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Human Anthropomorphic Gripper as an Automation Tool

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Abstract: This paper presents the design, development and implementation of a 14 DOF human anthropomorphic pneumatic gripper as a tool for teaching automation basics using pneumatics and PLCs. The dexterity of the human hand allows several types of power and precision grasps for interacting with various scenarios, these features have inspired the development of robotics mimicking the human hand in applications such as collaborative robotics workcells, where each finger is an actuated mechanism with a specific task. Collaborative actions through pneumatic and PLC programming basics using this hand allows enhancing the user's knowledge based on concepts and familiarity with the device. The pneumatic hand can be used on site, with the user directly operating it, and offline with a virtual reality tool for offering simultaneous accessible devices when multiple users need the hand. Robotics currently assists training surgical procedures, manipulation of elements in hazardous environments for us, kinematics, dynamics and path planning simulations for various industrial processes, or as didactic tools for inspiring school students for working with robotics. The pneumatic hand system is composed of an actuation, control and teleoperation subsystems, these interact for simulating the muscles, and the user's inputs for executing the chosen tasks.

Keywords: Anthropomorphic, Gripper, Pneumatics, Virtual Reality.

1. INTRODUCTION

As a result of features found in various species, several researchers and developers have found inspiration in these natural models (dams, submarines, airplanes and humanoid, quadruped and insect-like robots)[1][2][3][4]. The human body is no exception, the dexterity obtained from the Degrees of Freedom (DOF), make our hands remarkable tools [5]. The relevance of tool for achieving goals depends on how fit that tool is, similarly to the human hand, in robotics, the equivalent is the gripper. Some gripper configurations resembling the human hand are serial mechanisms like jaws and three fingered grippes used in several industrial applications for easing and improving robot teleoperation[6][7][8][9][10][11]. Robots and grippers are used for improving tasks in: welding, assembling, painting, assisting surgery and manipulation of delicate or hazardous materials [12]. With the continuous development of robots, currently they are used in many applications such as, teleoperation [13], offline programming [14], hazardous environments or prehensile tasks [15], [16], as well as grasp planning [17], design validation [18] and assisting rehabilitation [19]. Highlighted developments in robotic hands have resulted in the design and construction of experimental prototypes such as the Stanford/JPL [20], the Utah/MIT [21], the TUAT/Karlsruhe [22], the DLR [23], and the Nasa Robonaut [24] among several others [25]. Training of pneumatic, hydraulic, mechanical or electric actuators, programmable logic controllers (PLC) are benefiting from educational tools as these, allow optimizing the skills development time [26]. The training tools are constantly evolving, a main feature of simulators is the availability of a virtual device without needing the real one. Certain solutions allow simulating offline queues for training and learning where hardware limitations occur or, when validating processes is a requirement for avoiding damages during any practice. In this case, Virtual Reality (VR) increases robotics applications providing teaching aids in medicine [27], virtual architecture representations [28], robotics engineering training [29], and educational gaming [30], among others.

This work proposes the design and implementation of a pneumatic anthropomorphic robotic human-based hand as an automation tool for practicing online and offline pneumatics programming concepts using PLCs. The paper is organized as follows; in section II the human hand kinematics is studied; in section III the mechanical and pneumatic design is presented. In section IV the offline-programming tool is described and implemented; in section V the results, and finally in section VI the discussion and future works are presented.

2. HAND ANALYSIS

The human hand is composed of twenty DOF that allow us to perform several grasps for interacting with our environment [26]. These DOF are the result of having the flexion/extension and adduction/abduction rotations in each finger. In [31], Cutosky studied various grasping techniques and classified them in precision and power grasps. Most common grasped objects are based on prismatic and circular shapes as shown in Figure 1, and the main differences between these are the number of fingers in contact that is applied on the object.

