Pneumatic Active Suspension System (PASS)

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***Abstract*— Most current vehicles are suspended in the conventional manner which uses passive springs to absorb impacts. However, it only has a limited effect on controlling the vertical displacement of the wheels. Inspired by pneumatic articial muscles in soft robotics, we introduce a new design named pneumatic active suspension system (PASS), which uses pneumatic actuators to replace traditional expensive actuators. PASS is low cost and light-weighted. It achieved a better balance between precision, mass and cost. Here we demonstrate its prototype, a plate balancing platform, which takes the output from a bang-bang controller controller that uses a gyroscope sensor mounted on the platform as the input. It breaks through the limitation of the passive suspension system, which can actively provide cushion to balance the platform.**

I. INTRODUCTION

A vehicle suspension is the system that connects a vehicle to its wheels and allows relative motion between the two[1]. The aims of using a vehicle suspension are to enhance road handling and insulate the occupants from undulations in the road surface[2]. For road handling, the vehicle body and wheels should closely follow the vertical force from the road surface, while for ride quality, the suspension is supposed to isolate the vehicle from irregular roadway inputs. Therefore, there are always conflicts between road handling and ride quality. Conventionally passive suspension systems use springs by which a vehicle is cushioned from road conditions. Fixed springs can only achieve a limited level of compromise between those two demands[3], [4]. However, active suspension systems can overcome the limit of passive suspension systems by directly controlling separated suspension force actuators. It can vary its parameters depending upon current conditions to minimize the detriment of the conflicting demands of road handling and ride comfort.

Most studies in the actuators for active suspension systems have focused on using hydraulic and electromagnets[5], [6], [7]. The advantages of hydraulic or electromagnets active suspensions can be summarized as: (a) high force density, (b) active force control, (c) effective elimination of roll motions, (d) commercial availability of the various parts, and (f) commercial maturity[8], [9]. The disadvantages can be described as: (a) low-bandwidth due to high system time constant, (b) environmental pollution due to hose leaks and ruptures, where hydraulic fluids are toxic, (c) no energy regeneration due to irreversible actuator, (d) complex structure, and (e) high cost[8], [9]. Therefore, inspired by low-density, thin-walled polyethylene tubing pneumatic articial muscles from soft robotics, we introduce a new light-weighted design named PASS, which use pneumatic muscles to replace traditional expensive actuators. The main body is also simple to construct from low cost and readily available materials and requires no casting or molding. It achieved a certain level of compromise between precision, weight and cost. The prototype of PASS is shown in Fig. 1.

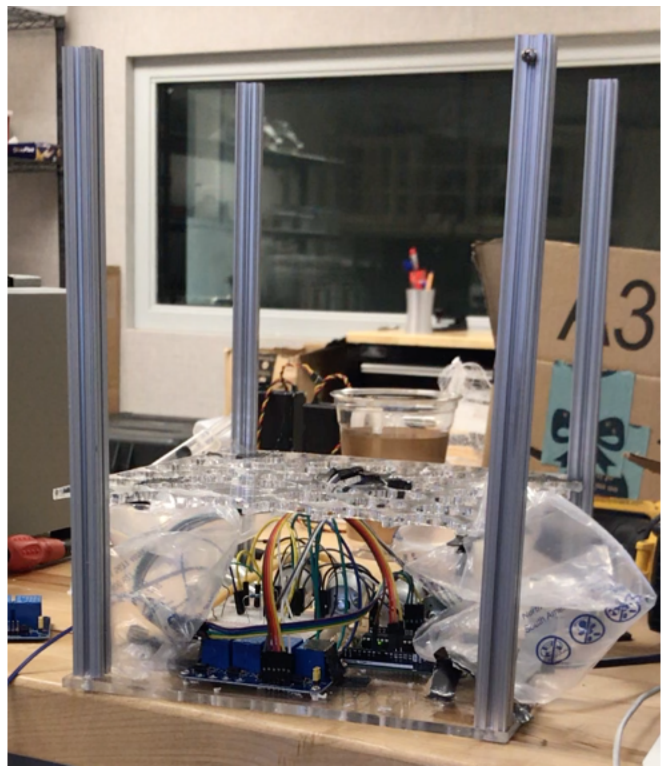

Fig. 1. Prototype of PASS.

This paper first describes the design and structure of PASS. Next we analyze its plate balancing behavior and test its performance by using different objects and methods to simulate the displacement of vehicles. Such a active suspension system has potential for its light-weight and low cost. Future work is described in the end because there are several places that can be improved.

II. DESIGN OF PASS

The plate balancing platform described in this paper has a body that consists of four parts: a top plate, four pneumatic muscles, a base plate and a control system (Fig. 2). The gyroscope sensor was attached to the top plate and the control system was mounted on the base plate.

