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New experimental and minimum mathematical bases for human gripping and micromanipulation

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Abstract: In this paper we present in a more complete and unitary way compared to similar studies the structural, constructive and functional characteristics of the human hand in order to be useful for the constructive and functional optimization of anthropomorphic grippers with fingers, for robots. Thus, we describe the bone structure of the hand and emphasize the observance of the golden proportion between some parts of the human hand. Substantial human hand configurations useful for grasping and micromanipulation are then highlighted. We are experimenting grasping of three significant types of objects and the minimum and sufficient mathematical conditions for static grasping are provided. We experiment micromanipulation of a rod-type object and the minimum mathematical conditions of safe micromanipulation are mentioned. We present, on the basis of our own experiments, adaptations of the author of Cutoksky's taxonomy, which is extended with two new grasping situations, and of grasping situations highlighted by Lyons.

Keywords: human hand, structure, grasping, micromanipulation, mathematical modeling, taxonomy.

1. Introduction

Grasping and micromanipulation with human hand is the most important starting point for constructive and functional design and optimization of anthropomorphic grippers with fingers for robots. Over time, there have been several studies in this direction, such as those presented in the papers: [1, 2, 3, 4]. Although some of the aspects presented in this paper are somehow included in these studies too, any attempt to present these aspects in some respects from another perspective is useful for deepening research to better understand the constructive and functional human hand particularities to obtain high-performance anthropomorphic grippers. In this paper,

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after a brief presentation of structural features of the human hand, we exemplify experimentally its various possible configurations, more completely and more suggestively than in other similar studies, then the experimentation of grasping for significant situations and micromanipulation is exemplified. For grasping and micromanipulation we also provide the necessary and sufficient elements for mathematical modeling in a simplified version.

2. Structural features of human hand biomechanism

Structurally, the human hand is based on a biomechanism represented by its skeleton. Obviously, the grasping and micromanipulation performances derive from the bone structure of the hand, respectively from: the number and the structure of each group of elements (bones); the number, structure and relative alignment of the fingers, the degree of mobility of the joints (couplings) between the elements (bones) in each group, and the association degree of a group with the next bones group and the relative size of the different groups of bones or even of different bones (such as the phalanxes). Thus, the skeleton of the hand consists of 27 elements (bones) that are grouped into three structures [5, 6, 7]: the group of carpal bones made of 8 carpal bones, the metacarpal bones group consisting of 5 metacarpal bones and the group of phalangeal bones or fingers consisting of 5 subgroups of phalangeal bones (5 fingers) consisting of 2 (for the thumb) or 3 phalanges (for the 4 fingers of the palm extension) with a total of 14 elements (bones - phalanges) as seen in Fig. 1.

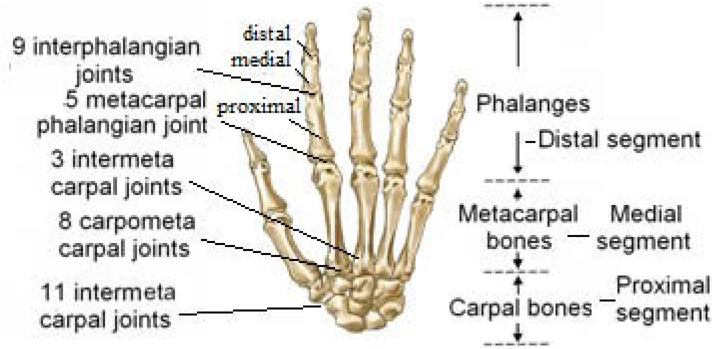
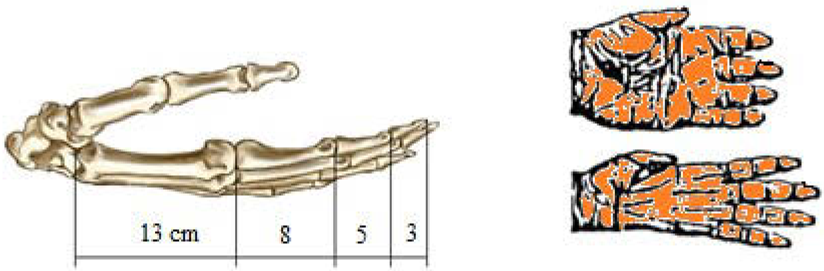


Fig. 1. Human hand skeleton.

Between the 27 elements (bones) there are 36 joints (couplings), which form the biomechanism of the human hand. Depending on the components considered, this biomechanism has different degrees of mobility. Thus, if it is considered that between the carpal and the metacarpal bones there are bimobile joints, as well as between the metacarpal bones and the phalanges, there is a degree of mobility M = 28. If we consider only metacarpal-phalangeal (bimobile) and interphalangeal (monomobile) joints, we obtain a mobility degree M = 20 [8].
It should be noted that the three main groups of bones form three segments called: proximal segment, corresponding to the group of the carpal bones, the medial seg-

ment corresponding to the metacarpal bones group and the distal segment corresponding to the group of the phalangeal bones (fingers), according to the same Fig.1 [6, 7]. These segments are also found in the structure of a finger, in which there are: proximal phalanx, medial phalanx and distal phalanx (see Fig. 1). Obviously, the relative arrangement of the 5 fingers (the thumb being opposable to the other 4 fingers) and the proportion between the different segments of the hand or even between the components of a segment are very important. It is remarkable in this respect the presence of *the gold ratio* of 1,618. Thus between the dimensions of the metacarpal bones and the first phalanx the ratio is (see Fig. 2a) 13 cm / 8 cm = 1.625; between the dimensions of the first phalanx and the second phalanx the ratio is 8cm / 5cm = 1.6; and between the size of the penultimate phalanx and the last phalanx the ratio is 5cm / 3cm = 1.66 (these dimensions correspond to the human hand of a mature person, over 25 years of age, with an average height of about 1.72 meters). The mention of these proportions is important because compliance with them leads to increased grasping capacity and micromanipulation compared to the situation when these proportions are not taken into consideration, as is the case with the gorilla and the orangutan hand (Fig. 2b).