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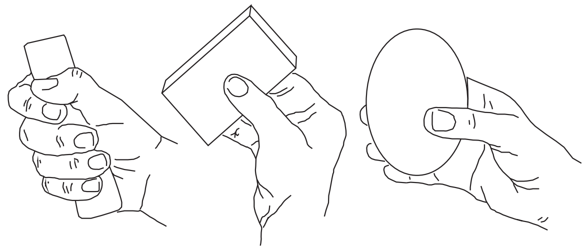

Fig. 1 Common grasps

Table 1 Finger Denavit-Hartenberg parameters

Phalanx	alpha	a	theta	d
Proximal	0	a_p	θ_p	0
Medial	0	a_m	θ_m	0
Distal	0	a_d	θ_d	0

3. KINEMATICS ANALYSIS

Through kinematics positions and orientations for each finger can be calculated. Similarly to how we reach objects from known shapes, where we rotate our fingers for making an specific grasp, the forward kinematics supplies sufficient information for executing both power and precision grasp tasks with the pneumatic hand. Each finger can be analyzed as an open kinematic chain represented by a serial mechanism modeled by three serial connecting bars. The rotational and translational information for each link can be calculated through the homogenous transform matrix analysis presented in Table 1, were a_p, a_m, a_d are the proximal, medial and distal phalanxes distances, and $\theta_p, \theta_m, \theta_d$ their corresponding orientations.

The homogeneous matrix (1) is obtained using the Denavit-Hartenberg notation [32], where i and j are the coefficients for the current and next joint, so the matrix allows calculating each joint kinematics or the overall from the base of the pal to the tip of the finger. This method was preferred over the geometric analysis, as it allows increasing the number of DOF without recalculating the kinematics models, and as the maximum number of DOF are 19, when solving the equations the amount of multiplied zeros does not affect the computing speed and processing, thus making it a suitable method.

$$^{j-1}\mathrm{T}_j = \begin{bmatrix} C\theta_j & -C\alpha_j \cdot S\theta_j & S\alpha_j \cdot S\theta_j & a_j \cdot C\theta_j \\ S\theta_j & C\alpha_j \cdot C\theta_j & -S\alpha_j \cdot C\theta_j & a_j \cdot S\theta_j \\ 0 & S\alpha_j & C\alpha_j & d_j \\ 0 & 0 & 0 & 1 \end{bmatrix} ,(1)$$

For validating the solution, the DH method implemented in [33] for use with hand-like grippers was applied to the pneumatic hand, obtaining the model presented in Figure 2, where the rotation of each phalanx is calculated by choosing the desired orientation for each finger accordingly to the object.

4. ANTHROPOMORPHIC AND PNEUMATIC DESIGN

The pneumatic hand was designed mechanically considering the human support or skeletal system, and pneumatically based on the muscular system.

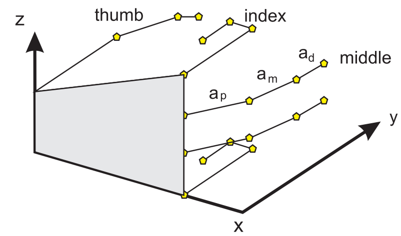

Fig. 2 Kinematics solution of a random grasp

4.1 Support System

The design process started by modeling each of the fingers phalanxes, this allowed us to focus on each of the joints motion and actuation system. For mimicking the tendons, nylon strings attached to the pneumatic actuators located at the forearm of the robotics hand the mechanism were configured for performing the extension and flexion rotations. The finger prototype and assembly is presented in Figure 3. Given that the most significant motions in grasping are the flexion and extension rotations, each finger abduction/adduction movements were not considered. The CAD models not only serve for developing the offline and VR module for the hand, but also as base for the rapid prototyping of the pieces.