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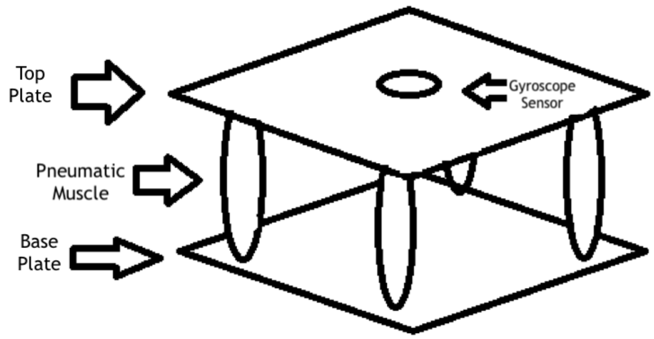

Fig. 2. Structure of PASS.

A. Components and materials

- The top plate and the base plate were made from clear plastic acrylic boards which were recycled from laser cutting materials.
- The pneumatic muscles were made using plastic packaging air bags.
- The electronic components of the control system and their connection are shown in Fig. 3. All processing was done on an Arduino Uno R3.

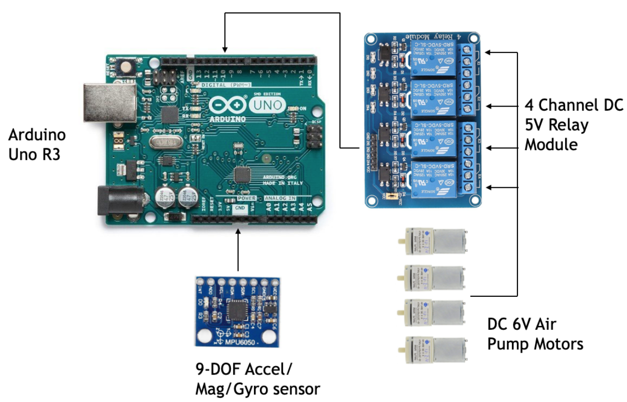

Fig. 3. Control system of PASS.

  - Arduino Uno R3 is an open-source microcontroller board, which has enough pins to support the multiple outputs for independently controlling four pneumatic muscles.
  - We use direct current (DC) 6 Volt mini air pump motors to actuate the pneumatic muscles. The air pumps and pneumatic muscles were connected by rubber tubing.
  - The DC 5V relays were used as on/off switches to establish the connection between the latter control board and the air pump motors.
  - We used the GY521 IMU sensor as a gyroscope sensor to monitor the tilting angle of the top plate.

The connection of the control system in PASS is shown in Fig. 4.

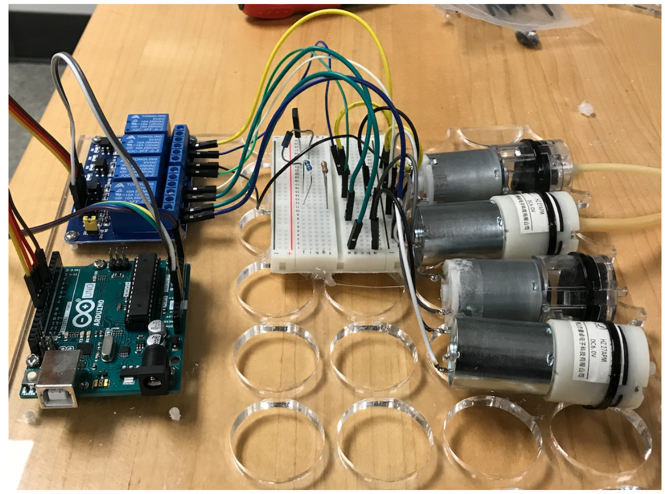

Fig. 4. Connection of the control system in PASS.

B. Workflow

The workflow of the control system is shown in Fig. 5. when the gyroscope sensor detects a tilt movement of the top plate, it will measure the tilting angle and send it to the Arduino controller. The controller will compare this angle with its preset threshold. If the angle is greater than the threshold, it will send independent on/off control signals to different air pressure control modules. Those switches will turn the air pump motors on/off to actuate the pneumatic muscles until the tilting angle of the top plate is below the predetermined threshold.

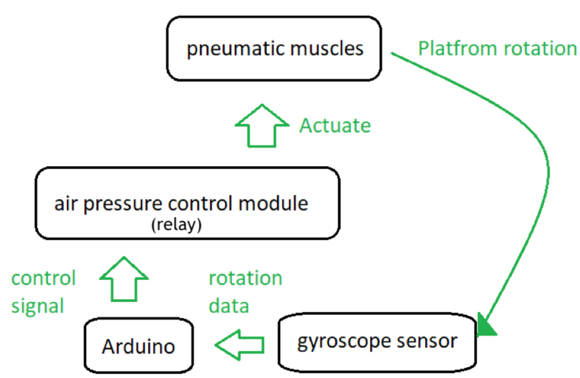

Fig. 5. Workflow of PASS.

