# DIDACTIC HUMAN ANTHROPOMORPHIC GRIPPER FOR AUTOMATION TEACHING

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This paper presents the design, development and implementation of a 14 DOF human anthropomorphic gripper as a didactic tool for teaching automation basics using pneumatics and PLCs. The anthropomorphic hand's fingers behave like serial robots and their motion allows performing several types of power and precision grasps just as the human hand, this collaborative motion can be seen as robotics workcell where each finger is an actuated mechanism with a specific task. Through the programming of each mechanism, the objective of the pneumatic hand is to enhance the student's skills for executing collaborative actions through pneumatics and PLC basic concepts over the device. Robotics has been widely used as a teaching assistive tool in several areas such as in 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 system's architecture is composed of an anthropomorphic gripper controlled by a PLC along with the pneumatic actuators for simulating the muscles, and the user's inputs for executing the chosen tasks. For overcoming the physical limitations of having just one device, an offline virtual environment is also developed, so several users may program and perform practices for later execution on the real device.

## 1. Introduction

You Innovative devices tend to find inspiration in natural designs (dams, submarines, airplanes, humanoid, quadruped and insect-like robots), the human physiology is no exception as it allows the development of better and more efficient robotic devices due to our bodies inherent dexterity. One essential device in a robotics workcell is the gripper, which depending on the application; it may perform several tasks such as, welding, assembling, painting, assisting surgery and manipulation of delicate or hazardous materials. Common activities when programming robots involve teleoperation [1], offline programming [2], hazardous environments or prehensile tasks [3], [4], as well as grasp planning [5], design validation [6], and assistive rehabilitation [7].

Some other solutions resembling the human hand based also on serial mechanism are jaw liked and three fingered grippes used in several industrial applications and training tools, as presented in [8], [9], [10], [11], [12], [13]. Over the years the dexterity of the human hand has given birth to the

development of devices mimics its functionality, this has resulted in the design and construction of experimental prototypes such as the Stanford/JPL, the Utah/MIT, the TUAT/Karlsruhe, the DLR [14], and the Nasa Robonaut [15] among several others [16].

Common educational tools available for teaching automation rely on laboratories pneumatic, hydraulic, mechanical or electric actuators, programmable logic controllers (PLC) [17], and automated conveyors with robotic arms. Additional to this hardware, certain software allow simulating offline queues for training and learning in cases where hardware limitations are present or for validating processes for guaranteeing that the hardware will not be damage during practices. For solving the need of simulation remote or local tools using interactive or virtual reality (VR) solutions provide access for assisting remotely the learning or training process independently of the physical workcell.

Considering the importance and impact of hand-based research and VR applications, this work proposes the development and implementation of an anthropomorphic robotic human hand for automation learning purposes focusing on the programming of various grasping scenarios through a CLP and the pneumatic muscles. An offline tool will also be used when several users may need to practice with the device so they can later run the programed solutions thus, overcoming the hardware limitations because of having just one hand.

This paper is organized as follows; in section II the human hand basics and the kinematics of the human finger are studied using the homogenous transformation matrix from forward kinematics analysis. In section III the anthropomorphic hand mechanical and pneumatic design is presented. In section IV the offline programming tool is described as well as the parameters for the virtual environment implementation, and finally in section V the results, the conclusions and future works are discussed.


## 2. Human Hand Analysis

The human hand has twenty DOF and it can perform various movements and geometry grasps [17], these DOF allow each finger to perform the flexion/extension and adduction/abduction movements. In [17] Cutosky, studied various grasping techniques and classified them in two main groups, precision and power types being the most common grasped objects based on prismatic and circular shapes. Main differences between these grasps, are the number of fingers used and the amount of contact that is applied to the object; therefore precision grasps may involve fewer fingers and solely their fingertips whereas power ones will need more fingers and greater contact with the object.

Similarly to how we reach objects from known shapes, where we rotate our fingers to prepare for a specific grasp, for calculating joint positions given known flexion/extension rotations, the forward kinematics supply sufficient information for executing both power and precision grasp tasks with the anthropomorphic proposed hand. Each finger can be analyzed as an open kinematic chain represented by a serial mechanism modelled as three serial connected bars and its behaviour studied with forward kinematics. The rotational and translational information for each link and its final effector can be obtained through the homogenous transform matrix analysis. This matrix can be obtained by using the Denavit-Hartenberg notation; this method was preferred over the geometric analysis as it allows increasing the number of DOF without recalculating the kinematics models, another reason is that, as the maximum number of DOF are 19 when multiplying the transformation matrixes the amount of zeros multiplied within each link do not affect the computing speed and processing, making it a suitable solution.

