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ORIGINAL

Design and Validation of Payload: Weight for a Bioinspired Inch Worm Wall Climbing Robot (IWWCR) Using Coppeliasim

Diseño y Validación de la Carga Útil Peso para un Robot Trepamuros Bioinspirado (IWWCR) Utilizando Coppeliasim

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ABSTRACT

In this growing era technology robots are replacing the humans by performing many risky operations enhancing the safety factor of human life. Particularly while considering performing task at high rise building or any high-altitude jobs, the need of wall climbing robot emerges. There are various types of wall climbing robot classified based on its adhesive mechanism and locomotive methods. Out of the various available method, Bioinspired type Robot has its own unique feature specifically when we talk about softbot. Bio inspired robots mimics the locomotion or any other specific feature of living creatures
In this paper, an novel approach is introduced for design and development of a Bio inspired Wall Climbing Robot (WCR) using a simulation software named Coppelialsim. An inch worm wall climbing robot is proposed mimicking the locomotion of inch worm is proposed as novel design. The design of the proposed WCR is validated with respect to payload(p): weight (w) value using the static and dynamic analysis both in simulation environment using coppeliasim software and real time experimental testing after fabrication. The flow of electromagnetic flux is further justified with the software called Finite Element Magnetic Method (FEMM) and the structural design of the proposed design is validated with respect to the Computer Aided Analysis (CAA) software. Thus, the proposed IWWCR possess the high p: w value when compared to all other existing bioinspired Wall climbing Robot.

Keywords: Inch Worm Wall Climbing Robot (IWWCR); Coppeliasim; FEMM; CAA; Payload(p); Weight(w).

RESUMEN

En esta era de crecimiento tecnológico, los robots están sustituyendo a los humanos en la realización de muchas operaciones de riesgo, mejorando el factor de seguridad de la vida humana. En particular, al considerar la realización de tareas en edificios de gran altura o cualquier trabajo a gran altitud, surge la necesidad de un robot trepamuros. Existen varios tipos de robots trepamuros clasificados en función de su mecanismo adhesivo y métodos de locomoción. De todos los métodos disponibles, el robot bioinspirado tiene sus propias características, especialmente cuando hablamos de softbot. Los robots bioinspirados imitan la locomoción o cualquier otra característica específica de los seres vivos. En este artículo se presenta un novedoso enfoque para el diseño y desarrollo de un Robot Trepamuros Bioinspirado (WCR) utilizando un software de simulación llamado Coppelialsim. Se propone un robot trepador que imita la locomoción del gusano.

El diseño del WCR propuesto se valida con respecto a la carga útil (p): valor de peso (w) utilizando el análisis estático y dinámico tanto en el entorno de simulación utilizando el software Coppeliasim y pruebas experimentales en tiempo real después de la fabricación. El flujo del flujo electromagnético se justifica además con el software llamado Método Magnético de Elementos Finitos (FEMM) y el diseño estructural del diseño propuesto se valida con respecto al software de Análisis Asistido por Ordenador (CAA). Por lo tanto, el IWWCR propuesto posee el alto valor p: w en comparación con todos los demás bioinspirados Robot trepamuros existentes.

Palabras clave: Robot trepamuros de pulgadas (IWWCR); Coppeliasim; FEMM; CAA; Carga útil(p); Peso(w).

