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DESIGN OF HAND PROSTHESES BASED ON DATA CAPTURED DURING REACHING TO GRASP ACTIVITIES OF THE HUMAN HAND

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I. INTRODUCTION

The design of upper limb prostheses must be done on realistic bases taking into account the present technologies and getting of the best efficiency in their use without ignoring the economical factors.

In authors' opinion, the basic idea in the prosthetic field is that the quality must be measured not only through the technical performances of the prosthetic system but mainly through the performances the wearers get in the daily use of the system.

Naturalness in operation beside cosmetics have to be the major factors in choosing of a certain type of prosthesis.

II. SPECIFIC ASPECTS ON UPPER LIMB PROSTHESES DESIGN

The prehension mechanisms of upper limb prostheses have to emulate the functional and cosmetic characteristics of the human hand.

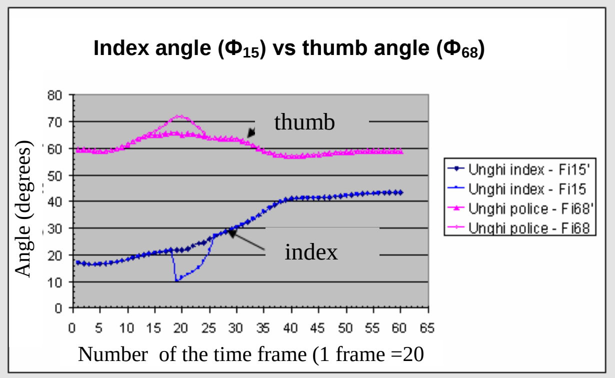


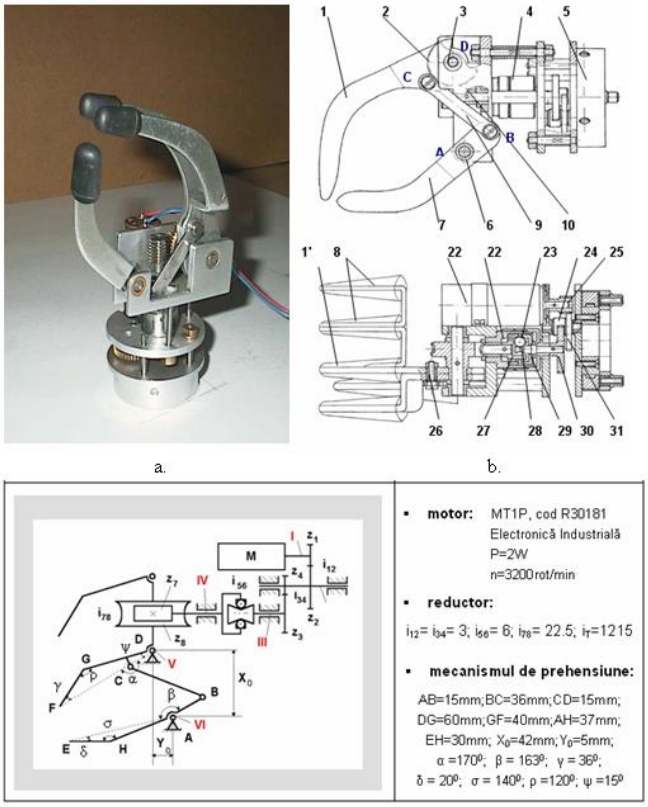
Figure 1

The studies performed in the motion analysis laboratories [1], [2], [3], [4], [9], [11] on the spatial kinematics of the human upper limb, with and without prosthesis, during reaching to grasp activities, pointed out the requirement of designing the prehension mechanisms with the active fingers (index and thumb) having different speeds. This would be in conformity with the biomechanics of the human hand (fig.1), in which the thumb, acting as a stabilizer, has a speed and an angular opening (Φ_{68}) [9] which are less than those of the index (Φ_{15}) which has the main part in the opening/closing activities of the hand (fig.1) [3]. Another finding of these studies has been that regarding the design of the fingers of prostheses which has not to be of anthropomorphic type as the human hand is [3].

Building of the fingers as a link chain, although useful in griping of the objects of complex shapes, asks for sophisticated control systems which give the prosthesis a higher cost these resulting in the danger for the prosthesis of being rejected by the wearer because of the difficulties he encounters in using of it.

III. DESCRIPTION OF THE EXEPRIMENTAL MODELS OF THE UPPER LIMB PROSTHESES

The four-bar mechanism is often used in the construction of prehension mechanisms, including those of prostheses, as it can be designed to reproduce a wide variety of kinematic conditions [12], [13], [14], [15].



a.

b.

c.

Figure 2

Figure 2 and 3 present such a mechanism and the models designed by the authors.

In the prosthesis from fig.2, a, b, c the fingers 1 and 7 are actuated by building them together with the four-bar mechanism ABCD.

The dimensions of the four-bar mechanism, for the initial adopted solution, in which the fingers move with same speed, are those in fig.2c.

