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Air Muscle Actuated Low Cost Humanoid Hand

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ABSTRACT

Due to the cost of precision Actuators, the control of humanoid robot hands has historically been expensive. In this paper ,we presented the design and implementation of a low-cost air muscle actuated humanoid hand developed at Sri Krishna college of Engineering and Technology. Ranging from the elbow to the fingers, this hand offers 10 individually controllable degrees of freedom, with overall control handled through a computer GUI. This to be achieved with simple and inexpensive components, and The hand is actuated through 20 McKibben-style air muscles, each to be supplied by a pneumatic pressure-balancing valve and it allows for proportional control. The number of human-equivalent tasks, such as grasping and relocating objects was successfully able to perform by hand.

Keywords: McKibben air-muscle, pressure balancing valve, low cost, humanoid hand, robotic arm

I. INTRODUCTION

Several work have been involved in the creation of a humanoid hand, where the size of the hand and the degrees of freedom and forearm are designed to be as much close as possible to human proportions over the recent years. By the time several authors have studied Jacobsen S, Iversen E, Knutti D, Johnson R, Biggers K. 1986.Design of the Utah/M.I.T. dextrous hand, Robotics and Automation. Proceedings [1]. Lovchik CS, Diftler MA., 1999. The Robonaut hand: A dexterous robot hand for space, Robotics and Automation, 1999[2]. Kawasaki H, Komatsu T, Uchiyama K., 2002. Dexterous anthropomorphic robot hand with distributed tactile sensor [3]. Chua PY, Bezdicek M, Davis S, Caldwell DG, GrayJO.2006. Tele-operated high speed anthropomorphic dextrous hands with object shape and texture identification, Intelligent Robots and Systems, 2006[5]

The main objective of this work was to design and computer control a pneumatic air muscle actuated robotic hand, incorporating basic human finger, thumb, forearm and elbow movements. For the human adult male size proportions, the hand was built. The goal of the hand and arm was to first design to pick up an object such as a small water bottle or soft drink. In the similar manner as a human would perform the task, this task was also to be performed. To the position on the arms radius, as specified by the user, the hand is then to transpose. Within its degree of freedom limitations, it would be possible to program it to perform many others while, if the hand could sufficiently perform this task. At a pressure of between 2 to 3 Bar, the hand was able to perform this task. With simultaneous PID algorithms which written into the driving software, have to control all the movement. With an 8255 interface board, the software was written to run on a PC. Also, using low-cost yet effective components, the hand was to be constructed.

II. SYSTEM OVERVIEW

In Figure 1, the entire physical system is illustrated. A thumb and elbow, all actuated with air muscles, the physical hand and arm comprises 4 fingers. Each air muscle requires a precisely controlled source of air pressure to accurately position the stroke-length of each air muscle, positioning the hand fingers and forearm in the required positions. Valve Board, supplies the controlled source of air.

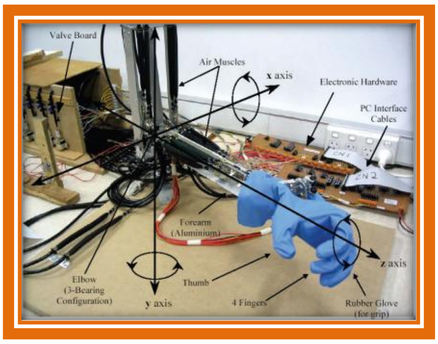


Figure 1. Physical Component Overview Diagram

To convert a single raw compressed air supply of approximately 2.5 Bar to 20 controlled pressure lines, the Valve Board uses 20 valves. To regulate the pressure required in each air muscle, each valve is fully proportional, and is electronically controlled. From the Electronic Hardware, the electronic control signals are provided. The Electronic Hardware consists of an input card and an output card. In the output card filters, buffers and amplifies PWM signals from a PC and sends the final signals to the valve board.

The analog feedback position signals from the Hand, and converts them into a digital signal suitable to interface to the PC is accepted by the input card. The PC, with a digital 8255 Input or Output Data Acquisition card, interfaces the Electronic Hardware with the PC. The system with PID algorithms is controlled by Purpose written software. The PC also interfaces the system to the user with a custom designed GUI, displaying system responses and allowing the user to PID gains ,input new set points, etc.

In Figure 2. In the block diagram, the interactions of the sub-systems are illustrated.

