Robot Control by Hand Movement Mirroring

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This project seeks to extend the manual and motor skills of the user using robots that replicate their movement, either for a production line or in remote stations, so that they can carry out movements at a safe distance and optimize production. With this, maquiladora factories where the same process is repeated by multiple people will only require an experienced worker and several robots to extend production, in turn, factories with dangerous processes that require expert or flexible handling of parts, to move it between stations or inspect it, they will not have to expose themselves to danger or delay production. The prototype consists of a precision 3D sensor and a wide-articulated robotic arm. The sensor is placed in front of the user, detecting each movement of the user's hands, and generating information in real time about the position of each joint. This information is fed into the control system that manipulates the motors of the robotic arm. The project seeks to improve the efficiency of production times and prevent the main risks faced by production workers in different industries by facilitating remote work and / or making more efficient jobs that involve repetitive activities. The physical prototype developed meets the proposed requirements in an acceptable but not outstanding way. Its movement is clearly an imitation of the user's movement, and the prototype is capable of copying and displaying basic signs, moving each finger individually and obtaining intermediate positions depending on the actual position of the user's fingers. On the other hand, the software or program developed to control the hand works excellently, and provides the necessary data at a high speed, with minimal error, and in a stable manner.

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1. Introduction.

The main idea of this project is the creation of a system that acts as an intermediate step between manual work and the complete automation of industrial processes. This is intended to be achieved through the use of robots capable of replicating the movement of a remote user, extending their manual and motor skills in a way that improves their performance. The scope of the project is delimited by two sectors. The first is aimed at factories or industrial plants with machinery and processes that present a risk to workers, or plants where the intervention of a trained operator on the production line either to solve a problem, configure the machinery, or simply perform a part of the process, need to be face-to-face, fast and accurate. The second is aimed at small and medium-sized factories around the world, whether they are maquiladoras, assemblers or producers with a large number of manual workers who repeat simple, specific, and repetitive tasks. In each of these environments, we seek to solve specific problems in each situation. On the technical side, the project is delimited by the capabilities of the system created, that is, by what the system could achieve in the industrial environment for which it was conceived.

Currently these types of situations are being solved through full independent automation, but automation of industrial processes brings with it both advantages and disadvantages. Among the most common benefits attributed to automation are increased productivity rates, efficient use of materials, better product quality, better safety, shorter work weeks, and reduced factory lead times. The top two reasons to justify automation are higher performance and higher productivity.

On the other hand, one of the disadvantages of automated equipment is the high capital expenditure required to invest in automation, they require a higher level of maintenance than a manually operated machine and, in general, a lower degree of flexibility in terms of possible products. Compared to a manual system, even flexible automation is less flexible than humans, the most versatile machines of all [1].

We believe that a good solution could be found down the middle, with the use of agile and versatile robots capable of remotely replicating the precision and movement of a human arm. It could give operators and workers the ability to address problems or perform actions within a production line without putting themselves at risk when approaching dangerous environments, all this without sacrificing the mobility and dexterity offered by working by hand in person. This project is about the development of a prototype that approaches this solution.

A large number of multi-fingered robotic hands have been developed in the field of research. As well as the prototype presented in this project, which is based on designs by Gaël Langevin (InMoov)[2][3], robots such as the Stanford-JPL hand [4] and the Utah / MIT hand [5] have also been developed that are driven by actuators that connect to the ends. fingers remotely from the base of the robotic hand via cables that function as tendons. The elasticity of the tendon cables tends to cause inaccurate control of the joint angle, and their great length can obstruct the robot's movement. These hands can become problematic and difficult to maintain due to their complexity, which is why robotic hands have also been developed such as the Omni hand [6] and the DLR hand [7] whose actuators are placed directly on the joints of the hand. This, however, means that its movements are different from that of the human hand.

