Monocular CAD-based 3D localization for processing large parts for shipbuilding

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***Abstract*—The growth of the manufacturing sector is closely linked to the development of new technologies, specifically automation and robotics. However, the lack of flexibility in industrial robotics and its design oriented to large series, results in that is economically unviable for small and medium sized business due to the need for complex positioning tools and highly skilled robotic operators. Robot work cells should adapt to variations in shape and size of the parts to process. Therefore, an industrial implementation in the shipbuilding sector of a monocular CAD-based 3D localization system is shown in this paper, which adds a new step and contributes to a new concept of hyper-flexible cell, enabling robotics introduce itself in this kind of demanding market.**

Keywords—Image processing; Flexible manufacturing system; Industrial robots; Shipbuilding.

I. INTRODUCTION

In the European Union (EU), the number of enterprises is about 20 million companies, of which 99.8% are SMEs (92.1% micro-enterprises) that play an important role in the European economy. Furthermore, the micro-enterprises employed in 2012 approximately 86.8 million people, which represent 66.5% of all European jobs for that year [1].

The SME sector as a whole delivered 57.6% of the gross value added generated by the private, non-financial economy in Europe during 2012. Therefore, the role of SMEs is crucial for the European economic recovery, because their number, employment capacity and value added constitute a large share of the European economy.

From a global perspective, the manufacturing sector is the major driver for economic growth in developing countries. In this context, research on new manufacturing technology, like robotics, is an important catalyst for industrial innovation [2].

However, the automation and adoption of robotic technology in the majority of SMEs is not a common practice. The main reason is that the robots do not meet the high-flexibility needs of SMEs with high costs involved when dealing with varying lot sizes and variable product geometries.

In other words, industrial and robot automation available is not flexible enough, designed for high volume and low variation processes. Therefore, it is economically unviable for small and medium sized business, but in contrast, the industry needs to remain competitive in the increasingly complex global economic environment, and it is crucial that they modernise their manufacturing base and strengthen the links between research and innovation.

Furthermore, SMEs have difficulty finding skilled workers capable of operating with robots. Therefore, new and more intuitive ways for people to interact with robots are required to make robot operating easier and accessible [3].

It is important to exploit the potential of industrial robots, because they constitute the most flexible existing automation technology. Robot work cells should adapt to variations in production flow or in maintaining the production rate in the presence of uncertainties. Work cells should be adaptable in case of work-piece variations or reconfigured when production volume or product changes occur.

This project attempts to contribute to the requirements of low volume production needs and the requirements of SMEs that search for systems easy to implement, highly flexible, and adaptable to operational processes. A system involving computer vision and software development for locate parts and objects in the robot workspace has been developed and integrated to add a new step to the concept of hyper-flexible cell, enabling robotics to introduce in this kind of demanding market.

The flexible robotic system proposed consists of an industrial robot that can be easily reconfigured with external cameras and can be adapted to variances of a production process by adjusting the robot coordinates using CAD data, and being independent of the size and shape of the object.

The work presented in this paper is enclosed in the SONIA project [4] and is focused on the automatic detection of the pose (position and orientation) of the object or part to process, specifically marine nozzles (Fig. 1) and the communication of the data to the robot controller in an automatic way.

The improvement provided by this project is the application of an existing localization algorithm that can fit CAD information on a machine vision image, in a real and industrial environment focuses on shipbuilding sector.

Furthermore, the algorithm mentioned was modified with the addition of an image preprocessing that can separate the object from the background, improving accuracy and robustness.

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Fig. 1. Marine nozzles.

II. INNOVATIVE CHARACTER

In robotic applications it is always necessary acquire the pose, in the robot coordinate system, of the part to be processed or manipulated.

Currently, in a real industrial application, the acquisition of the pose of the object to process in robot coordinates is a laborious and slow operation that involves manual operations, or in some cases expensive systems. Under this concept, very different techniques have been proposed in the context of both industrial and service robots, mainly manual and vision-based approaches.

Regarding to manual options, the first option is to manually move the robot using the teach pendant to the positions to carry out the task. Other similar approach is to use software functions to calculate a displacement frame from original known positions, to displaced positions [5].