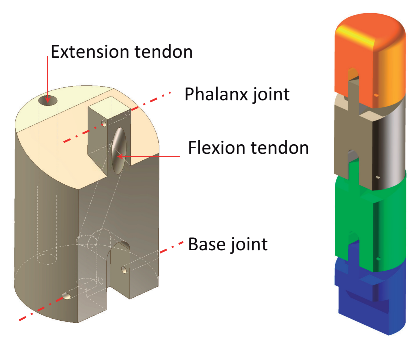

Fig. 3 Finger prototype

In Figure 4 the designed device and its human counter part are presented for highlighting their similarities. The DOF of the pneumatic hand were reduced for only considering the flexion/extension rotations, this simplified the mechanism and allowed validating the suitability of pneumatic muscles. These DOF simplifications improve and allow the development and implementation of a simple mechanics and actuation system that complies with the most common grasped shapes.

4.2 Pneumatic System

Pneumatic actuators were chose as suitable muscles given their resemblance with how our muscles work through contraction and expansion for performing flexion/extension rotations of our limbs. The system was designed using Festo's FC660PLC, which were preferred over direct current (DC) motors because of the convenience for programming basic automation interaction with PLCs for pneumatics training and familiarization. These actuators allow performing and controlling each

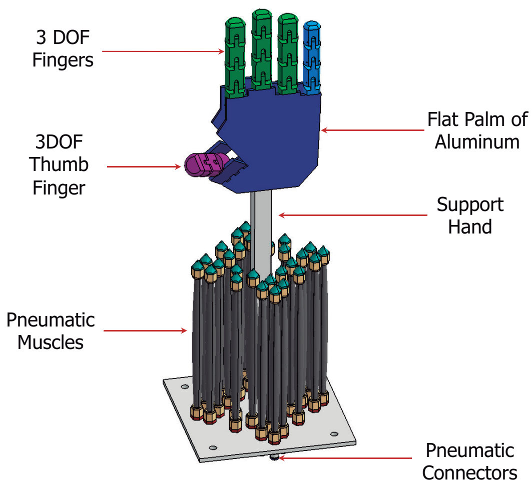

Fig. 4 Designed pneumatic hand

of the finger's flexion and extension rotations through its contraction and expansion, thus reassembling the human motion when grasping different objects. The actuator main components are presented in Figure 5.

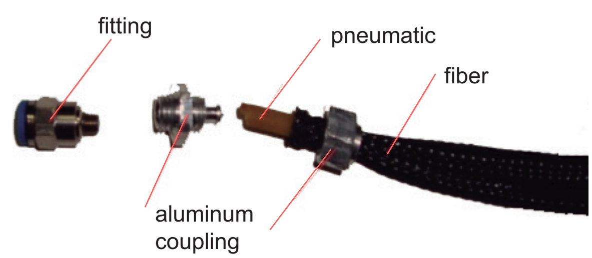

Fig. 5 Pneumatic Muscle and coupling

Each muscle is connected using nylon strings, composed of two sets of valves in communication with the corresponding PLC outputs. The activation and control of every single muscle is accomplished by controlling a logic sequence of instructions from the PLC. The hand is powered with 24V and it can be controlled manually or by a continuous sequences via Ethernet protocols, thus allowing its online and offline programming. The system setup for the muscles and control (PLC) subsystem is presented in Figure 6.

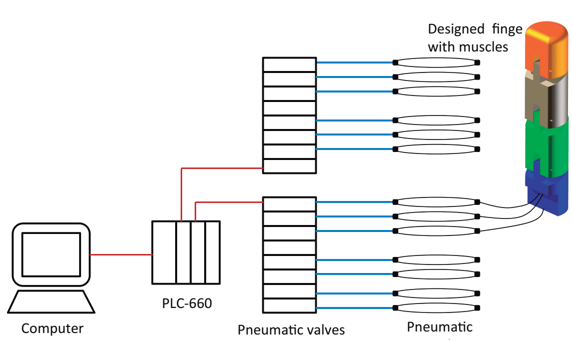

Fig. 6 Control and actuation squematics

5. OFFLINE PROGRAMMING - TELEOPERATION

A Java3D API implemented in [33] was chosen for using with the designed pneumatic hand. In Java3D the virtual assembly is organized following a hierarchical order, then by defining the common base of all the components, the relations between each finger can be defined so their pivots match the joints of the mechanical assembly. The palm of the anthropomorphic device is chosen as the base for all fingers, from it each finger is a branch, and each phalanx is located relatively to the branch's origin point on the palm. This guarantees that the virtual movement matches the real motion of the pneumatic hand. Figure 7 shows a representation on of such relations in the human hand.