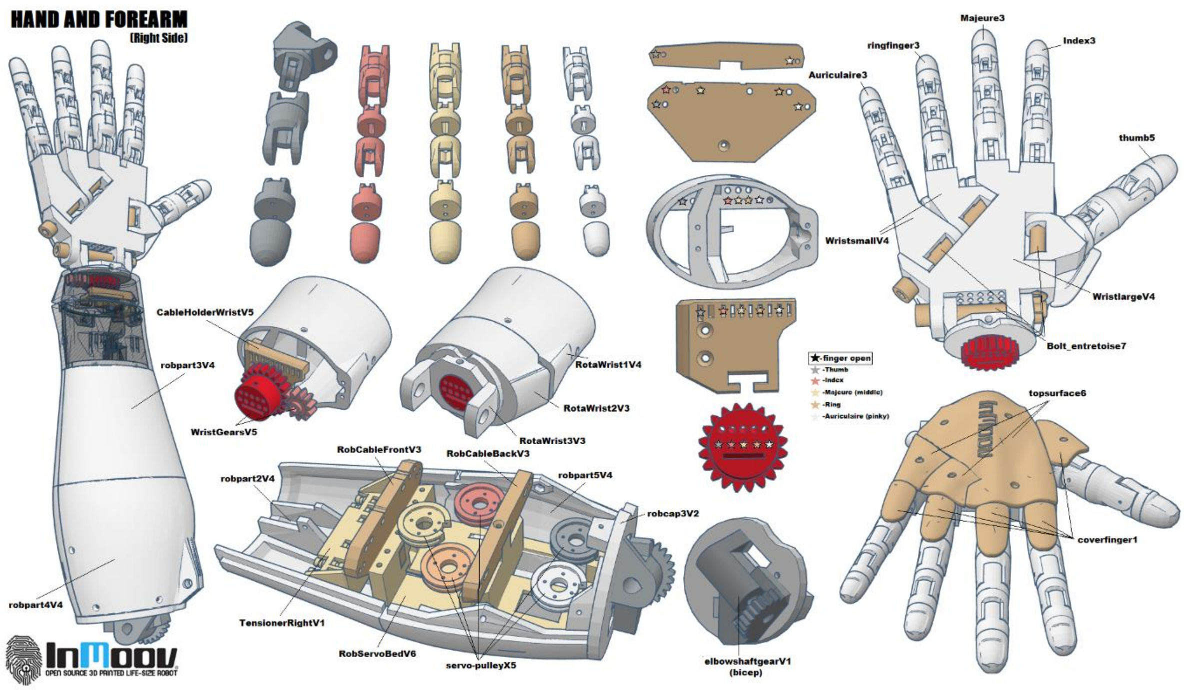
Another way to develop robotic hands is by focusing on tactility and haptic feedback. In 2018, the Gifu University in Japan developed a five-fingered robotic hand called the Gifu hand [8]. This hand features 16 degrees of freedom, a geometry similar to that of a human hand with a thumb opposite four fingers, and touch sensors and force sensors at the fingertips. This hand is used in conjunction and controlled by another robot named Hiro [9], also developed by Gifu University. When the user uses the Hiro robot, pressing their fingers against those of the robot, it obtains the information of the user's hand movement and sends it to the Gifu hand, which thus imitates the user's movements. The important thing is that this companion robot also functions as a multi-finger haptic interface, and mimics the resistance presented by objects manipulated by the gifu hand (the information on this resistance being provided by the sensors on the fingers of the gifu hand). In this way, the user can feel the resistance of objects manipulated remotely by the Gifu hand.

2. Work description.

Our objectives were to generate a prototype robotic arm capable of moving all the fingers to reach a fully closed, open, or intermediate positions. This is in order to properly simulate the movement of the control user's arm. Monitoring of the user's arm and hand will be done through an infrared motion sensor capable of obtaining the real-time position of the user's limbs.
Another objective is to program the data acquisition and transfer system to pass information from the motion sensor to the control system. The program must take into account the amount of data that can be processed for our controller and ensure a correct position of the hand and fingers in the area of 3D space captured by the sensor.
Finally, the aim is to have a control system capable of converting the coordinates given by the sensor into inputs to the arm motors and making the entire arm position stable. The controller must have a steady state and a transient state with minimal overshoot, so even if reaching steady state is slower, no action is taken that the sensor has not detected.

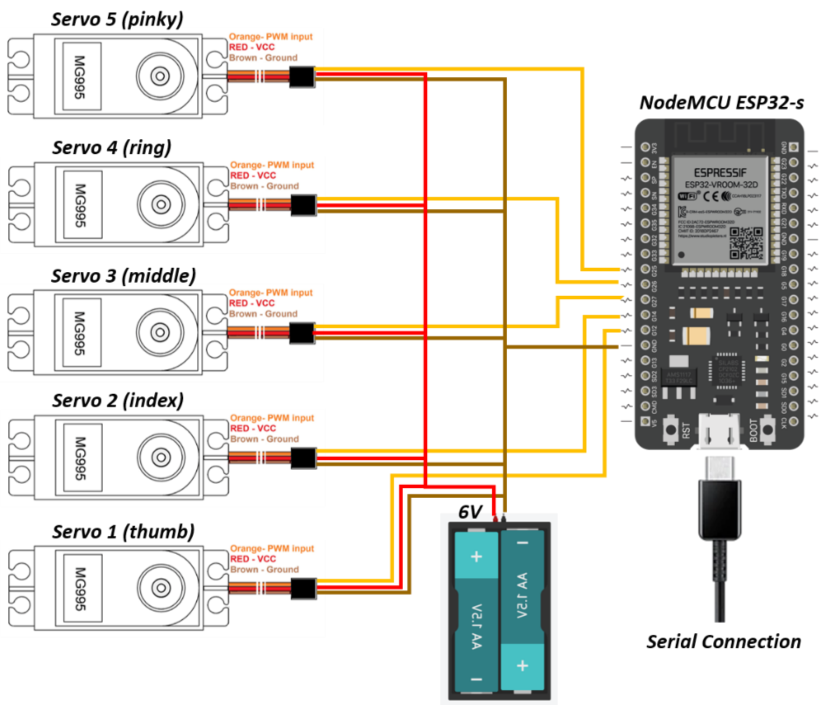
We developed a robotic hand of the type that uses tendon cables and actuators at the base of the hand. A 3D Leap Motion sensor is used that is placed in front of the user, detecting each movement of their hands, and generating information in real time about the position of each joint. This information is processed within the computer and sent to a microcontroller through the serial port. The microcontroller in turn sends the necessary signals to the required motors that control the robotic hand. All this results in a system capable of imitating the movement of the human hand remotely and in real time.

