COLLIE-GECO: A COOPERATIVE MULTI-ROBOT SYSTEM FOR CLEANING APPLICATIONS

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Abstract – **The contribution refers a two-robots system purposely designed to clean internal environments subjected to hygiene regulations. The mechanical design oriented to the life cycle has been developed. The tests and validation of the various solutions considered has been carried out using different simulation and virtual reality tools. Virtual mock-up is efficient design help when, as the present project requires, non-conventional solutions are prospected for every-day life problems.**

INTRODUCTION

Instrumental robots are assumed to increasingly replace humans for unpleasant duties and wearying assignments, as soon as the tasks are duly described and the operation surroundings acknowledged into social and environmental compatibility schemes. By now, industrial robotics has achieved wide agreement levels and important fall-off is transferred to other fields, at least, as for technological feasibility. Oddly enough, robots have, since when conceived by Karel Capek, close connection with every-day life and appear quite often as advertising hints for household appliances, but actually operating devices are far from covering the many repetitive and harassing jobs, we face for domestic chores.
The paper deals with a quite rule-driven duty, namely the cleaning of large kitchen and related food-processing rooms for communities restoration; the UE regulations are becoming very strict, both, in terms of work accomplishments and of registration charges, so that, replacing operators with robots is likely to grant return on investment, once the effectiveness of the work-cycles is checked, as automation by itself grants fulfilment of the planned scopes. Modern CAD development tools are fit out with special modules, further to standard solid modellers, to supply virtual product displaying and task animation, with proper range of rendering to make easy the checks on the technological compatibility of new (competing) solutions.

THE STATE OF THE ART

Among the service robotics branches, the cleaning one is that offering wide possibilities in developing industrial goods. Cleaning is a general term meaning several service operations, from the stripping to the sweeping, to the washing with various detergents, to the garbage collection.
In this field, representing in Europe about 100 milliards of ECUs with 1,9 millions of employees, a lot of projects and prototypes have been developed, but the more promising, from the engineering viewpoint, are the cleaning of almost horizontal smooth surfaces as indoor or outdoor floors and the cleaning of vertical walls as the glass fronts of civil buildings.
This kind of services has a good chance to spread on the market, in that the wide potential customers basin allows economy of scale and the application is related to structured (and well known) environments even if accidentally populated by human beings and/or machines.
The first cleaning robots born at mid 1980s:

- ✓ CABX as a project (sponsored by national french authorities) from the PROTEE consortium, involving Cybernetix, CEA e Comatec for the cleaning of the Metro stations of Paris;
- ✓ AXV-01 developed in Japan by Electrolux.

These pioneers were followed by more than twenty industrial prototypes; only few of them reached the market; it was guessed that less than 200 ones were sold.

Among the more interesting research projects and prototypes, it is worthwhile to recall the ones in the following.

Inside the Eureka EU1094 CLEAN project was developed the robot prototype for the cleaning ASM (Autonomous Scrubbing Machine). In the project there were involved: the GSF – one of the major cleaning french firms, the Robosoft – with expertise in the design of robots, the german Henkel Ecolab – a leader in chemical products and the Comac – an italian builder of cleaning machines. Today, ASM is on the market and its average cost is 30 000-50 000 US$ [Sem97].

ACRO (Autonomous Cleaning Robot with Task Level Programming) is a project supported by the UE ESPRIT 3 programme, ended in 1996. The project is driven by Hako-Werke Gmbh & Co, with the collaboration of CEA (Commissiariat à l'Energie Atomique), the Fraunhofer IPA, the Stuttgard University, the Consortium of maintenance and of technologies of Paris, the British Railways Board (UK), the danish Linak and the french ROL and SAGEM.

TEAM (Test Environments for Autonomous Cleaning Machines) is a project, still alive, supported by the UE in the framework of the ESPRIT 4 programme by the german firm Hako-Werke Gmbh & Co jointly with the french ROL and the german Microsonic Gesellschaft fur Mikroelektronic und Ultraschalltechnik Gmbh. The project avails itself of the results came out from ESPRIT ACRO e CABX/AUROR projects, supported by french government entities.

A still in progress project in the technical faculty of Nanyang, Singapore [Lia98] is about a robot for home use compelling floor cleaning, material transfer and monitoring tasks in a usual domestic environment. The robot is basically composed by a mobile platform and a control system. The control system, made by a PC and a communication interface, is used to boot the system, to communicate with the user and to establish and maintain the link with the moving platform along the task execution.