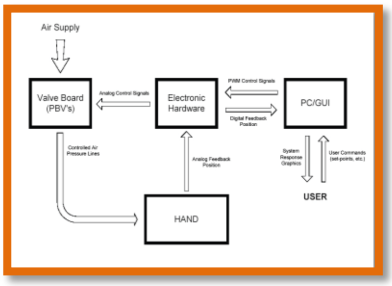


Figure 2. EntireSystem Overview Block Diagram

III. THE HAND AND AIR MUSCLE DESIGN:

Figure 3, Represents the hand system block diagram with three main subsections. It include the air muscles, the mechanical joints (fingers and elbow) and the feedback potentiometers. All sections are contained directly in the forearm (apart from those relating to elbow movement).

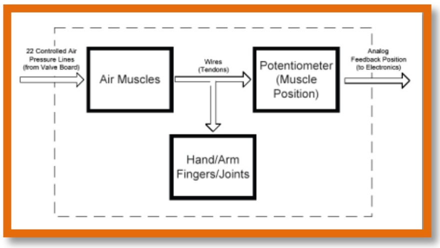


Figure 3. Hand System Block Diagram

With the use of air muscles, the complete actuation of the hand is obtained solely. To the hand and the Elbow, No electric means of actuation has been used to provide any movement. To the hand and the arm, From the Valve Board 20 controlled air lines connect directly to the 20 individual air muscles. In a complimentary configuration (retraction and contraction), each joint is connected to two air muscles. It contracts by up to 25%, when air pressure is supplied to an air Muscle. This provides the contraction or retraction of each joint. It directly controls the force an air muscle can provide, while Controls the air pressure in an air muscle. It provides the control over the joint position.

Similar to the tendons in a human arm, each air muscle is connected to a joint or finger with wires. With one degree of freedom each, the hand comprises 4 fingers, and a thumb with 3 degrees of freedom, and an elbow with 3 degrees of freedom. Each joint moves together simultaneously, and each finger comprises 3 joints. By the same angular measure, contracting and retracting has done. In a contract-retract configuration, each joint and finger comprises two air muscles. Force control is provided in both directions. Directly to a potentiometer, each degree of freedom is physically connected. The joint actuated by the connected pair of air muscles, depends on the displacement. Providing a corresponding analog voltage signal between 0 to 5V DC to the Electronic Hardware, the potentiometer position changed.

3.1 Air Muscles:

For this work, the choice of actuator was the air muscle, and it also known as the McKibben Pneumatic Artificial muscle or a Rubbertuator (Iovine, 2000). It was developed in the area of artificial limb research in the 1950's and 1960' ((Gavrilovic & Maric, 1969) cited in (Chou & Hannaford, 1996)) and patented by R.H. Gaylord and applied to orthotic appliances by J.L.McKibben ((Gaylord, 1958) cited in (Klute et al., 2002)). A McKibben air muscle contracts when activated, like a biological muscle, and that the device has force-length properties similar to biological muscle (Klute et al., 2002), demonstrates by experimental evidence. Making it often the preferred choice of actuator in the study of biomechanics (Iovine, 2000), this allows researchers to attach air muscles to a robotic skeleton at primary biological muscle locations.

Another properties, in the bio mechanic field include their softness and lightness (Iovine, 2000), that make the McKibben air muscle popular. They are also compliant with a high power to weight ratio (400:1), can be twisted axially, used on unaligned mountings and provide a contracting force around bends.

To manufacture, the McKibben air muscle is a simple actuator. Those supplied from party shops, a long-bladder balloon is suitable for use as the muscle's inner bladder (Masclet, 2003). Depending on the size of the air muscle required, polyester braided sheathing of various diameters, is available from many electronic distributors (Iovine, 2000). These main components are inexpensive and available easily. This allows a low cost air actuator to be built, is shown in Figure 4.

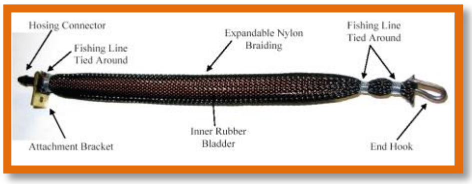


Figure 4. Air Muscle Component Break-up

To manufacture, each custom built air muscle cost approximately AU$2.00, made from the following components:

1 x Inner Rubber Bladder (long party balloon) ,1 x Expandable Braided Sheath (cabling accessory, Ø10mm nominal, Ø6mm min, Ø18mm max),1 x End Hook (nail bent into a hook shape),1 x Attachment Bracket (custom cut and drilled brass plate),1 x Pneumatic Hosing Connector (Reticulation hose joiner),1 x Nylon Fishing Line (Ø0.27mm, 3 x ~30cm lengths).

