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Gecko, a climbing robot for walls cleaning

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Abstract

In the paper a digital mock-up of Gecko, a robot for cleaning vertical surfaces and ceilings, is presented. The sticking is guaranteed by suction cups which provide also a two directions mobility. An innovative suspension is used for both, assuring modulated pressure in the cups and their pressing/withdrawal relative to the wall. The cleaning is ecologically and effectively accomplished through steam spraying, which after condensation is back collected. Simulation checks and tests in a virtual reality environment proved out the correct behaviour of the robot, while coping usual operative conditions. After a brief outline of the cleaning robots already available on the market, details about the architecture and the components of Gecko, are commented, with suggestion to the foreseen, out of the cleaning, applications.

1 Introduction

Robotics is quickly moving from industrial domain, to service fields. Potential applications are quite numerous, and may vary from replacing humans in doing repetitive or heavy tasks or work in unsafe and/or contaminated sites, to the assistance to aged or long-suffering people needing continuos help and care, to persons or material transportation, to rescue actions, to precision surgery, to cleaning unhealthy sites as oil tanks, and the likes.

Cleaning is one of fields which is expected to have a strong benefit by service robots: in Europe, it represents a market of more or less 100 billions of Euro per year, with a percentage of 80% of the figure due to mankind labour cost. In addition, bylaw regulations will soon enforce that sites devoted to food preparation for large communities are cleaned in the interval between one food processing and the following one, with objective standard quality: the candidate solution for this activity is a robot as it warranties that errors and mismatching likely introduced by humans are not made.

The collaboration between a leader company in household appliances and the PMAR lab from the University of Genova, led to turn out a robot, Gecko, as an equipment to automate cleaning operations in industrial kitchens, [1-3]. For reliability and economical reasons, in the design set-up, strong preference was given, whenever possible, to off-the-shelves components.

2 Overview of cleaning robots

Different models of cleaning robots already exist, [4-6], particularly for floor treating.

The interest about cleaning vertical surfaces, [7,8], is becoming increasingly relevant every time the job is classified as dangerous, with possible falls-out on the operator health or safety.

When walls need be cleaned, the major problem to solve is how to make a reliable sticking of the cleaning device to the vertical surface. For pool cleaning the Archimed's thrust is effectively exploited (Ultramax). The Skybot is a sky-scraper window cleaner robot, sustained by two wires leaning out from the top of the building. The sticking action can be obtained by suction cups: for example, the scaffolding climbing robot (patent US5213172), uses a system of sliding vacuum cups, moving along beams.

Similarly, the robot for vapour generators (patent US5467813), moves forward using vacuum cups. The device is equipped by three motors: two, drive the suction cups to slide along two guides; a third motor and two joints linked to the two guides, allow the robot to move on a 3D space. The robot can autonomously move from a wall to a wall perpendicular to the first one.

To combine sticking ability and mobility, different solutions have been proposed, for instance, a robot which moves thank to driving wheel put inside a big suction cup providing sticking (patent JP7095936), or the crawlers of the fast climber (patent JP5050955) with distributed suction cups.

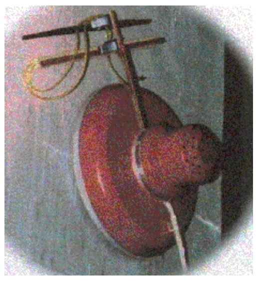

Figure 1. Robot of the Institute for Problem in Mechanics (Moscow).

A robot for large walls and windows cleaning, Figure 1, has been developed in Russia by the Institute for Problem in Mechanics [9], within the programme n° 96-01-00424 of the Russian Fund for Basic Research. The negative pressure for sticking is given by a fan, while a four wheel platform enables motion: opposite wheels rotate the same way for straight motion or opposite for allowing robot turn. The cleaning module consists of two wipers and a nozzle for cleansing dispensing.

