DEBUR - Automated robotic system for laser deburring of complex 3D shape parts

IK4-Tekniker (Coordinator)

Idelt

Final Report

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Section 1: Executive summary

- What was the goal of the project?
  The goal of the experiment was to design and set up an automated robotic station prototype for laser deburring of metal casting 3D parts.

- Why the solution to the problem was important?
  The deburring process is one of the most important finishing operations carried out during the manufacture of castings parts. The use of current cutting presses and robotized abrasive tools implies: imprecise cutting and unwanted geometric deviations, to use cutting dies and tools for each part geometry, and even to replace periodically the cutting tools due to wear.
  These aspects slow down the production and force to use additional operations like inspection and manual deburring and sanding what implies an extra costs.

- What was proposed as a solution?
  It has been developed a flexible, low-maintenance and environmentally friendly automated laser deburring prototype, able to replace the current hydraulic deburring machines and manual operations of casting industries, focussed on aluminium components with different geometry and burrs thickness (< 2.0 mm).

- What <u>was proposed</u> as an impact of your solution?
  - Cost reduction up to 20% per part for the deburring operation.
  - Volume of new lubricants and abrasives reduced by 30%.
  - Reduction of scrap parts by 30%.
  - Improved quality of the resulting parts, lower protrusion and smoother surface (roughness).
  - Reduction of manual operations and therefore increased safety for the workers, less injuries.
  - No need for abrasives and lubricating oil for the deburring process -> economy, ecology
  - 1 new job at the industrial partner.

- What is the final impact at the end of the project and what are the deviations in achieving the impact?
  - Cost reduction up to 20% per part for the deburring operation (to be measured 1 year after end of experiment).
  - Volume of new lubricants and abrasives reduced by 30% (to be measured 1 year after end of experiment).
  - Reduction of scrap parts by 30% (to be measured 1 year after end of experiment).
  - Regarding the improved quality of the resulting parts, lower protrusion and smoother surface (roughness), we have obtain difficulties to achieve this impact, mainly when trying to reduce the protrusion and maintain it below 0.2 mm, due to the loss of precision of the robot system used when for example, the deburring trajectories require long robot axis movements for small displacements of the TCP (Tool Center Point).

- The proper replacement of the conventional deburring technologies by the laser technology, allows us to avoid the use of abrasives and lubricating oils during the deburring process. In addition the automated robotic deburring system proposed implies the reduction of manual operations and injuries.
- 1 new job at the industrial partner (to be measured 1 year after end of experiment).

Section 1.1: Milestone overview

#	Description	status
M1	Development of Individual stations	Achieved
M2	Integration of the cell	Achieved
M3	Cell validation	Achieved

- M2: Instead of the development of an specific control for adapting the deburring speed according to the thickness of the burrs, it has been developed a monitoring system able to detect by means of photodiodes if the deburring / cutting process is well executed or not.

Section 1.2: Deliverable overview

#	Description	status
SB	Story Board	submitted
MMR	Multi-Media Report of the cell	submitted
RIF	Report on RIF visit outcome	submitted
D1.1	Design and requirements of the elements of the cell	submitted
D2.1	Laser deburring station	submitted
D2.2	Grasping and fine trajectory tracking stations	submitted
D3.1	Laser deburring cell	submitted
D4.1	Validation results	submitted

Section 1.3: Technical KPIs

#	Description	status
1	Precise 2D/3D vision to detect debur needs: accuracy ≤ 0.1mm	Achieved
2	Quality of resulting parts: protrusions < 0.2 mm and roughness Ra~ 1 µm	Deviated
3	Efficiency of the system: process speed > 150mm/s and cycle time < 90 s per part	Achieved

Section 1.4: Impact KPIs

#	Description	status
1	Cost reduction	
2	Reduction of scrap parts	
3	Improved quality of the resulting parts	Deviated
4	Increased safety for the workers, less injuries	Achieved
5	No need for abrasives and lubricating oil for the deburring process -> economy, ecology	Achieved
6	New jobs	