A great tool that was used extensively was the plastic 3D printer, since with it, it was possible to print most of the parts that make up the project. Other tools include the NodeMCU ESP32-S, Python and C ++ programs with their respective libraries, and the Leap Motion sensor.



Hand and Forearm models (Source: InMoov) [10]

The fingers, palm, wrist, joints and forearm where the actuators are located have all been printed on a 3D printer made of ABS and PLA materials. The models of these pieces were taken from the InMoov portal, based on designs by Gaël Langevin. Tension discs and nylon threads that act as tendons, five MG995 type servo motors, a 6V power source to power them and a NodeMCU ESP32-S type microcontroller were also used to control them. In addition, a high-precision 3D infrared sensor of the Leap Motion type and a computer capable of running python 2.7 with two USB serial ports are used.



Connection Diagram

A code file written and executed by python 2.7 was developed to connect to the libraries provided by the Leap Motion sensor and read the characteristics of the hand as well as the positions of the fingers, each time a hand enters the focus frame of the sensor a signal is received in the "listening" class where the parts of the hand and the nodes in the fingers are scanned, from here the direction of each bone is obtained and the distal direction is used, this being the direction of the Tip of the finger, once this address is obtained, the data is processed to move to a range of angles that the servo motors can accept, then each data is sent through the serial port to the microprocessor that will execute each angle respectively.

A C ++ code was also developed and downloaded to the microcontroller. This code has the task of receiving the data sent by the serial port, dividing it, concatenating it and processing it in packets readable by the system (with the help of a dedicated library) and distributing the information of the required angle to each servo as required. Each packet has a header that defines the servo number to which the information it contains is directed, this in order to facilitate the distribution of tasks and avoid interference. It is important to note that the serial channel is closed whenever there is no explicit information being sent through it, in order to save energy and avoid overheating.

3. Experiments.

Our first experiment was done once the hand was physically built and all the tendons and servos were in place. The first test runs were done using a manual version of the python script that worked with values inputted into an entrybox in the program. This way, all of the motors could be calibrated correctly and the tensioning of the nylon cables could be done in an orderly way. Once this was complete, another round of values was inputted to test the extended, middle, and contracted positions of each finger. This is where some of the first problems arose, as the tension in the cables sometimes was not enough to overcome the friction in the moving parts, resulting in half-movements and undesired finger positions. This is a problem that has not been solved.

A sixth servo motor was tested in the position of the wrist in order to add another degree of freedom to the robot, but unfortunately the power source could not provide enough energy to accomodate for an additional servo, and this caused spams from the other motors so the idea was scrapped.

A third test was carried out once the code that included the communication with the Leap Motion sensor was completed. In it we tested the maximum and minimum values of the coordinates for each finger of the user once they were closed or opened and used this to form our conversion factors. These were integrated into the code and used as the basis for the calculation of the degrees sent as signal to each servo. This was tested and viewed as a success after the hand clearly responded to the sensor inputs, copying the hand movements of the user.

A fourth and final test was done with the purpose of improving the movement of the hand. The code was modified so the angle signals would only be sent after a certain amount of change in finger position was reached. This was an attempt to reduce the amount of information sent over time and to prevent saturation of signals. We calibrated the code to only react when an angle of more than 4 degrees was reached. This was also a success and it really improved the overall movement of the system. A lack of time prevented further testing.

The physical prototype developed meets the proposed requirements in an acceptable but not outstanding way. Its movement is clearly an imitation of the user's movement, and the prototype is capable of copying and displaying basic signs, moving each finger individually and obtaining intermediate positions depending on the actual position of the user's fingers. The system is able to differentiate between the movement of each finger even when the user's hand is not consistently in one place and the coordinates of the fingers are correctly sent to the controller and the servo motors, so the system has some robustness. That said, certain model joints tend to get stuck given the high friction of plastic on plastic and given the limited range of angles of the servo motors, there are times when the tension of the nylon threads is not enough to overcome the friction of joints, making it difficult for you to show more precise and shorter movements in your fingers.