The Fraunhofer Institute for Factory Operation and Automation IFF of Magdeburg studied a robot for the cleaning of outdoor surfaces, Figure 2. Trials were made on the Leipzig Fair building (Germany): which has 25,000 square metres of glass tiles (carried on by a steels mesh) having the shape of a half cylinder with horizontal axis.

Figure 2. The Leipzig Fair building and the robot at work on the glass surface.

The robot is tailored on that structure and is basically a box of 300 mm height, and 1500 mm square side. A conveyor, running on the top of the dome has two hoists which raise and lower two equal cleaning robots through Kevlar® ropes: to avoid surface damage, four idle wheels are used, while for the cleaning, both cylindrical and disk rotating brushes are used in addition to warm water dispensing.

NINJA is a robot with legs jointly designed by the Tokyo Institute of Technology and the Isikawajima-Harima Heavy Industries Company Limited, [10]. Its purpose is not actually for cleaning but the structure might be easily adapted to that activity. Aim of the project was to settle a robot for climbing and moving on different surfaces (floors, walls, ceilings) and with high payload: foreseen applications are quite numerous, and include the possibility of replacing humans in dangerous jobs (inspection of skyscrapers or industrial plant walls, help in rescue, aid during fire extinguishing). The locomotion system adopts legs with vacuum cups in the feet allowing movements as illustrated in Figure 3.

The robot has legs with a 3-dof parallel mechanism that allow high forces, a new mechanism CP (Conduit-wire-driven Parallelogram) for the ankles, a vacuum cup VM (Valve-regulated Multiple) for high efficiency even when furrows or rough walls are encountered.

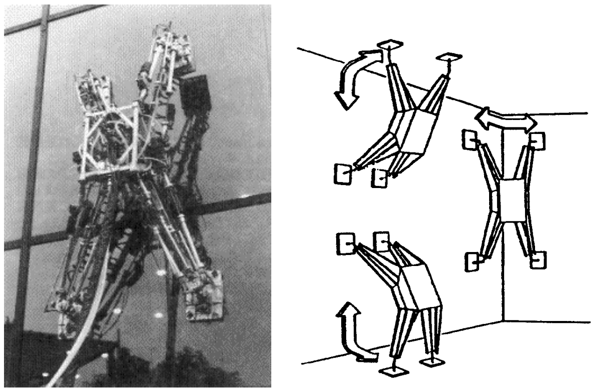

Figure 3. The NINJA-1 in action.

The robot size is 500x1800x400 mm, the mass is 45 kg, the thrusts and speeds in vertical and horizontal are, respectively, 4000 N, 0.15 m/s and 500 N, 1 m/s, vacuum total force reaches 1500 N.

In the Lab of Prof. Nishi of the University of Miyazaki, Japan, it has been built a flying robot having two rotating blades, Figure 4: it is able to sweep on outdoor surfaces and a practical use might be to extinguish fire. It is equipped with two internal combustion engines of 56 cc, has a speed of 0.5 m/s, and a weight of 20 kg.

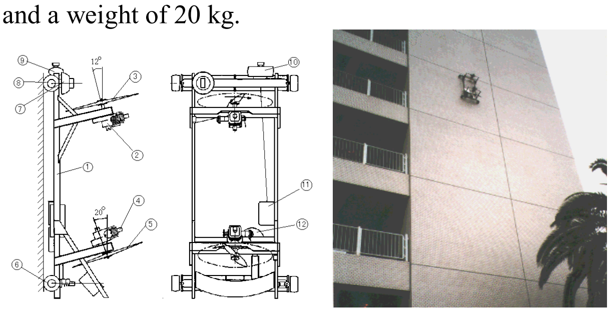

Figure 4. The flying robot.

In the same Lab, the suction robot and the biped robot have been conceived, Figure 5: the first one has a max speed of 0.5 m/s, a suction area of 1.2 m^2 and a weight of 40 kg; the second has a weight of 12 kg and enhanced mobility, and is capable to pass from floor to wall and to ceiling.