Assembly of the above components. Firstly, the inner bladder was inserted into the expandable braided sheath. Then fishing wire to create a seal is tied at the right end. Into the same end a nail (flat side) was then inserted and in the end of the nail, another piece of fishing wire tied around the braiding to lock. The remaining part of the nail was then bent into a hook shape.

Then at the left end of the rubber bladder, with the bracket (designed for easy connection onto the forearm) between the bladder and the joiner, a reticulation hose joiner was inserted. Then with another piece of fishing wire, the end was tied, sealing that end and locking in the bracket. The manufacturing of a single air muscle is completed. To make all 20 air muscles required for full actuation of the hand and arm, this process was used.

IV. VALVE BOARD SYSTEM DESIGN:

In Figure 5, the Valve Board system block diagram is represented.

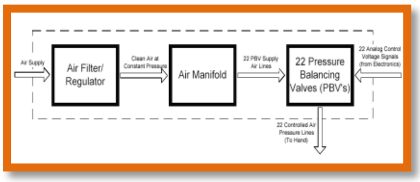
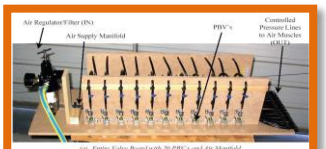


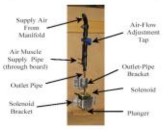
Figure 5. Valve Board System Block Diagram

Its main function is to supply 20 individually controlled air pressure is to interface the electronics with the compressed air-supply and to control the 20 air muscles in the hand, flow rates needed. With pressure continually above 3 bar, air is supplied to the system with an air supply. This air, first to be filtered to remove oil and water, to provide system stability over continuous usage. To maintain overall system pressure at approximately 2.5 bar, the air is then regulated, for the full functionality to the mechanical system, a sufficient pressure is to be provided. While preventing the pneumatic system from experiencing undue stress.

Then in a large air manifold, the filtered and regulated air enters. To provide continuous and consistent flow rates to each of the 20 air valve supply lines connected directly to the manifold, the manifold is needed. Due to the way they operate, the air valves designed have been named Pressure Balancing Valves (PBV) which is explained in the following section. In Figure 6 we presented the entire physical Valve Board.



(a) Entire Valve Board with 20 PBV's and Air Manifold



(b) Single PBV on Valve board

Figure 6. Valve Board (a) and PBV (b)

Custom and designed, and in Figure 6a from the Electronic Hardware, each PBV accepts an analog control voltage between 0 to 9V. The flow rate proportionally through the PBV, directly controls this voltage signal. In the corresponding air muscle Supply line, in turn controlling the pressure. Approximately cost of each PBV AU$15 to build.

4.1 PBV Design:

Between its minimum and maximum contractions, to move an air muscle to a required position. And the air muscle must be controlled by the air pressure inside the air muscle. With standard pressure regulating valves is a heavy and slow choice. (Van Ham et al., 2003) To control the position of an air muscle. The reason that fast and accurate pressure control is required (Van Ham & Daerden, 2003). For the preferred choice thus far has been to use fast switching On-Off valves. With the use of air muscles, such work involving accurate real-time position control in robot systems. And it is undertaken by the Shadow Robot Company and also by the department of mechanical engineering at the Vrije University in Belgium. For their air muscle control, both teams have utilised the same valve choice for their air muscle control. These valves are the Matrix 821NC 2/2 solenoid pneumatic valves. With their reported opening times of about 1ms, the flow rate of 180Nl/min and total mass of only 25g, currently they are about the fastest switching valves available (Van Ham et al., 2003).

Other work undertaken experimentally in the position control of air muscles where position accuracy is not critically important. From Mead Fluid Dynamics (Iovine,2000), have used valves such as the 2/2 Isonic solenoid valve. The main Applications involve using the muscle as either hard-on or hard-off. When compared to the maximum operating frequency of 500Hz with the Matrix valves These on-off valves have a maximum operating frequency of 20Hz, , for accurate pressure control, making the Matrix valves more attractive.

Currently available pneumatic valves, either on-off types or proportional. For both the cost limitations for this work exceeds. (Matrix 821NC 2/2 quote (Matrix, 2004).). Therefore for this work a custom made valve was designed and created specifically. In this particular idea, the PBV was developed and tested and due to the obtained results in Figure 15, the method used for air muscle position control was implemented. To control an air muscle, this idea requires the use of only one PBV, as opposed to the conventional method of using two on-off pneumatic valves.

