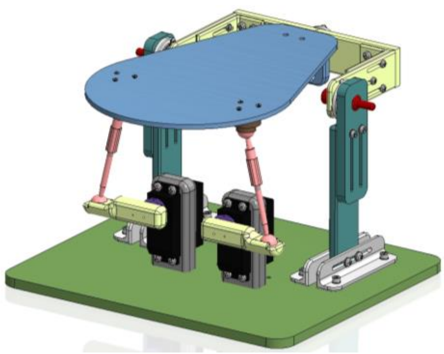


Fig. 2. Constructive solution CS-5 [21-24].

For CS-2 constructive solution, the angular values obtained in the mechanism simulation suggest that the mechanism does not provide the driven link with the necessary angular strokes for the rehabilitation of the ankle joint, for inversion / eversion movement. For this reason, this solution was not taken into account for practical realization.

For CS-5 constructive solution, the center of the ankle joint is at a point placed at 70 [mm] above the sole support plate (Fig. 3). Even if this solution proved that it offers linear variation of the driven link angular movement according to the driver link angular movement, suggesting smooth operation and achieving the proposed recovery exercises without problems, for both plantar flexion / dorsiflexion and inversion / eversion movements, it is desired that the center of the ankle joint should be at the intersection of the two rotational axes of the sole support plate. This is why, the CS-5 constructive solution will be optimized in the future work.

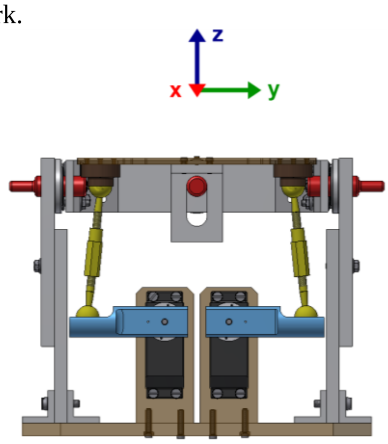


Fig. 3. Front view of the CS-2 CAD desing, with reference axis system of the ankle joint center [24].

3. Conclusions

Traditional rehabilitation therapies use simple devices such as elastic bands and foam rollers. They also require the constant assistance of a therapist. Rehabilitation exercises are long-lasting, repetitive and require effort from both the patient and the therapist. To counteract these disadvantages, high-performance robotic systems can be used for a complete recovery of the joint. However, the implementation of therapy assisted by robotic systems at the level of recuperative institutions is difficult, due to their high costs. This led to the need to carry out research in order to develop new solutions of robotic platforms, with a low cost, but with high functionality, which would allow a complete recovery of the ankle joint, but also the monitoring of the patient's progress.

Based on the adopted structural schemes, in the first part of the work, several constructive solutions have been proposed, which were subjected to a comparative analysis process, based on a series of imposed criteria. Among the discussed constructive variants, four solutions stand out that meet the most requirements, two variants based on the spatial four-bar mechanism and two variants based on the Scotch-Yoke mechanism. The simulations demonstrated that the first one could not provide the driven link with values of the angular strokes corresponding to the complete recovery of the ankle.

Finally, the constructive solution CV-5 was practically realized and some tests have been performed to demonstrate the effectiveness of the robotic platform in the rehabilitation process of the ankle joint.

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