Section 1.5: Dissemination KPIs

#	Description	status
1	Conferences: IEEE Conference on Emerging Technologies and Factory Automation, ICIRA. International Conference on Intelligent Robotics and Applications.	Achieved
2	Fair: BIEMH. Bienal Española de Máquina – Herramienta.	Achieved
3	Scientific Journal: A. Tellaeche, R. Arana, Robust 3D Object Model Reconstruction and Matching for Complex Automated Deburring Operations. J. Imaging 2016, 2(1), 8	Achieved
4	Periodic News in Newtek electronic bulletin, Newtek Magazine	Not Achieved
5	Youtube Video (IK4 Channel): www.youtube.com/watch?v=2KqTBzxh7kU	Achieved
6	Twitter (@IK4_TEKNIKER)	Achieved
7	Press releases to local press (El Correo, El Diario Vasco, etc.)	Not Achieved
8	Press releases to trade press (Estrategia Empresarial, etc.)	Not Achieved
9	Experiment website: http://deburexperiment.eu/	Achieved
10	IK4-TEKNIKER webpage news: 11-01-2016, 19-10-2016	Achieved

Section 1.6: Additional (unplanned) achievements

- None

Section 2: Detailed description

Section 2.1: Scientific and technological progress

➔ Explain here the tasks/subtasks and what was your approach of executing it. If you did one, explain how the RIF visit helped you in developing scientific and technological progress. 5 sentences at MAX per item. Feel free to put pics/video links.

- Task 1: Design and development of the laser deburring station. Its objectives were to precisely determine the requirements of the experiment, set-up the laser system and optimize the laser deburring process in open-loop configuration.

- Task 2: Design and development of the different modules of the cell: 2D camera based flexible grasping station, 3D measuring station and laser deburring station. Its objectives accomplished the design and construction of the different stations of the cell, to form the main demonstrator attending to the requirements generated by the parts selected by IDELT, the end user. For those parts several grippers were manufactured. The 2D and 3D workstations were designed and for the 3D workstation after testing different measuring approaches it was selected and constructed a 3D measurement unit, based in a two cameras sheet of light system considering its reduction of occlusions and its competitive price.

- Task 3: Cell integration and testing. Its objectives were to integrate all developed elements to let the cell ready for experimentation and validation. On this task, after integrating previous developments, the system was setting up and tuned in order to have the cell ready to work on real parts, coordinating their actions to test that the different operations were done correctly. The integration also comprised the laser station, where the laser deburring methodology was checked and optimized. Finally, the monitoring system based on photodiodes of the deburring process was integrated.

- Task 4: Experimentation and validation. This task oversees validation of developments and experimentation carried out. It was validated the approach of flexible grasping, by picking the part as it comes from the conveyor, taking advantage of the 3D vision system responsible for measuring the differences on the grasping stage. These deviations were sent to the robot and corrected, so that the part could be moved exactly along the defined trajectory. In principle, this method provides a good enough correction, so that the tolerances needed for a successful laser deburring are met.

Section 2.2: Scientific and technological achievements

➔ Discuss about the achievements, technical KPIs, patents, increase in TRL etc. If you did one, explain how the RIF visit helped you in developing scientific and technological achievements. 5 sentences at MAX per item. Feel free to put pics/video links.

- Deburring operations have traditionally been a manual task. This project presents an overall solution for automation of this complex and demanding task, increasing the original estimated TRL of 4 to a new value of 5-6 (technology demonstration and subsystem development).

- Development of a robust flexible gasping system has been developed especially aimed for complex geometries, with flexibility in the definition of the grasping points.

