International Journal of Computer and Information Technology (ISSN: 2279 – 0764)
Volume 04 – Issue 01, January 2015

Remote Controlled Electro-Pneumatical Climbing Robot For Cleaning Of Skyscrapers

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***Abstract*—In this work an electro-pneumatic robot considered for cleaning vertical surfaces like glass, chipboard or transparent plastic components is designed, controlled and implemented. Various motions of robot are obtained using different electro pneumatic valves and cylinders which are controlled through a micro controller (Arduino). The holding ability in vertical direction is provided by vacuum suction valves and elements. On the other hand the robot is supported with remote control and with appropriate equipment for maintenance, reparation and cleaning of high buildings such as skyscrapers.**

***Keywords*—micro controller; remote control; electro pneumatic; surface cleaning; robot**

I. Introduction

In recent years different kind of mobile robots are developed and found applications for different tasks. Meanwhile smooth surface climbing robots have been very popular especially as cleaning robots of high buildings with dressed front side windows, which found a great application in modern constructions. [3], [7]

In this work a prototype electro-pneumatically cleaning robot is designed and mechanically built up. The motion and suspension of the robot is provided electro pneumatically by cylinders and vacuum valves. The synchronization of motion is programmed and carried out by a micro controller (Arduino). The relevant digital outputs of micro controller are then used to activate the coils of (5 V) DC relays, which contacts are used then again to control the 24 V solenoid DC coils of pneumatic valves.

Following main design properties for the robot are supposed to be fulfilled:

- The robot will have the ability of hanging on the surface without slipping and moving vertically in all directions
- Synchronization and activation of different valves must be obtained for various motion modes by proper programming of micro controller
- A safe data communication and remote control action between main computer and micro controller must also be guaranteed for every status

After exposing above conditions prototype design can be considered in three sections; mechanical, pneumatically and control design.

II. Mechanical Design Properties

To meet the assumed motion properties, namely to have the ability of hanging on the surface without slipping and move vertically in all directions a proper mechanical structure existing of two sliding frames one within the other like a sliding bar, is projected in Fig.1. Two sliding frames produced by riveted aluminum bars and bands constitute the main body. Suction suckers are mounted to the inner and outer bodies (as seen in Fig.2) which are relatively moved to each other by pneumatic cylinders. All suckers are chosen and mounted considering the ability of assumed motions and the weight of whole body. On the other hand, considering the mass and working conditions, aluminum is chosen as body material. All drawings of the parts are projected and analyzed by Solidworks engineering software.

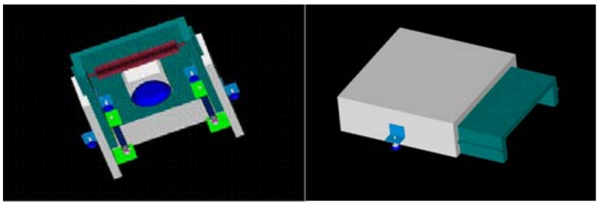

Fig. 1. Computer aided design of the climbing robot.

III. Motion Analyses

The robot is thought to realize linear and turning motions referring to the center of mass. Linear cylinders allow the translational forward and backward motion of the whole body. The rotational motion is provided by a rotational cylinder, which is mounted on the center of mass.

To provide the hanging on the surface without slipping the body is equipped with 7 suckers in whole; six of them providing suction effect during translational motion and one during rotational motion. According to the motion mode these are activated synchronously by relevant valves as illustrated in Fig. 3. During translational motion outer suckers first are actuated together with inner frame while inner suckers and outer frame remaining still.

In the second phase of translational motion inner suckers are actuated together with outer frame while outer suckers and inner frame remaining still. This motion goes on vice-versa.

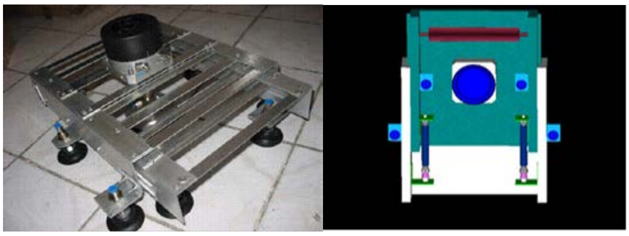

Fig. 2. Inner and outer frames with suckers and cylinders.

A 5/2 valve is used to activate the translational cylinders. During rotational motion rotational sucker with rotation valve will be activated firstly, while all other suckers remain still. These motion modes are demonstrated in Fig.3.

A. *Motion synchronization during forward mode*

Following synchronization execution is programmed during forward motion:

- By opening the power switch whole vacuum suctions will be brought in suction position.
- The front suctions will be released.
- All rest cylinders will be activated and inner (bottom) frame will be pushed forwards.
- Front suctions will be activated.
- Backwards suctions will be released.
- Valve of linear cylinder will be activated and cylinder comes again to the rest position.

With the end of this loop a forward step will be realized. By repeating this loop the continuous forward motion can go on till it will be shut down by “Stop” command.

