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# Portable Autonomous Window Cleaning Robot

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**Abstract:** The idea of having a compact and autonomous office or house window cleaning robot is quite simple and very attractive. This small window climbing robot with pneumatic suction cups should be able to move autonomously along an outside surface of high-rise building office window with a relatively large area and meantime clean and wash it. Being manually attached to the outside surface of the room window the robot will execute and accomplish the task of window cleaning automatically in a predefined pattern. The sensory system will help to navigate the robot. It is noted that window cleaning robots are commercially available but pricey (in the range of USD 5000 or more). The designed robot is lightweight, small size and cheap because it is driven only by one rotary actuator and system of properly arranged conventional belts and pulleys. It uses the suction cups to stick to the window pane and set of optical sensors to detect the window frame. The microcontroller is programmed to move the robot in a specific pattern depending on the sensory data. There are no similar reasonably priced rival products available in the market yet.

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## 1. Introduction

Normally cleaning of wide windows on tall and multi-story buildings is quite tedious and very dangerous procedure. It can be done outside either using hoisting machines with manual cleaning or very rare by sophisticated, complex, large, heavy and very expensive automatic cleaning machines operated manually from the ground floor. These large machines, besides, have to carry a bunch of umbilical pneumatic and electrical cables while cleaning the windows. As a result, they are not popular in housekeeping operations. Therefore, the use of autonomous window

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climbing and cleaning robots attracted the attention of many designers.

A detailed review of wall climbing robots categorizing them into six distinct classes based on the adhesive mechanism was presented [1]. The review concludes by expanding beyond adhesive mechanisms by discussing a set of desirable design attributes of an ideal glass façade cleaning robot. A small window-cleaning robot (WCR) was specially designed for utilizing in a domestic environment [2]. The robot climbs on the surface of window glass by means of four suction cups and wipes the surface simultaneously with a rotational wiper. WCR is characterized as lightweight and mini-size. Various shapes and mechanical structures of robots were designed by the researchers. The proposed was a robot which consists of a triangular frame and uses suction cup based adhesion technique to adhere to the glass surface [3]. The frame consists of an automated cleaner which is run by motors and pre-programmed microcontrollers. The automated cleaner moves in the vertical direction within the frame using the threaded shaft. Another work highlights the development of washing-cleaning or periodical inspection of operational robots systems, proposed to use at the exterior frontage of buildings that are built from modular glass panels [4]. Some other designed robots are able to independently climb and descend in the vertical direction and cleans in the horizontal direction [5]. It takes the circling tracks as supports for climbing up and down between strips and moving horizontally along one strip around the ellipsoid. In a separate work, a machine is proposed that can stick on dividers and climb upwards to clean the glass of high-rise buildings [6]. The aim of another work is to design, develop and implement Window Washing Robot which helps to achieve low-cost window cleaning device [7]. Some simulation studies were conducted to demonstrate the feasibility of a robot system to act and mimic the human operator; an end effector had to be designed to accommodate different tools such as applicator and squeegee; the payload for tool handling, sensory feedback requirements; force and compliance control; and finally the cost of the overall system had to be feasible [8]. Another work highlights the development of the window cleaning robot for cleaning a single large windowpane such as a show window [9]. It requires the following demands to apply the window cleaning robot for the practical use: 1) Clean the corner of a window because fouling is left there often. 2) Sweep the windowpane continuously to prevent making striped patterns on a windowpane. The other robot named Windro adheres to the surface of window glass by means of four permanent magnet pairs between an inner unit and an outer unit rather than using vacuum suckers for the energy efficiency and safety [10]. An inner unit and an outer unit are in charge of navigation and cleaning, respectively. A novel tethered window cleaning robot named a “SkyScraper-I” was also designed [11]. The SkyScraper-I has the functions to approach all the windows located on one side of a building by controlling the lengths of a pair of suspending tethers from the top of the building and to clean the whole surface of the windows. The robot consists of the vertically suspended sliding rod, a pair of clamping arms with clamping suction rollers on both ends, and a squeegee sliding mechanism to wipe the window.

