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A STUDY REGARDING USE OF KUKA LBR IIWA 7 R800 ROBOTIC ARM IN PERFORMING POST-STROKE REHABILITATION TASKS

BY

PAUL TUCAN[1,*], GIUSEPPE CARBONE[2] and DOINA PÎSLĂ[1]

[1]CESTER, Technical University of Cluj-Napoca, Romania
[2]LARM, University of Cassino and Southern Lazio, Cassino, Italy

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Abstract. The paper presents a simulated virtual environment containing a serial Kuka robotic arm equipped with a multipurpose gripper in order to perform various rehabilitation tasks of patients suffering from motoric deficiencies after a stroke. First part of the paper describes the necessity of using high repeatability devices in performing rehabilitation of impaired limbs of a post-stroke patient. The second part of the paper is focused in describing the equipment used in the rehabilitation process. Next, a series of limb rehabilitation scenarios are defined, analysed and implemented in a virtual modelling software. An analysis is conducted in order to identity the best solution for the end effector of the robot, a solution able to comply with various future rehabilitation tasks.

Keywords: Kuka LBR; cobot; post-stroke rehabilitation; rehabilitation scenarios.

1. Introduction

Stroke is one of the leading cause of death and in the same time of long disability (Arnao, 2016). At a global level there are 15 million new cases reported annually, from which approximately 5 million are death cases and

*Corresponding author; *e-mail*: paul.tucan@mep.utcluj.ro

other 5 million result in permanent disability (WHO, 2003). Patients who suffered a stroke are usually in risk of recurrent stroke, myocardial infarction and vascular death (Isabel, 2016). In order to avoid recurrent stroke the prevention and treatment phase should start right after the stroke. Most common effect of stroke is limb paralysis. In order to regain the motoric functions of the body a three phase rehabilitation is propose by (Knecht, 2011):

Phase 1: the patient cannot get out of bed and simple motoric exercises are performed to regain nervous connectivity of the impaired limb(s);

Phase 2: the patient regained nervous connectivity, is immobilized in a wheelchair and learns to walk again;

Phase 3: the patient regained the ability to walk and learns to walk rapidly and steadily under daily life conditions.

Regaining of motoric functions is achieved by repetitive practice of the possible motion of the impaired limb. The main objective of rehabilitation treatments is to achieve the autonomy of the patient in the daily environment and to psychosocially reintegrate the patient (Knecht, 2011).

As stated before, repetitive practice of motion is the key to post-stroke rehabilitation of the impaired limbs. In phase 1 the patient cannot move at all the impaired limb, so in order for the rehabilitation to be possible, another qualified person has to do the motion instead of the patient. As a result of high stroke incidence, some mechanical devices started to be developed in order to replace the physician performing the motion allowing personal medical to perform other adjacent tasks and in the same time to serve o higher number of affected patients. Along time a few robotic solutions for the rehabilitation of the impaired limb after a stroke were designed (Caffola, 2018; Vaida, 2017; Gherman, 2018), most of them widely analysed by (Pignolo, 2012). The majority of these robotic solutions were new robots especially designed for rehabilitation of a specific motion of the impaired limb or of the entire limb. To design a new widely accepted robotic rehabilitation solution a lot of resources are consumed (time, human, money, etc.) and as a result new products tend to appear quite rarely. This paper proposes a new approach in the post stroke rehabilitation by proposing a rehabilitation method using an existent, widely used collaborative robotic system.

2. Kuka LBR iiwa 7 R800 & End-Effector Selection

Kuka LBR iiwa 7 R800 arm is the first human –robot-collaboration compatible robotic system. The entire name of the robot is “Kuka Leichtbauroboter (Lightweight Robot) intelligent industrial work assistant 7 R800” a name that defines some characteristics of the robotic system (Kuka, 2018). The robot is part of small robots category (3-10 kg), having a standard articulated solution. The total weight of the robotic system is 22 kg with a payload of 7 kg and an action range of 800 mm. The number of controlled axes of the robot is 7 and it has a repeatability of ±0.1 mm. The Kuka LBR iiwa robotic system is presented in Fig. 1.

Fig. 1 − Kuka LBR iiwa 7 R800 (Kuka, 2018).

In order to be able to use the robotic system, especially in performing a rehabilitation task, the end-effector (tool) of the robot has to be chosen, for this an analysis of a few existent solutions on the market is carried on. A series of seven end-effector solutions are presented in Tables 1 and 2.

