The European Co-ordination Hub for Open Robotics Development

ECHORD++

2F - Flooring Fellow

Grout Cleaning Robot

ROBOTECH

Final Report

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Section 1: Executive summary

- The final goal of 2F is to make a new product for the building equipment market and to introduce robotics in construction yards by designing and developing a robot for grout cleaning and floor cleaning with acid during tile floor construction.
- Grout cleaning in tile floor construction is today still performed manually by construction workers using sponges or electrical sponge machines. This task, which is one of the essential steps in tile floor construction, is time consuming, expensive, risky and is usually perceived unpleasant. 2F aims at reducing the time spent by construction workers on the building site, with a consequent reduction of labour cost and accident risks, freeing construction workers for more skilled and valuable tasks.
- The proposed solution is a robot for grout cleaning and floor cleaning with acid consisting of a tracked mobile base, water bucket and hydraulic circuit, sponge tool and battery pack. Control system (CPUs and embedded motor drivers), navigation sensor (laser), navigation software, quality control vision system, allow the robot to perform autonomously its tasks in cooperation with construction worker.
- The expected impacts from the use of 2F are:
    - reduction of risks for construction workers and especially reduction of exposure to noise, vibrations, dangerous materials and electric shocks;
    - reduction of construction workers working time and economic savings for building companies;
    - turnover by the production of a new robot for the building equipment market;
    - turnover by the rental of a new product to the construction sector.
- The main output generated by the project is a prototype robot for grout cleaning and floor cleaning with acid which reached TRL7. The robot is light weight and portable, has a removable battery pack, adjustable sponge pressure and squeezing, and autonomous and manual control mode. The modularity of its design allows using the same mobile base with different tools to perform a variety of tasks in construction yards. Robot dimensions are (L x W x H) 725 x 430 x 410 cm and its weight is 40 kg. Typical speed of the robot is 0.07 m/s, productivity is 30 m^2/h, effectiveness is 80% of total floor surface, and battery runtime is more than 4 hours.
- A patent on the robot design titled “Machine for floor treatment” has been submitted in November 2016 and is currently pending.

Section 1.1: Milestone overview

#	Description	status
M1	Kick-off meeting	Timely achieved
M2	System design	Timely achieved
M3	F2 Prototype	Achieved with 2 months delay

- Milestone M3 has been achieved with 2 months delay due to additional developments, which allowed to improve significantly the performance of the robot, and to breakage of some components and related interventions for their fixing.

Section 1.2: Deliverable overview

#	Description	Status
FPR	First progress report	Submitted
SPR	Second progress report	Submitted
D1.1	System design	Submitted
D1.2	Detailed technical project	Submitted
D2.1	2F prototype	Submitted
D3.1	Report on 2F testing and validation	Submitted
D4.1	Market analysis and business plan	Submitted
RIF	Report on RIF visit outcome	Not submitted
MMR	Multi-Media report	Not submitted
SB	Story board	Not submitted

Section 1.3: Technical KPIs

#	Description	Status
1	Quality Precision	Achieved
2	User Interface	Achieved
3	Energy Autonomy	Achieved
4	Productivity	Achieved
5	Effectiveness	Partially achieved

6	Optimal Navigation Strategy	Not applicable
7	Noise and Vibration	Achieved

- Effectiveness is 80% vs. 90% expected. This is mainly due to the necessity to follow 45° trajectories with respect tiles orientation and to the reduced sponge speed. A procedure for finishing the work to increment effectiveness has been implemented, but reduces machine productivity. The right balance between productivity and effectiveness is selectable by the user.
- Optimal Navigation strategy is not applicable: random navigation is not possible since robot has to follow 45° trajectories with respect tiles orientation.

Section 1.4: Impact KPIs

#	Description	status
1	Economic Savings	950 €
2	Turnover by the rental of a new product to the construction sector	9.350 €
3	Patent	Submitted
4	Reduction of time spent by construction workers on the building site, with a consequent reduction of labour costs and risks	90%

- Patent pending:
  - Number: 102016000112690
  - Date: 09-11-2016
  - Title: “Macchina per il trattamento di superfici pavimentate” (Machine for floor treatment).
- All other KPIs have been estimated on the base of the current robot performances