These options lead to a manual movement of the robot to touch specific points of the part to carry out the process. It is necessary high accuracy to position the robot and always there is human error. This approach requires a skilled robot operator and turns unproductive the robot during this task. As well, they have mainly a probabilistic nature that might introduce ambiguities and lack of the accuracy achieved by a human operator.

Robot programming through the typical teaching method (usually using a teach pendant) is a tedious and time-consuming task that requires technical expertise. Furthermore, as a result of the size and complexity of the marine nozzle, this method requires that the operator define manually, not only the X, Y, Z coordinates, but also define the orientations of the robot TCP (Tool Control Point) on the workpiece.

An alternative approach that aims to achieve a more accurate localization, minimizing the error produced from a human operator, is the use of a laser tracker or an iGPS (Indoor global Positioning System) [6].

Both systems measure large objects accurately, determining the positions of optical targets held against those objects. Their accuracy is around 0.025 mm over a distance of several meters. The accuracy is very high but the process is slow, requires a high number of steps, besides of the expensive price of these types of devices. Furthermore, this approach still requires skills in robot operation and does not reduce time.

Robot positioning is easier to implement with these devices, however, the data acquisition process is relatively time consuming and the resolution of the identified parameters is limited by the external measuring devices. Moreover, for the robotic visual inspection system in the industrial field environment, it’s desirable that the system be capable of performing positioning without any expensive external apparatus or elaborate setups.

The automation level of this robotics solutions and the speed of the process can be improved markedly if the pose of the objects could be determined fast and reliably. The objective is to minimize the use of expensive positioning tools by means of recognition, position and orientation systems to locate in an accurate way the part or object inside the work space of the robot.

The actual robot position can be obtained and modified with high accuracy by means of external smart cameras and markers [7][8]. For example, visual servoing approaches can be used to control the movements of a manipulator over a visual sensor system, which usually consists of one or more cameras [9][10]. The TCP and/or features of a target object are tracked by the vision system and the algorithms in the control loop try to bring the TCP to a desired position and orientation.

Vision-based 3D (three-dimensional) technology is widely applied in positioning systems for its advantages of non-contact operation, fast acquisition speed, low cost and good stability. A typical approach is the use of a stereovision system or TOF (Time of Flight) cameras [11].

In some developments it is being used a CAD-based approach [12][13]. The goal of this approach is to fit a CAD model of the object on the acquired image by the vision system. Some of the important advantages of CAD-based robot vision are enhanced productivity, capability to handle a large class of objects of many different sizes or automatic generation of recognition and manipulation strategies in real time.

Nevertheless, the algorithm used to search and fit a CAD file inside an image with the part, is used in a laboratory or for a task of grasping objects, or in a controlled environment with high contrast backgrounds and objects easily localizable, because of its small size, simple design with plenty of angles and edges. In these conditions, it is very easy to locate the part. None of the papers listed in the literature show an actual and reliable industrial application.

Therefore, the work in this paper focuses on the practical application of one of the most robust and reliable CAD-based algorithms that use monocular vision without any other type of vision system [14].

In the work presented in that paper, an alternative, accurate and fast-programming approach has been developed. In order to readapt the robot coordinates to the real position of the object, a 3D monocular vision system is used to correct the position of the robot and get the necessary accuracy to carry out the subsequent machining processes. The algorithm is able to distinguish automatically the background of the image from the object to process and then, locates the object in the 2D image and generates the pose.

The main improvement and contribution of the present paper is the use of the mentioned algorithm in a real industrial application that involves mechanized work with very large parts in the shipbuilding industry, specifically marine nozzles. The developed work involves the creation of industrial software that applies the localization system in an automatic and easy way for the operator, and capable of achieve the optimal parameters.

Moreover, no external measuring device or elaborate setup is adopted in the calibration process, because it is integrated within the developed software. Therefore, it is well suited for the positioning systems in the industrial field where unpredictable environments are a major concern.

Therefore, in this approach, a CAD-based industrial localization is presented and solves the main problems of large and complex parts location. In addition, it is not necessary expert knowledge in robotics, the operator only needs to select the CAD design of the object to detect and then, the software locate the object in the image provided by the vision system.

III. EXPERIMENTAL PROCEDURE

The main objective of the work presented is the development of a system that is able to get the pose of a large workpiece in robot coordinates. The work is specifically focused on marine nozzles.