INTRODUCTION

The wall climbing robots has great impact on real time applications across many sectors. Especially such bot will play vital role in performing many industrial applications like nondestructive testing, water jetting and sand blasting in ship maintenance and repair industries. The wall climbing robots have many design parameters of which self-weight and payload remains as the key parameter for determining the performance of the bot. And these parameters are directly depended on the adhesive mechanism that we choose. On the other side the robots are classified into many types like aerial bot, underwater bot, bioinspired bot, industrial bot and service bot based on its application. Considering these two criteria, the focus is narrow downed to design and fabricate a bioinspired wall climbing robot with high payload capacity and less self-weight will be more suitable for many industrial application, defense applications etc. In this research work, an innovative design is introduced mimicking the inchworm locomotion for wall climbing robot and short it is named as IWWCR (inch Worm Wall Climbing Robot). The proposed design is subjected to statistical analysis using the Coppelialisim software. The structural analysis of the proposed bot is validated with help of CADD software and the flow of magnetic flux density from the electromagnet used in IWWCR is studied with respect to FEMM software. Initially an literature review is presented in detail mentioning about the Bioinspired WCR along with the payload and self-weight of the so far proposed bot from various authors and finally a comparison is made with that of the capability of IWWCR. The proposed design of IWWCR is fabricated and tested to measure its p:w value both in static and dynamic mode.

Literature survey on bioinspired robot

Though many research articles are available in this bioinspired type of Wall climbing Robot, very few authors have mentioned the details about the payload and weight capacity of their proposed bot, the authors have suggested their own design mimicking anyone living creature. The key parameters value such as payload and weight of each proposed bioinspired WCR is considered for tabulation as given in table 1,3, so that a novel design could be proposed with better p: w value. Rajendran et al (3,10) in his paper has already presented a detailed survey on this type in the form of DTA (Decision Tree Analysis).Shen et al[(22)] proposed magnetic adhesive mechanism with payload of 30kg.Sun et al[(29)] proposed a bioinspired inchworm bot with gait mechanism

Table 1. Bio inspired Wall climbing Robot

Author	Lam et al	Bartsch et al	Xu et al	Xu et al	Zhao et al	Wile et al	Daltorio et al	Funatsu et al	Spenko et al
Payload	1,75kg	20 kg	400g	250g	250 g	30g	26g	4g	1,5kg
Weight	4,6kg	23kg	800g	400g	400 g	128 g	130g	13,5g	3,8kg
P:W	0,38	0,86	0,5	0,625	0,625	0,23	0,2	2,66	0,39
Reference	01	04	05	06	07	11	12	13	14

Table 2. Bioinspired Wall Climbing Robot

Author	Bretl etal	Kotay et al	Chung et al	Zhang et al	Liu et al	Li et al	Jiang et al	Carlo et al	Murphy et al
Payload	510g	116g	500g	10kg	0,2kg	0,81kg	1,3 kg	80g,10g	100 g
Weight	7kg	566g	1kg	50kg	<2kg	4,9kg	431g	80g,10g	85g
P:W	0,07	0,204	0,5	0,2	0,1	0,16	3,01	1	1,17
Reference	17	18	19	15	23	26	02	08	20

Table 3. Bioinspired Wall Climbing Robot					
Author	**Birk Meyer et al**	**Sintony et al**	**Zhang et al**	**Liu et al**	**Bian et al**
Payload	100g	2 kg	2,7 kg	2000g	4,96 kg
Weight	15g	2 kg	27,8 g	922g	360 g
P:W	6,66	1	0,09	2,16	13,7
Reference	16	09	24	25	27

Mathematical analysis of static iwwcr

The free Body diagram method is used to analyze the force acting on the body (IWWCR) at various position as given in figure 1,4. The equation arrived for each cases gives the adhesive force required at each condition under static analysis. Considering the weight of the IWWCR as G,the adhesive force in case 1 is denoted as F_a^1,similarly the required adhesive force for case 2, case 3 and case 4 is denoted as F_a^2, F_a^3, F_a^4.

The adhesive force exerted by the electromagnet solenoid is denoted by X_i, since there are two electromagnet solenoids attached at two ends of the pneumatic cylinder, the X_i value is varied as 1 and 2. The angle ɵ is the angle of inclination of the inclined metal wall over which IWWCR is allowed to climb. Considering the weight of the bot (G)as 1 kg or 9,8N and adhesive force of the solenoid suction cup (X_i) is 147 N or 15 kg, the following table is arrived.