Section 1.5: Dissemination KPIs

#	Description	status
1	Experiment web site	Achieved
2	Bauma 2016	Achieved
3	Automatica 2016	Achieved

Section 1.6: Additional (unplanned) achievements

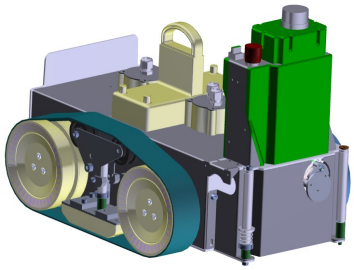
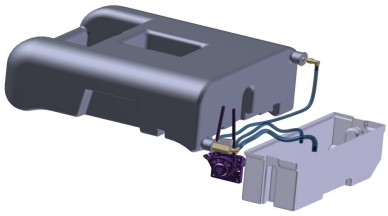
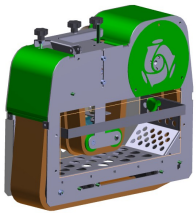
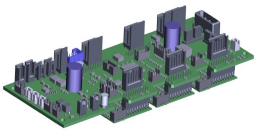
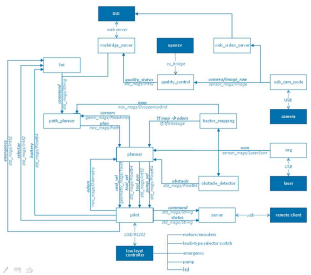
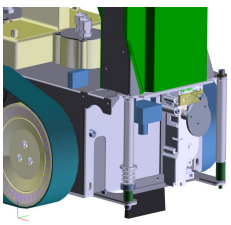
- Graphical user interface for Smartphone and tablet.
- Dry vacuum cleaner module as additional tool.

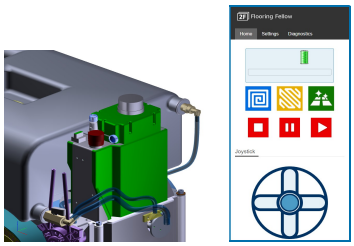
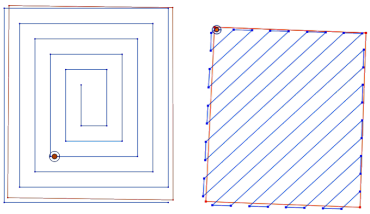
Section 2: Detailed description

Section 2.1: Scientific and technological progress

- The final goal of the project is to develop a new product for the building sector that will be introduced to the market in the next years. 2F approach was to exploit consolidated academia and industry know how in mobile robotics and construction equipment to develop a 'standard' mobile robot endowed with tools commonly used in the building site sector and able to perform the requested task.
- 2F employed enabling technologies like advanced lithium batteries, vacuum cleaner and lawnmower robotic know how, SLAM techniques and electronics to make 2F a solution mature for the market in terms of costs, industrial stability and use levels.
- The partnership includes IMER Group, international industry which produces and sells worldwide tools and equipments for the building sector and with a well established knowledge of the international market, and ROBOTECH, SME, R&D and academic spin off company, bridge between the market and the research in Robotics and committed to transfer research in Service Robots to the market.
- The project was structured into three main tasks which were related to system design, system development, and system validation and testing. Two milestones were established: system design at month 9, and prototype at month 15. The project includes also a task for dissemination activities and a task for market analysis and business plan.
- IMER has been mainly involved into the definition of robot functionalities and the design and development of the robot mechanics. ROBOTECH has been mainly involved into the design and development of the electronics and of the software of the robot. Thanks to the complementarity of the partner and the of the clear structure of the work plan, the project was able to realize in only 18 months a fully functional prototype starting from scratch.
- The main output generated by the project is a prototype robot for grout cleaning and floor cleaning with acid which reached TRL7. The only competitors of 2F are manual machines: in this context, 2F is a radical innovation from the market point of view and up to now is the only robot for the treatment of floor in construction yard.
- A patent on the robot design titled "Machine for floor treatment" has been submitted in November 2016 and is currently pending.

