Development of Pipe Inspection Robot using Soft Actuators, Microcontroller and LabVIEW

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***Abstract*—Pipeline transportation is particularly significant nowadays because it can transfer liquids or gases over a long distance, usually to a market area for use, using a system of pipes. The pipeline's numerous fittings, such as elbows and tees, as well as the various sizes and types of materials utilized, make routine inspection and maintenance challenging for the technician. Therefore, the compact and portable pipe inspection robots with pneumatic actuators are required for use in industry especially in hazardous areas. Flexible pneumatic actuators with clean and safe pneumatic energy have high mobility to move in complex pipelines. High safety features such as no oil or electrical leakage, which would be dangerous if used in an explosive environment are a major factor it is widely used nowadays. As a result, the goal of this study is to propose and present the development of pipe inspection robot that employ soft actuators and are monitored by LabVIEW for usage in a variety of pipe sizes and types. This research focuses on the movement of robots in the pipeline by proposing some important mechanisms such as sliding mechanism, holding mechanism, and bending unit to move easily and effectively in the pipeline. Experiments show that with an appropriate pneumatic pressure source of 4 bar, a flexible robot using the soft pneumatic actuator can bend and move in a 2-inch diameter pipe smoothly and efficiently. It has been discovered that the proposed mechanism may readily travel pipe corners while bending in any required direction.**

Keywords*—Soft pneumatic actuator; pipe inspection robot; flexible actuator; microcontroller; sliding and holding mechanism

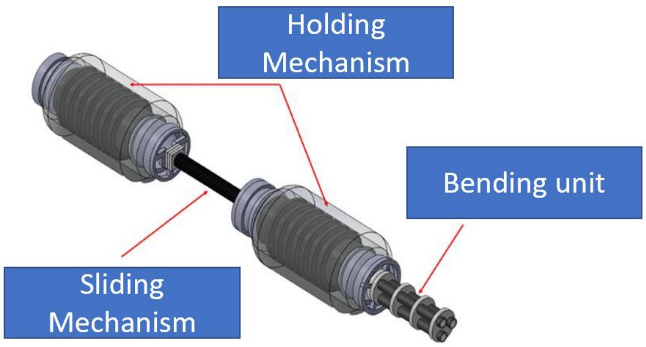
I. Introduction

Robotic development is currently one of the most important concerns of the twenty-first century, as robotics is widely used in a range of fields, including engineering, medical, agriculture, education, art, and more [1-4]. Robots have been built in a variety of ways in the industrial world to eliminate or limit human involvement in forced labor and hazardous working conditions [5-9]. Water and gas pipelines are extremely complicated due to the sizing and type of piping utilized, as well as the presence of massive numerical corners and joints. Furthermore, pipelines are the most frequent technique of transporting oil and gas from one location to another in the oil and gas business since they are more cost effective than other modes of transportation. Corrosion, fluid leakage, inefficiency, and other factors necessitate frequent maintenance of these pipelines. Furthermore, most pipelines are located underground or undersea, making direct inspections of the pipes difficult for technicians. As a result, robotic inspection has been created using a variety of pipe inspection technologies to accommodate varied pipeline configurations [10]. There have been various varieties of inspection robots produced, including the wheel type, walking type, inchworm type, pig type, and caterpillar type [11]. In pipe inspection, the robot must have good mobility to carry out the inspection operation, and it is even better if the robot has a flexible body that can alter naturally without causing any disruption or getting caught in the middle of the inspection.

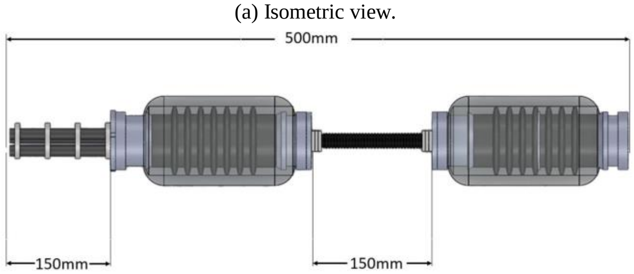
Pneumatic actuators, sometimes called air actuators, are low-cost and safe motion control devices that convert energy from pressurized gas or air into linear or rotational motion [12, 13, 14]. The scientific community has recently become more interested in appropriate and adaptable systems to investigate pneumatic actuation capabilities for increasingly complex occupations [15, 16, 17]. It is deemed feasible and safe for use in pipe inspection because it does not rely on electricity as its primary source of energy. Pneumatic actuators have been shown to be suitable for pipe inspection in different research situations [18, 19, 20] due to their ability to prevent explosions and short circuits. Furthermore, today's researchers have developed a variety of pneumatic actuators, one of which is the soft pneumatic actuator, which is widely employed in the rehabilitation sector [16]. This study used a soft pneumatic actuator on the front of the robot known as a bending unit to navigate the robot in the desired direction through the pipe. The inspection robot must include a specific mechanism, such as a holding and sliding mechanism, to stimulate robot movement during the inspection process [20]. In order to accomplish smooth and effective movement when operating inside the pipe, the pipeline inspection robot with a holding and sliding mechanism that utilizes flexible soft pneumatic actuators was designed and tested in this study.

