Information Based Remote Control system for Climbing Robot Applications

Navaprakash N[1], Uppu Ramachandraiah[2], G. Muthukumaran[3]

[1]*Research Scholar, Centre for Sensors & Process Control, Hindustan Institute of Technology and Science, Chennai, India*

[2]*Professor & Head, School of Electrical Sciences, Hindustan Institute of Technology and Science, Chennai, India*

[3]*Professor, School of Electrical Sciences, Hindustan Institute of Technology and Science, Chennai, India*

Abstract *— The development of robots for service application is growing rapidly due to constraints of the operation efficiency and cost-effective task completion. One among those is the climbing robots, which are developed for the inspection applications of high-rise buildings. Skyscrapers involve the humans for facades cleaning work, which is hazardous and laborious. For such requirements, the robotics are dealt to overcome hazardous situations, possessing high level of adaptability and flexibility. This paper presents novel design of intelligent information based remotely operated negative sliding suction pressure control for climbing robot using low cost NI-myRIO under LabVIEW environment. It also deals with robustness and stability of wall climbing robot with navigation and closed loop control mechanism. NI-myRIO has an inbuilt processor with FPGA, used to acquire and generate signals for processing and controlling of wall climbing robot remotely. The robot is simulated using the graphical user interface under LabVIEW environment. The robot was realized and controlled using handheld Tablet PC.*

Keywords — *robots, climbing, sliding suction, NI-myRIO, FPGA, LabVIEW, robustness, stability*

I. INTRODUCTION

Climbing robots are a device, which can be utilised for variety of applications starting from cleaning to inspection for different industrial non-destructive evaluation needs [1], [2]. These climbing robots must satisfy higher efficiency to overcome the human needs. Where the demand or needs of human operators are expensive, because of the inaccessibility of humans in hostile environment. The major demand in current scenarios of climbing robots is the control mechanisms, which is easy adaptability for its smooth operation. Wall climbing robot systems with adhesion mechanism are required to perform various operations such as inspection and maintenance of high-rise buildings, surveillance, inspection & cleaning of nuclear facilities etc. [2], [3]. The automated systems available as on date have limited capabilities. The remotely operated wall-climbing robot carries an on-board Suction Generator, Lightweight, Automatic operation and the robot system shall have highest payload capacity and safe mobility [1], [2]. The major difficulty in design aspects is the adhesion capability, which makes the robot traverse in vertical wall surfaces without sacrificing mobility. NI-myRIO is a fast processing real time embedded development board with LabVIEW environment by National instruments. The myRIO allows easy integration of remotely operable various embedded applications with analog and digital pinouts. Remote control works through shared variable concept embedded in NI-myRIO Wi-Fi communication.

II. LITERATURE SURVEY

Presently, the development of various robotics and automation are increasing worldwide. One among robotics development is the wall climbing robots, which are capable of climbing vertical walls. These robots include better stability in terms of holding and crawling on vertical surfaces. For such stability. Wall-climbing robots possesses better adhesion and locomotion systems [1], [2], [3], [4], [5]. The authors David Zarrouk, and Liran Yehezkel developed Rstar reconfigurable sprawl robot, which crawls on various planar surfaces including tubes and pipes. These robots are based on four bar extension mechanism. The main drawback is the locomotion mechanism and path planning were not implemented [6]. H. Wang and A. Yamamoto, designed electrostatic inchworm climbing robot based on electrostatic adhesion mechanism. These bio-inspired techniques feature high speed, lightweight and less energy consumption. Electrostatic adhesion mechanism fails because of the use of elastomer resulting contamination [7]. Yanheng Liu et al. used flat dry adhesion with four bar mechanism, which has advantage of increased speed, high payload and vertical climbing on walls and poles [8]. Embedded system plays a vital role in terms of control and instrumentation [9]. Apurva Harane et al. used NI-myRIO embedded platform for design and development of farm automation system [10]. It features a robot car moving around the field for monitoring and control of field conditions. Similarly, Tiago Caldeira and Hamad Al Remeithi developed rescue robot based on myRIO wireless protocol [11].