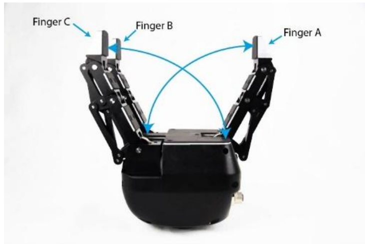
Table 1
Gripper Solutions

Solution	Name	Representation
S1	EGP 40 CO ACT(SCHUNK)	Fig. 2*a*
S2	3 Finger Robotiq	Fig. 2*b*
S3	2 Finger (85)Robotiq	Fig. 2*c*
S4	2 Finger (140)Robotiq	Fig. 2*c*
S5	3 Finger Barrett Hand	Fig. 2*d*
S6	Schunk MEG 50 2 Fing Parallel	Fig. 2*e*
S7	5 Finger Schunk	Fig. 2*f*

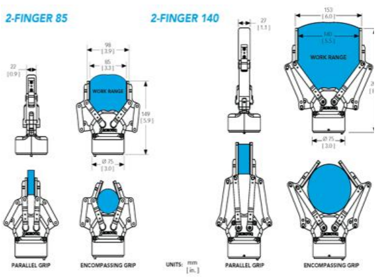
Table 2
Gripper Characteristics

Characteristic	S1	S2	S3	S4	S5	S6	S7
Grip Force, [N]	35-140	30-70	20-235	10-125	15-20	60 - 90	-
Grip points	2	3	2	2	3	2	5
Payload, [kg]	0.7	10	5	2.5	6	0.7	0.001 to 0.850
Work Range, [mm]	2-14	0-155	0-85	0-140	0-334	0-20	-
Size, [mm]	120x98	204x126	149xD75	209xD75	204x90	104.5x50	242.5x92
Weight, [kg]	0.7	2.3	0.9	1	0.98-1.2	1.42	1.3
Force sensor	Y	N	N	N	Y	N	Y

a) S1 (Schunk, 2018)



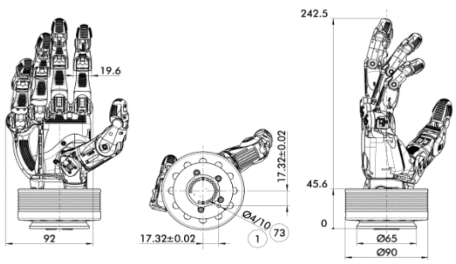
b) S2 (Robotiq, 2018)



c) S3 & S4 (Robotiq, 2018)

d) S5 (Barrett, 2018)

e) S6 (Schunk, 2018)



f) S7 (Schunk, 2018)

Fig. 2 – Gripper solutions proposed.

The next step for this trade-off was to evaluate the most important criteria needed to select a final end-effector for the rehabilitation task. It can be considered that grip points, size, precision, the existence of force sensors and payloads are few of the most important criteria to be evaluated in an end effector trade-off. The scores for each of the chosen criteria were given accordingly to each grippers technical performances keeping in mind the task requirements. Scoring for the criteria evaluation for each individual gripper where: 1-worst than most; 2- better than most; 3- good; 4-best.

Next table presents the results of the trade-off criteria for each of the proposed grippers (Table 3).

Table 3
Gripper Characteristics

Characteristic	S1	S2	S3	S4	S5	S6	S7
Grip Force, [N]	2	3	4	3	-	4	4
Grip points	2	4	2	2	4	3	4
Payload, [kg]	1	4	3	5	3	2	3
Work Range, [mm]	1	4	2	3	-	2	4
Size, [mm]	4	4	3	2	3	3	4
Weight, [kg]	4	1	3	2	3	3	3
Force sensor	4	4	4	4	4	4	1

As it can be seen in Table 3 the 3 finger Robotiq gripper seems to be the best option for the rehabilitation operations. Also has to be taken into consideration the fact that Kuka already has history in collaborating with Robotiq grippers.

Having the robotic system defined and the end-effector selected, next step is to define various rehabilitation scenarios for different parts of the human body. Scenarios and simulations were carried on for the wrist, elbow and ankle; due to the 7 kg payload of the robot and the added weight of 2.3 kg of the selected gripper, the remaining payload of the robotic system is of 4.7 kg, payload sufficient to manipulate only the extremities of the impaired limb.

3. Rehabilitation of the Wrist, Elbow and Ankle

First step in researching the rehabilitation of the human wrist is to identify its rehabilitation motions these motions are: flexion/extension, ulnar flexion/ radial flexion (adduction/abduction) and pronation/ supination (Major, 2016). All motions are exemplified in Fig. 3.