The following setup was implemented in Figure 7, for using a PBV to control the pressure in an air muscle. Where one branch of the tee connects to the air muscle and the other branch of the tee connects to a PBV, while air enters a tee. In PBV, the air flow rate is controlled and set with the 'Air Flow Adjustment Tap'. While controlling the amount of air that is allowed to flow out of the system directly controls the pressure in the outlet pipe. In the out of the system low flow rate means a high pressure in the outlet pipe, since than exiting more air is entering the tee. Conversely, in the out of the system high flow rate means low pressure in the outlet pipe. The air muscle supply pipe with the tee is directly connected to the outlet pipe. The pressures must be equal in both the outlet and air muscle supply pipes. By this way, the air muscle pressure can be controlled directly.

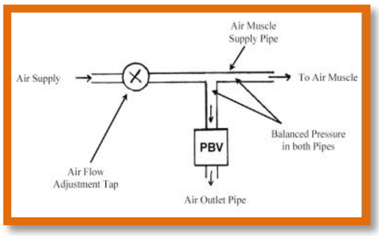


Figure 7. Air-Muscle/PBV Air Supply Setup

The flow rate out of the system controls proportionally and hence it controls the pressure in the air muscle, producing the force required from the air muscle. With the use of a modified solenoid in Figure 8, the controlled air flow rate out of the PBV was obtained. To provide a constant force on the plunger in the opposite direction of the electromagnetic force, positioning the solenoid vertically and upside down (plunger on the bottom) allows gravity. By applying different currents through the solenoid coil, the enabled air-gap distance to be directly controlled. In the out of the outlet pipe, pressure of the air flowing also provides a force in the opposite direction to the force provided by the solenoid.

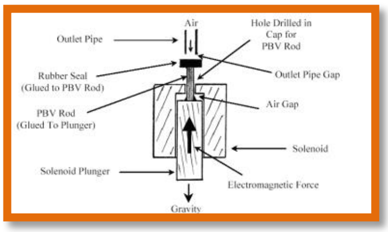


Figure 8. Modified Solenoid for PBV Usage

To the top of the plunger, attaching a rod with a rubber seal. And by controlling the solenoid's air-gap distance. In the out of the PBV direct control over the air flow rate was possible. Corresponding length to produces an 'outlet pipe gap', balancing the two opposing forces (air flow pressure and gravity verses electromagnetic solenoid force). Balancing force produced by the Proportional voltage control to the solenoid and it controls the PBV's outlet pipe air flow rate which in turn controls the air pressure in the air muscle. In the hand, complete pressure control of each air muscle is used and it was controlled solely with this custom designed PBV method. Fully proportional air pressure control to the attached air muscle directly corresponding to the current through the solenoid coil is provided by each PBV. The lack of friction makes this valve accurate for controlling fine pressure increments, since the solenoid plunger is ‘floating’. Example is by PBV method, each step of a feedback resolution of 255 steps was obtainable. To provide the required proportional control voltages, each PBV was connected directly to the custom designed electronic hardware.

V. ELECTRONIC HARDWARE SYSTEM:

In Figure 9, Custom designed and built electronic hardware represented as a block diagram, was used to interface the PC with an 8255 digital I/O card to the PBV’s. With the outputs providing limited current, the digital inputs and outputs from the 8255 card are TTL (0 - 5V / Off – On).

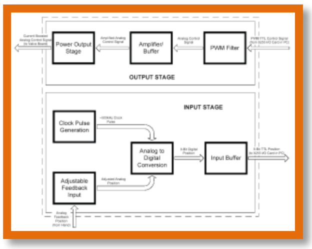


Figure 9. Electronic Hardware System Block Diagram

From the 8255 Card the PWM generated signals are not suitable for connection to the systems’ valves, as they require an analog voltage signal. The first stage that the raw TTL PWM signals must go through is a filter. Respective to the duty cycle of the PWM signal, this produces an analog voltage. This signal needs amplification and buffering. Amplification is needed to produce the required valve maximum input voltage limit while buffering is needed to provide suitable current gain to the signal. The Power Output stage is the final stage, where additional current gain is provided to the signal, at a level suitable to adequately control the air valves on the Valve Board.