II. Methodology

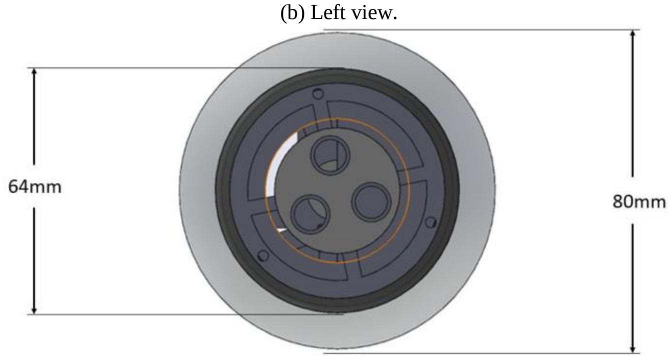
The pipe inspection robot's prototype design is shown in Fig. 1. The gripping mechanism, bending unit, and sliding unit make up the pipe inspection robot. The robot prototype is about 500 mm in length.



(a) Isometric view.



(b) Left view.



(c) Front view.

Fig. 1. Prototype Design of Pipe Inspection Robot.

The robot's prototype is shown in Fig. 2. As a navigator, this robot has a pneumatic soft actuator bending unit mounted on the front of the robot. The soft actuator can bend in any direction and adjust depending on the angle of the pipe's tees and elbows. The inspection robot's body is also equipped with soft actuator sliding and holding mechanisms. Because of its modest size, this flexible actuator is suited for use, allowing the flexible body to move organically in accordance with the soft actuator. The robot requires 6 ports for air pressure to be delivered to three primary parts: the bending unit, sliding mechanism, and holding mechanism. Because the bending unit needs to bend and regulate the direction of the robot on the X, Y, and Z axes, it has three air supplies. The holding mechanism requires two airports for the upper and lower bodies to keep the robot inside the pipe, whereas the operating and sliding mechanism only requires one port to push and pull the robot. However, as compared to the holding unit, the sliding and bending units employ different amounts of pressure. This is since the sliding and bending units are made of different materials and have different structures than the holding mechanism. The air pressure provided to the holding mechanism is lower than that to the sliding and bending unit. Only the holding mechanism component employed a 6 mm pneumatic fitting, whereas the rest of the pneumatic fittings were 4 mm.

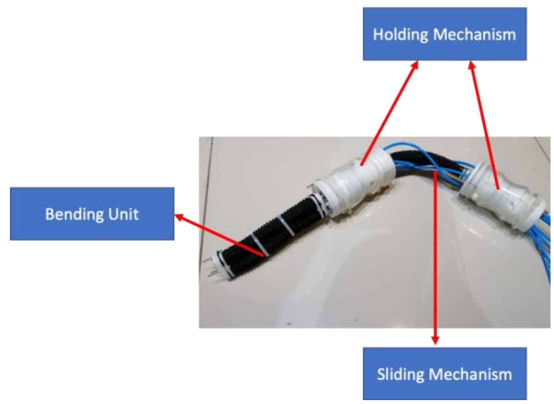


Fig. 2. Prototype of Robot.

III. Control System

Fig. 3 depicts the robot control system in block diagram. A sliding mechanism, six on/off control valves, an Arduino microcontroller (MEGA 2560 REV3), and a personal computer are used to build control system programming and send commands to the Arduino in the moving process.