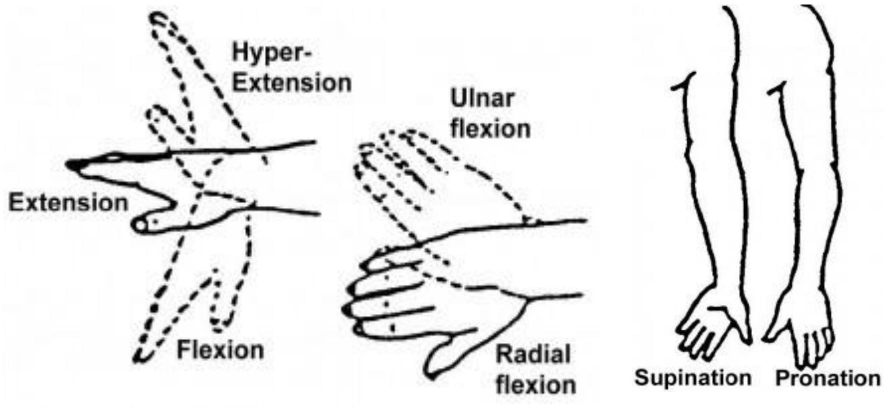
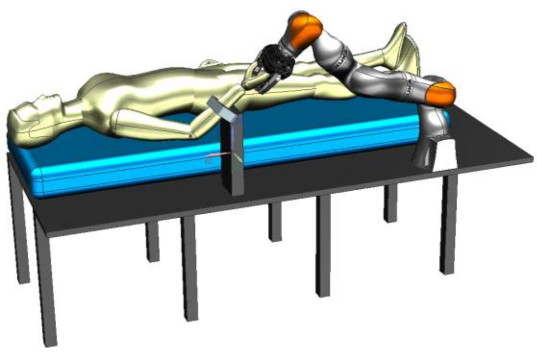
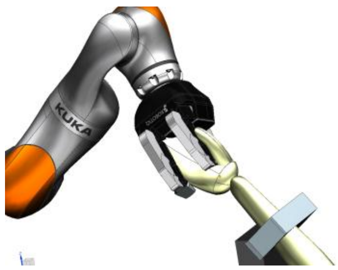


Fig. 3 – Rehabilitation motion of the wrist
(Brooksidepress, 2018).

After the motions were identified a special environment is designed using the Kuka robotic system, 3 finger gripper and a dummy. The patient has been placed on a bed that has a special part where the rehabilitation system is placed. On this bed, the robot can be moved and placed on the longitudinal and sagittal plane of the patient's body. The simulation of the rehabilitation motion was carried on by imposing the gripper trajectory and observing the angular displacement of the rehabilitated joint of the patient. The simulation environment is represented in Fig. 4, while the results of the simulation are displayed in Fig. 5.