The solution proposed in this work is to develop methodologies that help the final users to positioning a robot relative to an object to process in an intuitive way, quickly, and with a high-level of abstraction from the robot operation and without a lot of knowledge of computer vision or robotics.

To accomplish with these requirements, the localization system should be carefully applied to the nozzle in order to ensure the best fit of the real nozzle shown in the image to the theoretical -specified- form from CAD file.

Therefore, a flexible system to locate easily a large object like a marine nozzle will increase the productivity and the competitiveness of these manufacturing processes, improving the speed of the process.

Fig. 2 show the system flow chart, emphasizing the two main steps: configuration of the system and then, the localization of the object.

The propose location process involves the following main developments:

- Achieve the optimal parameters for the process.
- Create a virtual model to locate the part.
- Develop an image segmentation to erase partially or totally the background.
- Carry out the location.

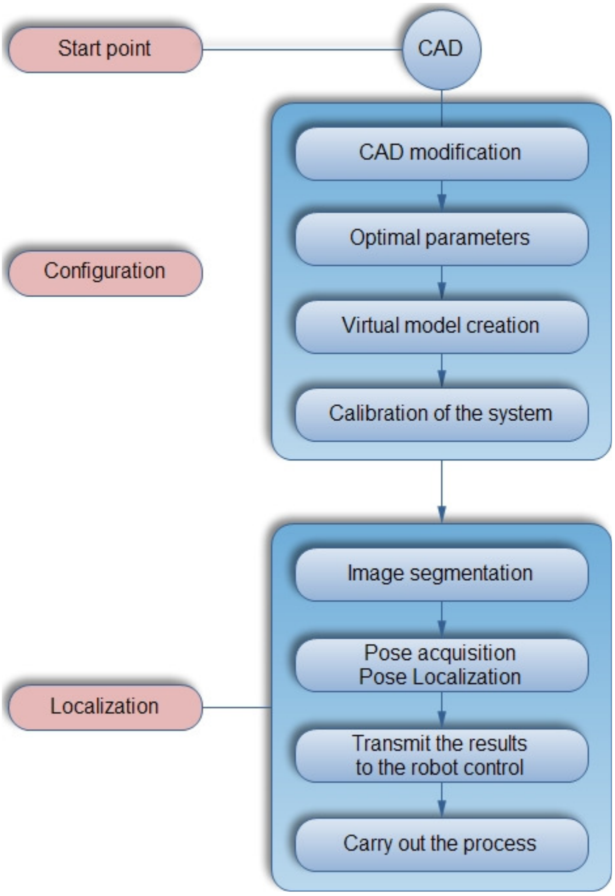

Figure 2. System flow chart.

A. *CAD modification*

The CAD file format used for the algorithm is DXF (Drawing Interchange Format, or Drawing Exchange Format). It is a CAD data file format developed by Autodesk for enabling data interoperability between AutoCAD and other programs. Besides, the DXF file is used by the application developed in SONIA project to extract robot trajectories, so it is important to use, in both developments, the same file type.

The first step is to modify and prepare the DXF suitable to use by the developed program. It is necessary to ensure that the surface of the object is modelled, not only its edges. A possible way is ensure that the surface of the 3D model is triangulated before it is exported to a DXF file.

B. *Achieve the optimal parameters*

In this important step the objective is to adjust the parameters used, not only in the creation of the virtual model, but also used in the localization of the CAD file, to achieve the optimal values.

The work was developed by means of the parameters modification, looking for optimal values and balance between accuracy, speed, robustness and computational load.

The main parameters modified are:

- Position and orientation ranges: The CAD model only will be recognized if the part is close to the position range specified.
- Number of levels: This value specifies the pyramid level number in which the model views are generated.
- Model tolerance: It is the tolerance of the 3D object borders.
- Search type: This value defines if it is a heuristic searching safe or not safe.
- Score: This parameter show the coincidence level between the CAD model and the image.

There are more secondary parameters that were analyzed, modified and tuned to achieve an optimal model and optimized subsequent search. All the parameters are explained extensively in [14].

C. Model creation.

Once the CAD model is appropriate and the parameters are adjusted, the next step was the model creation.

The 3D model is generated by computing different views of the CAD model within a specified pose range using virtual cameras around the object. Then, there is a projection of 3D model into the image plane of each position. The 3D representations are stored in the model.