Section 2.2: Scientific and technological achievements

Mobile base		- NEMH2O mobile base - 4 wheels, 2 non absorbing track belts and belt tension mechanism - 2 brushless motors with encoders - Spring guides to regulate sponge pressure - motor and mechanism to raise and lower the tool
Water buckets and hydraulic system		- 20 litres clean water bucket - 5 litres dirty water bucket - Pipes and pump for pumping water from dirty water bucket to clean water bucket - Pipes and mechanism to regulate water flow from clean water bucket to dirty water bucket.
Battery pack and battery charger		- Portable and light weight battery pack - 25.9 VDC Li-ion battery, 357 Wh, 13.8 Ah - recharging time: about 2 hours
Tools		- Portable, quickly exchangeable, and removable sponge tool - Brushless motor and reduction gear (35 rpm max) - Knobs and mechanism to manually regulate sponge tension and squeezing
Control system and navigation sensors		- Intel Core i3-5250U processor 1.3 GHz - microcontroller based main board - 3 microcontroller based motor drivers - Hokuyo URG-04LX-UG01 laser
Software		- ROS Hydro based software architecture - Pilot module - Planner and supervisor module - Trajectory planner module - SLAM module (Hector-mapping) - Obstacle detection module
Quality control system		- Small comb positioned after the sponge - USB Camera (ELP-USB130W01MT) over the comb - Comparison of the floor before and after the passage of a comb to detect cleaning quality

User interface and web based GUI		- Knob type selector to switch on/off the robot and to start predefined cleaning procedures - Emergency stop button - LED for signalling robot status - Comprehensive Web based GUI for Smartphone and tablet
3 autonomous cleaning programs		- robot follows a 'spiral' trajectory moving parallel to the walls at low speed - robot follows a 'zig zag' trajectory moving 45° WRT to the walls at low speed - robot follows a 'spiral' trajectory moving parallel to the walls at high speed

Section 2.3: Socio-economic achievements

From a social point of view the main impact expected from 2F is the reduction of the time spent by construction workers on the building site with a consequent reduction of risks, and especially exposure to noise, vibrations, dangerous materials, electrical shocks and more in general reduction of physical problems due to the use of non ergonomic machines.

Grout cleaning in tile floor construction is today still performed manually by construction workers using sponge or electrical sponge machines. This task, which is one of the essential step in tile floor construction, is time consuming, expensive, risky and is usually perceived unpleasant.

The use of manual sponge forces the worker to assume for long times kneeling positions which may cause problems to the joints, muscular system and back. Moreover, workers are forced to manage dangerous chemical products such as acid. Electrical sponge machines are heavy to operate and force the workers to give a lot of strength for their use causing problems to their back. They are usually noisy and vibrating, and bulky and weight. Moreover, they are usually powered with cables which may cause electrical shocks. 2F reduces significantly the time spent by construction worker doing grout cleaning task, with consequent reduction of exposure to noise and vibrations, chemical materials, and risks of electrical shocks, help preserving workers health.

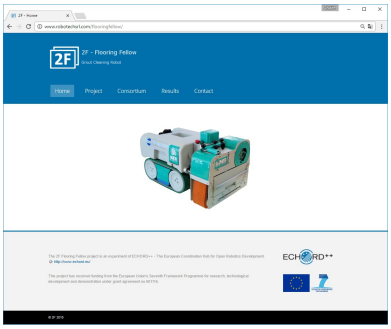
From the economic point of view, the approach envisaged for 2F to penetrating the market and overcome market entry barrier is renting. One of the main entry barriers to the building sector market, in which the main players are small construction companies and/or single skilled workers, is the cost: In fact high tech equipments, like robots, may result too expensive for them. For this reason a new model is spreading in this sector nowadays which consist in renting equipments from specialised companies with higher financial capability who brought and rent equipment.

The rental market of building machines has significantly grown during the last years: this fact has determined a reduction of the initial investment in machinery and the possibility of getting more specific machines for the tasks to be executed. The growth of rental market for this kind of

machines provides the opportunity of supplying to building companies solutions that otherwise would not be easily sustainable from an economical point of view.

From the economic point of view, the main impact expected from 2F is to create a new product in order to produce revenues for both the industry producing the robot and for the companies renting the robot. The main project impact can be achieved with the introduction on the market of at least 1,500 pieces of 2F and related tools (15,000 pieces). 2F can quickly gain market shares up to a sales volume of approximately 3,000,000 Euro, while also adding value to IMER Group product range. Rental companies major incomes have been estimated in 9.350 € per robot compared to the rent of traditional machines. Economic saving for workers or building contractor has been estimated into 950 € per year.

