Domestic-Chores Automation: Multi-Media Analysis and Assessment Study

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in collaboration with:

Electrolux
Zanussi Grandi Impianti
EUROCLEAN
Cleaning services: why the robotization?

• dirty job, boring, repetitive and, sometimes, dangerous and harmful for the health
• this field in Europe represents, globally, 100 milliards of ECU with 1.9 million employees
• the greater voice of the cleaning are given from the costs of job (between 70% and 80% also for minimum salaries)
• the cost of a cleaning employee (source: the European Cleaning and Support Services Statistics), excluded the additional costs (training, absenteeism) varies in the European Union:
  – 2.25 ECU/hour in Portugal
  – 14 ECU/hour in Belgium
• the large potential users market allows economies of scale
• wide possibilities to produce industrial products
Cleaning robots
Investigation aims

Building of a **sturdy, sure, independent** system

- for the cleaning of dirty pavements;
- for the cleaning of dirty walls (until 2 meters) and of elevated objects (hoods ...).
- for execution of pre-programmed cleaning paths (not trained personnel): interface simple and intuitive
- with duration of the cleaning operation: two-three hours;
- with a few modifications to the environment
- with reduced development and system costs: evolved planning methods, components from the market

services to top quality, availability, high reward, *legal regulation 29/6/97 (extended) penal liability*
System architecture

Base robot
- 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

Geco Robot
- walls cleaning
- planes for job cleaning

concept, cinematic model, Matlab simulations of the vehicle mobility, 3D modeling, multimedial simulation of the process animation

concept, design, 3D modeling, dynamics simulation structural analyses VR animation
Base robot

Locomotion
- 2 drive wheels

Arm
- skilful
  - 6 D.O.F.
  - R-P-R wrist
- cable
  - inner pipe Φ> 40 mm
- light
  - actuators mounted on the base
  - aluminium alloy

Technological cleaning modules
- 2 long hair brushes
- trash chopper
- 2 short hair brushes
- cleansing supply
- device for cleansing recovery

<table>
<thead>
<tr>
<th>Dimensions (mm)</th>
<th>Forearm</th>
<th>1100</th>
<th>105 (φ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm</td>
<td>1250</td>
<td>100</td>
<td>180</td>
</tr>
<tr>
<td>Turret</td>
<td>400</td>
<td>200  (φ)</td>
<td></td>
</tr>
<tr>
<td>Mobile base</td>
<td>220</td>
<td>600  (φ)</td>
<td></td>
</tr>
</tbody>
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Base robot: kinematics

Sheth & Uicker general approach [1971]

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.
Planning the cleaning procedures

- Robot
- Regulation
- Environment to be cleaned
- Dirtiness state
- Standard Library
- Developed Simulation Program
- SIMDRAW
- Statistics
- Procedures
- Journey path, duration, costs
- Monitoring
- Animation

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Simulation of the cleaning procedure
Geco I: components

- **Holding up**
  - vacuum pump (60 kPa)
  - valves
  - vacuum cups

- **Translation**
  - linear electric motors

- **Control**

- **Cleaning**
  - evaporator
  - nozzles
  - tank
Geco I: assembly
• 2 ASFTOMAS G/07-N-LC pumps
• Valves dimensioned with the Bermingham Controls, “Leslie Controls Engineering tables” (http://www.bermingham.com)
Calculation with vacuum cup adherent to the wall

\[ \Delta p = 600 \text{ mbar} = 8.57 \text{ psig} \]
\[ Q = 2 \cdot 2 \cdot 4 \text{ l/min} = 8.48 \text{ scfh} \]
\[ C_v = 0.04 \]
\[ p_i = 400 \text{ mbar} = 5.71 \text{ psig} \]
\[ Q = 4 \text{ l/s} = 8.48 \text{ scfh} \]
\[ T_i = 111 \, ^\circ \text{C} = 231.8 \, ^\circ \text{F} \]

• rigid vacuum cups
• supports of the vacuum cup of new conception
• new vacuum system

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Geco II

Actuators
- Rotating motor Aveox 1406/2Y (217W)
- screw\helicoidal wheel transmission THK C\ DCMB 8T

Redesign of the arm
- longer stroke
- less distance between robot and wall
Geco II

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Holding up system

Mechanism for the lifting up of vacuum cup: NEW CONCEPT DESIGN

PATENT PENDING
Cleaning system

Water in the tank
T = 27°C, p = 0.1 MPa

Water in the steam-box
T = 120°C, p = 0.2 MPa

Water under the robot skirt
(overheated steam):
T = 111°C, p = 0.1 MPa

Calculation of the steamer
E = 600 cal/g = 143.54 J/g
E_{tot} = m E = 358852 J
P_{tot} = 100 W
Geco II: dynamic analysis

Pro/MECHANICA Motion Model

\[
[M] \begin{bmatrix} \vec{\Phi} \\ \Phi' \end{bmatrix} \begin{bmatrix} \vec{q} \\ \dot{q} \end{bmatrix} \begin{bmatrix} T \\ \Phi_{\text{T}} \end{bmatrix} = \begin{bmatrix} Q^A \end{bmatrix}
\]

\[
[M] \begin{bmatrix} \vec{\Phi} \\ \Phi' \end{bmatrix} \begin{bmatrix} \vec{q} \\ \dot{q} \end{bmatrix} \begin{bmatrix} T \\ \Phi_{\text{T}} \end{bmatrix} = \begin{bmatrix} Q^A \\ \lambda \end{bmatrix}
\]

\( q \) is the vector of the generalized coordinates

\([M] \) is the generalized matrix of inertias

\( \Phi(q, t) = 0 \) is the system of the position equations

\([\Phi, q] \) is the jacobian matrix

\( Q^A \) is the vector of the active forces

\( \lambda \) is the vector of the Lagrange multipliers
Geco II: d.a. (Up step)

Frame acceleration  Frame velocity  Frame position

Force vacuum cup-wall  Force slide-vacuum cup  Skidding

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Geco II: d.a. (Lateral step)

Forces exerted by the corners of the skirt on the wall

Skidding
Geco II: structural analysis
Multirobot system