The working principle of the proposed robot is shown in Fig. 4. First, the pipe holding mechanism at the end of the robot expands so that it can hold the pipe (1). Next, actuators in the sliding mechanism are pressurized, then, the sliding mechanism extends (2). When the actuators reach at maximum length, the top of pipe holding mechanism expands to hold the robot inside the pipe (3). Next, pipe holding mechanism at the end of robot contracts (4). Then, the compressed air in chambers of three actuators is exhausted. At the same time, the sliding mechanism contracts and end holding mechanism moves forward (5). By repeating these processes from (1) to (5), the robot will move forward as an inchworm. On the other hand, the backward motion can be realized by using the opposite operation mentioned above. In the case to steer the robot toward desired direction in pipe joint, first, bending actuator of the sliding mechanism is generated by pressurizing one or two extension type flexible actuators. Next, from this condition of bending motion, three actuators in the sliding mechanism are pressurized. Then, the robot can move forward while changing moving direction. The robot can move to six directions by pressurized one or two extension type flexible pneumatic actuators on the sliding mechanism.

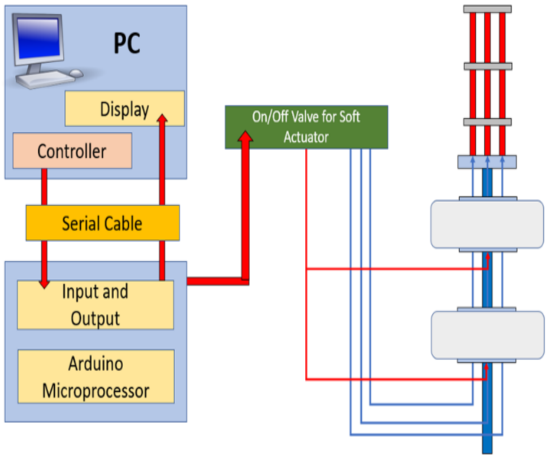


Fig. 3. Block Diagram of the Control System.

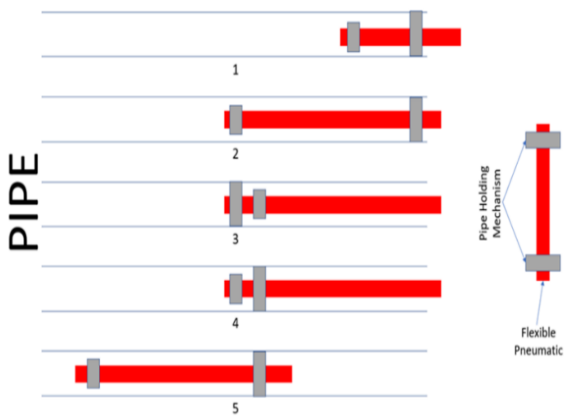


Fig. 4. Operating Principle of the Inspection Robot.

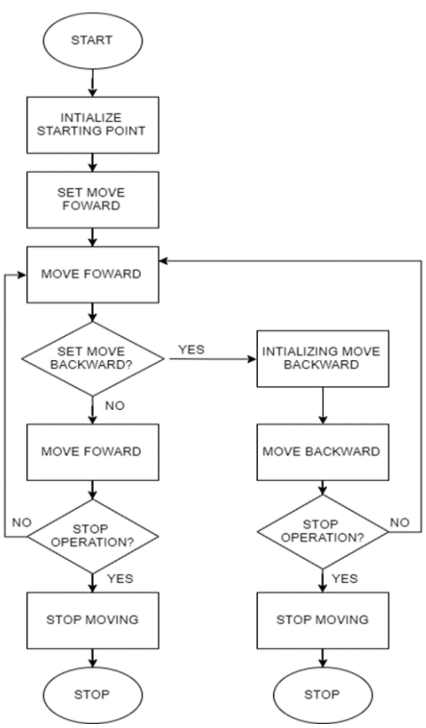


Fig. 5. Prototype Flow Chart.

The control system's flow chart is shown in Fig. 5. The operator can manually control and monitor the inspection robot in this investigation via a graphical interface. The Arduino will receive and process all input data from the interface before sending the output to the pneumatic valve. The pneumatic valve regulates the flow of pneumatic pressure into and out of the soft actuators and silicone rubber tube. The inspection robot can travel forward or backward, as well as bend left or right, while functioning in the pipe, due to the pneumatic valve's control system.

IV. Result and Discussion

The controller's interface is shown in Fig. 6. Each component that must be controlled by the operator is shown on the LabVIEW interface. The gear in the Fig. 6 determines whether to move the robot forward or backward when operating inside the pipeline. Toggle up for forward movement and down for backward movement. The program's block diagram alters as a result of the operator's instructions. When a component is turned on, the light turns green, as seen in the Fig. 7.