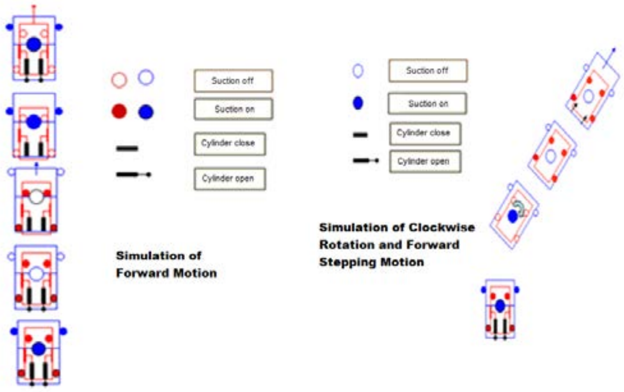

Fig. 3. Forward and rotational motion synchronization.

B. *Motion synchronization during rotation mode*

Rotation mode is given with following steps;

- Firstly rotation suction under rotational cylinder will be activated.
- All the rest vacuums will be released.
- All rest cylinders will be activated and inner (bottom) frame will be pushed forwards.
- Cylinder will be brought in rest position.
- Rotational cylinder will be activated.

During its motion whole body mounted on rotational cylinder can turnto right or left 90 degrees around the center sucker which will be fixed to surface. A 5/2 type rotation valve activates the motion of rotational cylinder, which must have the ability to rotate whole body.

C. *Motion synchronization during forward motion diagram and tables*

Before programming the Micro controller (Arduino), the synchronization logic for different motion modes are planned:

- Forward motion mode
- Backward motion mode
- Turning mode right
- Turning mode left

Table 1 and 2 demonstrates the logic sequences both for forward and backward motions. The pneumatically control scheme of the robot is given in Fig.4. The circuit exists of two 5/2, three 3/2 valves, two double effect linear cylinders and one rotational cylinder. A vacuum generator and suction valves provide the necessary vacuum for the suckers.

TABLE I. SYNCHRONIZATION TABLES OF FORWARD MOTION (H=HIGH, L=LOW)

FORWARD MOTIONS						
ACTIVATORS	MOTION SEQUENCES					
	Home	1st	2nd	3rd	4th	Home
Vacuum Generator	**H**	**H**	**H**	**H**	**H**	**H**
Outer Vacuum Pad	**H**	**H**	**H**	**L**	**L**	**H**
Inner Vacuum Pad	**H**	**L**	**L**	**H**	**H**	**H**
Big Vacuum Pad	**H**	**H**	**H**	**L**	**L**	**H**
Pneumatic Cylinder Push	**L**	**L**	**H**	**L**	**L**	**L**
Pneumatic Rotator Right	**L**	**L**	**L**	**L**	**L**	**L**
Pneumatic Cylinder Pull	**L**	**L**	**L**	**L**	**H**	**L**
Pneumatic Rotator Left	**L**	**L**	**L**	**L**	**L**	**L**

TABLE II. SYNCHRONIZATION TABLES OF BACKWARD MOTION (H=HIGH, L=LOW)

BACKWARD MOTIONS						
ACTIVATORS	MOTION SEQUENCES					
	Home	1st	2nd	3rd	4th	Home
Vacuum Generator	**H**	**H**	**H**	**H**	**H**	**H**
Outer Vacuum Pad	**H**	**L**	**L**	**H**	**H**	**H**
Inner Vacuum Pad	**H**	**H**	**H**	**L**	**L**	**H**
Big Vacuum Pad	**H**	**L**	**L**	**H**	**H**	**H**
Pneumatic Cylinder Push	**L**	**L**	**H**	**L**	**L**	**L**
Pneumatic Rotator Right	**L**	**L**	**L**	**L**	**L**	**L**
Pneumatic Cylinder Pull	**L**	**L**	**L**	**L**	**H**	**L**
Pneumatic Rotator Left	**L**	**L**	**L**	**L**	**L**	**L**

IV. ELECTRONIC IMPLEMENTATION AND SOFTWARE

General electronic connection scheme of the system is shown in Fig. 5. A reasonable software code according to the control logic is then written by using Arduino programming language. As logic supply +5 V is applied to micro controller (µC=Arduino) and to relay coils which are activated from digital ports of µC. To trigger the coils of pneumatic solenoids and to supply the relay contacts, 24 V-DC is used. A Bluetooth connection provided the remote data transmission from PC (as master controller), to µC as slave controller

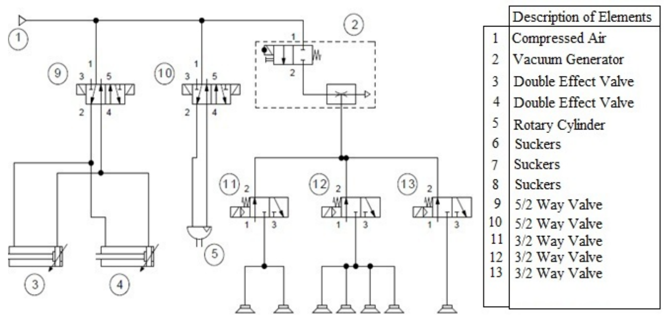

Fig. 4. General pneumatical scheme of the robot.