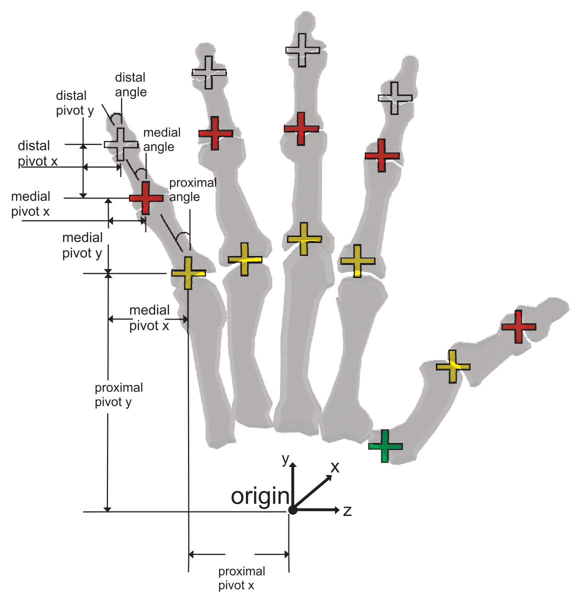

Fig. 7 Pivot hierarchy

5.1 Offline Programming

The offline/online programming flowchart is presented in Figure 8. The program follows an initial configuration step where the 3D model is set up accordingly to its anthropometric measurements and the Virtual Reality Modeling Language (VRML) model imported from the CAD software, this process guarantees that the virtual representation is visually and functionally the same as the real pneumatic hand. Then, the kinematics module reads the anthropometric data so its ready for calculating the positions of each finger during the grasp execution. Once the user chooses wether is going to execute the offline or online programming, each process if followed as presented in Figure 8, where he identifies the shape, move the fingers, execute and adjust the grasp and save the information for posterior analysis or later execution.

6. EXPERIMENTAL RESULTS

The pneumatic anthropomorphic hand was assembled and connected following the mechanic and pneumatic design. The modularity of the parts allows its fast and sim-

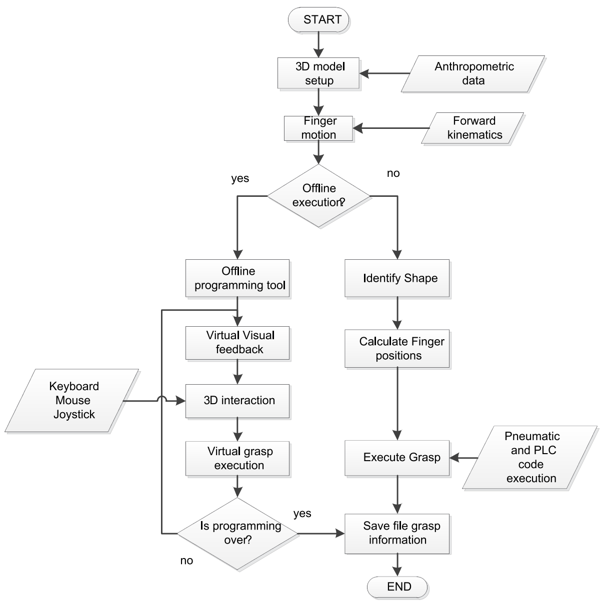

Fig. 8 Application flowchart

ple assembly along with easy maintenance when necessary. Each joint supports continuous motion so the device is physically adequate for training and teaching automation basics. The mechanism and its pneumatics muscles are suitable for reproducing several types of grasps, for testing it various shapes where programmed using different valve configurations, thus resulting in the finger positions presented in Figure 9.