All robotic systems are started using the start pushbutton as a switch mechanism. The system will not function unless this button is pressed. Head (H), Body (B), and Tail (T) indicators are key components for the holding and sliding mechanism. Holding mechanisms that utilise silicone rubber tubes as holdings between pipes and robots are designated by the letters H and T. For push and pull approaches, B is for the sliding mechanism that uses a soft actuator to extend forward or backward. The 3-axis controls X, Y, and Z in Fig. 6 are used to control the robot's direction. This controller can move in six directions: X, Y, Z, XY, XZ, and YZ. When the robot reaches the pipeline intersection, this navigation system is required.

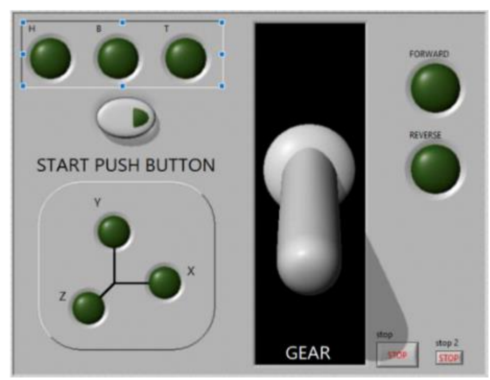


Fig. 6. LabVIEW Controller Interface.

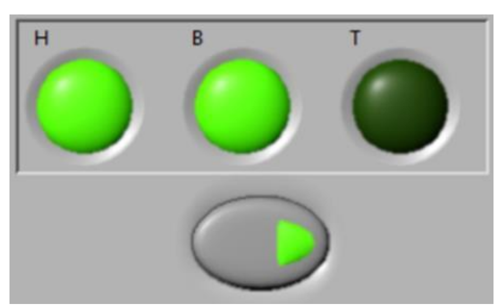


Fig. 7. Light Green Colour on Interface.

Fig. 8. View of the Curving Movement using a Bending Unit.

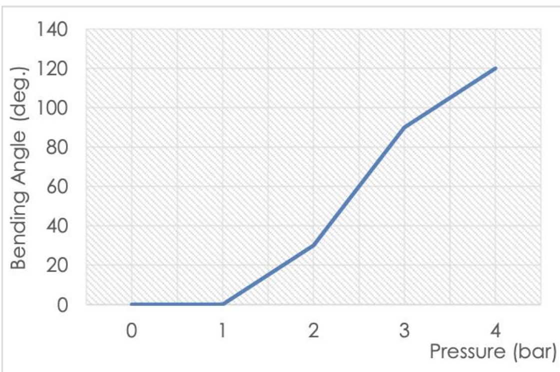


Fig. 9. Graph Bending Angle against Pressure.

For the bending unit, it consists of three pneumatic soft actuators that are joined together and can bend when pressure is applied to it. A silicone rubber tube with a diameter of 2 mm on the inside and 4 mm on the outside makes up these soft actuators. The soft actuators are placed parallel every 120 degrees from the center of the disc. By placing three soft actuators in the X, Y, and Z axis positions, the bending unit can generate 6 directions to bend in the X, Y, Z, XY, XZ, and YZ axes. The bending motion was caused by a combination of artificial muscle contraction and expansion concepts. When air pressure is applied to the soft actuator, the resulting force increases as the air pressure is increased. Fig. 8 depicts the use of a bending unit to create a curved movement. Fig. 9 depicts a bending angle graph when pressure is applied to a bending unit. Based on Fig. 9, with a pressure of 4 bar, the maximum bending angle can be achieved up to 120 degrees. However, if the air pressure is less than 1 bar, the bending unit will not have enough pressure to move and bend in the appropriate direction.

The diagram of the holding mechanism when expanding and contracting outside and within the pipe is shown in Fig. 10. The mechanism is made from a single silicon rubber tube that may expand and shrink. The device has a 50 mm exterior diameter and a 100 mm length. The following is the working theory for pipe holding. As supply pressure is applied to the tube, it can expand until it reaches the inside diameter of the pipeline. A maximum outer diameter of 80 mm can be attained with a supply pressure of 2 bar. When the input pressure is withdrawn, the mechanism returns to its previous shape by restoring the force of the rubber. This device can prevent the robot from slipping in the pipe by using silicone rubber as the main material and repeating the processes specified. Because of the robotic mechanism's ability to expand to meet piping sizes, the robot can be employed in a variety of piping systems. Robots with the ability to work in several dimensions of the piping system will cut inspection costs and make the operation easier to complete.