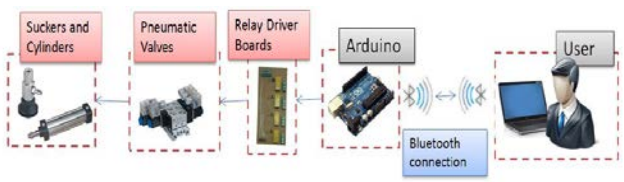

Fig. 5. General communication scheme of the system.

General views of electronic with pneumatic connections and of the robot itself are seen in Fig. 4 and Fig.7.

V. SURFACE CLEANING AND SELECTION OF VACUUM SUCTION

A cleaning roller with cleaning spray unit is mounted on the front side of robot. The spray water will be spread out in motion direction so that a continuous cleaning by motion can be synchronized. The pushed out water with spray on the surface will be squeezed by a ribbon brush mounted on the back side.

After mechanical design and decision of control units proper suction valves and suckers of the firm FESTO are chosen regarding to the whole weight of robot and by using relevant Festo manuals [4],[6]. For the selection of vacuum units following basics are considered:

- Total weight of robot with control equipment on it
- Material and roughness of moving surface
- Calculation of necessary holding force F_H
- Holding safety factor S according to the climbing conditions
- Selection of proper suckers.(Sucker type and number)

With respect to the above criteria and with following numerical values the holding force F_H is calculated as in the following:

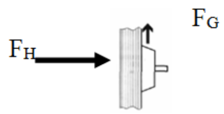

Fig. 6. Sucker and affecting forces.

TABLE III. VARIABLE TABLE

Symbol	Definition	Value	Unit
M	Total robot weight	4	kg
μ	Friction coefficient	0.2	-
S	Safety factor	1.5	-
g	Gravity on earth	9.8	m/s^2

$$F_H = \frac{M}{\mu}(g + a)\, S \tag{1}$$

$$F_H = \frac{4}{0.2}(9.81 + 0)\, 1.5 = 294.3\ N \tag{2}$$

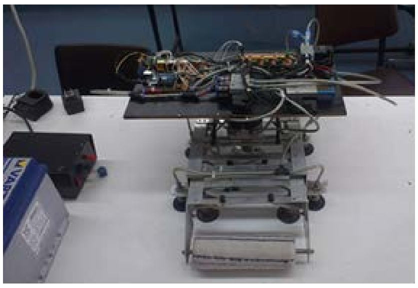

Fig. 7. General view of robot.

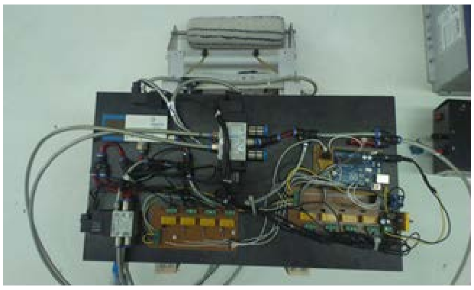

Fig. 8. Electronic and pneumatic connections.

By using 4 suckers both in forward and backward motion the calculated force can be divided by 4 and so for each sucker a holding force $F_A = F_H/4 = 73.6\,N$ can be presupposed. Assuming a suction pressure of -0.7 Bara "Deep Type" *Φ*50mm Sucker fromFestomanual is selected [4].

In the same manner the middle turning sucker is calculated as *Φ*100 mm "Deep Type".All of four inner suckers and two outer frame suckers are selected as *Φ*50mm and the middle turning sucker is calculated as *Φ*100mm as given ın the bottom:

$$F_A = \frac{F_H}{n} = \frac{294.3}{4} = 73.6\,N \qquad (3)$$

Here, $F_A$represents the single sucker holding force, and n the number of suckers.

VI. Conclusion And Future Work

In this work a new electro-pneumatically mobile robot is designed, built up and control implementation is realized. Although a similar prototype robot was built up and tested in a previous work successfully, some considerable disadvantages of this implementation are eliminated with this new design and application. [1] The great disadvantage of the previous implementation was the separated body and control devices, which was connected to each other with very long electrical cables and pneumatic hoses. In this new application all control equipment (electronically and pneumatically) are mounted on the body and the use of remote control application was the most important highlight point of the implementation. With this configuration a very simple and practical use of the robot even in very far ranges and difficult work circumstances, was obtained. On the other hand through the new implementation a great cost reduction has been available.

Although the implementation is considered as a cleaning robot for cleaning vertical surfaces like glass, chipboard or transparent plastic components, it can be used also for other purposes like maintenance, restoration, renovation works of high buildings together with cleaning of the glass surfaces and similar applications. During experiments different working frequencies and motion abilities are tested. Because of constrains concerned with delayed responses and time constants of the used pneumatic equipments, working velocities till to 2-3 Hertz could be reached without any faultless. Better responses can be obtained by using better air supply units and quicker new generation valves.

Although with its present configuration as a prototype, the implementation has proved itself as very satisfactory. With more professionally designs and equipments a practice oriented implementation can be realized.

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