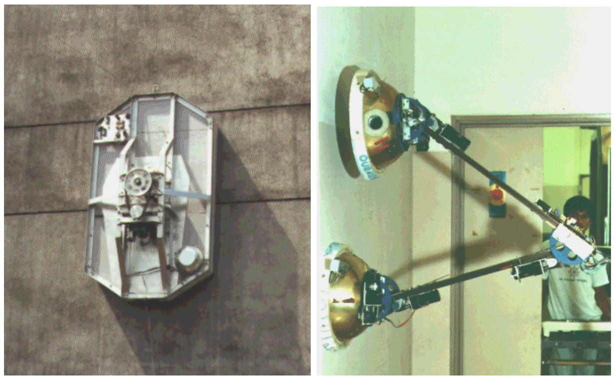

Figure 5. The suction Robot and the biped climbing Robot.

2.1 Raising and holding up techniques

The force for withstanding the gravity may be exerted with several technologies. A brief overview is hereby recalled: - fan, allows to have no limit in the reachable height, but requires a combustion engine due to the high power needed; - pressurised steam, may be used for both cleaning and thrust (similarly to a rocket), but has low efficiency; - magnetic adhesion, is effective and quite insensitive to the state (dirty, irregular, with furrows) of the surface, which, nevertheless, has to be made of ferromagnetic material; - cart and telescopic arm, hold-ups the cleaning module and allows a reliable, but heavy, large and expensive solution; - use of vacuum, the negative relative pressure is easily created with moderate power consumption, on condition that proper sealing limits the vacuum losses: the drawback is that high roughness, grooves or deep junctions (along the surface to stick on) hinder the effectiveness of the solution.

3 Gecko's outlook

The functional requirements of Gecko were set after an investigation of the typical environments the robot shall deal with, i.e., large kitchens for mass restoration. The usual location and dimensions of benches, hangings, hoods, etc. and the allowable space among them, suggested the optimal shape and size of the robot. For the tasks programming, a control unit accomplishing trajectory planning, motion driving and cleaning duty co-ordination is needed, [11,12]. Because the same kitchen has to be cleaned each day, the environment may be considered "structured" so, the first time, the user, by means of a remote controller, teaches the robot the right cleaning sequence and path. A basic control algorithm was developed, using the object oriented language Modsim III for simulating the whole cleaning procedure. Gecko, as it will be shown in the following, has some autonomy limitations, in that, for example, it cannot overcome corners: an ancillary robot (Collie) which might assist Gecko is provided; nevertheless, when Gecko operates, Collie may be assigned to the cleaning of floors and low height equipment.

3.1 Shape

The locomotion of a robot is critically influenced by overall dimensions and masses, so these are to be chosen as a compromise by weighing various aspects. For economy reasons and for easy sticking, a reduced size is welcomed, even if a large base area (and a high speed of the vehicle) helps shortening the required time for cleaning up.

A round robot makes simple the spinning, but hinders the cleaning of regions near corners. A rectangular one solves the last problem: as a result it has been decided to use a square shape because it has the smallest perimeter, once the area is fixed, so minimising steam and vacuum losses; furthermore, for the same translational speed, the cleaning rate does not depend on the direction.

The trouble about body spinning has been overcome giving the robot two perpendicular straight movements. Ultimately, Gecko has a box shape with a 300 mm square base, while its total mass is around 6 kg, Figure 6.

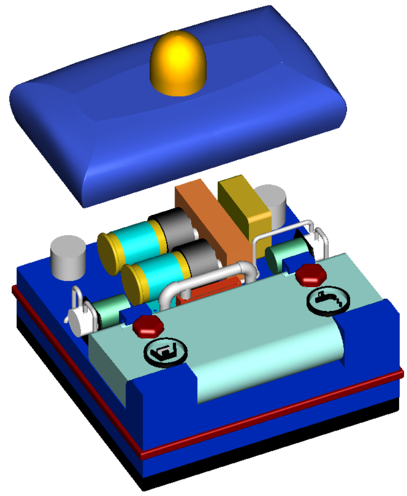

Figure 6. A view of Gecko with the cover disassembled.