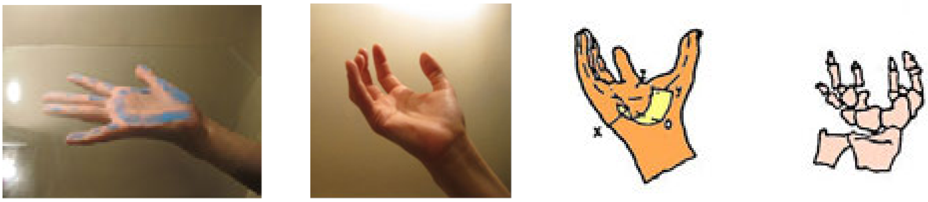


a b

Fig. 2. Dimensions of the human hand (a) and the hand of the gorilla and the orangutan (b).

3. Characteristic configurations of the human hand

The specific configurations of the human hand are obtained due to the number of elements (bones), the number and degree of mobility of the joints, and the proportion of the various components of the hand. Even though there are more studies on this subject [5, 9, 10, 11], any new approach is useful to highlight less detailed issues so far. Thus, the transition from the flat palm configuration, in which the carpal bones occupy relative limit positions (Fig. 3a) to the crucible shape (Fig. 3b, c) is possible due to relatively small displacements occurring in the intercarpal joints. The crucible position of the palm is mainly the result of the movements of four metacarpal bones in relation to the carpal complex (Fig. 4), obviously to which we add the semi-closure of the fingers by the movements of the metacarpal-phalangeal and interphalangeal joints. It should be noted, from this stage, that the crucible position corresponds to the extent of a sphere which is not possible in the hands of other primates, such as the gorilla and the orangutan (see Fig. 2b).



a b1 b2 c

Fig. 3. The flat and crucible shape of the human hand.

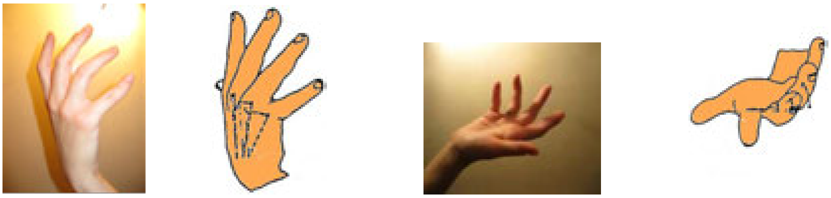


Fig. 4. Relative positions of the metacarpal bones.

Interesting positions of the bones of the hand for various gripping positions also appear in Fig. 5 [12].

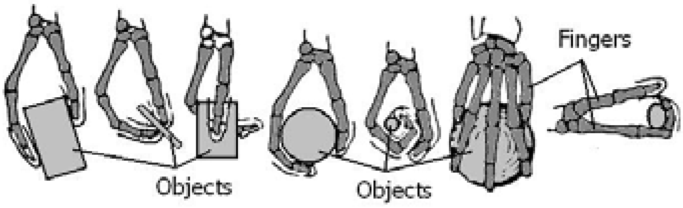
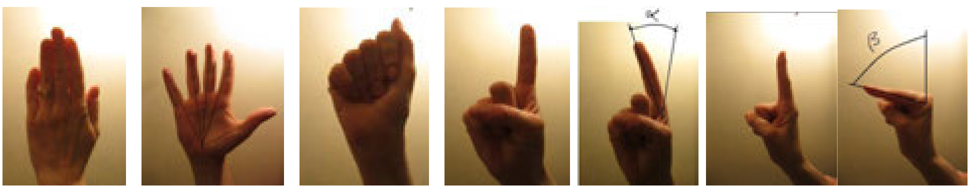
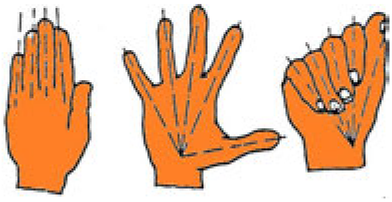


Fig. 5. Relative positions of hand bones for various gripping positions.

For the phalanges, the characteristic relative positions (Fig. 6) are possible due to the metacarpal-phalangeal bimobile joints, which are spheroid joints (also called condylaneous joints) except for the thumb [5, 13]. These joints make possible the main movements of finger abduction-adduction (Fig. 6a, b) and flexion-extension (Fig. 6a, c). Thus the composite movement of abduction-adduction and flexion-extension of the index finger is shown in Fig. 7, and the adduction-abduction and rotation movements of the thumb result from Fig. 8.





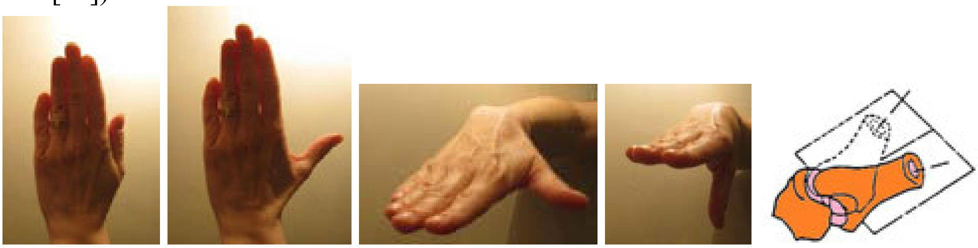
a b c

Fig. 6. Phalanges characteristic adduction positions.