An experiment was carried out to assess the consistency of the tested flexible sliding mechanism. The sliding mechanism is made up of a single soft actuator that connects the robot's head and tail. To archive a maximum movement, this actuator will extend to its maximum length. After the upper body robot grips the pipe, the pressure is released, and the robot's lower body is pulled, and the process is repeated. The experiment of extending a soft actuator in pushing and pulling action is shown in Fig. 11. The movement of the robot can be viewed using a ruler as a reference, and if the pressure is maintained, the soft actuator will continue to stretch. Because the actuator may burst, the maximum pressure supplied must not exceed 5 bars. The greatest extension, as indicated in Fig. 11(4), can be seen.

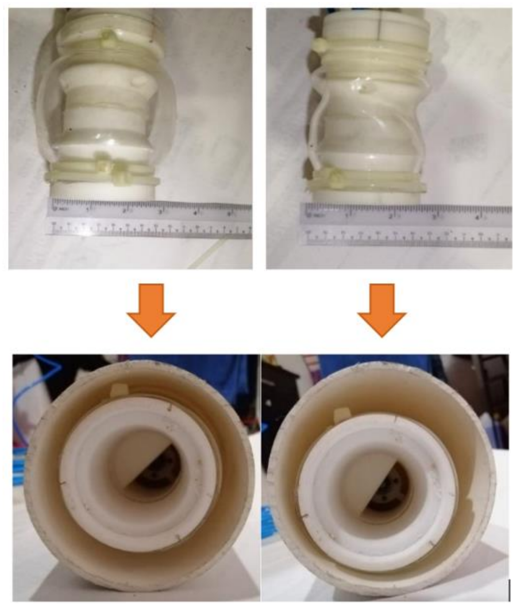


Fig. 10. Diagram of the Holding Mechanism when Expanding and Contracting Outside and Inside the Pipe.

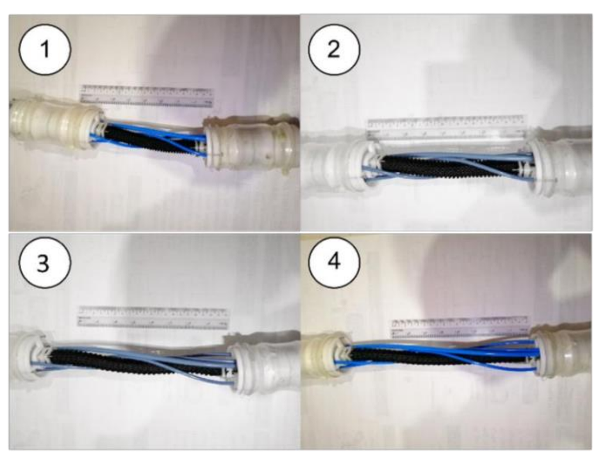


Fig. 11. Extension Testing of Soft Actuator.

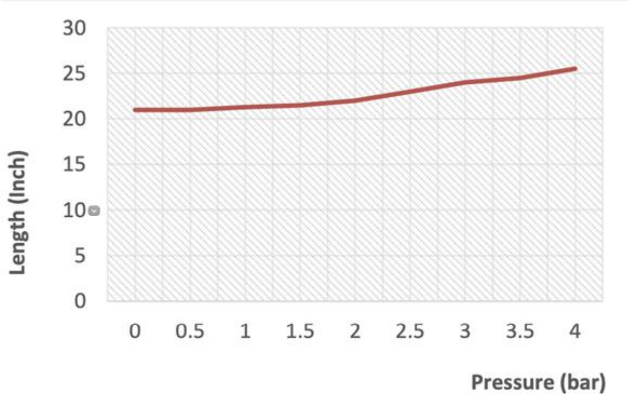


Fig. 12. Extension (Inch) against Pressure (Bar).

The extension of the sliding mechanism against pressure is shown in Fig. 12. During extension testing, we discovered that when the air pressure is below 2 bar, only minor movement is visible. As a result, the air pressure provided to the actuator must be greater than 2 bar in order to see some physical change on the soft actuator. Data was logged from the soft actuator's initial length (150 mm) to its maximum extension (180 mm). We can determine the amount of pressure required to move the robot at the ideal speed and length using this graph.