A few authors have developed an autonomous small-sized robot which can be used for glass window's cleaning even on not fully-flat walls [12]. In their design, there are two major ways for the motion control of the autonomous cleaning mobile robot, which are reaction-based control method and model-based control method. The efficiency of the cleaning using the reaction-based method is lower than one using the model-based method. Another study aimed to develop high efficiency and high reliable glass cleaning robot [13]. The robot is simple in construction and serves for glass and floor cleaning. The proposed robot is of hanging type and motion is given to it by using special rigging designed. Thrust fan is provided to provide thrust between the brush and wall for proper cleaning. Spraying of soap water and pure water is controlled by a microcontroller. A separate work has proposed a robotic building facade cleaning system which is directly subjected to minimize human labor [14]. The sensor for detecting contamination of building's outer-wall glass was proposed. Kalman filter was used for estimating robots' status with the contamination of the window glass. Through the simulations, an effective way of task execution is introduced and the feasibility was verified with the proposed sensor-based motion control algorithm. Another robot was developed that can climb the vertical pane by rotating a crawler that has general purpose suckers [15]. The robot can climb more simply and safely than other methods because it uses a simple mechanism. A description of another robotic facade cleaning system (denominated *CAFE*) is proposed and, after that, the selected control architecture and the implementation of this concept in the real system are implemented [16]. There is another autonomous mobile robot, which moves on both, horizontal and vertical surfaces using an electro-pneumatically vacuum cups attachment system [17]. The original robot construction, developed as a cleaning robot, includes two triangular platforms that provide a lightweight. The literature review shows that there many researchers who are interested in designing robots for windows cleaning. It becomes especially important for high rise building where the safety of the human is an essential task. The following describes the design and implementation of a lightweight and small size autonomous robot that is energy efficient because of a single actuator drive to track the window.

## 2. Robot overview

The robot is a compact 37x18 cm rectangular device weighing about 3.5 kg which is able to move around the window and clean the glass with its soaked in detergent sponges (Fig.1). It sticks to the window glass with 8 vacuum cups separated into two groups of 4 pneumatically connected cups (Fig. 2).

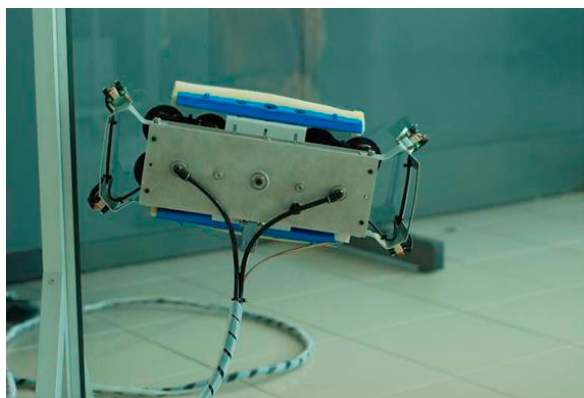


Fig. 1. Developed robot

By alternatively releasing and pneumatically powering these two groups of vacuum cups and simultaneously turning body using specially designed belts and pulley system the robot is able to take steps i.e. move along the window pane. The cleaning is done by the pair of sponges attached on both sides of the robot and dragged along the path.



Fig. 2. Internal components

The pneumatic, electrical and electronic control units of the robot are located in a specially designed compartment on the top of the pneumatic compressor (Fig. 3). The umbilical cords and pneumatic pipelines are tight together and deliver power from the controller to the robot moving on the window glass.



Fig. 3. Pneumatic compressor with the controller box

### 3. Robot subsystem

The robot is electrically and pneumatically activated. It consists of the electrical and electronic controller unit, pneumatic drive system, and mechanical structural and transmission components.

#### 3.1 Robot Mechanical Subsystem

The core of the mechanical subsystem is pulley and timing belt subsystem driven by one input DC motor (Fig. 4). The motor drives the belt-pulley mechanism through a worm gear system.

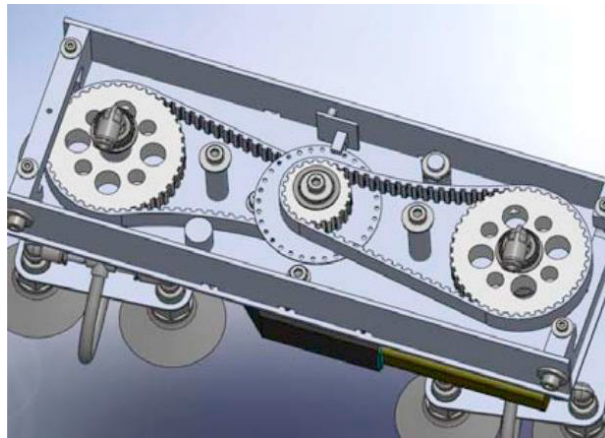


Fig. 4. Belt-pulley system

When one of the groups of suction cups are attracted to the window surface and the motor at the middle shaft is actuated the entire body of the robot will rotate through a preprogrammed angle ( $\alpha$ ) about the axis of the stationary suction cups. The motor transmits the motion via one of the timing belts. Meantime the other (free) group of suction cups will rotate in the counter direction an angle ( $-\alpha$ ). The motor then transmits the motion via a second timing belt. This mechanical arrangement can serve two purposes at once:

- Rotate the body of the robot in order to advance it along the window surface

- Restore the original orientation of the suction cups while the body rotates with respect to the stationary frame of the window surface. It will thus successfully prevent the twisting and tangling of umbilical pipelines that supply an air to the cups

While moving along the surface the robot wipes the glass with two sponges on a special bracket fastened to the swinging robot body (Fig. 1).

### 3.2 Robot Pneumatic Subsystem

The pneumatic subsystem consists of 8 suction cups connected in two groups, two directional control valves (generator and ejector), vacuum generator valve, flow control valve, non-return valve, vacuum switch, silencer and air compressor system with an accumulator. Fig. 5 shows the view of controller box with pneumatic components. Both directional valves are solenoid actuated and spring returned.

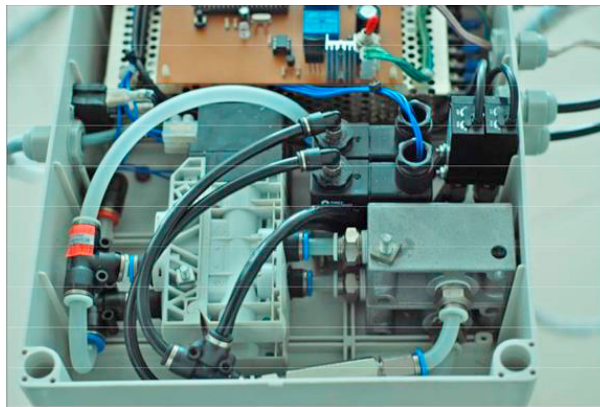


Fig. 5. Two directional control valves

The schematic diagram of the pneumatic subsystem is shown in Fig 6. The operation of the pneumatic subsystem takes place in the following order:

- When generator valve (A) is on, vacuum generator (C) is activated. It creates a vacuum in the suction cups (G) and non-return valve (D) is opened due to the generated difference in pressure on both sides of the valve.
- Once the desired vacuum level has been reached, the vacuum switch (F) sends a signal to the controller which will turn off the generator valve (A). This technique is implemented to save air accumulated in the tank, reduce the use of the compressor and save the energy consumed by the robot
- When the generator valve (A) is off the non-return valve (D) will cut off the supply line to the cups due to the spring and ball closing the non-return valve passage. At this stage, the negative pressure is maintained in the suction cups although the vacuum generator is inactive.
- The robot controller is continuously monitoring the state of the vacuum switch (F). If vacuum level drop below the set value, the controller will activate the generator valve (A) to restore the required vacuum.
- To release the suction, the ejector valve (B) needs to be actuated to enable access of small amount of air into the suction cups through the variable flow control valve (E). The advantage of blowing the air out of the suction cups is to repel slightly the cups from the window glass to take a step. It will prevent free cups from rubbing against the glass while the body is swinging to take a step along the glass.