The analog voltages are the input signals returned from the Hand, with magnitude directly corresponding to air muscle contraction with a potentiometer. This analog voltage must to be converted to a digital TTL signal which is suitable to interface to the 8255 I/O card in the PC. The first stage on the hand, the analog signal passes through adjusts the feedback range of the potentiometer. Maximizing available resolution regardless of the full contraction length of the particular air muscle. The analog feedback voltage adjusted is then converted to a digital 8-bit word, the maximum resolution of the position potentiometer on the Hand to have 255 steps is allowed. A separate 555-timer circuit provides the necessary clock pulse to the ADC. The converted 8-bit represented position then undergoes buffering before connection to the 8255 I/O card in the PC.

Single Channel PWM to Analog PBV Control: To accurately control the air pressure in the attached air muscle the PBV’s require an input analog voltage between 0 to9V at 200mA. A low-cost yet effective method to do this was to pulse one TTL output channel from the 8255 Card in the PC, followed by circuitry to filter out the harmonic components of the PWM waveform, leaving only the DC component.

A brick-wall filter would be most desirable, to eliminate harmonic components contained in a particular waveform. These however are expensive and very difficult to build (Palacherla, 1997). However, is to use a simple 2nd order passive R-C low pass filter, designed to filter out the high frequency harmonic components of the PWM signal. The result of such filtering allows only the DC component of the waveform to be transmitted through the filter. In this method, an analog voltage directly corresponding to the duty cycle of the PWM signal is produced.

In Figure 10 it shows the simulated effect that the low-pass second order filter had on a PWM signal (0-10V) with a 50% duty cycle in the time domain at

100Hz. In Figure 10 the ripple of the filtered waveform has peaks at 5.146V and at 4.853V, giving a maximum variation of approximately 0.3V. This corresponds closely to the physical measured value of 0.32V peak-peak. The PBV did not noticeably react to the 0.3V ripple, the result as required being a steadily positioned air muscle.

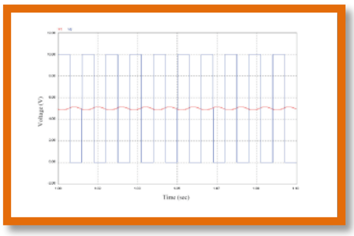


Figure 10. PWM simulation before/after filtering (100Hz)

VI. PC/GUI SYSTEM

The control heart of the overall system is the PC and Graphical User Interface (GUI), represented in Figure 11, as a block diagram. By means which the entire system is controlled, by the user how control parameters based on the system's response can be implemented.

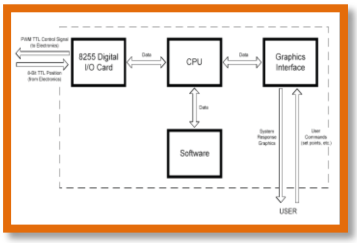


Figure 11. PC/GUI System Block Diagram

With the software using PID control algorithms total control of the system is obtained, compiled and run on a 233MHz Pentium PC. For the Hand's movement, the software contains all control algorithms and by means of a GUI that allows the user to interface with the Hand simply and easily. The software written GUI allows the user to adjust control parameters of the system (such as PID gains) to any of the Hand's joints and to see the position response at the low level. Higher level GUI usability allows the user to select individual or concurrent finger/elbow joint movements of the hand or to run a predefined sequential task program (such as picking up a bottle of water).

Data Acquisition 8255 Digital Input/output Card, attached to the PC internally. This card allows 48 separate digital TTL bits to be connected to the external electronic hardware. The card is configured so that 24 of the digital TTL bits are Inputs and the other 24 are Outputs. In the configuration, each of the 20 air muscles contained in the mechanical hand system via PWM is controlled by 20 of the digital output bits. Similarly, for the 10 degrees of freedom 16 digital inputs are used to obtain the feedback response position. (Configured as two 8 channel, 8-bit ADC's in parallel.)

VII. OVERALL PERFORMANCE

The primary objective was to create a robotic hand closely like mimic a human hand in size and to perform some manipulation tasks. Mechanically, the major one is dealing with the design of the air muscles, elbow, fingers, thumb, and forearm, proved successful in accomplishing the task of picking up an object of similar shape to a can of soft-drink. Because of the lack of feedback resolution used throughout the elbow joint then, a can of soft-drink proved to be too short to position the hand accurately to grasp the can consistently. The width of the palm of the hand is similar in height to the soft drink can. Suppose the hand was not lowered far enough, the thumb and index finger would grasp only air and not the can. This problem will be eliminated while substituting a water bottle for the soft-drink. The diameter of both objects are similar, however, by about half the water bottle is longer than the soft-drink can. The thumb to grasp around the object from the extra length allowed, producing consistent results. In Figure 12 the hand holding up a half-filled water bottle is shown.