Siemens has completed a prototype navigation system for service robots devoted to the cleaning of big stores. The project, still active, is carried on by the co-operation of three partners: the stores chain Albert Heijn B.V., the expert in cleaning RTB, both of them dutch, and the builder of cleaning machines Hefter Cleantech (HCT).

At the University of Canberra, in Australia [anu98] it has been developed a robotic system for floors cleaning: this system is used as the basic set for the study of the in-real-time communication and control methods of cooperating architectures.

At the City University in Hong Kong it was designed and is now used as research bench a moving robot for cleaning purposes in commercial, industrial and domestic sites called SVC Smart Vacuum Cleaner [SVC98].

An example of mobile robot on the market is the Koala; its structure is simple: the movement is given by two wheel trains located on the lateral sides of the platform. This essential structure may face difficult situations using easy control strategies. The number of wheels adopted is six: this let the device climb small obstacles like the door steps.

The Institute for the science of materials of the University of Hanover and the german firm Schmalz developed a small robot called Hydra II which, being able to ascend vertical walls and very sloped surfaces, is even suitable to cleaning tasks [RiM95].

A curious robot for the cleaning of vertical walls and flat smooth roofs, in particular large windows and wide glass surfaces, has been developed in Russia by the Institute for Problem in Mechanics of the Russian Academy of Sciences [GRK97]. The work was made inside the project 96-01-00424 of the Russian Fund for Basic Research.

The Fraunhofer Institute for Factory Operation and Automation IFF of Magdeburg developed a robot with a specific architecture for outdoor walls cleaning. The structure taken as the reference one is the building of the fair of Leipzig (Germany): 25 000 m^2 are covered by

glass. The vault has a half-cylinder (with the axis laying horizontally) shape and is made of glass panels hold by means of a steel mesh having 3.12 m sides squared cells; the distance between the and the glass surface is 0.35 metres.

THE ROBOTIC SYSTEM AIMS

The aim of the present investigation is to develop and design a sturdy, sure, independent system for the cleaning of dirty pavements and dirty walls with reduced development and system costs. The robotic system will execute pre-programmed cleaning paths not requiring trained personnel, the human/machine: interface being very simple and intuitive at the lower (execution) level.
The duration of the cleaning operation may be two-three hours for typical room dimensions: 6m long and large and 2 meters height and for the cleaning of elevated objects (hoods ...).
Only few modifications to the environment will be necessary for using this cleaning system.

THE ROBOTIC SYSTEM ARCHITECTURE

The robotic system is composed by two cooperating robots.
A base robot COLLIE is used for:

- removal of the solid refusals from the pavement
- cleaning of the pavement
- cleaning of the oven and of the refrigerator
- positioning of the Geco robot.

A climbing robot GECO is used for walls cleaning.
Figure 1 shows the two robots at work in a synthetic environment.

Fig. 1. Cooperative robots at work

THE BASE ROBOT

The base robot is designed as a mobile arm. The locomotion, based on two drive wheels, allows for quick and agile manoeuvres in narrow passages. The arm is an open kinematic chain with 6 degree of freedom; the RPR wrist is purposely designed for dexterous applications. All the actuator are mounted on the base.
This robot is endowed with some technological modules:

- 2 long hair brushes
- a trash chopper
- 2 short hair brushes
- cleaning supply
- device for cleansing recovery.

Figure 2 shows the base robot arrangement and some cleaning process components.
The kinematic model has been written following the Sheth & Uicker general approach [1971], under the following hypotheses:

- rigid members
- no more than a joint steering for wheel
- mobility on flat surface
- steering axes normal to the land
- sliding absence between wheel and land
- negligible rolling friction.

The studied model will be useful for navigation and control problems.

Fig. 2. Collie robot assembly and details.

THE CLIMBING ROBOT

The Geco robot can translate on quite plain surfaces. The locomotion is executed through electric actuation and a vacuum system made by a vacuum pump, cups and valves. Two solutions have been studied using linear and traditional electric motors.
New conception supports of the vacuum cups has been conceived and purposely designed.
The implemented cleaning process foresees simple apparatus as an evaporator, a particular tank, nozzles and feeding plant.
Figure 3 shows the assembly and the exploded view of the climbing robot.

