GECKO-COLLIE: HOMECLEANING AUTOMATION OF FLOORS, WALLS AND CUPBOARDS

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ABSTRACT

The domain of food processing is requiring the replacement of human front-end operators to grant standard cleaning conditions and to achieve health and safety thresholds, according to Authorities rules. The development of instrumental robotic equipment is considered with interest, but, at the moment, actual implementations face lags in their acceptation. The paper considers a co-operating built-up, based on modular devices, properly tailored to given sets of duties; the robotic rigs can be enabled at different levels of sophistication, each time covering further tasks.
The example case deals with the cleaning of community kitchens, severally assuring floor sweep-out, cabinets tidy up, surfaces steam washing; duty-driven fixtures are designed, with attention on operation leanness, to avoid not strictly necessary jobs.
The developed set-up characterises by a tender fixture (*Collie*) and a climbing module (*Gecko*), each one with proper operation capabilities. Architectural feasibility and functional behaviour are dealt with by means of digital mock-ups and virtual reality testing. The investigation leads to the novel *Char-robot* concept, namely, a modular lay-out, with the expected operation capabilities and the effectiveness of, both, duty bent and expansible modularity.

KEYWORDS: Mobile/Climbing Robots - Automatic/Autonomous Cleaning - Integrated Design - Life-cycle Virtual Mock-up Testing.

1 INTRODUCTION

The paper considers a co-operating robotic fixture, *Gecko-Collie* (1), designed for cleaning up internal precincts, submitted to hygiene regulations. The over-all set-up is assessed about life-cycle issues, with example development properly related to the washing and sanitising requirements for large kitchens and similar food processing spaces involved in preparing people and community meals. The throughout acknowledgement of competing solutions is carried out by virtual mock-up testing and by task simulation, once actual operation conditions are duplicated. These design steps provide effective support when, as the present project shows, out-of-the-way solutions are prospected for every-day life (mainly unstructured) problems; as first instance, their success conventionally depends on operation sequences accepted or rejected under the prick of habits, with little effort made to find out (better structured) options less conditioned by anthropocentric views.

With improved insight, the choice of the instrumental robotics, to replace humans for unpleasant duties and wearying assignments, leads to task-driven equipment, tailored for duly described action sequences and acknowledged into effectiveness and environment evenness schemes. The approach is successful for industrial automation, with falls-off and technology transfer granting feasibility for housework automation (2)(3)(4)(5)(6). Oddly enough, robots have, since when conceived by Karel Capek, close connection with every-day life; they appear quite often as advertising hints for household appliances; still, actually operating devices are far from covering the many repetitive and harassing jobs, we face for domestic chores. Deficiencies would be removed on condition to provide goal-oriented equipment, so that operation reliability could win extended approval (and return on investment).

The professional cleaning of inhabited premises is estimated to rise at about 100 billions Euro, with some 2 millions employees in the EU only; therefore, several projects have been ran, with lot of prototypes operating on outdoor and indoor floors and on vertical walls and glass fronts of civil buildings. Extended versatility autonomous robots are, most of the times, considered, with doubtful issues in terms of efficiency (as for given set of principal duties) and reliability (as for achievement accreditation). The present study looks after a split-task setting, with strict functional bent and proposes the co-operative facility *Char-robot*, Fig. 1, based on goal-driven co-operation; leanness and sturdiness are preferred, with essential man/machine interfaces and intuitive programming/execution levels.

The up-keeping of food and beverage processing rooms deserves increased attention, as Health Authorities expand regulations with meticulous charges, so that replacing human operators by robots is likely to reach economical returns to grant tiding up standards and achievement repetitiveness margins. Looking a little more into technicalities, task analysis shows inherent conflicts between cleaning vertical walls and areas needing high sanitising levels, or collecting piled up garbage and scraping and sweeping floor surfaces. Resort to special purpose fixtures further enhances task setting, to distinguish the climbing (*Gecko*), from the tender fixture (*Collie*), each one with proper abilities and work-cycles.

2 THE *CHAR-ROBOT* ARCHITECTURE

Instrumental robotics achieves effectiveness from specialising implements by duty bent; this resorts to *lean* enabling technologies, avoiding function versatility and redundancy whenever the tasks are accomplished by simpler means.