Figure 12. Hand Manipulating a Water Bottle

From all joints at a level high enough to pick up an object in a predefined position, smooth mechanical movements were obtained. To improve the hands 'grip'. the only addition made was the addition of a rubber glove inserted over the hand. With the addition of the rubber glove, this slip was no longer a problem. First trailed without a rubber glove, the grasped object repeatedly slipped out of the hand. With the rubber glove, this slip was no longer a problem. To mimic certain human hand positions such as giving a 'thumbs-up' after completing a preset control sequence (such as transposing a bottle) the hand was also programmed or making a fist and when shaking it if the bottle were dropped. With direct comparison to a human hand these positions can be seen in Figure 13 and Figure 14.

Figure 13. Mimicking 'Thumbs-up' Position

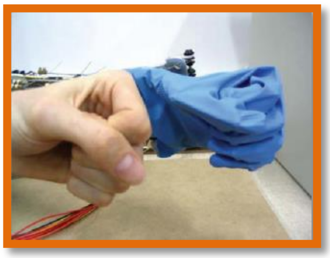


Figure 14. Hand Mimicking Fist Position

PWM to PBV to Air Muscle Position Control.

The total feedback system, encompassing the PWM to analog filtering, PBV response from the control signals, and the potentiometer A/D 8-bit feedback, all running under PID control, provides a simple low-cost yet effective means of control over the contraction percentage of each air muscle. Fig 15, shows the simple test rig was setup with an air muscle, potentiometer and PBV under PID control, and a typical response obtained. The target input was a 180 bit step sent at approximately 3.5 seconds.

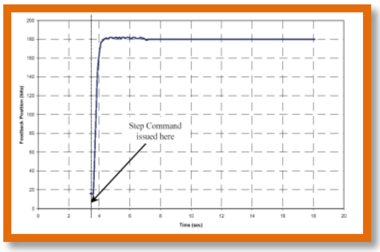


Figure 15. Tuned Response of a Single Air Muscle (at 2.5Bar supply pressure)

In Figure 15 a tuned PID control response with minor overshoot, actuating to the set-point of 180 bits (out of 255) in less than 1 second. Considering the used methods and the custom designed PBV's used to control the air pressure in each air muscle, the results proved more than adequate in providing a suitable method for actuating the entire hand-arm mechanical system is shown in Figure 15.

VIII. CONCLUSION

Overall, in building an air muscle actuated humanoid hand the design of the entire system proved successful and to accomplish the task of picking up a small water bottle.

Mechanically, the hand performed to a level satisfactory to manipulate simple objects in the manner in which a human hand would perform. The subsystems designed to. This task also proven satisfactory in terms of overall accuracy and response speed, they proved small enough in the overall scope of work performed not to hinder the creation and performance of the hand.

The primary goal of this work was to design, build and computer control a pneumatic air-muscle actuated robotic hand. It was to incorporate basic human finger, thumb, fore arm and elbow movements, and was to be built to human sized proportions. The additional goals included picking up a full can of soft-drink, grasping the can in a human like manner, and transposing the can to another position. While a soft-drink can proved to be slightly too short to be used, the hand had no problems with manipulating an object of similar diameter but slightly longer, such as a water bottle. Reliability of the hand proved accurate to pick up an object as planned once PID tuning was completed, at a 'gentle' speed.

This goal was, as once programmed in the set position without noticeable failure (dropping the object, etc).the hand would repeatedly pick up the object PID control was also accomplished, and able to control all 20 air muscles at once, with a GUI interface. At a pressure between 2 and 3 Bar as desired, all actuation was also accomplished.

Include picking up an empty can of soft-drink, and picking up a tennis ball, were also achieved additionally. Due to the lack of feedback accuracy, Picking up a ball by itself was not possible. However if the user placed the ball firstly in the hand's palm, the hand was able to grasp a ball firmly. GUI goals are the ability to control each finger individually. To move the hand's fingers in a natural way a simple demonstration sequence was also created, at a gentle speed At last, designing the entire system with a 'low-cost', enabled the entire system (excluding the PC and air compressor) to be built for less than AU$1500.

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