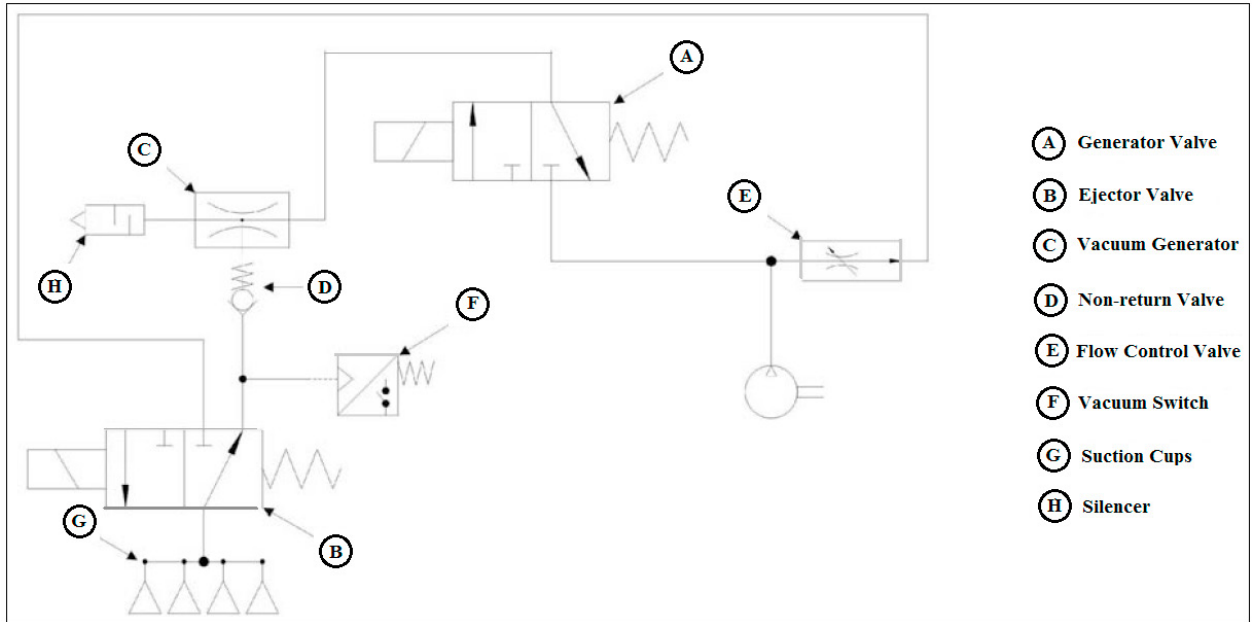


Fig. 6. Schematic diagram of the Pneumatic subsystem

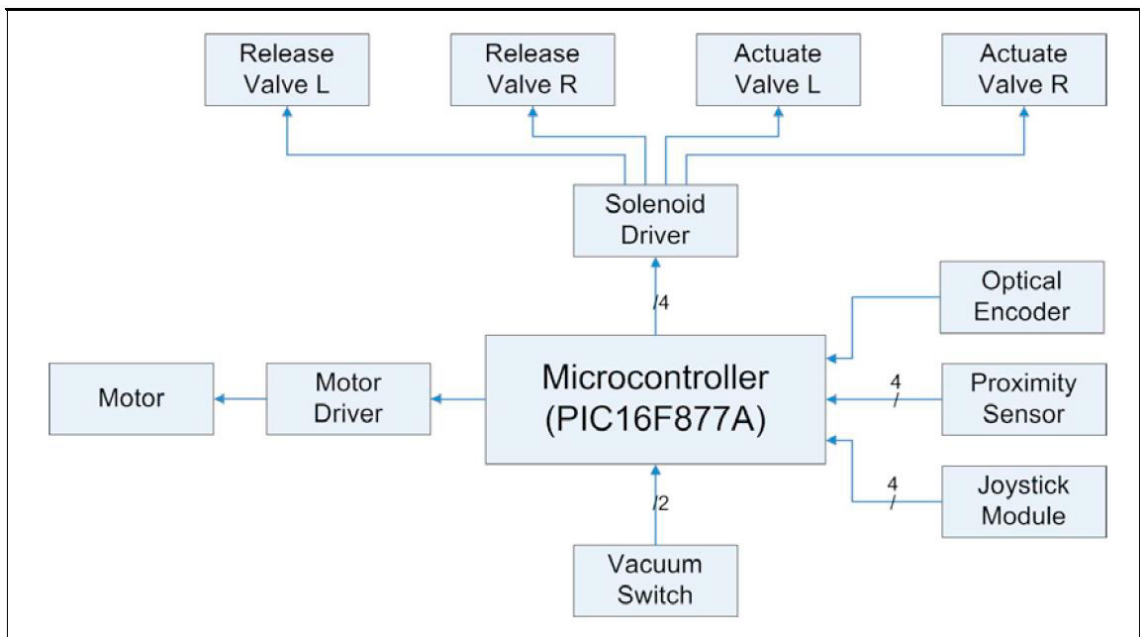


Fig. 7. Schematic diagram of the Pneumatic subsystem

#### 4. Robot operation

The robot can be operated in two distinct modes:

- i) *Automatic mode* – when the operator places the robot on the lower left or right corner of the window pane and the robot move autonomously according to the preprogrammed pattern. The program controls the angular motion of the robot body as well as the timing when the two groups of suction cups are alternatively powered or unpowered. The decision making in this mode depends on reading from the four proximity sensors located at every corner of the robot body and facing down to detect the reach of the window sash (Fig. 8). According to the program, the robot starts its motion from one of the corners and ends up its motion by coming back exactly to the same corner. Few sequential positions of the moving robot from initial left bottom corner position is shown on computer generated drawing Fig. 9.