The authors Yogesh Angal and Anita Gade designed a myRIO based controlled robot with sensor interfacing for object handling [12]. These robots are capable of holding the object based on acquiring sensor inputs and driving the actuation mechanism for handling.

III. METHODOLOGY

The remotely operated wall climbing robot block diagram is shown in Figure. 1. It consists of an embedded development board (Ni-myRIO) capable of acquiring sensor data and control remotely. The myRIO is kept standalone with wall climbing robot and it continuously sends robot signals wirelessly. Front end and programming is done through LabVIEW environment and the control communication works with Wi-Fi based shared variable concept. Shared variable is the network-connected web IP, through which handheld PC, which is made activated for control and monitoring. The advantage includes fast transmission, increased communication range. In addition, myRIO devices also act as a router by creating a wireless network. Control operation of wall climbing robot using shared variables works through a GUI created through Ni Dashboard app installed in handheld Tablet PC.

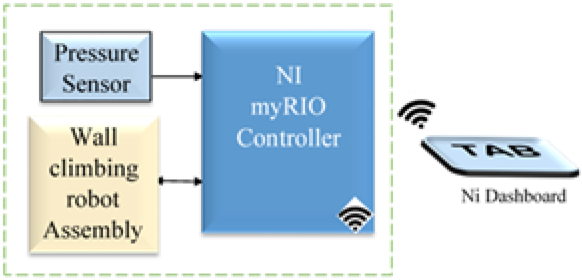

Fig. 1 Block diagram of proposed system

The remote operated wall-climbing robot functions with a single suction generator to provide necessary adhesion. Locomotion is achieved using four-wheel individually driven motor and suitable skirting to provide leakage. The functional block diagram of sliding suction based wall climbing robotic system is shown in Figure. 2.The Ni dashboard virtual interfaces is used to define an intelligent control algorithm using logic functions to remote operate the suction motor speed thereby varying the suction pressure to adhere and traverse in vertical wall surface without scarifying mobility. This process is achieved by getting the closed loop control mechanism between the pressure and motor speed relationship.

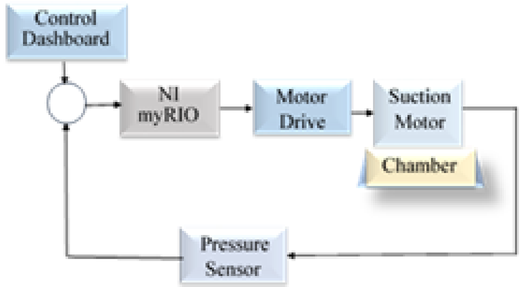

Fig. 2 Functional block diagram of wall climbing robot

IV. THEORETICAL MODELLING

The model kinematics of motion governing the wall climbing robotic system deals with relationships of control pressure variables and the atmospheric pressure acting downwards i.e., towards gravity. For mathematical analysis, primarily single suction chamber system was considered with the force balance diagram Figure. 3.

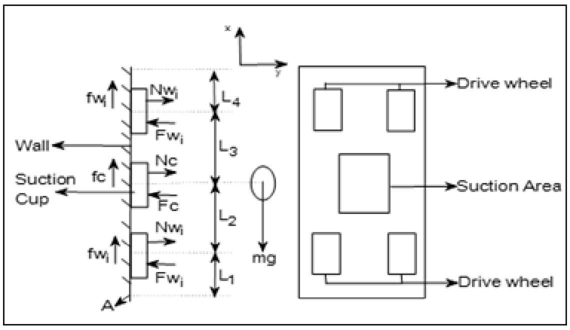

Fig. 3 Wall climbing robot Force Balance Diagram

NOMENCLATURE	
N_c	Reactional force exerted by robot body
$N_{w1}, N_{w2}, N_{w3}, N_{w4}$	Reactional force exerted by the drive wheels
f_c	Friction force between the wall surface and robot body
$f_{w1}, f_{w2}, f_{w3}, f_{w4}$	Friction force between the wall surface an drive wheels
m	Total mass of wall climbing robot
o_1	Orientation from the rear wheels and the bottom edge
L_1	Length from the rear wheels and robot body
L_2	Length from the front wheels and robot body
o_2	Orientation from the front wheels and the top edge
h	Height from the wall surface to the center of gravity of robot body
F_c	Adhesion force of the suction cup
μ	Static frictional coefficient