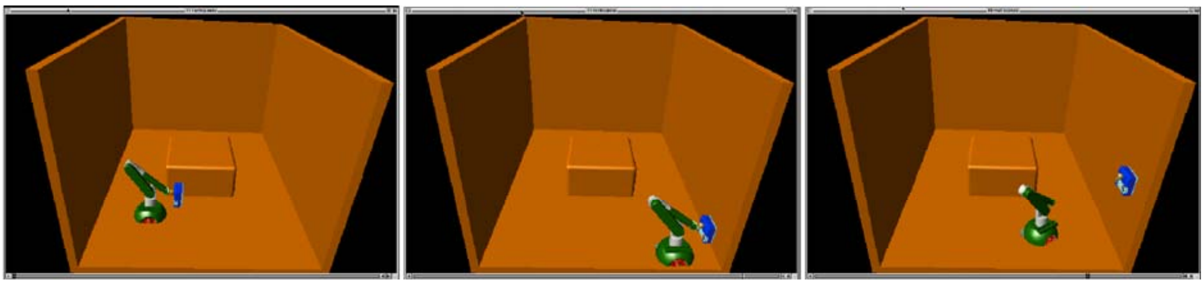


Figure 1 - Co-operative robots at work (frames captured from a movie)

Duty split is issued by requisites concurrence: • vertical walls could be 3 m and more high, with size (and stability) limits for the walking fixture; • cleanness rules impose the separation of tidy-up agents and means depending on the requested duty. *Gecko* is, thus, purposely developed to accomplish steam wiping, matching cleaning requests for work-surfaces, without contamination promiscuity or undue sanitising effects on food. As soon as a task-driven set-up is fixed, feasibility has to be assessed for actual running conditions on the whole work-cycle span, according to an *integrated design* approach.

Thus, functional and structural checks of prototypal fixtures are performed on virtual mock-ups; properties are investigated by an associative CAD code, starting from a solid modeller with annexed FE modules, using animation aids for task recognition, applying a dynamics analyser to fix the governing logic and running sets of virtual-reality tests on competing solutions. Typical results covers: • task planning, to establish effective *Char-robot*'s tidy up policies and *Gecko*'s dispatching strategies; • restitution of robots-at-work engagements, to show their soundness in front of unexpected occurrences; • analysis of the *Gecko*'s gait, for vertical and lateral trajectories; • on-process checks of steam spraying and dirty liquid recapture; • lay-out investigation, with component's choice to rise the effectiveness and lower the cost; • consistency examination of structural details, to inspect stability and reliability; • and the likes. In the following, hints on the concept-design issues are summarised, separately dealing with the co-operating fixtures.

2.1 The floor servicing equipment *Collie*

The tender *Collie* is a mobile platform with a 6 d.o.f. arm, Fig. 2; mobility is supplied by an idle spherical element and two powered disks, assuring easy path tracking with sharp turns; the bottom frame includes: two long hair brushes; a trash chopper; two short hair brushes; a cleanser supply; means for cleansing recovery. The design avails of standard technologies: **-** mobile devices are extensively used for floor washing and garbage picking and example implementations are offered for autonomous running; **-** conventional arms could be added for special tidying (shelves, cabinets, ovens, etc.) and *Gecko* handling, as case arises, e.g. to transfer *Gecko* from a given surface to a perpendicular one, detaching and reattaching it when arrived in proximity of a corner. The recharge of the batteries and the filling of the on-board tanks is made off-line from a fixed stand similar to the HYPOS one (7).

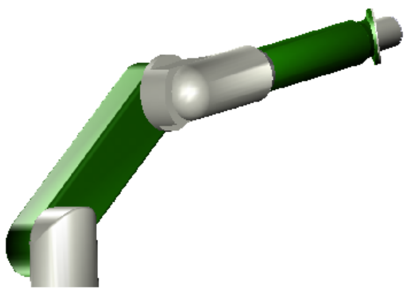


Figure 2 - The six D.O.F. arm

Task *supervised* autonomy is considered: attendants clear the kitchen and *Collie* starts his duties, following structured contexts. Routine paths are tracked, with proximity sensors to keep obstacles out; dirty kind and level are recognised by optical sensors, to repeat given sequences up to the requested quality; *Collie*'s locomotion, based on two driving disks and a spherical wheel, allows for quick and agile manoeuvres in narrow passages. Planning is verified on a **MODSIM** III simulator, with proper interfaces to display kitchen floor and job progression, Fig. 3.