3.2 Sticking system

After an investigation on the several possibilities for holding up and moving, it has been decided to use four rigid vacuum cups (chosen from the market); two of them are fixed to the robot frame, the other ones are properly guided by linear actuators, Figure 7: all the cups are endowed with a pair of automatic suspensions which press or retract the cups against the wall.

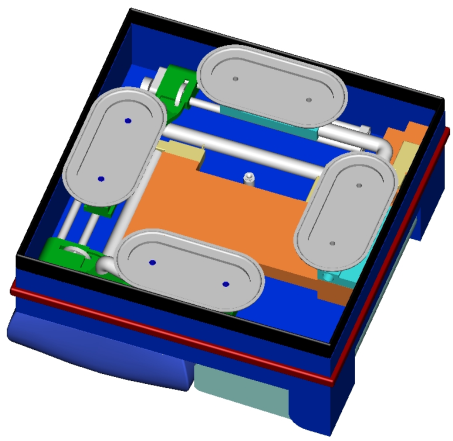

Figure 7. Bottom of Gecko.

3.3 Vacuum creation

The vacuum is created by two commercial pumps (ASFTHOMAS G/07-N-LC), operating in parallel to enhance reliability, having overall weight of 0.7 kg, and max vacuum of -800 mbar.

3.4 Valves

Three electrical 3-way valves (Humprey Nereus NK5) are adopted: in fact, as the two static cups work synchronously, only one valve is needed for their managing. The valves are connected to three ducts and this allow to create vacuum in the cup or to forward part of the steam used for cleaning inside the cup for an easier detachment.

3.5 Suspension of the cups

When the robot moves, only one cup is hanged to the wall. To avoid slipping of the three idle cups, they must not be in contact with the surface; actuators might be devoted to this task, but this implies more weight and complex control. A mechanism which could move forth and back the cups, exploiting the power of the vacuum pump has then been ideated, Figure 8. Basically, it consists of two chambers crossed by a hollow rod with three polar series of holes strategically placed; when no vacuum is applied, a spring holds the cup up; as vacuum is created in the upper chamber, the rod goes down, till the cup touch the wall and in the meantime the holes assume a configuration such that the vacuum flows in the second camera and from this enters in the rod and in the cup at the end, Figure 9.

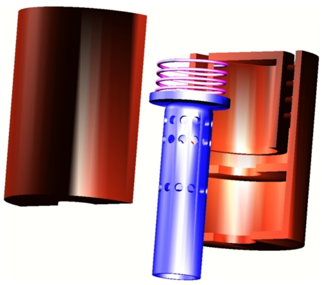

Figure 8. The automatic suspension

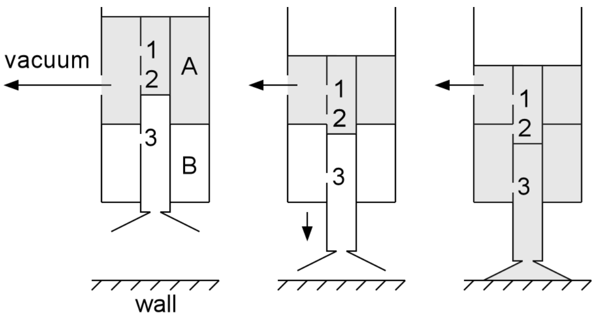

Figure 9. Principle of the automatic suspension: till holes 1 and 2 are in chamber A, the hollow rod moves down; when hole 2 arrives in B, vacuum (in grey) flows in the cup thanks to opening 3.