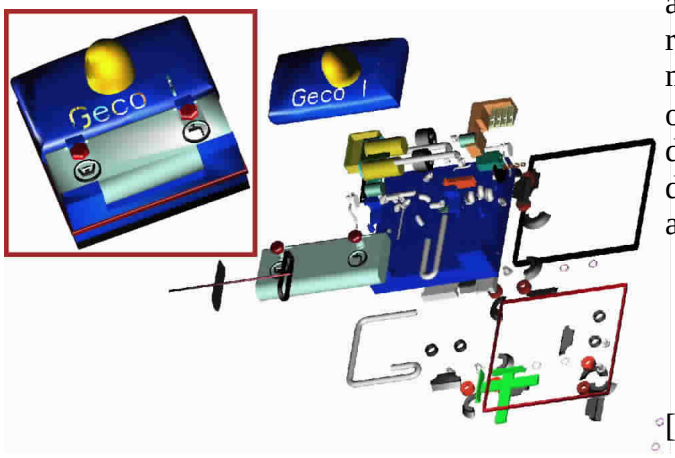

Fig. 3. Geco robot assembly and exploded view.

COMMENTS AND CONCLUSIONS

The cleaning service application oriented robot project issued into a complex equipment, splitting operations between a tender-robot, **COLLIE**, for basic (floor, inner spaces, etc.) cleaning and a climbing-robot, **GECO**, timely serviced by the tender, cleaning the vertical surfaces.
The project aimed at developing the main structural components (in order to assess, both, configuration feasibility and functional effectiveness), with joint acknowledgement of the operation friendliness, by presenting the task progression through virtual reality restitution.
Design requests are closely examined, focusing on a pertinent multimedia displaying of the operation abilities of the climbing robot, **GECO,** conceived, with several technological innovations to be consistent with the unusual job of washing vertical walls. The **GECO** sticks to surfaces by means of suction cups, has a walking logic to accomplish bi-directional paths and performs the cleaning by steam-jets and dirty recycling.
The paper covers structural and functional details, with due concern of actuation and servicing fixtures; sample restitution of robots-at-work engagements show the technical appropriateness of the suggested equipment.
The virtual reality options look to be useful to win popularity for contrivances alien to common habits. In fact, as initially recalled, domestic robots fail to be accepted for current applications, until their friendly effectiveness is recognised and appreciated. The here discussed multimedia results, it should be said, are all obtained with the use of standard CAD codes, to day, widely available by mechanical design departments for use to improve the preparation and training of to-day engineers.

REFERENCES

[anu98] http://www.syseng.anu.edu.au/rsl/

[ASG.96] H. Asama, M. Sato, N. Goto, H. Kaetsu, A. Matsumoto, I. Endo: “Mutual transport of cooperative mobile robots using forklift mechanism”, IEEE Intl. Conf.

Robotics and Automation, Minneapolis, April, 1996.

[CMM99] F. Cepolina, R.C. Michelini, R.M. Molfino, R.P. Razzoli: "Domestic-Chores Automation: Multi-Media Analysis and Assessment Study" 11th ADM International Conference on Design Tools and Methods in Industrial Engineering" Palermo, December 8-12 1999, pp.139-146

[EFL.98] H. Endres, W. Feiten, G. Lawitsky: "Field test of navigation systems: autonomous cleaning in supermarkets", IEEE Intl. Conf. Robotics and Automation, Leuven, May, 1998.

[FeK.91] A. Feng, B.H. Krog: "Dynamic steering control of conventionally steered robots", J. Robotics Systems, vol. 8, n° 8, 1991.

[FUS.98] S. Fujiawa, T. Umemoto, Y. Shidama, K. Ohkubo, T. Yoshida, H. Yamaura: "Design of an omnidirectional spherical robot and its moving properties", Intl. Conf. Advanced Robotics Beyond 2000, Birmingham, April, 1998.

[GKK.98] 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, August, 1998.

[GRK.97] V. Gradetsky, M. Rachkov, S. Kalinichenko, E. Semenov: "Service robot for cleaning vertical surfaces", IARP Workshop, Genova, October, 1997.

[Lia98] Liang K.S.S. "Domestic Service Robot" Advanced Robotics Beyond 2000, Birmingham, UK, 27 April-1 May , 1998

[PCK.97] R.T. Pack, J.L. Chistofer, K. Kawamura: "A rubbertuator-based structure-climbing inspection robot", IEEE Intl. Conf. Robotics and Automation, Albunquerque, April, 1997.

[RiM95] RM " Un Robot "Scalatore"", Rivista di Meccanica N° 1074 Maggio 1995, p.80

[Sem97] Semerano A. "New Promising Applications for Service Robotics: Collective Organizations " IARP International Advanced Robotics Programme Service and Personal Robots: Technologies and Applications, Genova, Italy, 23-24 October 1997

[SVC98]http://personal.cityu.edu.hk/~meptse/research_works/#SVC98