The manipulator has box-shaped limbs with shoulder's drivers and a specially conceived wrist for extended dexterity (in view of the tiding up within constrained spaces) and *cast* attitude (in view of enhanced safety), by irreversible remote drivers. Automatic tip replacement is scheduled: two series of end-effectors are considered: **-** brushing and wiping tools for cleaning internal spaces, with sharp inner corners; - a coupling plug for *Gecko* handling and unlatching at the required locations.

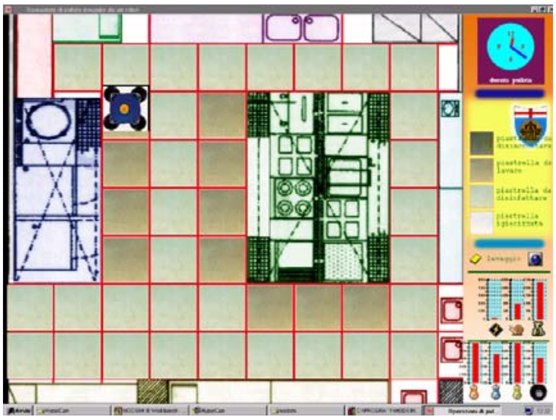


Figure 3 - Example kitchen floor for testing of the planning algorithms by simulation

Several duty-cycles might be considered. Basically, *Collie* starts by choosing the surface to be washed by *Gecko*, to be allowed the cleaning up in parallel of given cabinets; typically *Gecko* is charged of longer tasks and *Collie* is get free to accomplish the tidy up of the floor. Unmanned sequences might, in principle, be planned; a more realistic view, presently, assumes supervised duty-cycles, so that at unexpected occurrences, the operator is alerted and enabled to modify the ongoing work.

2.2 The wall servicing equipment *Gecko*

The proposed *Char-robot* mainly characterises by the co-operating *Gecko*, Fig. 4. It is devoted to operate on vertical surfaces being the floor already cared by *Collie*. For its vertical motion, this avails of a vacuum (cups and valves) gear, with four independently actuated limbs; cleaning, as said, is steam operated, with autonomous tank, feeding plant, nozzles and recovery device. The concept of self-sufficient device makes task parallelism easy, as previously recalled; moreover, duty bent enables, each time, to have resort to the appropriate tidy up means. The device is electrically powered, with an umbilical coming from *Collie*, where a cable rewinding block is located.

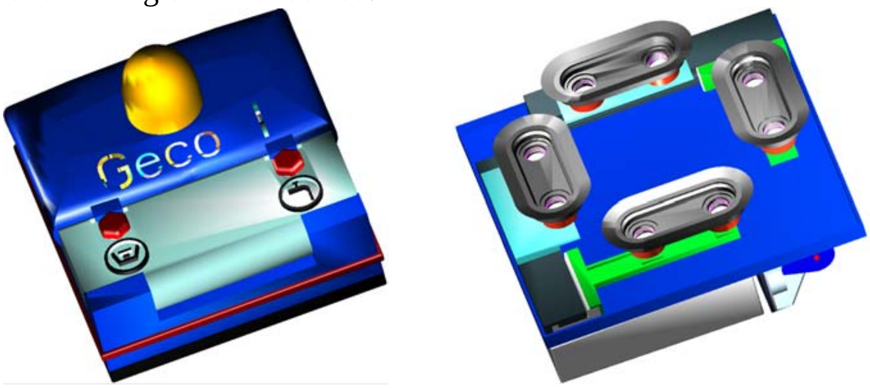


Figure 4 - Two views of *Gecko*

Gecko's climbing needs to select four suction cups, Fig. 5, with pumps granting proper sticking stability during operation (all cups enabled) and gait (two cups acting each time); control is performed by a valve-and-manifold device, Fig. 6; extensible limbs makes safe locomotion on the smooth and continuous surfaces of food processing premises. Tidy up, typically, follows vertical tracks and horizontal displacements are used to reach a new track, avoiding gravity bias effect.