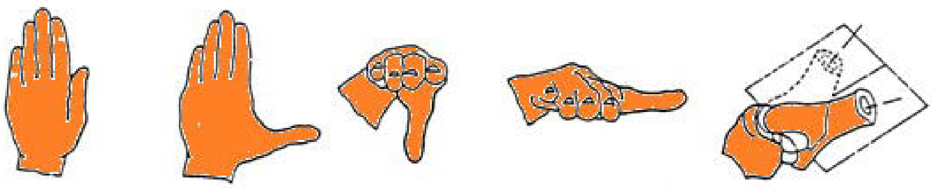
a b

Fig. 7. Index finger abduction – and flexion – extension compound movement.

The thumb has specific movements due to the carpal-metacarpal bimobile joint, which is also called saddle joint, due to the hyperbolic paraboloid form (saddle - Fig. 8e, see and [13]).



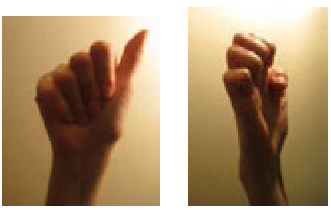
a b c d e



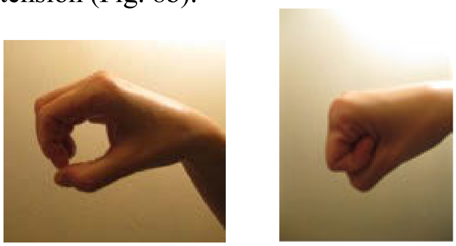
a b c d e

Fig. 8. Thumb abduction – adduction (a, b) and rotation (c, d).

Between the phalanges, the finger bones, there are monomobile joints of trochlean type (see Fig. 9c and d). In the proximal interphalangeal joints (Fig. 9a), the amplitude of flexion exceeds 90º, and that of distal interphalangeal joints is generally lower. The angles characterizing the amplitude of the flexion in an intermediate position and in the final position are shown in Fig. 10. It's specified that in the active extension limit position, the phalanges of the fingers are in extension (Fig. 8b).



a b



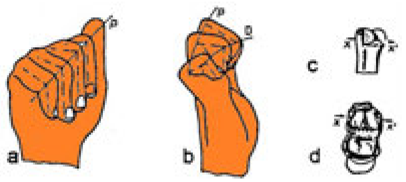


Fig. 9. Interphalangeal trochlear joints.

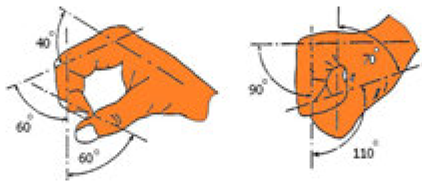


Fig. 10. Fingers medial and maximum flexion.

On the basis of the above it can be concluded that the complex structure and the dimensions of the hand skeleton make possible the very varied spatial configurations, in general, and of grasping, in particular. To be more suggestive in the figures above in addition to the images made by the author, which capture the different configurations of the human hand, we added sketches that better outline the specific situations studied [5]. It can also be mentioned that due to this complex structure, but also to the proportions of the component elements, the hand has remarkable possibilities to achieve the displacement of an object grasped between fingers, displacement which can be considered micromanipulation. Several significant situations where micromanipulation is possible are shown in Fig. 11, first through images created by the author then sketches to which are added the significant movements that can be imposed to the object we grasp.

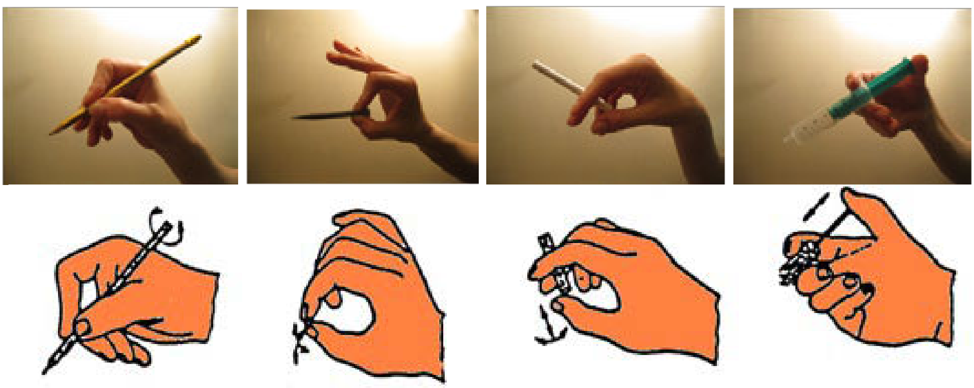


Fig. 11. Positions of human hand micromanipulation.

As mentioned above, the study of these situations is particularly useful in the design of anthropomorphic (hand-like) grippers used in robots but also for prostheses.

4. Particularities of grasping with human hand

Grasping is the most important action the human hand can perform to catch objects and move them from one position to another. Obviously, only objects of certain dimensions and weights can be safely grasped. Additionally, we can grasp by means of two fingers small, even very small objects too, by so-called precision grasping. Experimenting the possibilities of human hand grasping is always useful because we can highlight useful details less reflected in similar studies.

4.1. Experimenting gripping for significant cases

4.1.1. Grasping of a rod-type object

For experimenting with such grasping, a linear pencil-type object was used that was successively grasped with a finger, two fingers, three fingers, four fingers and five fingers (see Fig. 12, a, b, c, d, e).