When choosing the Offline programming, the tests proved to be realistic as the virtual model moved as the real pneumatic hand. Although the fingers were moved to several positions, the focus remained on the execution of the three most common grasps, planar, spherical and cylindrical. The navigation and button location gives the user a comfortable environment for using the application. Figure 10 shows a screen capture of the application, presenting from left to right the predefined shape buttons, the 3D canvas and finally the single finger movement buttons. Figure 10 also shows the pneumatic hand executing the three main grasps with and without objects.

7. CONCLUSION AND FUTURE WORKS

The designed pneumatic hand proved to behave and move similarly to its human counterpart. The pneumatic muscles acted just as expected fulfilling their roll as suitable actuator for performing extension and flexion rotations for generating several types of grasps for each finger when grabbing an object. The use of simple programming allows newcomers to easily configure and manipulate the devices applying basic automation concepts for online and offline programming the hand. Another feature to highlight is the low cost of this device, it made it affordable as a laboratory tool that students can build, adjust, improve and customize by their own according to their needs or imagination. The similarity with the human hand was achieved thanks to the selected mechanism

Fig. 9 Executed grasps

as allowed us to concentrate the actuators in the forearm rather than with motors in the hand, that would have resulted in a bigger and less anthropomorphic device.

Along with the offline programming tool, the physical device was successfully assembled proving its scalability and easy maintenance. Its programming allowed moving each finger as an isolated mechanism or as a workcell when various fingers are needed according to the task at hand. At this point, the device is suitable for teaching and executing several grasp types and for grabbing different objects using visual feedback for estimating how to grab the targets without extreme force. The anthropomorphic model was successfully exported through VRML and the files successfully edited for working properly in Java 3D for programming the device. This allowed the successful execution and grasp of cylindrical, spherical and planar objects, along with data for actuating the PLC.

Finally, the integration of the hardware with the offline tool allow users to practice CLP programming first in a virtual environment without comprising the real device while a larger number of users can practice with the virtual hand while the real is being used. With this tool, users can relate to kinematics, biomechanics and CLP programming basics with tasks easily compare with those performed with our hands. This integration allows having an open platform for implementing further developments in areas such as control, computer vision, artificial intelligence and others.

Substantial work needs to be done in other to improve its control and grasping performance, so other DOF such as the abduction/adduction rotations can be considered.