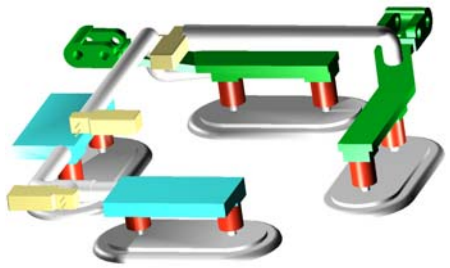


Figure 5 - The cups and vacuum ducts

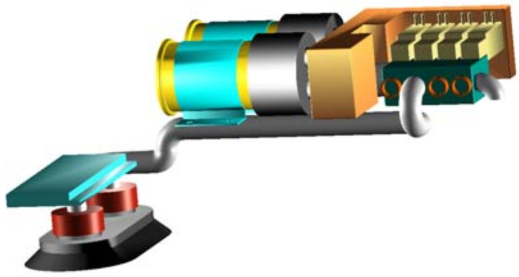


Figure 6 - Detail of pump and valves

The duty requires: - production of steam, from water supplied by a specially built tank, Fig. 7; - sprinkling on the surface each time covered by *Gecko*; - recapture and feeding back of the condensed water, to a separate tank portion. Constructive details of boiler, Fig. 8, and tank, Fig. 7, show the basic task abilities. The autonomy depends on the tank capacity and is chosen to cover the overall duty.

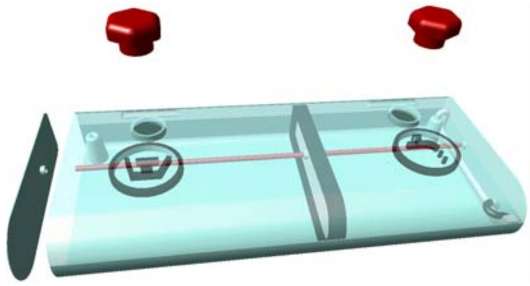


Figure 7 - Exploded view of the tank

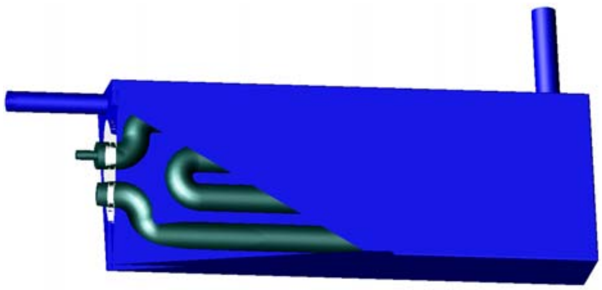


Figure 8 - Partial view of the boiler

2.2.1 *Holding-up and locomotion devices for Gecko*

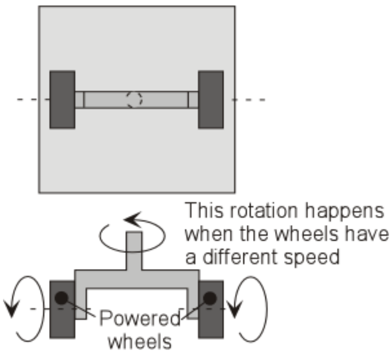
To outline the *Gecko's* architecture, different competitive alternatives are conceived aiming at the most effective lay-out. First, various holding systems are compared: a synthetic overview is given in Fig. 9: among them the vacuum system (8) was preferred because of low weight, size and cost and for the capability to cope with kitchens usual surfaces.

FAN	STEAM	VACUUM	MAGNETIC	TELESCOPIC
***Advantages**: virtual unlimited reachable heights acting on the power and orientation of the fan*	***Advantages**: the thrust of the steam for cleaning can be used for the holding up*	***Advantages:** low power is required for the holding up (if the chamber has limited losses …)*	***Advantages:** no matter about junctions and surface state (rough, dry, …)*	***Advantages:** robust structure, being the part held by an extendable cylinder fixed to a base*
***Hindrances:** low efficiency within enclosed spaces*	***Hindrances:** low energetic efficiency*	***Hindrances:** no deep junctions between panel are allowed*	***Hindrances:** requires ferromagnetic surfaces*	***Hindrances:** large dimensions, high weight*

Figure 9 - Comparison table among different holding-up systems

As for *Gecko's* shape, the square base is selected to reach sharp corners, since the mobility grants two orthogonal way paths; indeed several alternatives are possible for wall locomotion such as: • 2 powered wheels: the relative rotation of the wheels allow the translation and rotation (as it happens for tanks), Fig. 10; • 4 wheels and 2 motor: every motor drives an axle on which two wheels are mounted; the axles are perpendicular and four idle wheels are provided at the corners, Fig. 11; • 2 vacuum cups and 1 linear actuator: this system allows the vehicle to move in one direction only, Fig. 12; • 2 vacuum cups and 2 lateral linear actuators: these ones are located near the sides of the box to avoid their overlapping; a problems is that the body, while moving, is not balanced, so that the moment generated by the weight tends to elastically warp the cup with the result of a non-straight path, Fig. 13; • 4 vacuum cups and 2 linear actuators: in this case there are two additional fixed cups granting the robot to be well balanced as it climbs, Fig. 14.