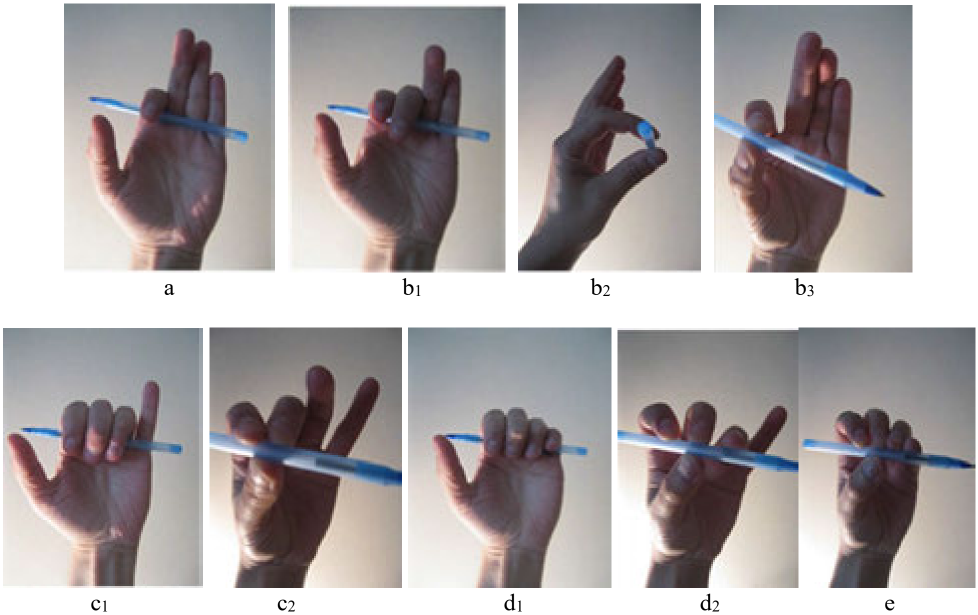


Fig. 12. Grasping situations of a rod-type object.

It can be noticed that grasping can be achieved by encompassing without opposing fingers (see Fig. 12a, b_1, c_1, d_1) or with two or more opposable fingers. From this experiment, it is significant that only gripping using one finger through grasping, two fingers, and three fingers through grasping or using opposing fingers. Using more than three fingers no longer increases grasping precision or safety because there is some redundancy, using the fourth finger or fingers four and five is useless.

4.1.2. Grasping an object of random and small size

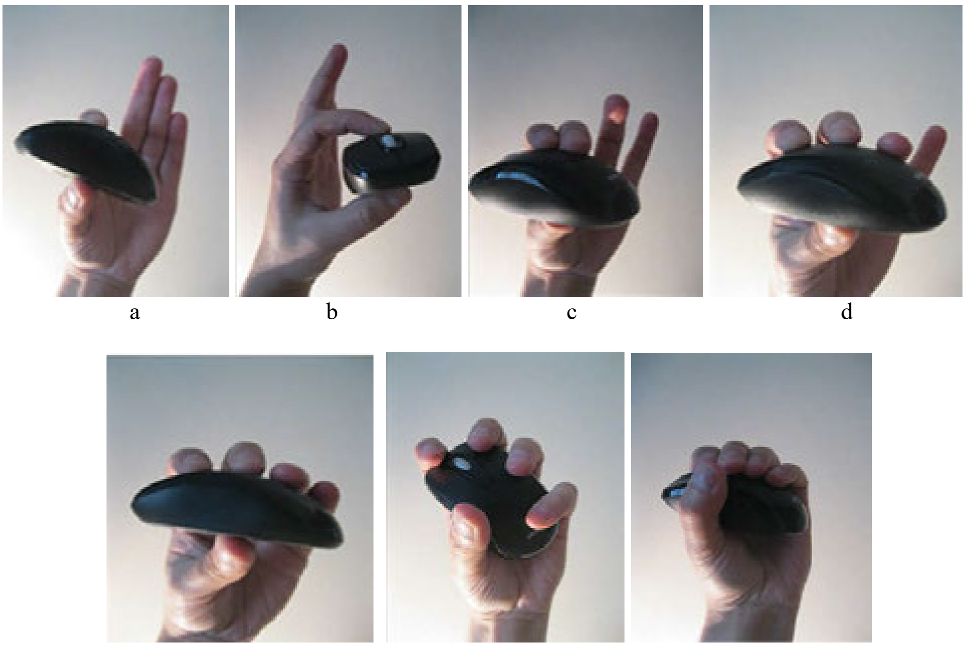
For an approximately spherical small object with an average diameter of about 10 mm, it can be seen that if theoretically grasping can be imagined as being performed with a finger up to five fingers, basically grasping can be achieved only using one finger or two fingers (see Fig. 13, a, b, c). It can be seen that in this case only grasping through encompassing with one finger and two opposing fingers are significant (see Figures 13a and c), the use of one more finger or two, three and four fingers is not necessary due to the impossibility of contact with the piece with these dimensions. So it is useful to use only two fingers, in a limit case of three fingers, in which case there is some redundancy of grasping.

a b c

Fig. 13. Situations of grasping a small object.

4.1.3. Grasping an object of random shape and average size

If the size of the grasped object increases, compared with the previous case, it is no longer possible to grasp with only one finger, but with at least two fingers, and the three, four or five fingers have another utility. Possible grasping situations for such a case with application to a mouse-type object are shown in Fig. 14.



a b c d

e_1 e_2 e_3

Fig. 14. Grasping situations of an average size object.

It is noted that in this case grasping becomes even more stable as the number of fingers is bigger, the safest grasping being in the case of the use of 4 or 5 fingers, and the maximum safety is possible if it is possible to encompass the object, which depends on the dimensions of the object relative to the crucible volume of the hand, as in the case of Fig. 14e$_2$ and e$_3$.

4.2. Minimum mathematical conditions for static grasping

Grasping experiments conducted leave room for a brief presentation of the mathematical modeling of grasping. Thus, from the case of a random shaped object, such as that of Fig. 4e$_1$, in which we represented the contact forces F_i applied by the fingers at the contact points P_i on the grasped object according to Fig. 15a, we shifted to the general case of a solid object grasping according to Fig. 15b. Further, the following explanations are given regarding the simplified mathematical modeling of static grasping[7].