Fig. 13 shows the prototype moving effectively through the 2-inch pipe. According to the statistics, depending on the air pressure, the time necessary for the prototype to flow through the pipeline will grow or decrease. The prototype moves more quickly at high pressure than at low pressure because high pressure air allows the sliding mechanism to expand further and reach its full length. From the experimental results, with a supply pressure of 4 bar, the proposed robot can move through a 2 -inch diameter pipe as far as 3 meters for 37.8 s. As a result, the suggested inspection robot is particularly efficient in terms of speed relative to size, thanks to its compact and lightweight body size and ability to move fast inside the pipe.

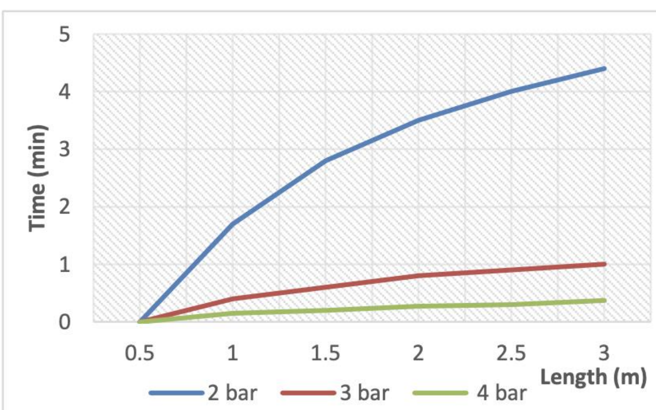


Fig. 13. The Graph of Distance Compared to Time (Min).

Fig. 14 shows a picture of the holding mechanism being tested when the applied pressure is 0 kPa and 200 kPa. When the applied pressure is 200 kPa, the holding system can hold 3 inch-diameter PVC pipe, as can be seen on the right side of Fig. 14. The radial orientation of the rubber tube expands when the input pressure is applied to it. When a supply pressure of 200 kPa is applied, a peak exterior diameter of 80 mm can be attained. The device returns to its previous condition when the input pressure is released.

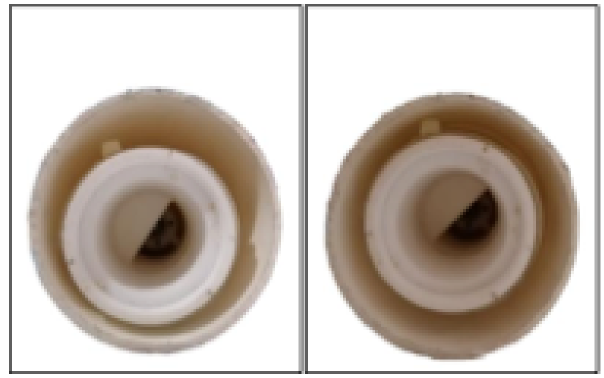


Fig. 14. Holding Mechanism Testing.

The holding mechanism has no effect on the robot's speed because it just serves to grab the pipeline. The holding mechanism can assist the robot in moving inside the pipe more efficiently with proper movement operation and steps. Furthermore, when fed with a pressure of 200 kPa, the holding mechanism may adjust the size of the rubber tube up to a maximum of 80 mm in diameter, preventing the robot from slipping inside the pipe. This will enable the inspection robot travel more smoothly in the pipe with many tees, elbows, and sockets, in addition to the robot configuration that includes a bending unit and sliding mechanism.

V. Conclusion

The purpose of the project is to develop the soft actuator inspection robot that can move smoothly and efficiently in different pipe sizes. The proposed inspection robot is equipped with a bending unit, sliding mechanism, and holding mechanism to help it move inside the pipe more quickly and smoothly. To control its navigation, the project has also built an interface using LabVIEW to operate the robot more easily and securely. This interface can also instruct the robot to bend in 6 predetermined directions in addition to moving forward or backward. From the experimental results, with a supply pressure of 4 bar, the proposed robot can move through a 2 - inch diameter pipe as far as 3 meters for 37.8 s. Moreover, by supplying a pressure of 4 bar, the bending unit can produce a maximum bending angle of 120 degrees. Then, when supplied with a pressure of 200 kPa, the holding mechanism can change the size of the rubber tube to a maximum of 80 mm in diameter and can prevent the robot from slipping inside the pipe. In conclusion, the aims of this project have been accomplished with a soft actuator robot that can travel smoothly in the pipe and the proposed control system can control the path of the robot using the constructed interface.

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