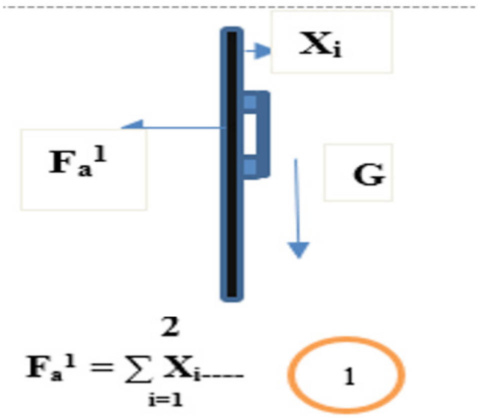

Figure 1. IWWCR on vertical wall

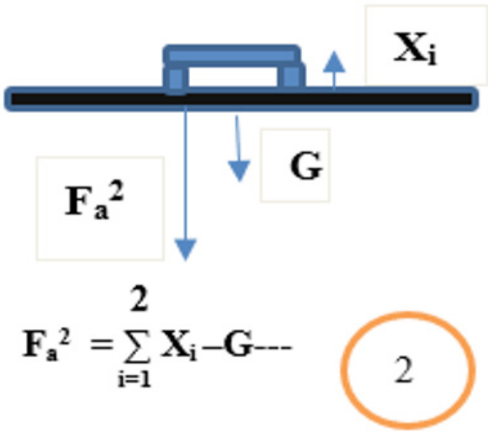

Figure 2. IWWCR on ground

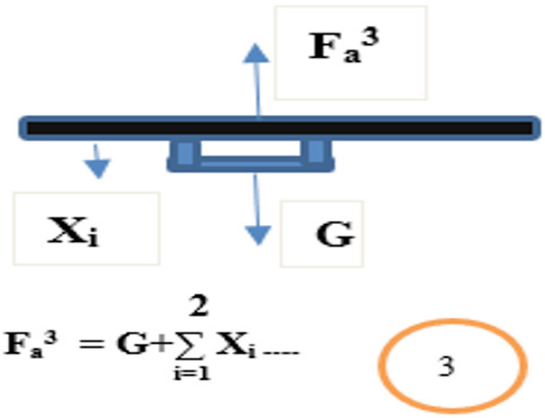

Figure 3. IWWCR on upside down inverted

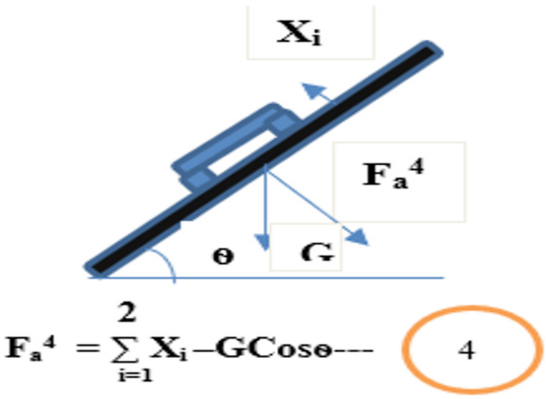

Figure 4. IWWCR on inclined wall

Table 4. Bioinspired wall climbing robot			
S. No:	**Case Number**	**Denotation**	**Adhesive forced Required (kgf)**
1	Case-1 IWWCR on vertical wall	F_a^1	30
2	Case-2 IWWCR on ground	F_a^2	29
3	Case-3 IWWCR on upside down inverted	F_a^3	31
4	Case-4 IWWCR on inclined wall with 45 degree inclination	F_a^4	29,29

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This free body diagram analysis is done as mentioned in the article proposed by a study and the result is tabulated as shown in table 4.

Flux density analysis of iwwcr using femm

FEMM software as shown in figure 5,8, is used to design and analyze how the magnetic flux density is flowing along the length of the IWWCR.As there are two electromagnetic solenoids at the end of the pneumatic cylinder, the flux density plot shows the magnetic flux density value between 2 to 2,12 tesla value over the metal vertical wall which is more than enough for a better adhesion for this IWWCR. A study helps us to determine the flow of flux density in simulation mode before actual fabrication.