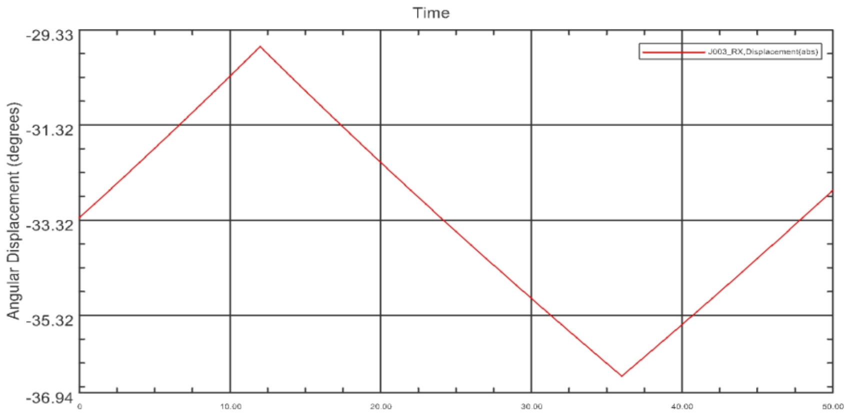


a) Rehabilitation position

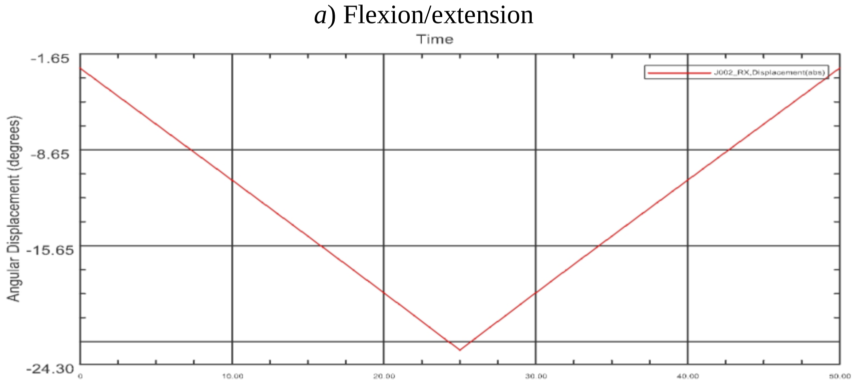


b) Rehabilitation gripping

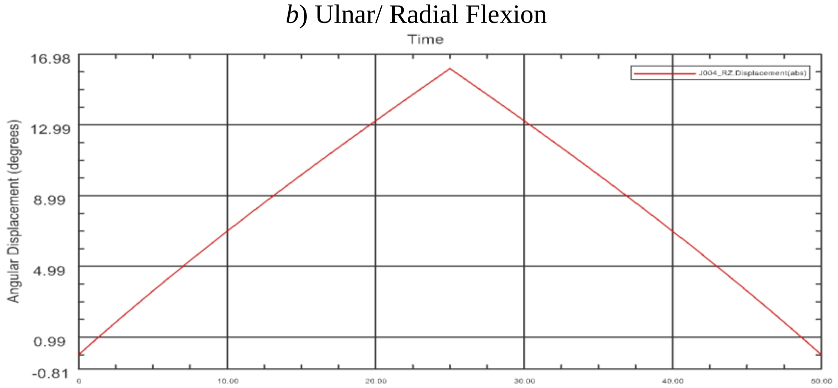
Fig. 4 – Rehabilitation environment.



a) Flexion/extension



b) Ulnar/ Radial Flexion

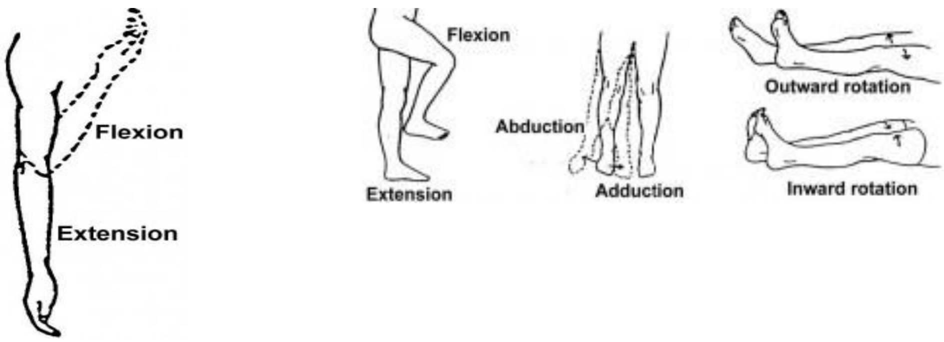


c) Pronation/ Supination

Fig. 5 – Simulation results.

The result of the simulation yielded that the angular displacement of the wrist during the rehabilitation motion is contained within the safety limits of the human motion capability.

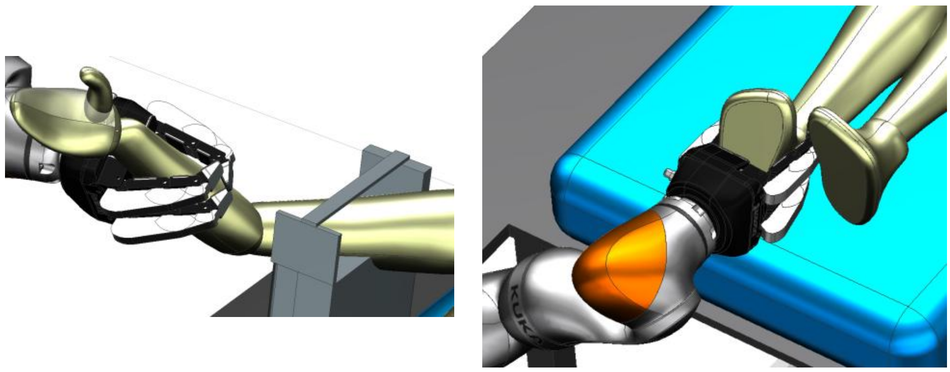
Same approach is used in testing the robotic system in performing the rehabilitation of the elbow and ankle. First the rehabilitation motion are identified and displayed in Fig. 6*a*, for the elbow, and Fig. 6*b* for the ankle:



a) Elbow's motion *b*) Motion of the ankle

Fig. 6 – Motion of the ankle (Brooksidepress, 2018).