Because of symmetry in the drive wheel system.

$$N_{w1} = N_{w2} = N_w \qquad (1)$$

Case 1: Holding condition of wall climbing robot

$$m_h = (o_1 + L_1 + L_2)(N_{w3} + N_{w4}) + (o_1 + L_1)(F_c - N_c) + [o_1(N_{w1} + N_{w2})] \qquad (2)$$

Case 2: Moving condition of wall climbing robot

$$F_c \le \mu N_c \qquad (3)$$

Case 3: Falling condition of wall climbing robot, i.e., zero reaction forces applied to the suction chamber

$$f_c + f_{w1} + f_{w2} + f_{w3} + f_{w4} \le \mu(N_c + N_{w1} + N_{w2} + N_{w3} + N_{w4}) \qquad (4)$$

$$m \le \mu(F_c + 4F_w) \qquad (5)$$

TABLE 1. Drop-off and Holding force with equivalent suction pressure Equations

	Suction chamber Force F_c (N)	**Suction chamber pressure P_c (kPa)**
Drop-off	10.07	-1.06
Holding	35.97	-3.78

Table 1 represents the dropping and holding suction pressure required for climbing on vertical surface without falling down. WCR operates by maintaining suction pressure between -1.06 to -3.78 kPa on the surface or wall without sliding.

Adhesion unit: The generation of suction pressure is developed through EDF BLDC suction motor shown in Figure 4. This motor is capable of rotating at the speed of 40000 RPM with 12v power input. The advantages of using brushless motor is for electronic control of motor withstanding high power to weight ratio. The electronic speed controller designed specifically for BLDC suction motor is shown in Figure 5.

Fig. 4 BLDC Suction motor

Fig. 5 Hobbyking ESC 60amp

V. WALL CLIMBING ROBOT

A. *Hardware design*

The hardware parts in development of wall climbing robot features two major assembly unit named adhesion, locomotion and control unit. Adhesion unit comprises of a suction motor assembled with impeller. Locomotion unit comprises of 4-wheel drive mechanism carrying geared DC motor with motor driver. Control unit comprises of Wi-Fi enabled Ni-myRIO embedded development board.

The electronic speed control (ESC) of suction motor can produce constant 60amp current with 5v input. It has inbuilt voltage protection circuit with minimum cut off voltage and can generate 8 to 16 kHz of PWM frequency.

Locomotion Unit: Wall climbing robot operates with four-wheel drive mechanism consisting of DC geared motor with L298N motor driver circuit. The motor driver, which operates in the range of 5 to 12v and is connected with the control unit for navigation of the wall-climbing robot.

Control Unit: The heart of entire setup of wall climbing robot is the control unit made of reprogrammable embedded development board as shown in Figure. 6. This plays a role in monitoring, control and managing the wall-climbing robot in achieving better traction and stability on vertical wall surface.

NI-myRIO is interfaced with ESC of adhesion unit and L298N motor driver of locomotion unit. The control operation done through standalone PC and through shared variables communicated by Wi-Fi enabled handheld Tablet PC.

Fig. 6 Ni-myRIO embedded reconfigurable kit [12]

Fig. 6 Ni-myRIO embedded reconfigurable kit [12]

B. Software design

The simulation and control panel comprises of LabVIEW environment with myRIO bundle toolkit provided from National instruments. Simulation pane consists of a front-end graphical user interface (GUI) works with Backend Virtual instruments (VI) programming.

The front end GUI is shown in Figure. 7 and backend VI is shown in Figure. 8.