## 3. Anthropomorphic Hand Design

The mechanism design was based upon the skeletal human hand system as it gives the support for the fingers, in the same manner; the actuation system was inspired on muscles and tendons that were configured and implemented using pneumatic actuators. In Figure 1, both, the human inspiration and the projected device are presented; it is worth noting the physical resemblance between them, which guarantees a similar dexterity according to the considered DOF
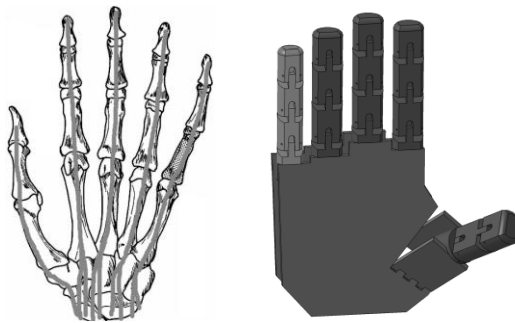


Figure 1: Hand-based inspiration and mechanism proposal.

In order to correctly design the gripper, we started by modeling each of the fingers, this allowed us to focus on each of the joints motion and actuation system through nylon strings attached to the pneumatic actuators located at the forearm of the robotics hand. The hand prototype is presented in Figure 2, from it, can be seen where the phalanx rotates and where the tendon passes through. Given that the most significant motions in grasping are the flexion and extension

rotations, each finger abduction/adduction were not considered for simplifying the mechanism and actuation system. The CAD models serve as base for the rapid prototyping of the pieces so the physical model for validation is built faster than made manually
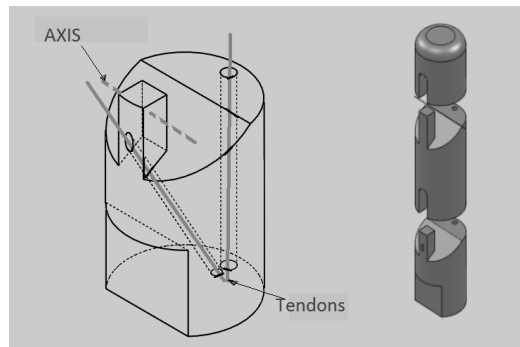

Figure 2: Phalanx and finger prototype.

For the actuation system, the pneumatic muscles were implemented using Festo's FC660PLC, these were preferred over direct current (DC) motors given the goal of pneumatics teaching and programming. The chosen actuators allow performing and controlling each of the finger's flexion and extension rotations through its contraction and expansion, and their main components are presented in Figure 3.
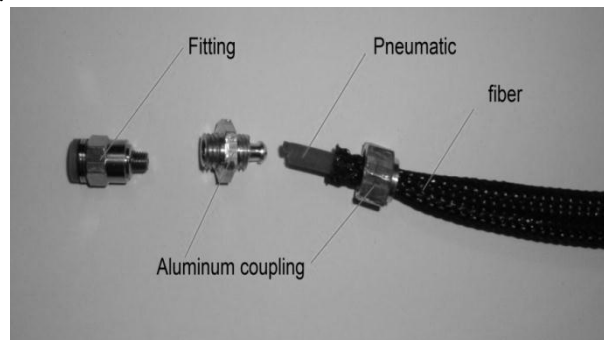

Figure 3: Pneumatic muscle.

Once each of the muscles was connected to the nylon strings, theses were connected to two sets of valves in communication with the corresponding outputs of the PLC. The activation and control every single muscle is done by controlling a logic sequence of instructions from the PLC. The hand is powered at 24V and it can be controlled manually or by a continuous sequence via Ethernet protocols. The setup for the muscles and PLC is presented in Figure 4, where the connection schematic is presented.
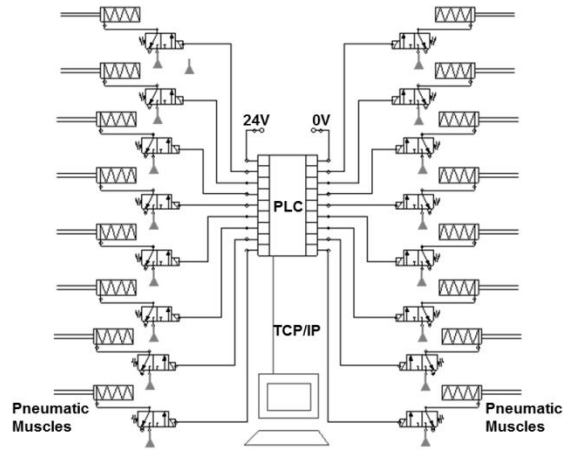
Figure 4: Connection schematics.