On the other hand, the software or program developed to control the hand works excellently, and provides the necessary data at a high speed, with minimal error, and in a stable manner. Finger position tracking is also done in a great way, and the data processing leaves very little to be desired, especially with the use of such a low-caliber controller and unspecialized data transfer network.
In general, the project is considered a success, but there is still a lot of room for improvement, especially in the mechanical area and quality of components.

4. Conclusions.

The main advantages of the project developed would be that it is a very simple and cost effective robot that even if it may not perform perfectly, its set up as a proof of concept, especially as a showcase for the developed code, which performed, to our eyes, in an outstanding way. This model is also easily upgradeable and the fact that it is 3D printable allows for easy modifications and possibly better materials and quality. Another advantage is that the microcontroller used has wifi and bluetooth capabilities, therefore it can easily be made to work in an even more wireless manner.

That being said, there are a multitude of disadvantages. First of all is the practicality of the prototype, as it really can’t take on any but the simplest of tasks, such as showing signs and grabbing very light and grabbable objects. The second great disadvantage is its limited mobility. Our initial goal was to create a product that could mimic human hand movements, and it can (within reasonable sets of grading parameters), but its ability and dexterity is nowhere near that of a human hand, and therefore, one would be hard pressed to accept it as a viable replacement in any task.

As for cost-benefit analysis, we have concluded that its cost is on par with its benefit, as it is very cheap but not that useful. The good thing is that this relationship may be maintained when talking about scalability of prototypes, in other words, using more expensive materials, better technologies and better designs may make it more expensive, but it would also make it proportionally beneficial, as it could actually start to replace a human hand in some tasks, which would in turn save a lot of money and perhaps even save lives, as it could not only be used for, as we mentioned, hand assembly lines and dangerous industrial processes, but for even more things, such as robot assistance in space and deep underwater jobs.

The human hand is a truly complicated and difficult system to replicate. Its capacity, skill potential and versatility are unattainable by any technology that exists today, so its role in industry, that of labour, cannot be replaced, or even not without an army of machinery and equipment. robots. It is for this reason that seeking to develop a system that can catch up is a goal worth pursuing. For this you need the correct materials, neither too heavy nor too light; Simulated tendons that can perform to the same magnitude as real ones are needed, or in the absence of tendons, mechanisms that can simulate the full range of joint motion high data processing speeds, fast and stable connections are needed; precise and robust sensors and systems capable of producing large forces without sacrificing precision of movements; easy-to-maintain hardware and software, all in a cost-effective way. This project shows first-hand that it is not an easy goal to achieve, but it is a goal that can already be approached.

5. Bibliography.

[1] Groover, P. (2021). Automation - Advantages and Disadvantages. Encyclopedia Britannica. Recovered from: https://www.britannica.com/technology/automation/Advantages-and-disadvantages-of-automation

[2] Langevin, G. (2015). Finger Starter: Assembly of the Finger Starter. InMoov.fr. Recovered from: https://inmoov.fr/finger-starter/

[3] Langevin, G. (2015). Hand and Forarm. InMoov.fr. Recovered from: https://inmoov.fr/hand-and-forarm/

[4] J. K. Salisbury and J. J. Craig, “Articulated hands: force control and kinematic issues,” Int. J. of Robotics Research, Vol.1, No.1, pp. 4-17, 1982.

[5] S. C. Jacobsen, D. F. Wood, D. F. Knutti, and K. B. Biggers, “The Utah/MIT dexterous hand: work in progress,” Int. J. of Robotics Research, Vol.3, No.4, pp. 21-50, 1984.

[6] M. E. Rosheim, “Robot Evolution – The Developments of Anthrobotics,” John Wiley & Sons, 1994.

[7] H. Liu, J. Butterfass, S. Knoch, P. Meusel, and G. Hirzinger, "Multisensory articulated hand," IEEE Control Systems, Vol.19, No.2, pp. 47-54, 1999.

[8] Kawasaki, Haruhisa & Mouri, Tetsuya. (2019). Humanoid Robot Hand and its Applied Research. Journal of Robotics and Mechatronics. 31. 16-26. 10.20965/jrm.2019.p0016.

[9] V. Daniulaitis, M. O. Alhalabi, H. Kawasaki, Y. Tanaka, and T. Hori, "Medical palpation of deformable tissue using physics-based model for Haptic Interface RObot (HIRO)," Proc. of IROS2004, pp. 3907-3911, 2004.

[10] Langevin, G. (2015). Hand and Forarm assembly 3D views. Recovered from: http://inmoov.fr/build-yours/hand-and-forarm-assembly-3d-views/