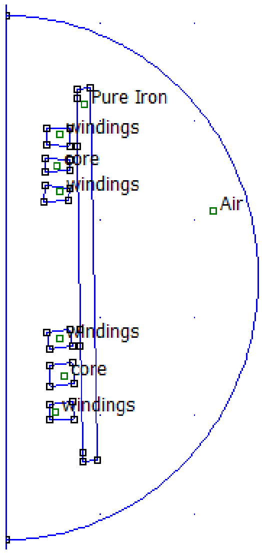

Figure 5. Nodes and Materials declared with two solenoids on metal vertical wall

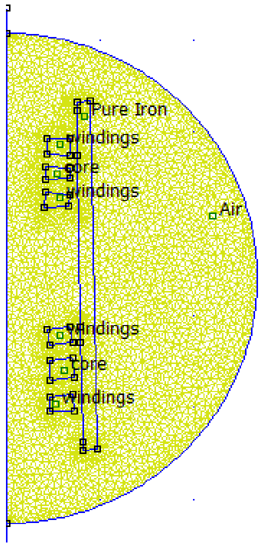

Figure 6. Mesh Created in FEMM

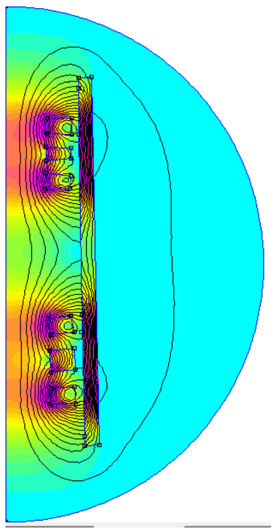

Figure 7. Flux density Plot

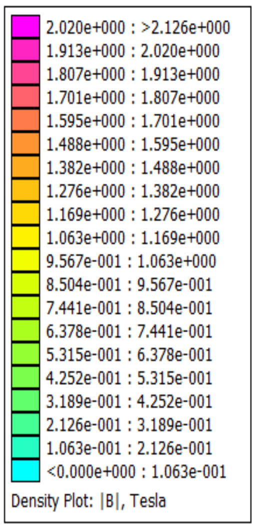

Figure 8. Color indication with Flux desnity value in Tesla

Structural analysis of iwwcr

The structural analysis of wall climbing robot could be done using many software like Solid works, Ansys, Comsol multiphysics, fusion etc. Here in this research work, the structural analysis of the proposed IWWCR is done using Solid works and the simulated result is as shown in below figure 10. The VonMises stress is found to be in the range of 8,790e+01N/m^2 to 1,904e+05N/m^2.The structural analysis of the proposed IWWCR says that the bot could withstand a payload with yield strength of 6,20422e+08 N/m^2 and tensile strength of 7,23826e+08 N/m^2**.** The figure 9 is the courtesy from https://wandamacavoy.com/2018,10/03/lessons-from-an-inchworm.