Section 2.4: Dissemination activities

Web Site	The experiment web site is available at the following address: www.robotechsrl.com/flooringfellow/	
BAUMA 2016	2F has been presented at Bauma 2016 (Munich, April 11-17, 2016), the world's leading trade fair for construction, building material and construction vehicles and equipment. The prototype has been exhibited at the TUM stand in the framework of the "Bayern Innovative" technology transfer initiative supported by the state of Bavaria and TUM.	
Automatica 2016	2F has been showed at Automatica 2016 (Munich, June 21-24, 2016), the 7th International trade Fair for Automation and Mechatronics. The prototype has been exhibited in the ECHORD++ booth (see picture below). During the fair, 2F ranked third in the E++ Best Picture Award competition.	

Section 3: Resource usage summary

	Budget			Spent		
	IMER [€]	RT [€]	Total [€]	IMER [€]	RT [€]	Total [€]
Personnel costs	219.000	116.200	**335.200**	232.000	117.462	**349.462**
Other direct costs	29.500	8.300	**37.800**	22.500	9.730	**32.230**
Indirect costs	49.700	74.700	**124.400**	50.900	76.316	**127.216**
Total costs	**298.200**	**199.200**	**497.400**	**305.400**	**203.508**	**508.908**
Request	149.100	148.440	**297.540**	152.700	151.059	**303.759**
Person months	32	33	**65**	34	27	**61**

Section 4: Deviations and mitigation

A 2 month extension of the project was necessary due to the delay in achieving Milestone M3, 'robot ready for testing'. Reasons for delay were additional developments, which allowed to improve significantly the performance of the robot, and the breakage of some components and related interventions for their fixing.

Additional developments were the springs for unburdening the weight of the tool, and the buoyant for the regulating water flow necessary for improving efficiency of the hydraulic system.

Breakages affected the laser, the wheel joints and the water container: the interventions and the supply, fabrication and repair of the broken components required some time, moreover more than expected due to the coincidence of these events with the summer holidays and relative closure period.

Section 5: Future work

The final goal of 2F is to make a new product for the building sector market. At the current stage of the project, is expected to be on the market in middle 2018, with the preseries production of 5 robots. Before exploiting project results, some technical developments have to be tuned and assessed. Moreover, it is not perfectly clear yet how well the markets will value Flooring Fellow's innovative contents. For this reasons, the first steps planned before the commercialization of 2F will be:

- meeting and demonstration with FILA in order to set up the product;
- product homologation and certification;
- built of a pre-series of 5 samples to perform market test.

FILA (http://www.filasolutions.com/en) is an Italian company, world leader in the production of materials for the finishing, the protection and the care of surfaces in marble, natural stone, porcelain, ceramic, stoneware, terracotta and wood. Among FILA products are different type of cleaning solvents in order to remove grout and wash tiles. A partnership with FILA is considered

fundamental as promotion channel and to set up correctly the robot to provide the best performance with FILA products. Moreover, from the marketing point of view, a partnership with FILA is crucial for penetrating quickly the market. Contacts with FILA have been already established and a meeting with FILA for demonstrating the robot potentiality is under organization.

An agreement with ZCS ROBOTICS (http://www.zcscompany.com/), a company focused on robots mainly for B2C market such as lawnmower and swimming pool cleaner robots, has been already established for the furniture of components such battery, robot chassis, motors, etc.

Section 6: Lessons learned (optional)

ECHORD++ has been a great opportunity for both partners to learn best practices in project management, state of the art of technologies and specific markets needs. The different and complementary company backgrounds allowed intense knowledge exchange and favour technology transfer. For IMER ECHORD++ has been the opportunity to approach Robotics technology and the Robotics community. For ROBOTECH, ECHORD++ has been the opportunity to get more in contact with the market and learn how to develop a strongly market oriented robot (needs and price).

ECHORD++ has been really useful for the internal dissemination and to promote industrial partnership between project partners and external companies like FILA and ZCS Zucchetti Centro Sistemi.

ECHORD++ scheme allowed to realize and demonstrate in less than two years a prototype starting from scratch: the prototype reached TRL 7 and is ready for the next stage of industrialization.

Important lesson learnt during the project was on the study of the robot architecture: during the writing of the proposal and in the initial stage of the project development, the original idea was to develop a robots starting from a standard machine architecture. Thanks to the project development, in order to full fill requirements of product dimensions and weight and general market needs, the 2F choice architecture has been completely reviewed shifting to:

- a more robotic oriented system;
- a more simple, less costly, and reliable human interface exploiting smart devices and M2M communication facilities.

About the last point, an important lessons was the optimization of the human interface interacting with final users.