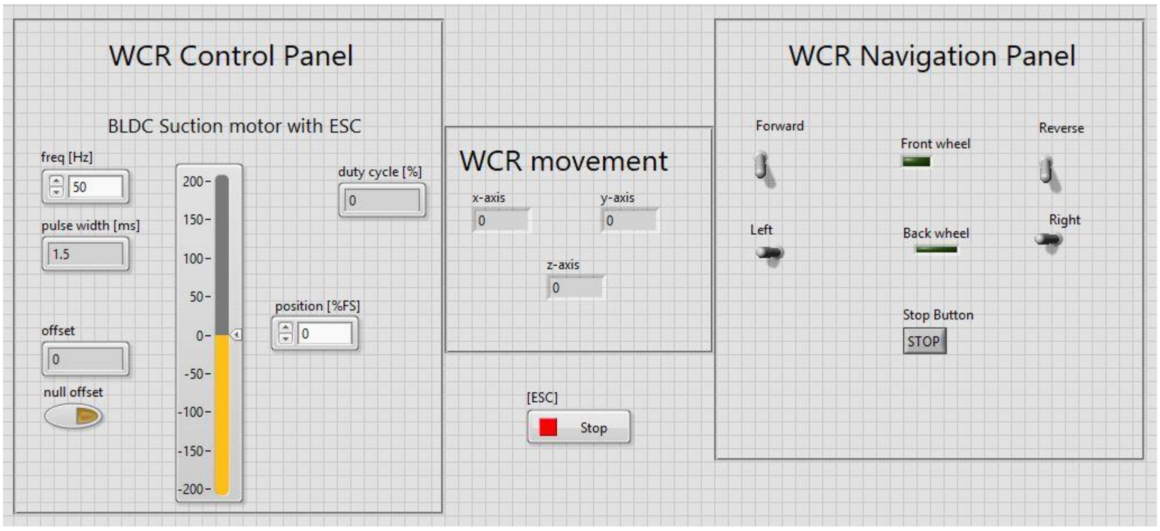

Fig. 7 Wall climbing robot (WCR) Front End GUI

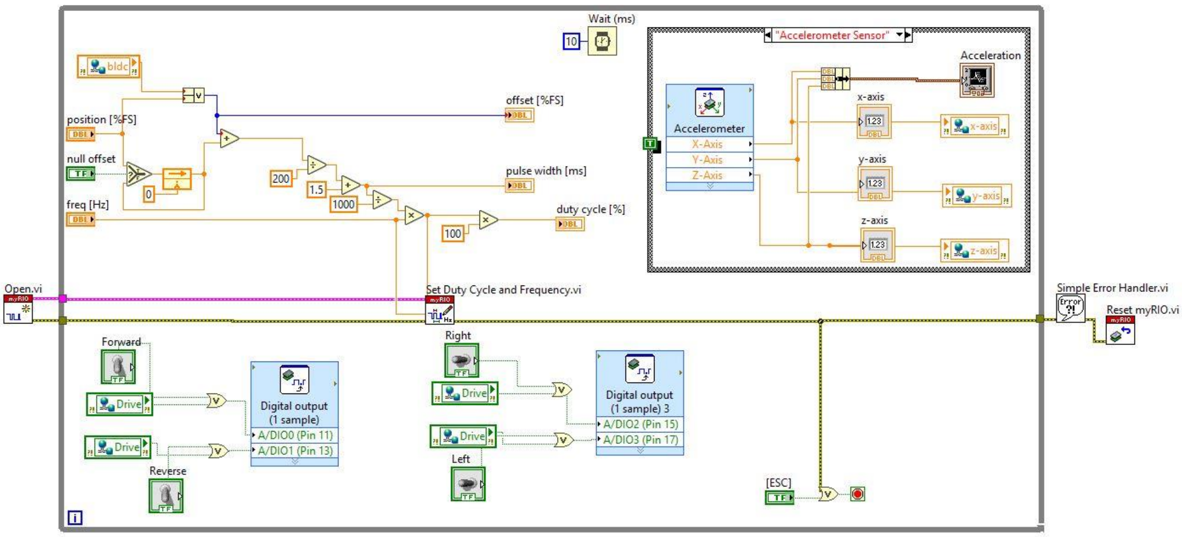

Fig. 8 Wall climbing robot (WCR) VI

VI. PRINCIPLE OF OPERATION

The Experimental prototype is shown in Figure 9. WCR works on the principle of sliding suction control, i.e., the negative pressure developed by WCR must be equal to or more than the gravitational pressure acting downwards. The WCR climbs vertical wall by maintaining suction pressure little more than the gravitational pressure. The 5 RPM, 12v DC geared motor was used to crawl the WCR on walls. The overall weight of WCR is 1.775 Kg with traversing speed of 0.009 m/s. The WCR prototype is developed using acrylic foam sheet with open trapezoidal contour for distribution of suction pressure [2]. The Figure 10 shows the WCR suction chamber contour view.

VII. RESULTS AND DISCUSSION

In the designed approach, embedded development board (NI-myRIO) is used as the heart of overall wall climbing robotic system starting from control, monitoring and management of robot to move smoothly in wall without falling down at any instants. Initially, The