Figure 9. Actual Inch worm

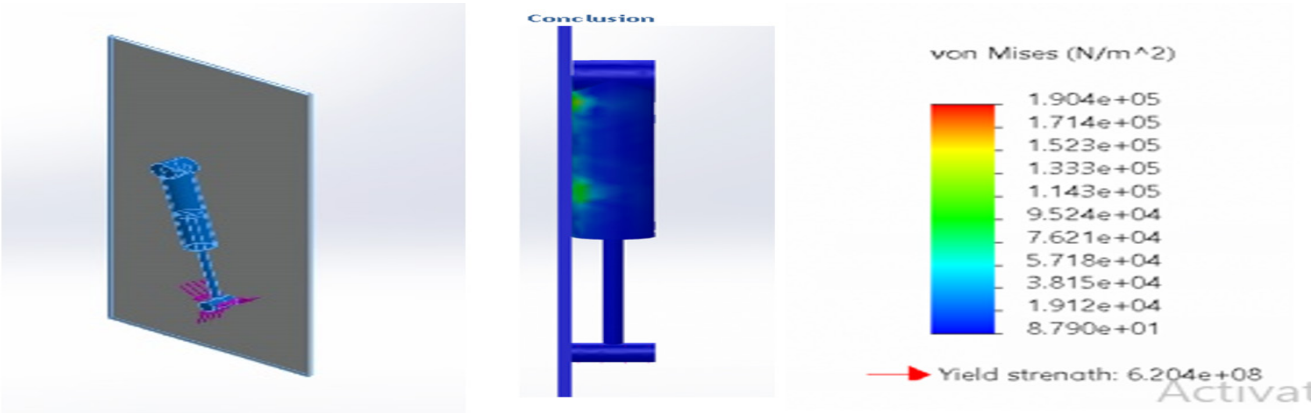

Figure 10. Structural analysis using solidworks

Coppeliasim framework for iwwcr

Coppleiasim is one of the design software (as shown in figure 12) which is used for simulating the performance of the robot under various environment for the stipulated time period. The key input parameters like self-weight of the bot could be varied and fed as input before starting the simulation and the ability to withstand the payload could be easily determined over the time period. The figure 11 depicts the overall framework of the simulation environment. The entire tree body of the object declared in this simulation environment is developed using the lua script. In this research work. The static analysis of IWWCR is justified with Coppeliasim software as already proposed by a study and it is shown in figure 10. The IWWCR consists of two electromagnet solenoids fixed to a pneumatic cylinder. The overall weight of the IWWCR is fed as input to Coppeliasim software.

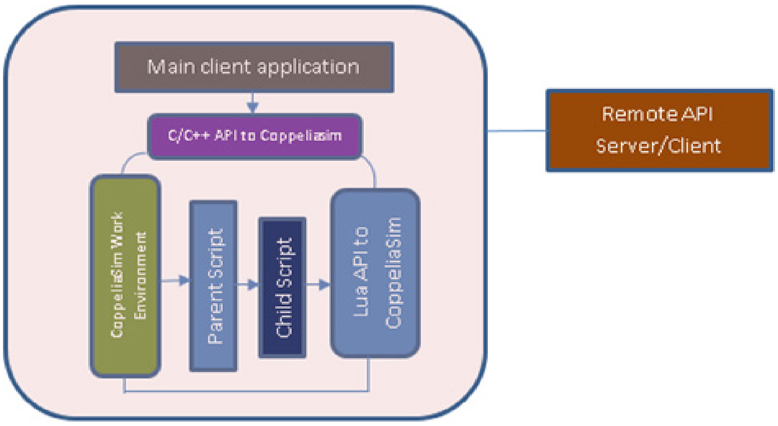

Figure 11. Coppeliasim framework

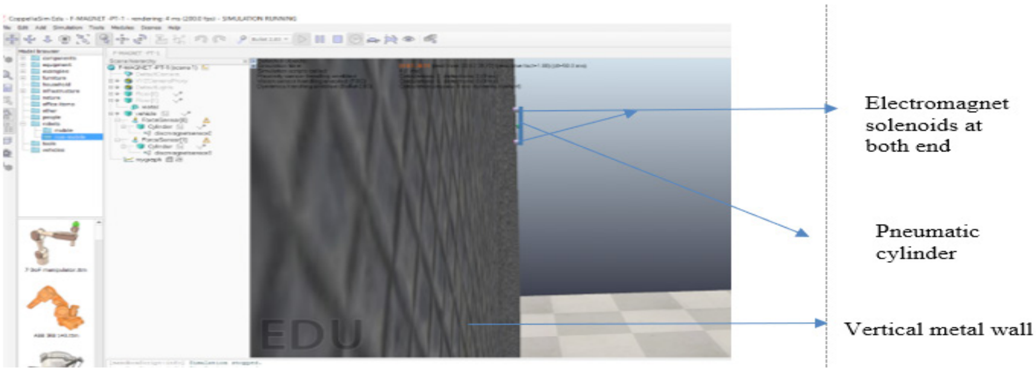

Figure 12. Coppeliasim simulation environment with IWWCR on metal wall

The adhesive force of the electromagnetic solenoid is fed via the lua script. Assuming usage of electromagnet solenoid having 15kgf or 147 N adhesive force exerted from each solenoid. The overall weight of the bot is considered to be 660 gram and it is found to lift a payload of 20 kg in static mode.