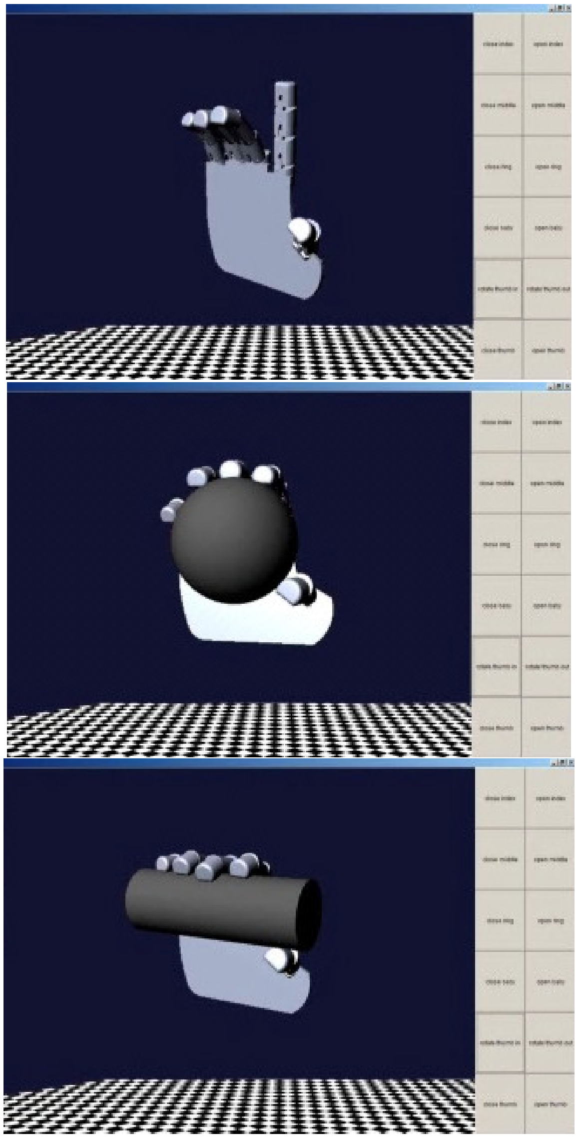

Fig. 10 Virtual executed grasps

Further developments can be made by using 3D user interfaces such as the Wiimote, Kinect or haptic gloves for increasing user immersion and interaction. Adding more objects for simulating interactions between the hand can enhance the virtual environment effectiveness.

8. BIBLIOGRAPHY

REFERENCES

[1] R. Ayres and S. Miller, *Robotics: Applications and social implications*. World Future Society,Bethesda, MD, 1983.

[2] M. Ceccarelli, *Service Robots and Robotics: Design and Applicatio*. IGI Global, 2012.

[3] J. Rosen and B. H. author Richard M. Satava, eds., *Surgical Robotics: Systems Applications and Visions*. Springer, 2010.

[4] T. Brunl, *Embedded Robotics: Mobile Robot Design and Applications with Embedded System*. Springer, 2008.

[5] C. L. Taylor and R. J. Schwarz, "The anatomy and mechanics of the human hand," *Artificial Limbs: A Review of Current Developments*, vol. 2, pp. 22–35, 1955.

[6] H. Hirukawa, T. Matsui, S. Hirai, K. Konaka, and S. Kawamura, "A prototype of standard teleoperation systems on an enhanced vrml," in *Proceedings of the 1997 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 1997.

[7] M. Haage and K. Nilsson, "On the scalability of visualization in manufacturing," in *7th IEEE International Conference on Emerging Technologies and Factory Automation*, 1999.

[8] E. Freund and J. Rossmann, "Multimedia and virtual reality techniques for the control of era," in *Proceedings of the 2001 IEEE international Conference on Robotics & Automation*, 2001.

[9] R. Safaric, R. M. Parkin, C. A. Czarnecki, and D. W. Calkin, "Virtual environment for telerobotics," *Integrated Computer-Aided Engineering*, vol. 8, pp. 95–104, 2001.

[10] X. Yang, Q. Chen, D. Petriu, and E. Petriu, "Internet-based teleoperation of a robot manipulator for education," in *The 3rd IEEE International Workshop on Haptic, Audio and Visual Environments and Their Applications*, 2004.

[11] U. Kartoun, H. Stern, and Y. Edan, "Virtual reality telerobotic system," in *e-ENGDET 2004 4th international conference on e-engineering & digital enterprise technology*, 2004.

[12] N. P. Belfiore and E. Pennestr, "An atlas of linkage-type robotic grippers," *Mechanism and Machine Theory*, vol. 32, no. 7, pp. 811 – 833, 1997.

[13] K. E. Afshari and S. Payandeh, "Toward implementation of java/vrml environment for planning training and tele-operation of robotic systems," in *Americas Conference on Information Systems-AMCIS*, 1999.

[14] I. R. Belousov, R. Chellali, and G. Clapworthy, "Virtual reality tools for internet robotics," in *VIII IEEE International Symposium on Distributed Simulation and Real-Time Applications*, 2004.

[15] A. T. Miller and P. K. Allen, "Graspit! a versatile simulator for robotic grasping," *Robotics & Automation Magazine*, vol. 11, pp. 110–122, 2004.

[16] A. Miller, P. Allen, V. Santos, and F. Valero-Cuevas, "From robotic hands to human hands: a visualization and simulation engine for grasping research," *Industrial Robot: An International Journal*, vol. 32, pp. 55–63, 2005.

[17] C. Goldfeder, P. Allen, C. Lackner, and R. el Pelossof, "Grasp planning via decomposition trees," in *ICRA 07*, 2007.