3.6 Legs actuation

The translational movement of the two orthogonal cups could be fulfilled by means of linear motors; here, for economy, the translation of each cup is obtained combining an electric motor which after an initial speed reduction through a worm/wheel gear, rotate a second worm (THK DCMB 8T) which drives the arm bearing the cup, Figure 10. The DC motors are 1406/2Y from Aveox and have a power of about 200 W, at a speed of 7,000 rpm; the pitch of the worm is 12 mm, so for the desired arm speed of 75 mm/s a gear with i=19 is required. The actuation system allows Gecko to move upward, downward, left and right, without the need to rotate the robot itself. To produce a horizontal translation of the robot, e.g. from left to right, Figure 11, the following steps are completed: - depression of the right suction cup only; - translation of the arm having the suction cup depressurised (the robot moves from left to right); - depression of all the suction cups; - depression of all the suction cups except the right suction cup; - movement of the suction cup arm from left to right; iteration of the above cycle.

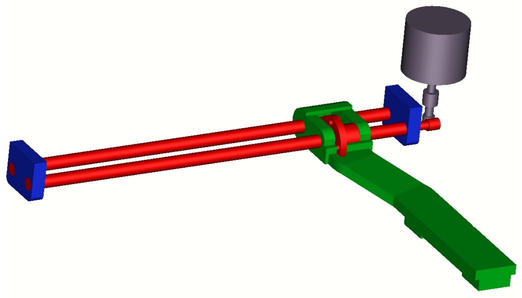

Figure 10. Driving system of the arm supporting an active cup (the cup is here not shown).

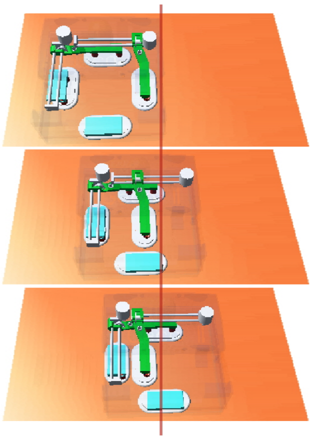

Figure 11. Rightward movement schematic.

3.7 Cleaning system

Gecko cleans the walls using steam. The solution is effective, environmentally friendly and cheap; high temperature steam not only cleans, but sanitizes the surfaces, as well. The water is drained by a pump from a tank and forwarded to an electric resistance boiler, Figure 12; here, steam at 120 °C is generated and sprayed to the surface of the wall through nozzles: a special skirt along the underneath perimeter of Gecko prevents steam spreading in the environment. The steam dissolves the grease and condenses in contact with the cold surface; micro-channels recover the dirty water and a pump collects it in a tank.

To make as compact as possible the robot a unique tank is built up: as the clean water leaves, a fence moves and create a room for the dirty water storage, Figure 13. Because of the high rate of steam production (about 2 g/s), a fast lock-unlock device for tank extraction and refilling is provided.

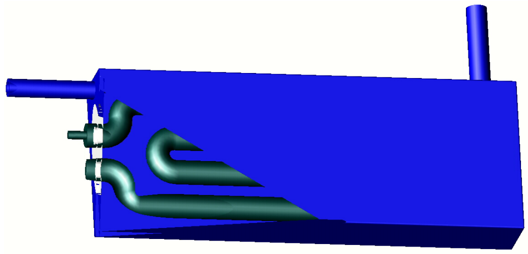

Figure 12. Detail of the boiler.

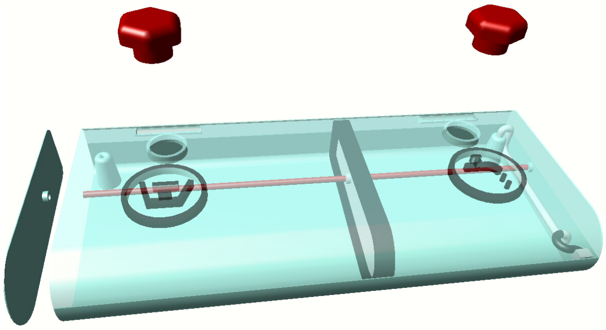

Figure 13. Exploded view of the tank. The separator and the inlet/outlet ducts are evident.

4 Comments and conclusions

Despite Gecko is an effective cleaning robot, specially conceived for walls cleaning, it might be used as a platform for scaled climbing robots, to accomplish other tasks, among them are worthy the following ones are worthy to be cited: rescue of people, hazardous places exploration, navy dock analysis, etc. The investigated rig, in fact, characterises by the ability of independent and safe sticking and walking mechanisms, for enhanced job skill.