Block diagram of the working principle

The figure 13 shows the overall flow of control from program Logic Controllers to Direction Control Valve (DCV) which in turn connected with the pneumatic cylinder. There is another flow of control from PLC to the electromagnetic solenoid X1 and X2 which helps in bringing the adhesive force making the bot to climb. The step-by-step procedure (as shown in table 5) for both positive and negative cycle depicts the working principle of the IWWCR.

Table 5. Working Principle of the IWWCR

Working principle	Positive cycle	Negative Cycle
Step 1	Electromagnetic Solenoid X1 energized	Electromagnetic solenoid X2 energized
Step 2	Electromagnetic solenoid X2 de energized	Electromagnetic Solenoid X1 de energized
Step 3	Pneumatic Cylinder Expansion	Pneumatic Cylinder retraction

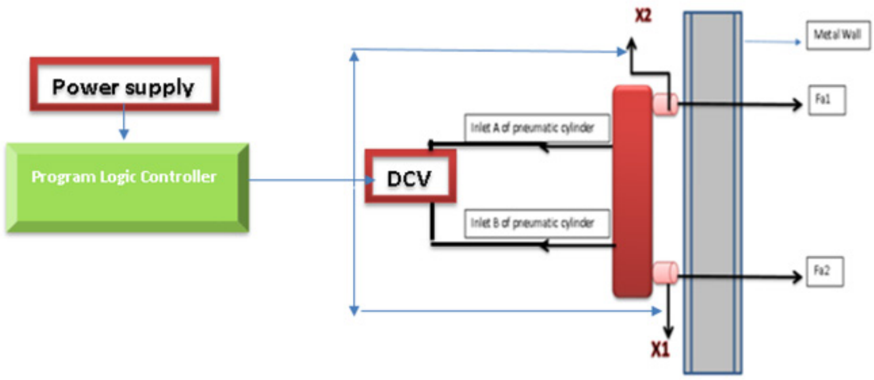

Figure 13. The Block diagram showing the flow of control from PLC to IWWCR

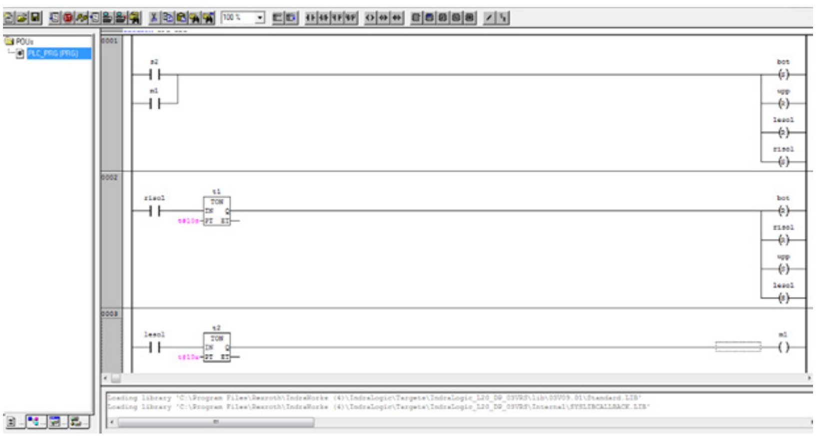

Figure 14. The Ladder diagram controlling the IWWCR

The figure 14 depicts the ladder diagram drawn in Indra Logic software used for PLC kit L20db03 VRS from Bosch Rexroth. The figure 15 depicts the real time experiment of IWWCR while climbing metal wall.