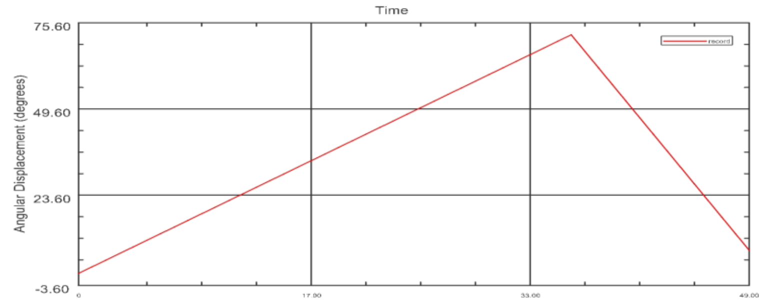
The designed environment for the rehabilitation task remains the same, only the gripping of the forearm and of the foot changes to allow the rehabilitation; the gripping method is shown in Fig. 7.



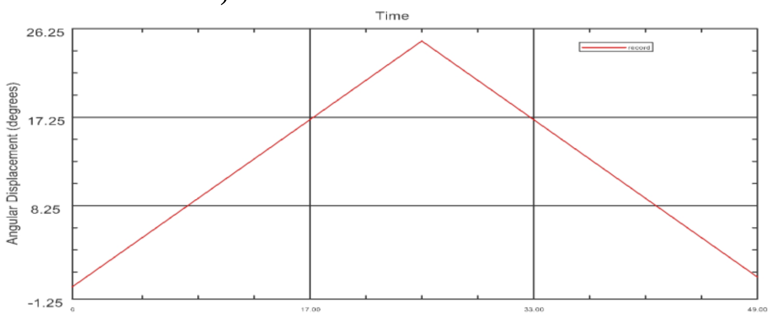
a) Forearm grip *b*) Foot grip

Fig. 7 – Gripping of the forearm and of the foot.

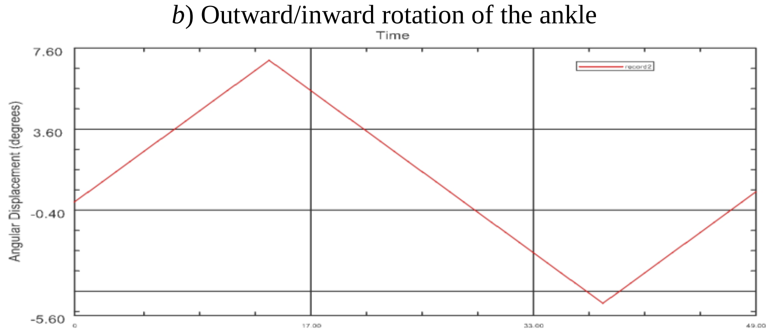
The simulation procedure was the same as in simulating the rehabilitation of the wrist, by imposing trajectory of the end-effector and recording the angular displacement of each joint (human joint) the results of the simulation are displayed in Fig. 8.



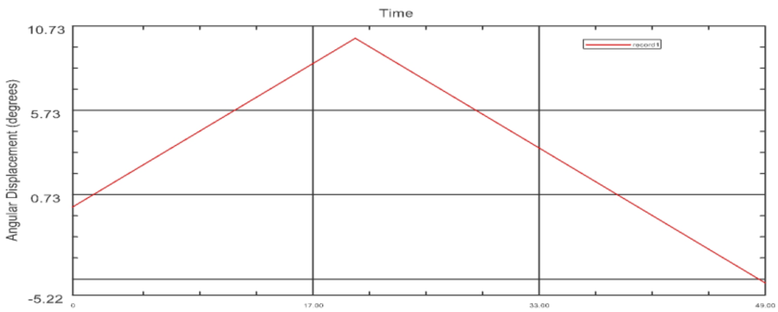
a) Flexion/extension of the elbow



b) Outward/inward rotation of the ankle



c) Dorsal/plantar flexing of the ankle



d) Pronation/supination of the ankle

Fig. 8 – Simulation results of the elbow and ankle.

The simulation was performed using Siemens NX software, where a simple trajectory of the end effector has been imposed only to test the displacement in the human articulations and in the same time to test the configuration of the robot during the simulation. The simulation was perform to test only one repetition of the rehabilitation motion considered to be sufficient for the testing of the rehabilitation system.