- The adequacy of robots for deburring tasks has been assessed, overcoming, in the development, the problems associated to fix trajectory programming. This use of robots for deburring tasks is also dependent of the laser source used. Due to possible inaccuracies in robot positioning, more powerful laser sources may be needed depending on the geometry of the part to be deburred. This automated system saves approximately 20% of costs per part, indirectly obtained by the time reduction obtained when deburring each part. Finish quality of the parts has been improved, and it is estimated that scrap parts could be reduced a 35% using robotic deburring.

- Use of ad-hoc control system applied to robot motion correction, considering the inaccuracies grasping the part. The real position of the part is measured by a 3D vision scanning system and the trajectory of the robot is corrected according to the real grasping position detected.

- This flexible grasping leads to the feasibility of using robots to the deburring operation overcoming the inaccuracies in robot motion. This serves to compete against more accurate machines equipped with CNCs, but that besides being more expensive could be inflexible due to the limited number of axes. Robots are less stiff and accurate than CNC machines however they offer larger work volumes and more controllable axes at a lower-cost.

- The RIF visit helped to clarify the possible limitations or weaknesses to face in the whole process, depending on the elements used (type of robot, laser, etc.). It also was worth to assess the possibilities of implanting the process in a real industrial setup.

- Analysing the different developments done it seems clear that elements like the laser head and monitoring devices as well as the 3D measurement system are also suitable for exploitation independently. The 3D measurement system was developed using commercial and economical components in order to achieve a competitive solution. It was analysed whether it could be patented, but faces the inherent difficulty of being mainly a software development. DEBUR partners will spread its use to companies that produce robotic cells and automatic lines allowing them integrating a 3D measurement system on its developments.

Section 2.3: Socio-economic achievements

➔ Discuss about the achievements, impact KPIs etc. If you did one, explain how the RIF visit helped you in developing socio-economic achievements. 5 sentences at MAX per item. Feel free to put pics/video links.

- First and obvious social impact is the improvement in the work conditions and health of the operators previously in charge of deburring the parts manually. The demonstration setup shows clearly the possibility of automating the process so that the operators can oversee other task in the process more suitable to their health, avoiding previous common injuries.

- The use of a laser to perform the deburring also has a beneficial impact in the pollution generated in the overall process. The manual deburring operations typically uses lubricating oils for the cutting and abrasives at the deburring stage. Laser deburring solution lacks all these needs, generating a significant smaller quantity of waste to get rid of.

- Automatic deburring also assesses the same quality for all the parts, no matter the production and work shifts. The variability present in a handmade process disappears when a robot is used. Assuring a high quality for all the parts reports economical advances in production and also in the final price.

Section 2.4: Dissemination activities

➔ Discuss about the dissemination activities e.g. publications, trade fair visits, demos, dissemination through social (fb, twitter, linkedin, youtube), development of a web site, individual contacts etc. 5 sentences at MAX per item. Feel free to put pics/video links.

The main dissemination activities carried out has been listed previously on section 1.5. The most important are detailed below:

- The article " Robust 3D Object Model Reconstruction and Matching for Complex Automated Deburring Operations" was published in the journal "Journal of Imaging", *J. Imaging* 2016, *2*(1), 8; doi:10.3390/jimaging2010008 , to explain the process of the burr detection using as input the 3D reconstruction of the part under inspection and the original CAD model. Full article can be found at http://www.mdpi.com/2313-433X/2/1/8/htm.

- Project results were presented on the IK4-Tekniker stand of the BIEMH (Bienal Española de Máquina – Herramienta) Fair, held in Bilbao from 30 May to 4 June. A brochure of the project was prepared for the occasion (http://deburexperiment.eu/public-documents/).