Hardware testing

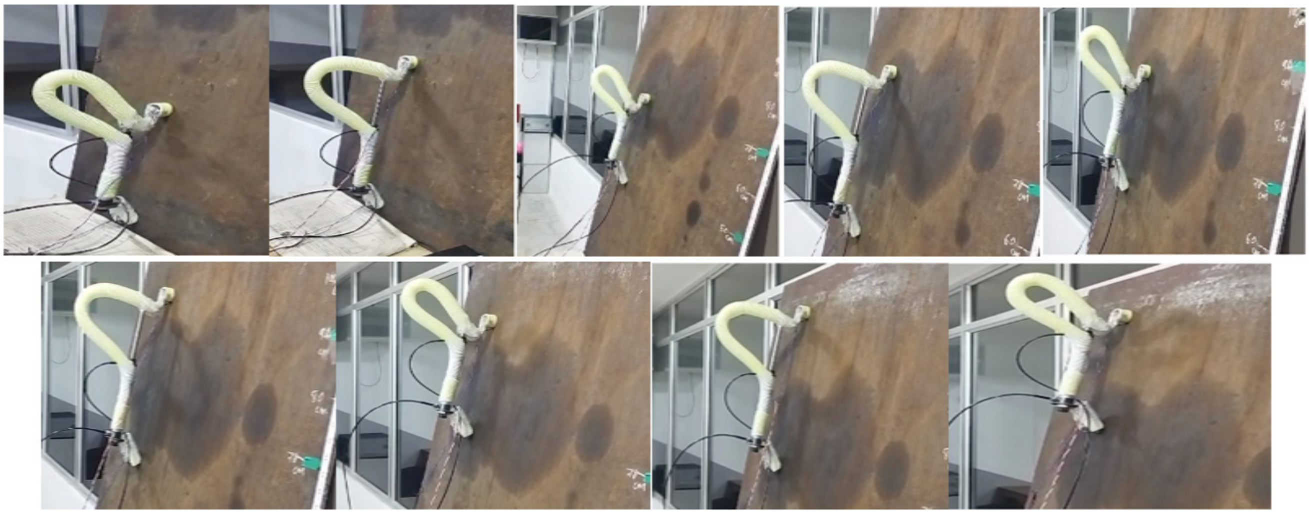

Figure 15. Bioinspired inch worm robot (showing Expansion and retraction) climbing the vertical metal wall with 8mm thickness

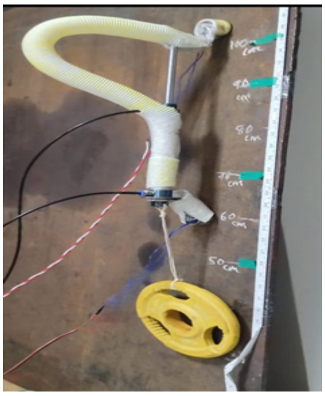

Figure 16. IWWCR in dynamic mode lifting 1,2 kg

Figure 17. IWWCR in static mode lifting 15,25 kg

DISCUSSION ON RESULT

The pattern of the motion speed of the designed IWWCR is found to be common both in case of simulation and actual experimental method as shown in the below graph figure 18. The IWWCR is allowed to carry a weight of 1,2 kg and the distance covered is measured with the help of the measuring tape ticked on the vertical wall for the given fixed time of 1 minutes as shown in figure 16. The distance covered keeping the time fixed as 1 min (60 seconds), both in case of simulation and the real time experiment is noted and tabulated as given in below table 6.