The model creation and the object search are related, so the parameter values are influenced each other, therefore it was important choose them carefully. Furthermore, the values have been focused on enhance the robustness and the speed, searching for an equilibrium between them.

The model generation is included in the application developed as shown in Fig. 3, which also allows changing the parameters of the model for quick setup.

D. Image segmentation

A background with a good contrast to the object is the perfect environment, thereby, the background can be clearly separated from the object, but in an industrial environment this is totally impossible.

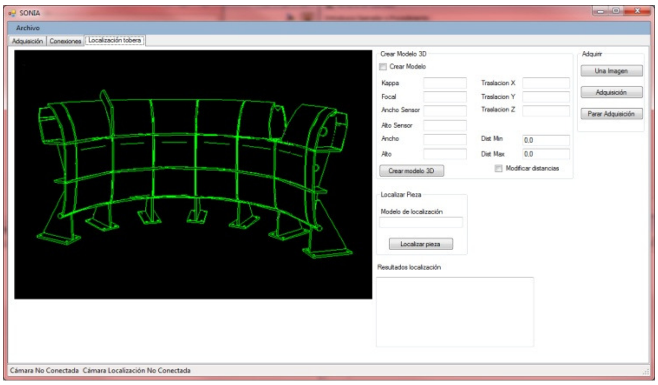

Fig. 3. Model creation.

Therefore, it is necessary an image preprocessing to carry out a gross localization of the nozzle in the image. Thus, it is possible to make a clear distinction between the part to locate and the background.

Multi-channel, e.g., color images contain more information and thus typically lead to a more robust edge extraction. This characteristic was used to discriminate the nozzle from the background so the option finally used was a colour decomposition function [15]. Color in natural images provides a good mean for efficient segmentation in preprocessing steps. The function decomposes a colour image into a series of three grey scale layers, where each layer values dictates the amount of red, green, and blue light assigned to this colour.

This decomposition allows the image transformation from the RGB colour space to a colour space in which can differentiate the object from the rest of the image. The use of perceptual color spaces and color models has shown suitable to carry on these tasks [16]. In particular, the HSV color model has provided excellent results in general segmentation tasks [17] [18] with an equilibrium between the computationally intensive models and the information required.

In this paper a simple color segmentation using histogram thresholding in the hue (H) component has been found to provide results robust enough to discriminate between the nozzle and the background.

A low pass filter to the image obtained by color segmentation was applied to smooth the image and remove the existing noise. Specifically, a median filter [19] was used to reduce the typical fuzzy effect of this type of filters.

The resulting image enables the implementation of a binary threshold that delimits the image in two regions, due to the different gray level. The region corresponding to gray level closest to black is the marine nozzle.

The image acquired delimits the part of the image with the nozzle and feeds the next phases of the algorithm, discarding all unnecessary details, improving the computational load and facilitating the processing.

The algorithm steps are shown in Fig. 4.

E. System calibration

When applying one of the calibrated perspectives matching approaches, 3D poses are returned and describe the relation between the model and the found model instance in world coordinates. To use such a pose, e.g., to visualize the matching result by overlaying a structure of the reference image on the matching the search image, a 3D affine transformation is needed.

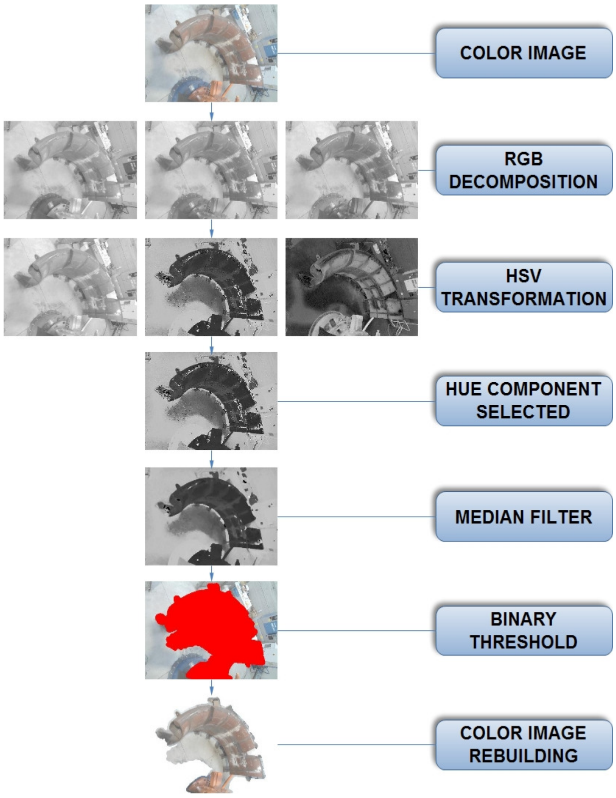

Fig. 4. Segmentation algorithm.