Robot is made still for developing sufficient suction pressure approximately -2.1 kPa. This is done remotely through Ni-Dashboard app installed in Handheld Tablet PC based on Wi-Fi protocol. WCR (Wall climbing robot) control panel acquires pressure sensor data and provides necessary information on input variables to generate and control required suction pressure. Based on Accelerometer and pressure sensor data is acquired, WCR navigation panel provides the decision on navigation and stability control of wall climbing robot. The control dashboard in handheld Tablet consists of a slider bar, a navigation pad, pressure and accelerometer sensor display indicators. Based on the slider control the speed of the suction motor is changed thereby affecting the suction pressure required for sliding and holding WCR.

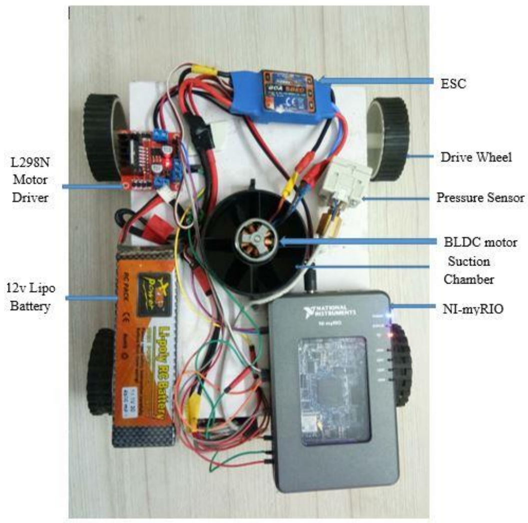

Fig. 9 WCR Experimental setup

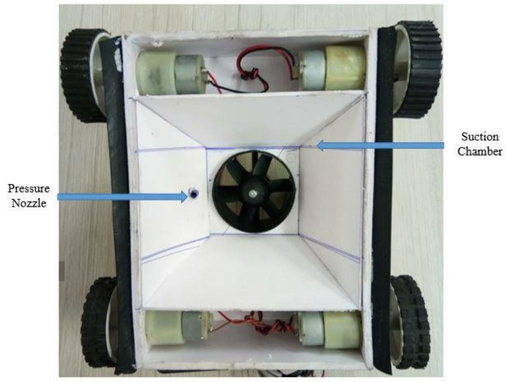

Fig. 10 WCR suction chamber contour

The accelerometer sensor output is shown in figure 11. It is the raw accelerometer data is acquired through myRIO while robot is moving on vertical plane.