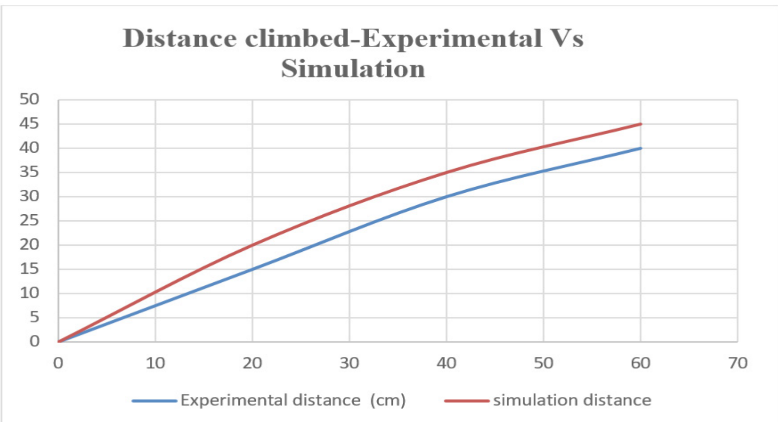

Figure 18. Dynamic Analysis of IWWCR -Simulation Vs Real Time Experiment

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Table 6. Performance Exp/Simulation Vs Time

Time (seconds)	Experimental distance (cm)	Simulation distance (cm)
0	0	0
20	15	20
40	30	35
60	40	45

Table 7. P:W of proposed bot -Static and dynamic

Performance of Proposed Bot	Payload in Actual Experiment	P:W
Static mode	15,25 kg	23,11
Dynamic mode	1,2 kg	2

Table 8. Ranking of proposed bot with static P:W value

SNO:	Author	P:W
1	Proposed IWWCR	23,11
2	Bian et al	13,7
3	BirkMeyer et al	6,66
4	Xu et al	3,01
5	Funatsu et al	2,66
6	Liu et al	2,16
7	Murphy et al	1,17
8	Sintony et al	1
9	Carlo et al	1
10	Bartsch et al	0,86
11	Zhao et al	0,625
12	Xu et al	0,625
13	Xu et al	0,5
14	Chung et al	0,5
15	Spenko et al	0,39
16	Lam et al	0,38
17	Wile et al	0,23
18	Daltorio et al	0,2
19	Zhang et al	0,2
20	Kotay et al	0,204
21	Li et al	0,16
22	Liu et al	0,1
23	Bretl et al	0,07
24	Zhang et al	0,09

Table 9. Ranking of proposed bot with dynamic P:W value

SNO:	Author	P:W
1	Bian et al	13,7
2	BirkMeyer et al	6,66
3	Xu et al	3,01
4	Funatsu et al	2,66
5	Liu et al	2,16
6	Proposed IWWCR	2
7	Murphy et al	1,17
8	Sintony et al	1

9	Carlo et al	1
10	Bartsch et al	0,86
11	Zhao et al	0,625
12	Xu et al	0,625
13	Xu et al	0,5
14	Chung et al	0,5
15	Spenko et al	0,39
16	Lam et al	0,38
17	Wile et al	0,23
18	Daltorio et al	0,2
19	Zhang et al	0,2
20	Kotay et al	0,204
21	Li et al	0,16
22	Liu et al	0,1
23	Bretl et al	0,07
24	Zhang et al	0,09

During the Static analysis (as shown in figure 17) of the real time experiment, the 660 gm bot is able to lift a payload of 15,25 kg. The p:w value in this mode is 23,11 During the dynamic analysis of the real time experiment, the bot with 660 gm weight is able to climb with a weight of 1,25 kg. The p:w value in this mode is 2.

CONCLUSION

The figure 16 depicts that the simulated result using Coppeliasim is found to be more or less same with the experimental result. Though the theoretical adhesive force is ranging between 25kgf to 30kgf, the actual experimental value says its 15,25 kg. Thus the p:w of the proposed IWWCR is compared with the all the existing one and from referring the table 7,9, it is clear that the proposed IWWCR has the highest p: value in case of static and ranks 6th while considering the p:w value under dynamic analysis. The stability of the bot with respect to various inclination angle could be the future study of the work.

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CONFLICT OF INTEREST

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