The calibration is based on providing multiple images of a known calibration object. But in contrast to the camera calibration, here the calibration object is not moved manually but by the robot, which moves either the calibration object in front of a stationary camera or the camera over a stationary calibration object. The pose, i.e., the position and orientation, of the robot tool in robot base coordinates for each calibration image must be known using robot controller.

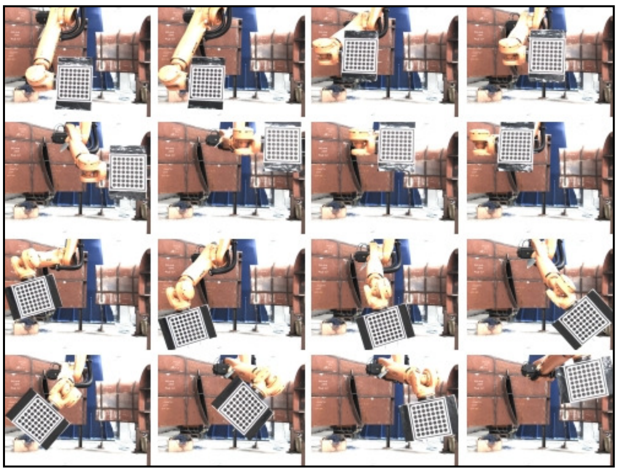

Fig. 5. Calibration images.

There is a chain of coordinate transformations. In this chain, two transformations (poses) are known: the pose of the robot tool in robot base coordinates ($^{Base}A_{Tool}$) and the pose of the calibration object in camera coordinates ($^{Cam}A_{Cal}$), which is determined from the calibration images.

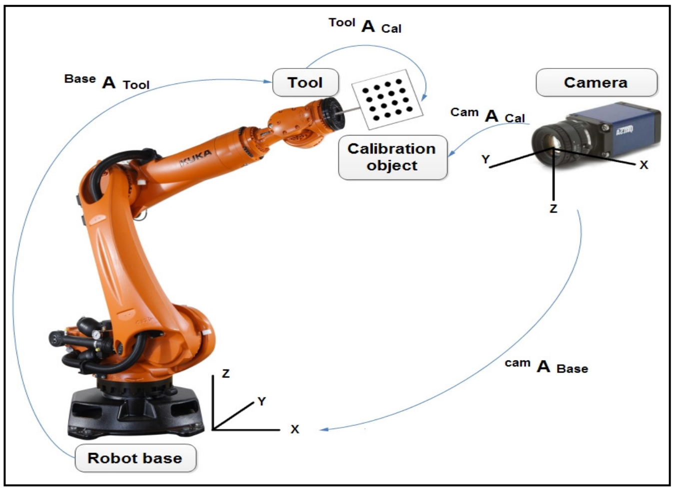

Fig. 6. Transformations chain.

The camera-robot calibration estimates the other two poses, i.e., the relation between the robot and the camera ($^{Cam}A_{Base}$) and between the robot and the calibration object ($^{Tool}A_{Cal}$), respectively.

IV. Application of the Algorithm

The final step is the application of the created 3D model and the segmentation algorithm to the image acquired and determining the 3D pose of the object in robot coordinates.

It was used two different nozzles to analyze the software performance, one smaller than the other. The nozzles were placed in a distance of, approximately, 4 meters from the camera.

The image of the marine nozzle was acquired by CMOS image sensors. The proposed GigE camera is based on C1400 camera from Teledyne Dalsa. An optic lens with 8.5mm of focal length is integrated into the camera. The small value of the focal length allows working with large object without the need of place the camera far from the robotic cell. It is possible to decrease the focal length to enlarge the area, but it can be possible that appear deformations and optical aberrations in the image.

The processed of the image were performed on a computer architecture based on Intel Core i5 dual-core CPU with 4 Gigas of RAM memory and a graphic card NVS 3100M from NVIDIA.