- A video about the laser deburring cell working was submitted to Youtube portal: www.youtube.comwatchv=2KqTBzxh7kU

- Main information of the project can be seen in the following website: http://deburexperiment.eu/

Section 3: Resource usage summary

➔ Put a table on your resource usage

- IK4-Tekniker:
  MM resource usage:

	Design and Assembly	Laser process	2D & 3D workstation and Robot	Total
Task 1	2	3	2.5	7.5
Task 2	2	3.1	4.8	9.9
Task 3	3	3	3.6	9.6
Task 4	0.5	2.5	7.4	10.4

Human resources are distributed under three concepts. The first, Design and Assembly, comprises all work related with the design and manufacturing of different elements of the cell like the grippers, selection of the tool quick changer, protection fence due to laser radiation. Also includes those activities related with the preparation required for the different test done for vision and laser tests. The second comprises the efforts spent by the laser process and tests. The third column comprises the efforts spent on the design, development and testing on 2D and 3D systems, the robot and on the integration of the cell.

"Other Costs" have been 21.685€. These costs include travel costs on the visit to the RIF. Also, includes the costs of cameras, lightings, grippers, photocell, laptop for images analysis and cell integration, materials, cell enclosure to protect against radiation, tool quick change system, different materials, processing gases, etc.

- Idelt:
  The total experiment effort of Idelt has been 7 Person Months, distributed between Task 1 and Task 4.
  For Idelt, planar samples, different parts, tools and travel expenses have been charged to "Other Costs".

Section 4: Deviations and mitigation

➔ Explain deviations reported in the previous sections and steps taken to mitigate them. Max 10 sentences per item. Feel free to put pics/video links. (If you planned to visit a RIF and you did not, please justify).

- The system developed is flexible in the sense that it is possible to change the part to deburr in a fast way, loading a new CAD definition. The tests with different parts have led to the identification of a problem in the movement of the robot. Depending on the geometry, the final error positioning of the laser beam over the burr can slightly vary. This problem can be mitigated increasing the power of the laser source for deburring operations.

- Regarding the improved quality of the resulting parts, lower protrusion and smoother surface (roughness), we have obtain difficulties to achieve this impact, mainly when trying to reduce the protrusion and maintain it below 0.2 mm, due to the loss of precision of the robot system used when for example, the deburring trajectories require long robot axis movements for small displacements of the TCP (Tool Center Point). This problem can be mitigated by using a more precise robotic system.

- Instead of the development of an specific control for adapting the deburring speed according to the thickness of the burrs, it has been developed a monitoring system able to detect, by means of photodiodes located on the laser head and oriented to the laser interaction area, if the deburring/cutting process is well executed or not. We can record the signal of 4 symmetrically positioned off-axis photodiodes in a narrow bandwidth around the wavelength of the processing laser. The signal has a dependence on the cutting speed but also saturates in case of incomplete cutting process due to the increase of laser scattering. The latter feature might be used for controlling cutting tasks. In case of laser deburring, this signal informs about the removal of the burr and might be used to determine if further cutting trajectories should be carry out in addition to the first calculated laser treatment.

Section 5: Future work

➔ How the work will be carried forward further. What technical work will be done in the near future? When the product is expected to be in the market? Do you have a plan to reach the market? Do you already have contacts with potential customers? What are funding means to carry forward this work? Increase in turnover? Product derivatives? New markets? Spinoffs?

- More in depth tests are needed with different parts with significant differences in their geometry to strengthen the process and detect possible weaknesses.

- Further study of different robot geometries and capacities (especially precision) is needed to choose a set of optimal robots depending on the size and shape of the parts.

- Vision systems need to be industrialized in form of a set of already selected hardware elements and mechanical geometries. Also, the overall system setup must be defined in a standard way.

Section 6: Lessons learned (optional)

➔ Tell us what lessons did you learn during the project? How it should have been done the different way by you, E++ management or EC.

The DEBUR experiment has permitted us to demonstrate the feasibility of a new concept of deburring injected casting parts by means of laser technology in an automatized way by reducing the number of typical finishing additional operations used in non-ferrous casting industries. It is important to remark that this work has been developed through the intense and complementary team work carried out by a group of researchers with experience in different disciplines, like robotics, laser material processing and casting processes.