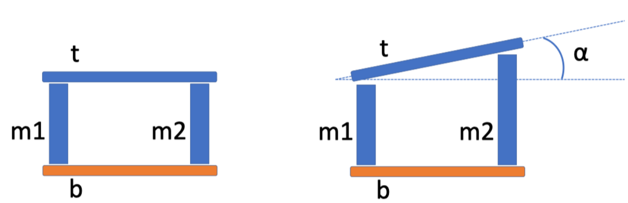

Fig. 6. Model of PASS.

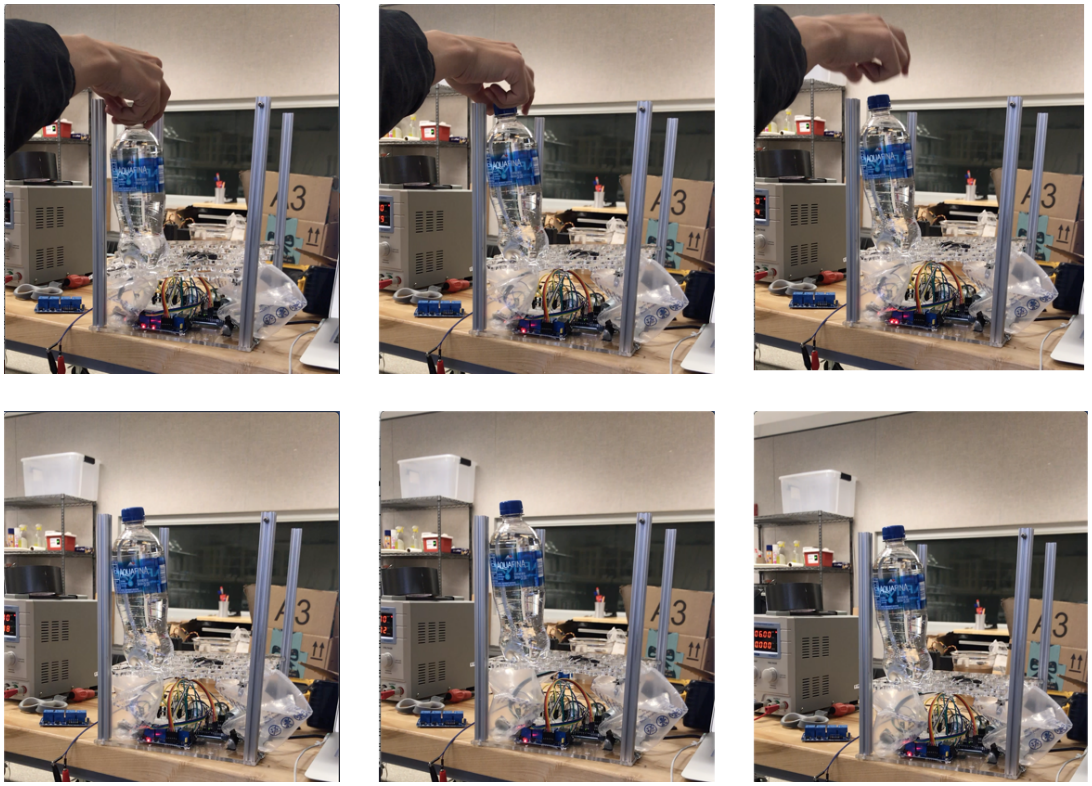

Fig. 7. Result of PASS.

C. Modeling

Here we present a model for PASS (Fig. 6). Any vertical displacement of the top plate can be decomposed into two orthogonal components: roll and pitch, thus we simplified our design by placing two pairs of symmetric pneumatic muscles along the diagonal lines of the top plate, one pair to control the roll angle and another pair for the pitch angle.

As shown in Fig. 6, $m1$ and $m2$ are one pair of pneumatic muscles at the diagonal, t is the top plate and b is the base plate. When there is an angle α along roll/pitch axis, $m1$ will inflate until $m1$ and $m2$ are in the same height where α becomes zero. Therefore, the top plate remains horizontal. The same idea is applied to another pair of pneumatic muscles

Based on this model, any vertical displacement can be corrected by controlling height of two pairs of pneumatic muscles via inflation and deflation. Note that this system cannot handle the horizontal displacement of the top plate since the entire top plate stay at the same horizontal location when there is a movement along the vertical direction.

III. RESULTS

We conducted many experiments to test PASS under different conditions. It was able to correct vertical deviations and remain still horizontally. Fig. 7 shows the result of one test when a water bottle was placed on the corner of the top plate of PASS. First, the top plate was uneven, then the control system of PASS started to reduce the tilting angle of the top plate by inflating the pneumatic muscle closest to the bottle. In the end, the top plate would remain being leveled horizontally.