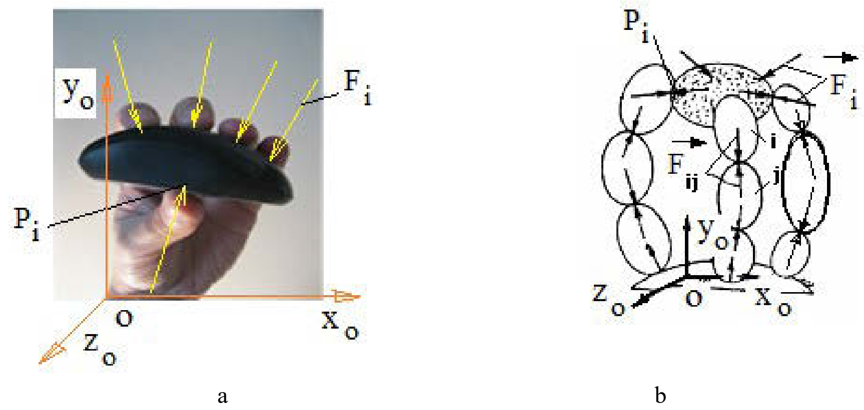


Fig. 15. Non-deformable solids system.

4.2.1. Equilibrium of a Solid Body System

If a system of non-deformable (rigid) solids is considered-see Fig. 15b, actuated by external forces and reactions $\{\vec{F}_i, \vec{M}_i\}$, i = 1, ..., n and internal reaction (in coupling) $\{\vec{F}_{ij}, \vec{M}_{ij}\}$ (i, j $\in$ N, i $\neq$ j) the balance conditions of the system made of external forces and internal and external reactions, are:

$$\begin{cases} \sum_{i=1}^{n} \vec{F}_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \vec{F}_{ij} = 0 \\ \sum_{i=1}^{n} \vec{r}_i \times \vec{F}_i + \sum_{i=1}^{n} \vec{M}_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \vec{r}_i \times \vec{F}_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{n} \vec{M}_{ij} = 0 \end{cases} \quad (1)$$

where $\vec{r}_i$ and $\vec{r}_j$ are position vectors of forces $\vec{F}_i$ respectively $\vec{F}_{ij}$.

A number of scalar linear equilibrium equations can be obtained, projecting equilibrium conditions along tridimensional reference axes, applied to determine internal or external reactions to the system.

The mechanical gripping system, respectively gripping mechanism is first treated as a rigid entities system, one of them being the grasped entity.
Based on this simplified case we can proceed to approach the situation considering deformability of elements in the contact area with the grasped object.

4.2.2. Minimum Conditions of Static Grasping

First we consider the simplified case of a solid, elastically deformable entity gripping, actuated only by contact forces $\vec{F}_i$ (see Fig. 16), normal to the entity surface in Pi (i = 1 ,..., n) points, through the gripper contact elements.
In each point P_i is attached a reference tridimensional system $\{P_i x_i y_i z_i\}$, with versors i_i, j_i, k_i, such that z_i axis coincides with $(P_i n_i)$ normal to the entity surface.
In addition, every P_i point is considered gravity center of a contact area of surface Ω_i located in a plane (Π) tangential to the entity surface in point P_i (the contact force $\vec{F}_i$ is considered generated by a solid S_i which contacts that entity in point P_i).
Under these assumptions in the points P_i the following forces are developed: a contact force $\vec{F}_i$, which has as support the $P_i n_i$ normal to the entity surface, a friction force $\vec{F}_{if}$ located in the tangent plane to the entity surface and a pivoting friction momentum which has as support the same $P_i n_i$ normal (the rolling friction momentum is neglected)[7].

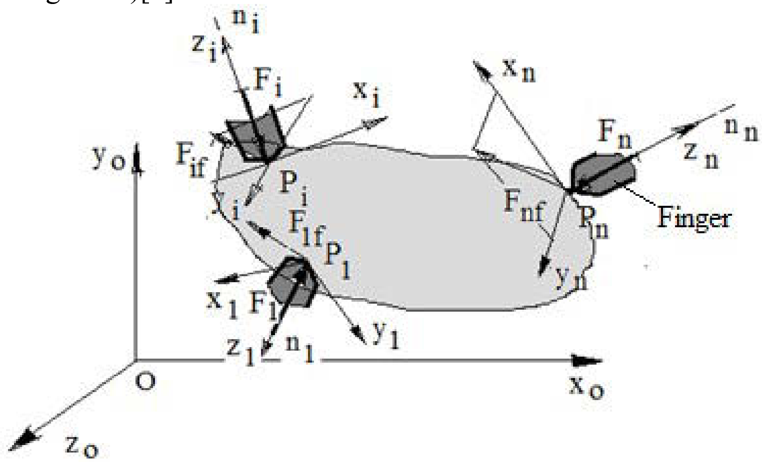


Fig. 16. Contact forces general case on a deformable solid gripping.

With twist expressed in the fixed reference system[7], we can form the matrix denoted by G and called **gripping matrix:**

$$G=\left[\vec{\tau}_0(\vec{F}_1) \quad \vec{\tau}_0(\vec{F}_2) \quad \dots \quad \vec{\tau}_0(\vec{F}_i) \quad \dots \quad \vec{\tau}_0(\vec{F}_n)\right] \tag{2}$$

Under these assumptions, the necessary gripping condition of the entity considered, against the fixed reference system origin is:

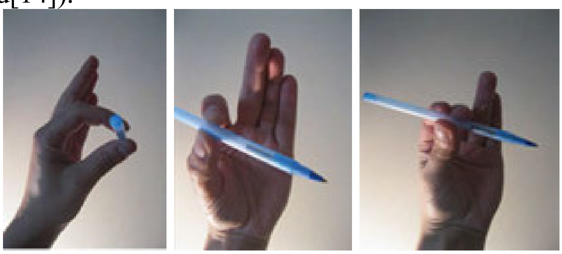
$$rank\, G = 6 \tag{3}$$

This means that through the contact forces action on the gripped entity surface, 6 linear independent forces are generated, which will block the 6 possible independent linear movements.
At the above condition, for achieving gripping, we must add as well the connection (contact) of static equilibrium condition of the system of forces. If a system of six independent links (of rank 6) were used, the static equilibrium condition would lead to a homogeneous system of six equations with six unknowns, which admits only the trivial solution; obviously, in such case, the entity gripping is not possible. Therefore, to achieve the entity gripping, generally, at least seven external links ($\Sigma c = 7$) of C_{12}=6 rank are necessary; indeed, in such case static equilibrium condition leads to a homogeneous system of 6 independent equations with 7 unknowns. As a result, six of the link forces can be calculated based on the seventh force that is indefinite (independent); the entity gripping is achieved through the latter.
Synthetically the necessary and sufficient condition for an entity gripping, considering only contact forces, can be expressed as follows:
An entity gripping, involving cancellation of C_{12}=6 freedom degrees, must use a system of a minimum C_{12} +1 links ranking C_{12} .

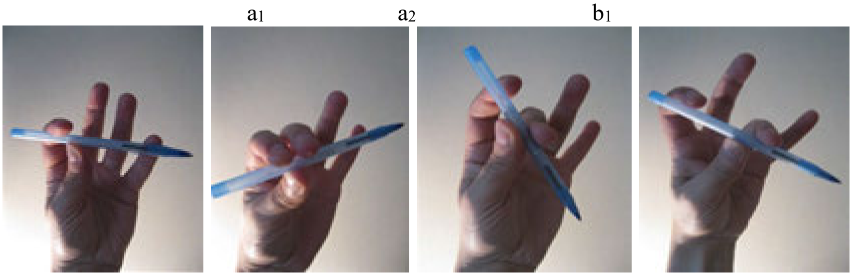
5. Features of human hand micromanipulation

5.1. Experimenting micromanipulation of a rod-type object

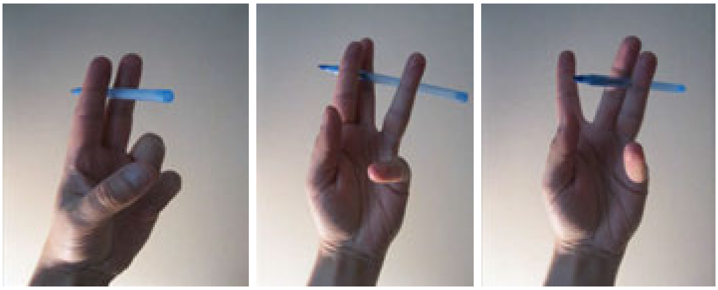
As an example of micromanipulation, characteristic of anthropomorphic grippers with articulated fingers, it is shown the micromanipulation of a rod-type object, using a simple cylindrical pen (Fig. 17). It can be noticed that the manipulation can be done with at least two fingers and it has, with increasing number of fingers more and more hypostases(see and[14]).



a_1 a_2 b_1



b_2 b_3 b_4 b_5



c1 c2 c3

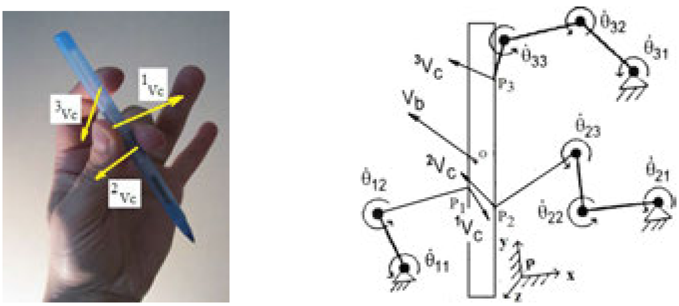
Fig. 17. Handling with two fingers (a), three fingers (b) and transfer between the first two fingers to second two fingers (c).

5.2. Minimum mathematical conditions for stability of micromanipulation

Micromanipulation is the possibility of changing the position of the grasped object relative to a reference system due to the ability of the fingers to allow it, with or without changing contact points with the object.

In general, if $[\Omega]_0=[\omega_x, \omega_y, \omega_z, V_{ox}, V_{oy}, V_{oz}]^t$ is the velocity imposed on a point O attached to the grasped object, and $[\Omega]_j$ is the matrix of the corresponding motor movements of each finger (see Fig. 18b) can be written, by adapting after [7, 15, 16, 17], the relation:

$$[\tilde{\Omega}] = G^t [\Omega] , \tag{4}$$



a b

Fig.18. The kinematic scheme of micromanipulation.

where [Ω] groups all absolute finger velocity transmitted through contacts with the grasped object, and G is the gripping matrix.

Because:

$$[\tilde{\Omega}] = J[\dot{\theta}] , \tag{5}$$

where J is the jacobian of the biomechanism corresponding to the fingers, in this case of three fingers, and $\dot{\theta}$ the velocity in the joints of the fingers, obtaining velocity of the joints, necessary for the movement on the micromanipulated object:

$$[\dot{\theta}] = J^{-1} G^t [\Omega] . \tag{6}$$

6. Contributions to experimentation and extension of human hand taxonomy

Presently, in the specialty literature on grasping it is well known the systematization of grasping situations using the human hand proposed by Cutkosky [18], to which some other somehow similar approaches were added [19, 20, 21]. Cutkosky's systematization is performed from two main perspectives: precision and power. This systematization is shown in Fig. 19, adapted under the coordination of the author and completed with two situations, namely: grasping between two fingers of the four of the palm extension and power grasping with two opposing fingers, the thumb and the first finger of the four in the palm extension(with red), an object of ovoid shape, and average to maximum dimensions about hand grasping options, limited by finger size and finger ability to encompass (useful contact) a grasped object.