4. Conclusions

Within this paper a rehabilitation method of upper and lower limb has been presented. The proposed method implies use of existing robotic system in performing rehabilitation of the wrist, elbow and ankle. A Kuka LBR iiwa 7 R800 robot is described and proposed as a kinetotherapist motion replacement. The robot uses a 3 finger gripper as an interface between the robot and patient and several fixture points to immobilize and isolate the motion of the impaired limb. An virtual environment is designed and the robotic system is embedded within along with the dummy of the patient. The motion of each impaired limb is simulated and the angular displacement of the human articulation is recorded and proved to be within considerable limits. The study provided data for rehabilitation of the extremities of the human limbs, while stating the fact that to perform the rehabilitation of the entire limb, additional systems have to be used as weight reducers or even two Kuka robots. Further work implies designing of the fixture elements and testing of the system in a real environment.

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REFERENCES

Arnao V., Popovic N., Caso V., *How is Stroke Care Organized in Europe?* Presse Med., **45**, e399–e408 (2016).

Barrett, https://www.barrett.com/about-barrethand/ (2018).

Brooksidepress, http://www.brooksidepress.org/brooksidepress/ (2018).

Cafolla D., Russo M., Carbone G., *Design and Validation of an Inherently Safe Cable-Driven Assisting Device*, International Journal of Mechanics and Control, **19**, *01*, 23-32 (2018).

Gherman B., Carbone G., Plitea N., Ceccarelli M., Pisla D., *Kinematic Design of a Parallel Robot for Elbow and Wrist Rehabilitation*, Proceeding of 12th IFToMM International Symposium Science of Mechanisms and Machines-SYROM'2017, Iași, Springer Book (2018).

Isabel C., Calvet D., Mas J.L., *Stroke Prevention*, Presse Med., **45**, e457–e471 (2016).

Knecht S., Hesse, S., Osetr, P., *Rehabilitation After Stroke*, Deutsches Ärzteblatt International, **108,** *36*, 600-606 (2011).

Kuka, https://www.kuka.com/ro-ro/produse-servicii/robotics-systems/industrial-robots/lbr-iiwa (2018).

Major K.A., Major Z.Z., Carbone G., Pisla A., Vaida C., Gherman B., Pisla D.L. *Ranges of Motion as Basis for Robot-Assisted Post-Stroke Rehabilitation*, HVM Bioflux 2016, **8**, *4*, 192-196 (2016).

Pignolo L., Dolce G., Basta G., Lucca L.F., Serra S., Sannita W.G., *Upper Limb Rehabilitation After Stroke: ARAMIS a "Robo-Mechatronic" Innovative Approach and Prototype*, 4th IEEE RAS & EMBS Int. Conf. Biomedical Robotics and Biomechatronics (BioRob) Rome, Italy, 1410–1414 (2012).

Robotiq, https://robotiq.com/ (2018).

Schunk, https://schunk.com/us_en/gripping-systems/highlights/svh/ (2018).

Vaida C., Carbone G., Major K., Major Z., Plitea N., Pisla D., *On Human Robot Interaction Modalitiesin the Upper Limb Rehabilitation After Stroke*, Acta Tehnica Napocensis, Applied Mathematics, Mechanics and Engineering, **60**, *1*, 91-102 (2017).

World Health Organization, *The World Health Report 2002*, Midwifery (2003).

UN STUDIU REFERITOR LA FOLOSIREA ROBOTULUI KUKA LBR IIWA 7 R800 ÎN EXECUTAREA DE SARCINI DE REABILITARE ÎN URMA ACCIDENTULUI VASCULAR CEREBRAL

(Rezumat)

Lucrarea prezintă un mediu virtual simulat care conține un braț serial Kuka echipat cu un efector final multifuncțional pentru a efectua diferite sarcini de reabilitare a pacienților care suferă de deficiențe motorii rezultate în urma unui accident vascular cerebral. Prima parte a lucrării descrie necesitatea utilizării dispozitivelor cu repetabilitate ridicată în efectuarea reabilitării membrelor afectate ale unui pacient care a suferit un accident vascular cerebral. A doua parte a lucrării este axată pe descrierea echipamentului utilizat în procesul de reabilitare. O analiză este efectuată pentru a identifica cea mai bună soluție pentru efectorul final al robotului, o soluție capabilă să se conformeze diferitelor sarcini viitoare de reabilitare.

O serie de scenarii de reabilitare a membrelor sunt definite, analizate și implementate într-un software virtual de modelare.