[18] Y. Tsepkovskiy, L. Antonov, C. Kocev, F. Palis, and N. Shoylev, "Development of a 3d and vrml virtual hand models for different mechanical gripper," *Journal of the University of Chemical Technology and Metallurgy*, 2007.

[19] R. S. A. Kollreider, D. Ram and P. Grieshofer, "Robotic hand/finger rehabilitation for apoplexy patients," in *European Symposium Technical Aids for Rehabilitation*, 2007.

[20] C. Loucks, V. Johnson, P. Boissiere, G. Starr, and J. Steele, "Modeling and control of the stanford/jpl hand," in *Robotics and Automation. Proceedings. 1987 IEEE International Conference on*, 1987.

[21] S. Narasimhan, D. Siegel, J. Hollerbach, K. Biggers, and G. Gerpheide, ""implementation of control methodologies on the computation al architecture for the utah/mit hand," in *Robotics and Automation. Proceedings. 1986 IEEE International Conference on*, 1986.

[22] N. Fukaya, S. Toyama, T. Asfour, and R. Dillman, "Design of the tuat/karlsruhe humanoid hand," in *Intelligent Robots and Systems, 2000. (IROS 2000). Proceedings. 2000 IEEE/RSJ International Conference on*, 2000.

[23] J. Butterfass, M. Grebenstein, H. Liu, and G. Hirzinger, "Dlr-hand ii: next generation of a dexterous robot hand," in *Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation*, 2001.

[24] C. Lovchik and M. Diftler, "The robonaut hand: a dexterous robot hand for space," in *Proceedings. 1999 IEEE International Conference on Robotics and Automation*, 1999.

[25] A. Bicchi, M. Gabiccini, and M. Santello, "Modeling natural and artificial hands with synergies," in *Philosophical Transactions of the Royal Society*, 2011.

[26] J. ya Nagase, N. Saga, T. Satoh, and K. Suzumori, "Development and control of a multi-fingered robotic hand using a pneumatic tendon-driven actuator," *Journal of Intelligent Material Systems and Structures*, 2011.

[27] D. T. Nicholson, C. Chalk, W. Robert, J. Funnell, and S. J. Daniel, "Can virtual reality improve anatomy education? a randomised controlled study of a computer-generated three-dimensional anatomical ear model," *Medical Education*, vol. 40, pp. 1081–1087, 2006.

[28] X. Yin, P. Wonka, and A. Razdan, "Generating 3d building models from architectural drawings: a survey," *IEEE Comput. Graph. Appl.*, vol. 29, pp. 20–31, Jan. 2009.

[29] G. Burdea, "Invited review: the synergy between virtual reality and robotics," *Robotics and Automation, IEEE Transactions on*, vol. 15, pp. 400 –410, jun 1999.

[30] J. Leven, D. Burschka, R. Kumar, G. Zhang, S. Blumenkranz, X. Dai, M. Awad, G. Hager, M. Marohn, M. Choti, C. Hasser, and R. Taylor, "Davinci canvas: A telerobotic surgical system with integrated, robot-assisted, laparoscopic ultrasound capability," in *Medical Image Computing and Computer-Assisted Intervention MICCAI 2005*, 2005.

[31] M. R. Cutkosky and R. D. Howe, "Dextrous robot hands," in *Dextrous robot hands* (S. T. Venkataraman and T. Iberall, eds.), ch. Human grasp choice and robotic grasp analysis, pp. 5–31, New York, NY, USA: Springer-Verlag New York, Inc., 1990.

[32] J. Denavit and R. S. Hartenberg, "A kinematic notation forlower-pair machanisms based on matrices," *Applied Mechanics*, pp. 215–221, 1955.

[33] A. J. Uribe, J. M. Rosrio, and O. F. Avils, "Anthropomorphic gripper virtual environment for automation grasping task," *International Review of Mechanical Engineering IREME*, vol. 3, pp. 547–552, 2009.