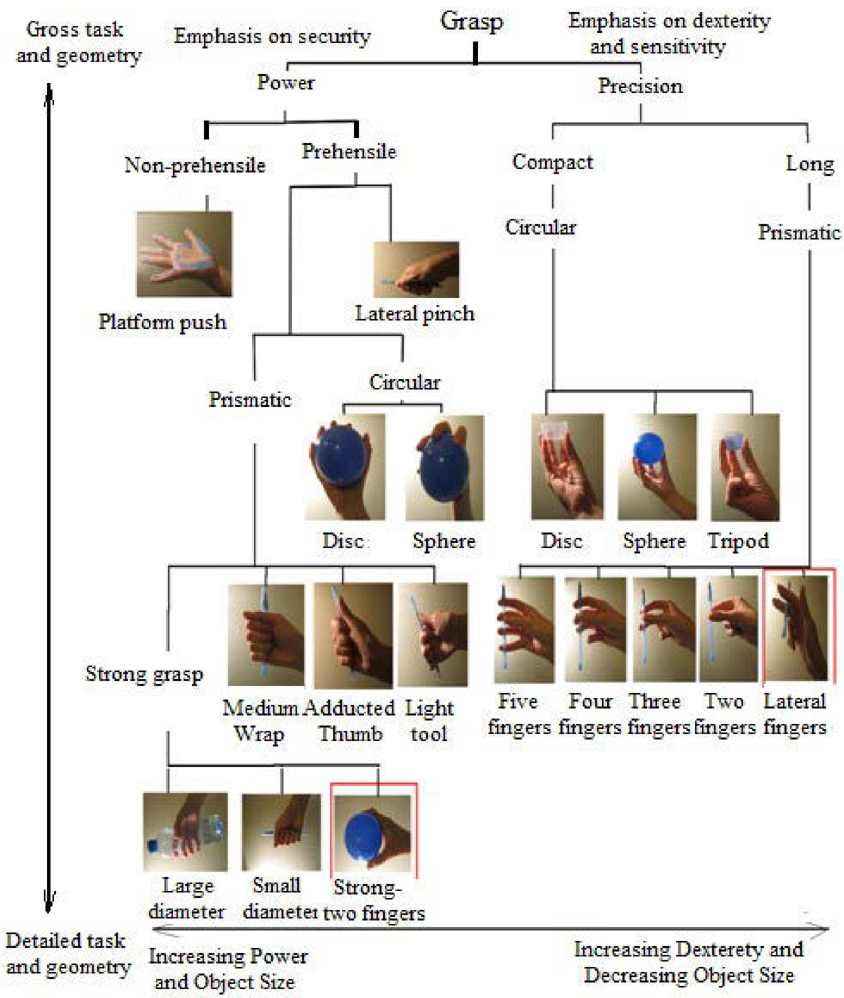
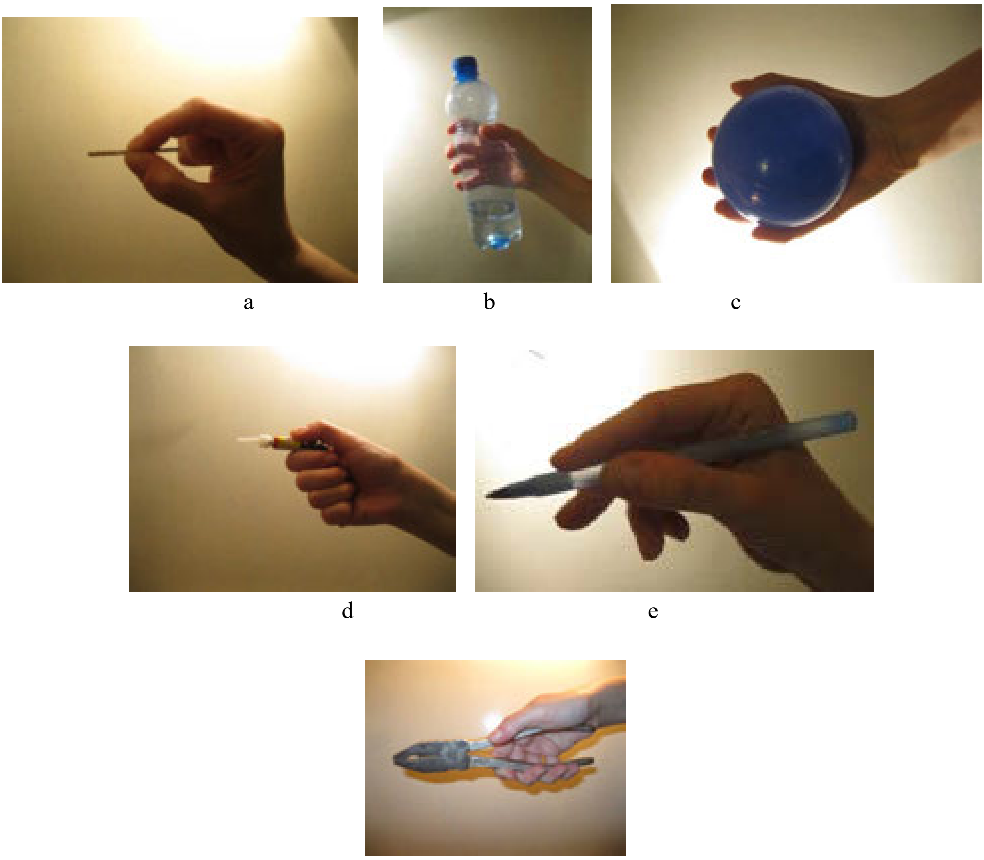


Fig. 19. Cutkosky taxonomy adapted and extended under the coordination of the author.

Also for some other systematization somewhat in terms of precision and power, namely that of Lyons [22], there is an adaptation proposed by the author in Fig. 20.



a b c

d e

f

Fig. 20. Lyons's grasping situations adapted by the author.