## 4. Offline Programming

The proposed offline programming architecture is presented in Figure 5; it covers input/output devices and information, kinematics processing, virtual instrumentation and task execution.
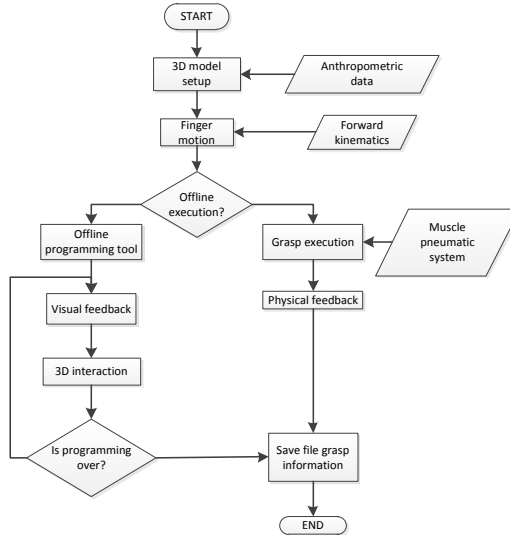


Figure 5: Proposed System architecture.

Java with its Java3D API (Application Program Interface), along with the Virtual Reality Modeling Language (VRML) standard are chosen given their portability and operational system independence. The implementation was based upon the work presented by Uribe in [18]. In Java3D the virtual assembly is organized following a hierarchical order, considering as base the palm of the

 anthropomorphic device, from it each finger is a branch, and each phalanx is located relative to the branch's origin point on the palm.

## 5.  Experimental Results

Following the CAD design, the anthropomorphic hand was assembled and connected following the presented system's architecture. The modularity of the parts allow its fast and simple assembly and maintenance when necessary, each of the joints supports continuous motion so the devices is physically adequate for training and teaching automation basics. For testing the developed anthropomorphic hand, various grasps where programmed using different valve configurations resulting in the finger positions presented in Figure 6.
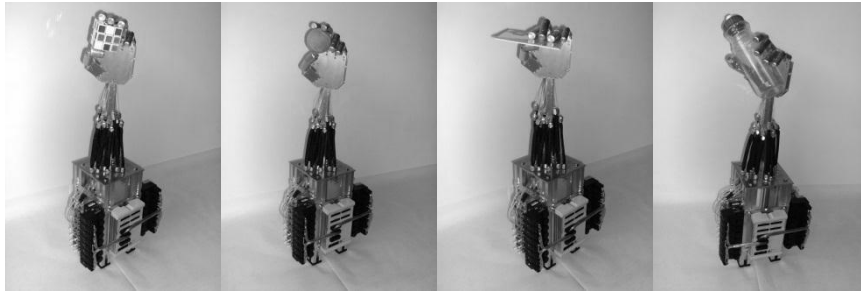


Figure 6: Executed grasps.

Virtual tests proved to be realistic when mimicking the finger's movement and the way it grasps the three predefined shapes. The navigation, lightning and button location gives the user a comfortable environment for using the application, Figure 7 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.
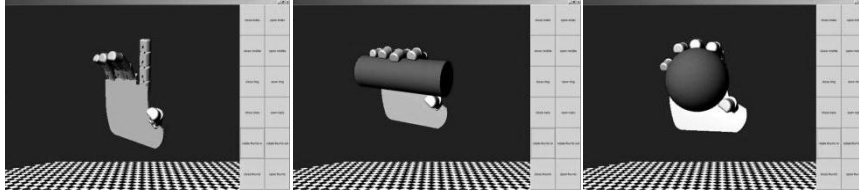


Figure 7: Virtual reality test performing a grasp motion.

After following the proposed methodology from this CAD assembly, the model was successfully exported through VRML and the files successfully edited for working properly in Java 3D for programming the device.

Finally the following conclusions can be obtained from the previous work. First, the proposed methodology allows the use of various geometries regardless of the 3D creation software, as VRML can be obtained from them. This characteristic offers the user portability as no specific modelling software is required; it also achieves low cost and OS independency when combined with the Java Application Program Interface, proving the viability of VR as a tool for complying with the needs of new devices.

**Future work**

Substantial work needs to be done in other to improve the performance of the hand in the areas of grasping and manipulation control. The system requires to uses different and more effective control model is the next major stage, and also, improve the mechanical joins of the fingers. Further developments can be made by using 3D user interfaces such as the Wiimote, Kinect® o haptic gloves for increasing user immersion and interaction. The virtual environment will be enhanced by adding more objects for simulating interactions between them and the hand.

**Acknowledgments**

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