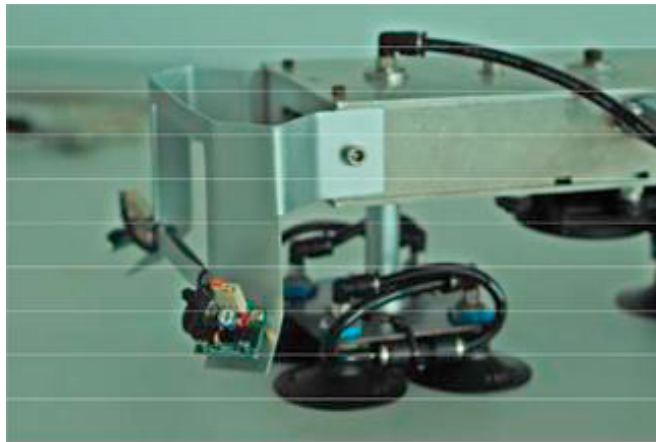


Fig. 8. Robot facing the widow

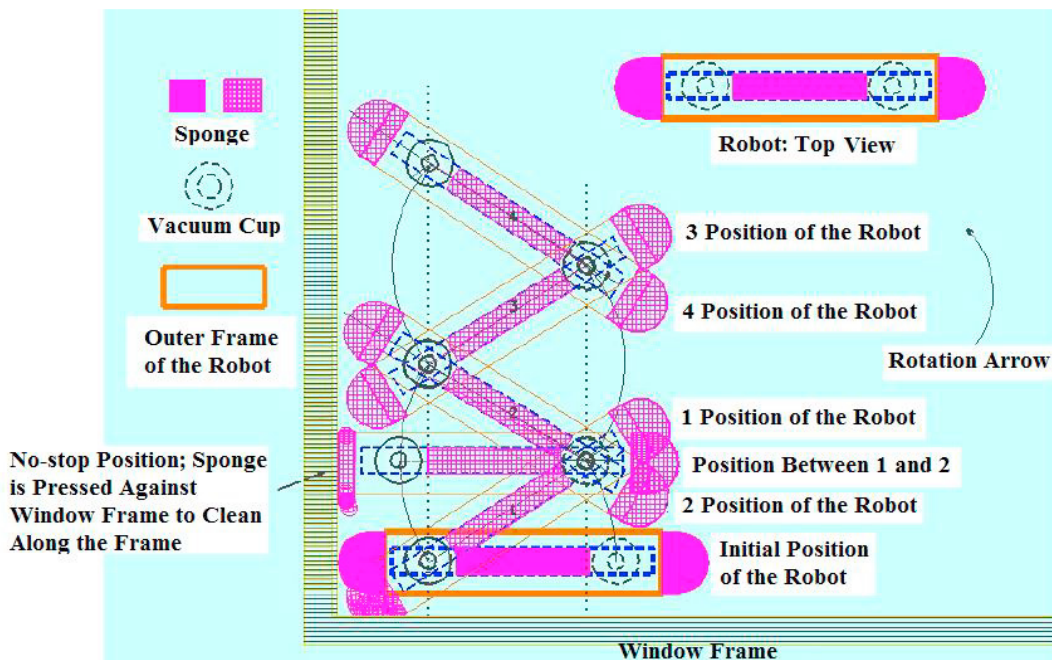


Fig. 9. Sequential movement of the Robot

- i) *Manual mode* – when the operator can move the robot in any direction along the window using ordinary

computer joystick device. This mode is usually used as a backup mode in a case when the automatic mode is stopped functioning for some unexpected reasons.

## 5. Conclusions

The paper introduces a new small size, light, and inexpensive window cleaning robot. As compared to other available window cleaning robot, it has the advantage of being operated by a single electrical motor and system of suction cups. The single motor is able to advance the robot body in a preprogrammed swinging pattern on the 2D plane of the window pane and simultaneously clean the window with the sponges attached to the swinging robot body. It can be operated in automatic and manual mode. It will provide a safe cleaning of the office or home windows, especially for high-rise buildings. The test run of the robot has demonstrated the efficiency of the robot.

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