The dc motor 22, is of MT1P type (Electronica Industriala), 2W and 3200 rpm. It actuates the fingers through gears 24,25,30 3, the planetary friction gear 4 and the worm gear 2 which prevent the hand to be opened accidentally.

The opening time is about 2 s and the objects to be manipulated with the prosthesis can be of up to 75 mm diameter.

The construction of this prosthesis is simple and as the motor 22 is placed in the palm, the prosthesis can be use for all levels of amputation including the long forearm amputations. The system 5 allows for passive supination. The control of prosthesis is of myoelectric, on-off type.

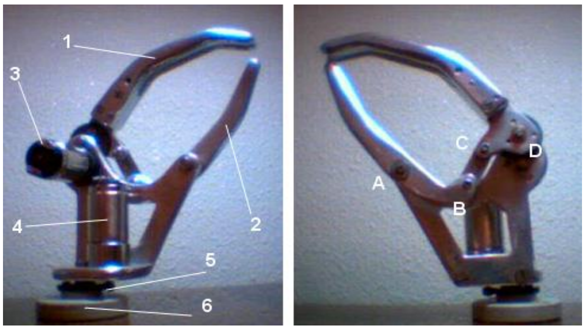


Figure 3

Prosthesis from fig.3 achieves prehension and supination in an active way, using for this two dc motors 3 and 4 (Escape 23L11213P-22) with planetary gears (reduction rate of 128:1), 12V and 7200rpm.

The prosthesis has an opening time of less than 1 s and develops a grip force of about 50-60N. The control of prosthesis is proportional and the electrode are Otto Bock, 13E125=50

IV. PROSTHESES OPTIMISATION AND 3D MODELS

In order the prostheses emulate the kinematics of the human hand the first step was to do the synthesis of the four-bar mechanism [14],[15].

The prosthesis having the rigid fingers shaped corresponding to the resting position of the hand was designed imposing five associated positions: $\varphi_{3i} = \varphi_{3i}(\varphi_{1i})$, i = 1, 5, the values for the angels , Φ_{15} (index) and Φ_{68} (thumb) being chosen from the graph from fig. 1 [1]

The equations projected on the coordinate system of the vectorial equation:

$$\overrightarrow{DC} + \overrightarrow{CB} = \overrightarrow{DA} + \overrightarrow{AB} \qquad (1)$$

for the independent contour ABCDA, give a nonlinear system of 10 equations with unknown parameters BC, CD, AD, φ_1, φ_3, φ_{2i}, i = 1, 5:

$$\begin{cases} DC\cdot\cos(\varphi_1+\varphi_{1i}) + CB\cdot\cos(\varphi_{2i}) = X_A + BA\cdot\cos(\varphi_3+\varphi_{3i}) \\ DC\cdot\sin(\varphi_1+\varphi_{1i}) + CB\cdot\sin(\varphi_{2i}) = Y_A + BA\cdot\sin(\varphi_3+\varphi_{3i}) \end{cases} \qquad (2)$$

Solving of the above system of equations was done using a program named *mecanism_proteza* in which were used as initial conditions for BC, CD, AD, φ_1, φ_3, the already known dimensions of the mechanism (fig.2c).

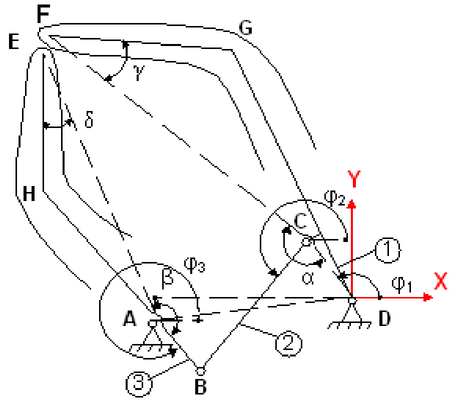


Figure 4

The final dimensions were obtained by multiplying the components of the vector X[i] with adopted valued for AB. The optimal solution for the mechanism was determined with an error ε= 0, 000082, and was as follows:

X[1] = 2.2822812029E+00,
X[2] = 4.6987603654E-01,
X[3] = 2.7611665259E+00
X[4] = -7.980942925E-01X[5] = 1.8380572414E+00

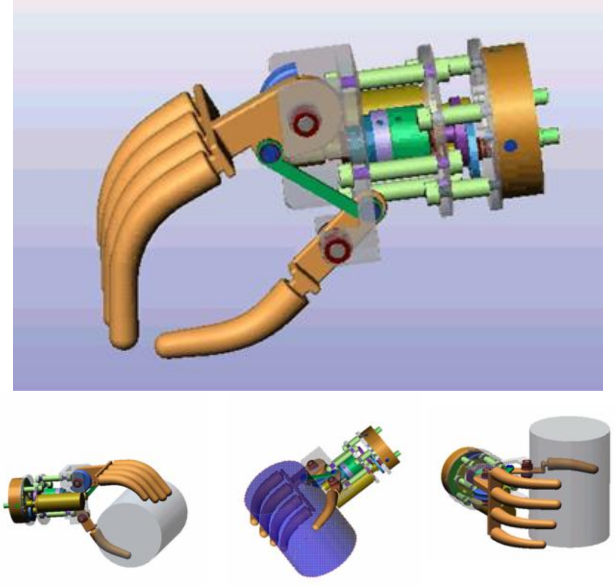


Figure 5

For AB=15 mm it was got:

$$BC = AB \cdot X[1] = 34.23mm;\ CD = AB \cdot X[2] = 7.08mm;$$
$$AD = AB \cdot X[3] = 41.41mm;$$

$$\varphi_3 = X[4] = -0.798 rad; \quad \varphi_1 = X[5] = 1.838 rad$$

The designed mechanism analysed from kinematic point of view allow to obtain for the links CD (index) and AB(thumb) of different angels and speeds, the ratio OM31= ω_3 / ω_1, having the values form the table 1.

TABLE 1
THE RESULTS OF THE KINEMATIC ANALYSIS OF THE REDESIGNED MECHANISM

I	FI11	FI21	FI31	OM1	OM2	OM3	OM31	EPS2	EPS3	EF
	[grd]	[grd]	[grd]	[rad/s]	[rad/s]	rad/s]	-	[rad/s²]	[rad/s²]	[m]
0	105.3129	216.8984	144.1941	-0.262	-0.0355	0.12	-0.4578	-0.0185	-0.0049	0.0543
2	107.3129	217.1603	143.2759	-0.262	-0.0331	0.1206	-0.4603	-0.0189	-0.0046	0.0505
4	109.3129	217.403	142.3531	-0.262	-0.0305	0.1212	-0.4625	-0.0192	-0.0042	0.0468
6	111.3129	217.6263	141.4261	-0.262	-0.028	0.1217	-0.4645	-0.0195	-0.0038	0.043
8	113.3129	217.8297	140.4951	-0.262	-0.0253	0.1222	-0.4664	-0.0197	-0.0034	0.0392
10	115.3129	218.0131	139.5607	-0.262	-0.0227	0.1226	-0.468	-0.02	-0.0029	0.0354
12	117.3129	218.1762	138.6233	-0.262	-0.02	0.123	-0.4694	-0.0202	-0.0024	0.0316
14	119.3129	218.3187	137.6834	-0.262	-0.0173	0.1233	-0.4705	-0.0204	-0.0019	0.0279
16	121.3129	218.4405	136.7415	-0.262	-0.0146	0.1235	-0.4713	-0.0205	-0.0013	0.0242
18	123.3129	218.5414	135.7984	-0.262	-0.0118	0.1236	-0.4718	-0.0207	-0.0007	0.0206
20	125.3129	218.6212	134.8546	-0.262	-0.0091	0.1237	-0.472	-0.0208	0	0.0171
22	127.3129	218.68	133.9108	-0.262	-0.0063	0.1236	-0.4718	-0.0208	0.0007	0.0138
24	129.3129	218.7176	132.9677	-0.262	-0.0035	0.1235	-0.4712	-0.0208	0.0015	0.011
26	131.3129	218.734	132.0262	-0.262	-0.0008	0.1232	-0.4702	-0.0208	0.0024	0.0089
28	133.3129	218.7292	131.0872	-0.262	0.002	0.1228	-0.4688	-0.0208	0.0032	0.0082
30	135.3129	218.7033	130.1513	-0.262	0.0048	0.1223	-0.4669	-0.0206	0.0042	0.0092

V. CONCLUSIONS

The 3D models of the two prostheses are presented in fig. 5 and 6. The program Solid Works used to build the models incorporates the module Cosmos Works with which can be done kinematic and dynamic studies very useful in the practice of mechanism design.

The theoretical results can be verified on the virtual models which validate the solutions and allows for optimisation of equipment, the overall cost of the final product being minimized because of the low conversion costs being implied.

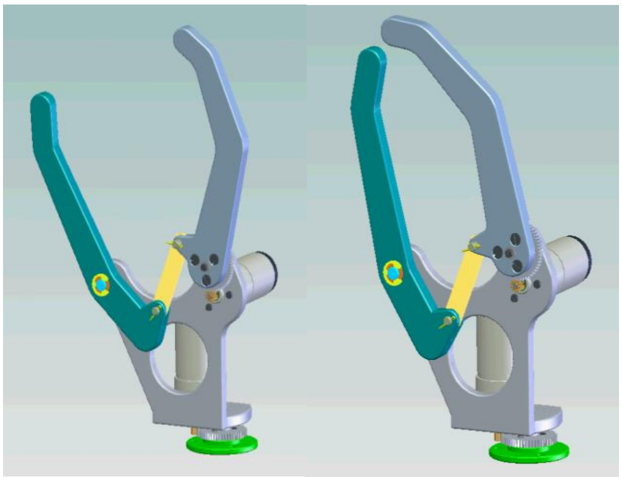


Figure 6

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