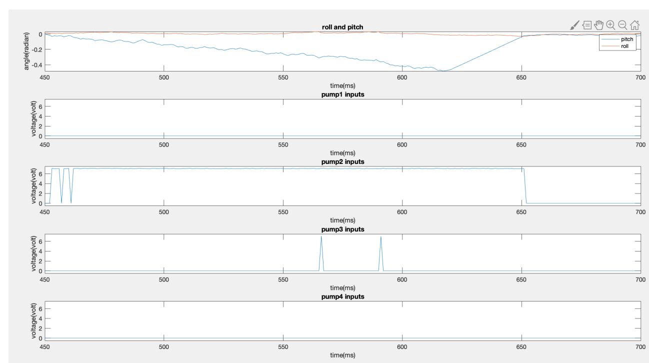

Fig. 8. Control signals from Arduino.

In order to have a better understanding of our system, we ran several experiments on PASS and exported the angle of the gyroscope sensor and control signals of the four actuators from the controller to MATLAB to plot working states of four air pumps. Fig. 8 shows the process when there is an angle of pitch on the top plate. The first subplot illustrates the variation of the roll and pitch angle. The rest four subplots displayed different working status of the air pumps.

If the top plate of the system is horizontally balanced, the roll and pitch angle will be zero. In the beginning, all air pump have low electric potential. When there is a slight tilt along the pitch axis, only the pump 3 receives the “on” signal

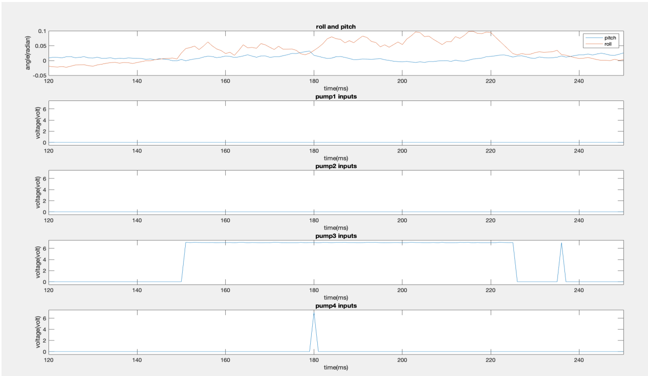

Fig. 9. Control signals from Arduino.

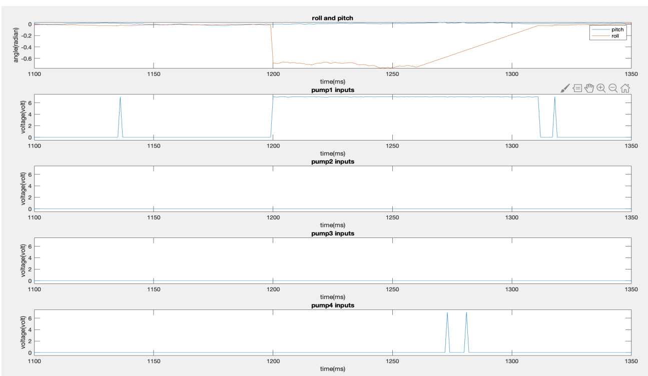

Fig. 10. Control signals from Arduino.

to inflate its pneumatic muscle until the pitch angle becomes zero. Similarly, Fig. 9 depicts the actuator response to a change of roll angle, and Fig. 10 shows the actuator response when there is a change of both the roll and pitch angle. According to our experiment result, PASS's load bearing capacity is very strong. It can even balance heavy objects such as a brick or a shot put.

IV. CONCLUSIONS

Prior studies of passive and active automotive suspension systems have been reviewed in this paper. Furthermore, structures, models, and features of various automotive suspensions have been summarized. This paper compared various automotive suspensions from the aspect of structure, weight, cost, ride comfort, handling performance, reliability, dynamic performance, energy regeneration, and commercial maturity.

Active suspension systems will be the future trend of automotive suspensions due to its simple structure, accurate and flexible force control, high ride quality, good handling performance, and energy regeneration. Inspired by the bright future of active systems and soft robotics, we designed PASS. In this paper we demonstrate its design, configuration of control system and mathematical model. We also proved its feasibility with experiments and demos. PASS shows its excellence in light weight, low cost, acceptable accuracy and high force density.

Still, the current PASS is a prototype with drawbacks, due to the limitation of materials. In the future, we can improve its structure by removing hard materials to make it more soft. Also we can replace the bang-bang controller with a proportional integral derivative (PID) controller. Compared with the bang-bang controller, the PID controller enables better control over the process.

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