The operative functionality, the robustness and the overall reliability of the robot have been checked by means of extended use of early structural, thermal, dynamic analyses, carried out on the virtual prototype of Gecko. Testing and evaluation of the right consistency of the device were achieved following the life-cycle approach to cover the steps from conceptual design to dismantling.

The solution is obviously open to betterment: Gecko's autonomy, as above mentioned, is not full, as it needs an operator or a second robot for re-positioning; the latter one could also act as energy supplier, by replacing Gecko's on-board batteries. Competing policies have been investigated, with appropriate virtual prototypes, to run feasibility checks up to considerably sharp definition. The different checks show that suitably high performance is achieved, whether the prospected duty-cycle is known and proper strategies are enabled.

References

[1] F. Cepolina, R.C. Michelini, R.M. Molfino, R.P. Razzoli "Domestic-chores automation: multi-media analysis and assessment study", *Proc. XI ADM Intl. Conf. on Design Tools and Methods in Industrial Engineering*, vol. C, pp. 139-146, Palermo, 8-12 Dec. 1999.

[2] F. Cepolina, R.C. Michelini, R.M. Molfino, R.P. Razzoli "Collie-Gecko: a co-operative multi-robot system for cleaning applications", *Proc. 3rd CLAWAR 2000, Intl. Conf. on Climbing and Walking Robots*, pp. 803-811, Madrid, 2-4 Oct. 2000.

[3] F. Cepolina, R.C. Michelini "Gecko, the walls cleaner", *Industrial Robot*, Emerald pub., pp. 538-543, vol. 29, No. 6, 2002.

[4] R.D. Schraft, M. Hagele, R. Dillmann "Technologies, state-of-the-art and challenges in service robot technology, design and applications", *IARP International Advanced Robotics Programme service and personal robots: technologies and applications*, Genova, Italy, 23-24 Oct. 1997.

[5] M. Schofield, S. Deltour "Commercial development of fully automated cleaning machines", *IARP International Advanced Robotics Programme service and personal robots: technologies and applications*, Genova, Italy, 23-24 Oct. 1997.

[6] H. Endres, W. Feiten, G. Lawitsky "Field test of a navigation system: autonomous cleaning in supermarkets", *Proceedings of the IEEE International conference on Robotics & Automation*, pp. 1779-1781, Leuven, Belgium, May 1998.

[7] Y. Wang, S. Liu, D. Xu, Y. Zhao, H. Shao, X. Gao "Development & application of wall-climbing robots", Proceedings of the IEEE International conference on Robotics & Automation, pp. 1207-1212, Detroit, Michigan, May 1999.

[8] T. Yano, S. Numao, Y. Kitamura "Development of a self-contained wall climbing robot with scanning type suction cups", *Proceedings of the 1998 IEEE International conference on Intelligent Robots & Systems*, pp. 249-254, Victoria B.C., Canada, Oct. 1998.

[9] V. Gradetsky, M. Rachkov, S. Kalinichenko, E. Semenov "Service robot for cleaning of vertical surfaces", *IARP International Advanced Robotics Programme service and personal robots: technologies and applications*, Genova, Italy, 23-24 Oct. 1997.

[10] A. Nagakubo, S. Hirose "Walking and Running of the Quadruped Wall-Climbing Robot", *Proc. IEEE Int. Conf. on Robotics and Automation*, pp. 1005-1012, 1994.

[11] V. Gradetsky, S. Kalinichenko, L. Kravchuk "Transition control of multilink mobile robot with two platforms", *IV ECPD Intl. Conf. Advanced Robotics, Intelligent Automation and Active Systems*, Moscow, Aug. 1998.

[12] F.E.H. Tay "A software framework for an automated wall cleaning robot" *Robotics and Mechatronics Congress*, Singapore, 6-8 June 2001.