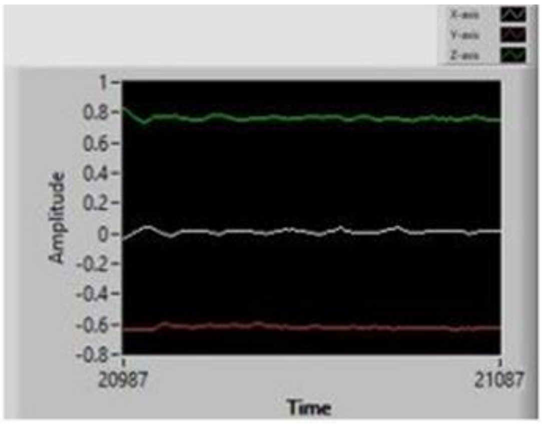

Fig. 11 Accelerometer sensitivity (mV/g) vs Time (s)

The experimental WCR is tested in real time smooth and semi constructed brick wall surface where the gap of minimum 2mm is observed. Figure 12 and figure 13 depicts the wall climbing robot maximum speed and thereby developing the pressure. The maximum required rotational speed of the adhesion motor to fully hold and traverse on vertical wall surface is around 1879 rpm and negative suction pressure of around -2 kPa maintains the robustness and stability.

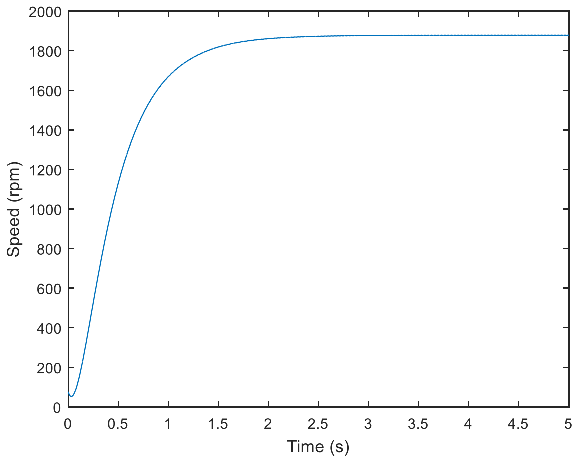

Fig. 12 Adhesion motor speed (rpm) vs Time (s)

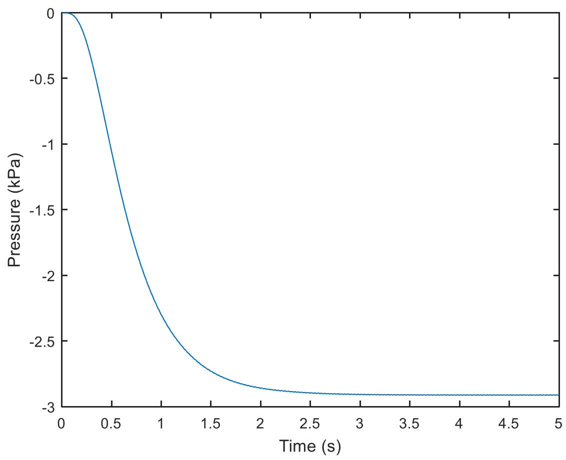

Fig. 13 Aerodynamic Drag pressure (kPa) vs Time (s)

Figure 14 represents experimental result for generated negative suction pressure with gap of 1mm, 2mm and smooth surface without gap between suction chamber and the surface.

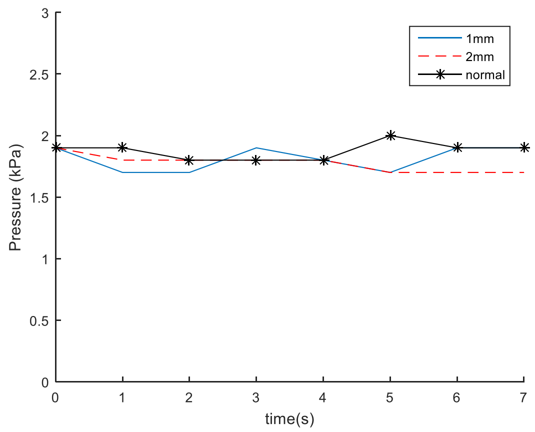

Fig. 14 Experimental analysis: Suction pressure (kPa) vs Time (s)