These last two adaptations after well-known taxonomies confirm the usefulness of resuming known aspects, which by new experimentation can highlight useful details.

7. Conclusions

On the basis of the information presented in this paper, the following conclusions can be drawn: the human hand has its structure and construction that provides a very good functionality compared to all other natural grippers, first of all the hands of the other primates; emphasizing specific configurations through appropriate experiments is useful as studies of this kind are more rigorous; the complex structure and relative dimensions between the components of the human hand allow for the grasping of objects of varied sizes and shapes, and the micromanipulation, especially of smaller sectional objects and longer lengths; experimenting with significant grasping and micromanipulation situations is useful for structural, constructive and functional optimization of anthropomorphic grippers (with) fingers for robots.

References

[1] Albrecht I., Haler J., Seidel H-P., *Construction and Animation of Anatomically Based Human Hand Models*, Eurographics/SIGGRAPH Symposium on Computer Animation, 2003, D. Breen, M. Lin (Editors).
[2] Kumar A., Mundra T. S., Kumar A., *Hand Anatomy*, available on https://pdfs.semanticscholar.org/e620/737dd7c7183 d1e6efa36e62e92a15683948e.pdf, 2008.
[3] Taylor C. L., Schwarz R. J., *The Anatomy and Mechanics of the Human Hand*, O&P Library, Artificial Limbs, 1955, Vol 2, Num **2**, 22 – 35, available on http://www. oandplibrary.org/al/1955_02_022.asp.
[4] Pitarch E. P., *Virtual Human Hand: Grasping Strategy and Simulation*, PhD thesis submitted to Universitat Polit`ecnica de Catalunya, UPC, 2007.
[5] Dudiță Fl., Diaconescu D., Gogu Gr., *Mecanisme articulate. Inventică. Cinematică*, Ed. Tehnică, Bucureşti, 1989.
[6] Staretu I., *Elemente de robotica medicala si protezare* (in Romanian), Ed. Lux Libris, Brasov, 2005.
[7] Staretu I., *Gripping systems*, Derc Publishing House, Tewksbury, Massachusetts, SUA, 2011.
[8] Staretu I., Neagoe M., Albu N. *Mâini mecanice. Mecanisme de prehensiune antropomorfe pentru protezare şi roboţi*, Ed. Lux Libris, Braşov, 2001.
[9] Lin J., Wu Y., Huang T. M., *Modeling the Constraints of Human Hand Motion*, Proceedings Workshop on Human Motion, Austin, USA, 2000, available on https://ieeexplore.ieee.org/document/897381.
[10] Rhee T., Neumann U., Lewis J.P., *Human Hand Modeling from Surface Anatomy*, I3D'06 Proceedings of the 2006 symposium on Interface 3D graphics and games, California, SUA, 2006, p. 27-34.
[11] Kurihana T., Miyata N., *Modeling Deformable Human Hands from Medical Images*, Eurographics/ACM SIGGRAPH Symposium on Computer Animation, 2004, R. Boulic, D. K. Pai (Editors), Grenoble, France, 2004, p. 355-363.
[12] Puschel F., *Künstliche Hände Künstliche Arme*, Technischer Verlay Herbert Cram, Berlin W35, 1955.
[13] Chang L.Y., Matsuoka Y., A *Kinematic Thumb Model for the ACT Hand*, Proceedings of the 2006 IEEE International Conference on Robotics and Automation Orlando, Florida – May, SUA 2006, p. 1000- 1005.
[14] Hashimoto H., Yacota S., Chugo D., Mitsuhashi, K., *A Digital Hand to Mimic Human Hand in Real Time Operation-Making of Digital Finger with Partial Soft Skin and Rigid Bone*, In Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016) - Volume 1: GRAPP, Rome, Italy, 2016, p. 99-104.
[15] Kerr J., Roth B., *Analysis of multifingered hands*, Int. J. Robot. Res., **4**, no. 4, 1985, p. 3–17.
[16] Salisbury K., Roth B., *Kinematic and force analysis of articulated mechanical hands*, ASME J. Mech., Transmiss., Autom. Design, 105, no. 1, 1983, p. 35–41.
[17] Nakashima A., Uno T., Hayakawa Y., Kondo T., Sawada S., Nanba N., *Synthesis of Stable Grasp by Four-Fingered Robot Hand for Pick-and-Place of Assembling Parts*, 5th IFAC Symposium on Mechatronic Systems, Marriott Boston Cambridge, Cambridge, MA, USA, Sept 13-15, 2010, p. 669-676.
[18] Cutkosky M., On Grasp Choice, *Grasp Models, and the Design of Hand for Manufacturing Tasks*, IEEE Transactions on Robotics and Automatation, 5, nr. 3, 1989, p. 269-279.
[19] Feix T., Romero J., Schmiedmayer, H-B., Dollar, A. M., Kragic, D., *The GRASP Taxonomy of Human Grasp Types*, IEEE Transactions on Human-Machine Systems, **46**, no. 1, 2016, p. 66-77.
[20] Pollard N. S., *Evaluation of Dexterous Manipulation "In the Wild"*, Carnegie Mellon University, http://clem.dii.unisi.it /~malvezzi / graspquality/wp content/uploads/2016/05/ WSbenchmark -Pollard.
[21] Liu J., Feng F., Nakamura Y. C., Pollard N. S., *A Taxonomy of Everyday Grasps in Action*, This research is supported by NSF award IIS-1218182, School of Computer Science, Carnegie Mellon

University, 5000 Forbes Ave, Pittsburgh, PA15213, USA- available on http://www.cs.cmu.edu/~ynakamur/papers/TaxonomyEverydayGrasps.pdf.
[22] Lyons D., *A simple set of grasps for a dextrous hand*, Proceedings. 1985 IEEE International Conference on Robotics and Automation, St. Louis, MO, USA, 1985, p. 588-593.