The last one happens to be the best solution; next step is the evaluation of the power of the mobility actuators and of the vacuum pump by an iterative procedure.



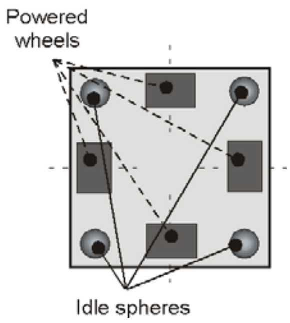
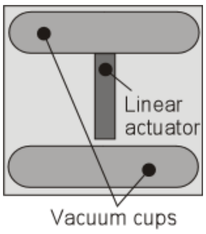


Figure 10 - Two powered wheels **Figure 11 - Four powered (coupled) wheels**



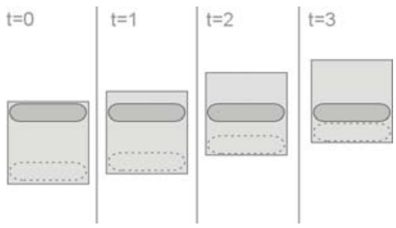
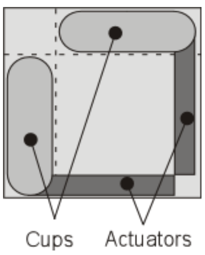


Figure 12 - Two vacuum cups (1 actuated, 1 fixed) and vertical movement (on the left)



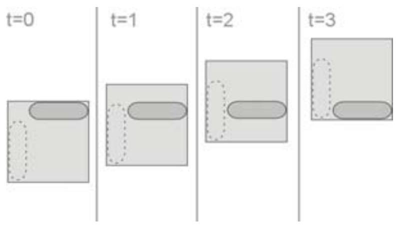


Figure 13 - Two vacuum cups (both actuated) and vertical movement (on the left)

Figure 14 - Four vacuum cups (the left and the bottom are fixed) and vertical path

3 COMMENTS AND CONCLUSIONS

Char-robot presents as a worthwhile suggestion for duty-driven automation. Health and safety protection acts require certified levels of cleanness and contamination freedom, to be achieved within standard thresholds. This pushes toward robotic handling when food processing or related duties are accomplished; the exclusion of front end human operators assures visibility of the task schedules and issues. The last remark is, possibly, basic aspect for the return on investment, aiming at fixture leanness, strictly within duty-cycles stated by health protection Authorities.

Tidy up-keeping and cleaning of the food processing spaces belong to domains where instrumental robotics should expand; the case of community kitchens is considered with interest by specialised manufacturers, with offers that take into account smooth spreading of automation. *Char-robot* concept characterises by modularity and step-wise inception. The (tender) *Collie* is a conventional (autonomous) floor-washing machine, with an added arm for special purpose cleaning and, if case arises, for *Gecko* handling; it might be used as stand-alone device, at different completion levels and tailored task planning abilities with further developments addressed at improving the autonomy of the system. Task discrimination into classes (floor sweep-out, cabinets tidy up, surfaces steam cleaning) addresses the architecture modularity, each time bounding the device functions at proper levels of sophistication.

The actual implementation has been based on the previous testing of digital mock-ups, properly developed to specify the functionality of each module. The tests are carried over to check mechanical lay-out, co-operative environment and performance achievement. For the exemplified application, task programming shows that overall cleaning operations could last two-to-three hours (for a square 6x6 m wide, 3 m height room); it is, thus, fully accomplished in between the two (midday and evening) sheets, requested as conventional daily-cycle of usual community kitchens. Partial checks are also ran on each module, to acknowledge the *Char-robot* functions at the pertinent capability level.

One should, perhaps, stress that replacement of humans by robots is often delayed by the maxim: "*things always happened that way and changes are not required*". Virtual reality investigation is, then, useful to help popularising contrivances alien to common habits; indeed, domestic robots are mostly rejected from current support, unless their friendly effectiveness is actually recognised and appreciated, and return on investment verified (by respect of charges in view of certifying health and safety rules). The study, carried over by an integrated simultaneous engineering CAD code, gives hints on the innovative co-operating robotic equipment, with results properly displayed by effective multimedia tools. Virtual mock-up, in our case, is not only an efficient design aid; it, as well, provides sufficient operation details, to give evidence of the actual behaviour of the fixture under actual running conditions.

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