VIII. CONCLUSION

This paper presents the design and development of information based remotely operated wall climbing robot by providing active negative sliding suction chamber system. Remotely operable wireless validation proves the closed loop suction control mechanism by evaluating suction motor speed and thereby achieving required negative suction pressure to maintain wall-climbing robot stand still and traverse without losing mobility. The objective of this study was to provide a low cost, low noise information based remote control robot capable of traversing through walls of different surface conditions. It is obvious that the requirement of adhesion pressure varies for different surface. Thus, the impact of handheld control of suction pressure keeps the wall-climbing robot adaptable for various applications including NDE. This study further provides improved closed loop accelerometer based automated remote actuation mechanism for traversing horizontally and vertically.

REFERENCES

[1] N. Navaprakash, U. Ramachandraiah, G. Muthukumaran, V. Rakesh, and Ashutosh Pratap Singh, ""*Modeling and Experimental Analysis of Suction Pressure Generated by Active Suction Chamber Based Wall Climbing Robot with a Novel Bottom Restrictor*", *Procedia Computer Science*, vol. 133, pp. 847–854, 2018.

[2] N. Navaprakash, U. Ramachandraiah, G. Muthukumaran, V. Rakesh, and Ashutosh Pratap Singh, "*Live Demonstration: 'Wall Climbing Robot Using Fuzzy Based Adaptive Control System*", 2018 Ieee Sensors, New Delhi.

[3] G. Muthukumaran and U. Ramachandraiah, "*Development and Analysis of Robotic Sliding Suction Cup System for Wall Climbing Applications,*" vol. 9, *Indian Journal of Science and Technology*, no. S1, 2016.

[4] K. H. Cho, Y. H. Jin, H. M. Kim, H. Moon, J. C. Koo, and H. R. Choi, "*Multifunctional Robotic Crawler for Inspection of Suspension Bridge Hanger Cables: Mechanism Design and Performance Validation," IEEE/ASME Transactions on Mechatronics*, vol. 22, no. 1, pp. 236–246, 2017.

[5] M. F. and J. A. T. Machado, "*A Survey of Technologies and Applications for Climbing Robots Locomotion and Adhesion*," *Climbing and Walking Robots*, Jan. 2010.

[6] D. Zarrouk and L. Yehezkel, "*Rising STAR: A Highly Reconfigurable Sprawl Tuned Robot*," *IEEE Robotics and Automation Letters*, vol. 3, no. 3, pp. 1888–1895, 2018.

[7] H. Wang and A. Yamamoto, "*Analyses and Solutions for the Buckling of Thin and Flexible Electrostatic Inchworm Climbing Robots*," *IEEE Transactions on Robotics*, vol. 33, no. 4, pp. 889–900, 2017.

[8] Y. Liu, H. Kim, and T. Seo, "*AnyClimb: A New Wall-Climbing Robotic Platform for Various Curvatures*," *IEEE/ASME Transactions on Mechatronics*, vol. 21, no. 4, pp. 1812–1821, 2016.

[9] A. Khamis, D. Zydek, G. Borowik, and D. S. Naidu, "*Control System Design Based on Modern Embedded Systems," Computer Aided Systems Theory - EUROCAST 2013 Lecture Notes in Computer Science*, pp. 491–498, 2013

[10] A. Harane, S. Bhoir, T. Patkar, and D. Karia, "*Design and development of farm automation system using NI myRIO*," *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, 2017.

[11] T. Caldeira, H. A. Remeithi, and I. A. Raeesi, "*MyRIO based mobile robot for rescue competitions*," *2017 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)*, 2017.

[12] Y. Angal and A. Gade, "*LabVIEW controlled robot for object handling using NI myRIO*," *2016 IEEE International Conference on Advances in Electronics, Communication and Computer Technology (ICAECCT)*, 2016.

[13] NI myRIO https://ni.com/pdf/manuals/376047a.pdf/