It was developed a software application in C# that communicate with the vision system to acquire the image, create the model, change the parameters and carry out the localization, see Fig. 7.

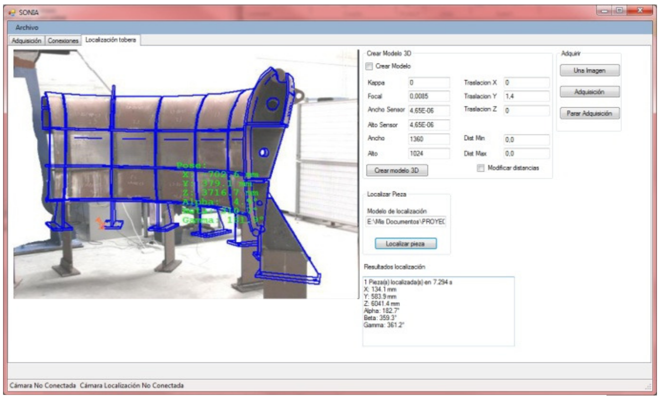

Fig. 7. C# application software.

V. Results

The final results of the process are used to check the final accuracy, the time consumption and the robustness obtained with the machine vision system and the algorithms implemented.

F. *Robustness*

Once the problem of the dirty background was solved by means of image segmentation, the main problem that can happened is the occlusion of the part by another object or even a person.

Images were acquired with objects and people between the marine nozzle and the camera to test the system reliability and robustness. The results are shown in Fig. 8.

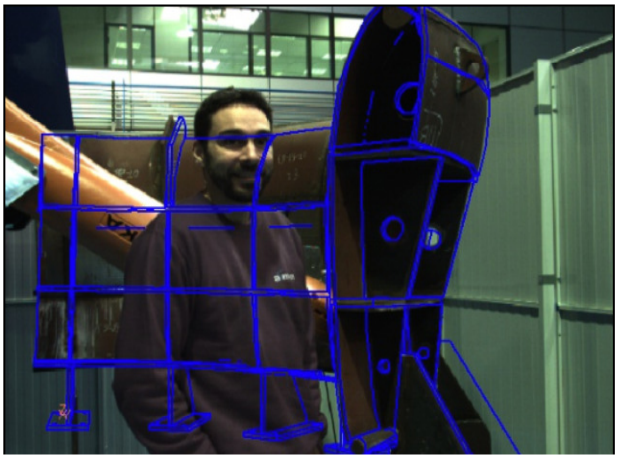

Fig. 8. Occlusion with people.

Furthermore, the CAD models used are not the same as the real part. However, the system is able to locate them properly. It can see an example in Figure .

G. *Time consumption*

The amount of time of the process can be divided in two phases: the time use to create the model and the time of localization.

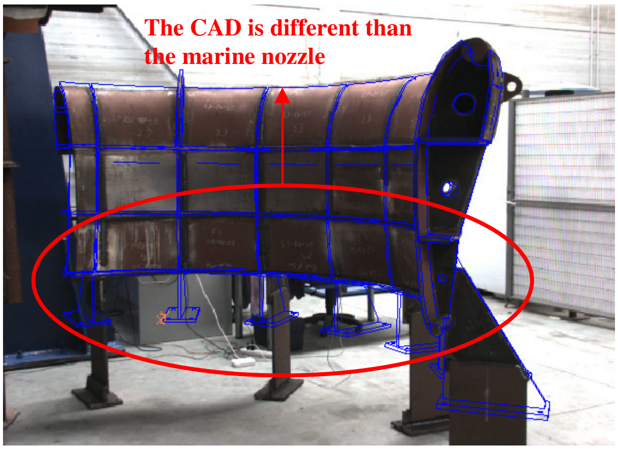

Figure 9. CAD model dissimilar.

The time to create the model depends mainly of the camera range configured in step 2. If the object can be placed in any position, the model needs to store many positions, so the time can be large. In our tests, the maximum quantity of the model creation was about 30 minutes and the minimum was about 5 minutes. However, the model creation is performed only once, so the important point is the localization time.

In this case, the time varies between 1 and 20 seconds depending of the noise in the background. Nevertheless, the time with a dirty environment can be improved with the application of the segmentation algorithm. The main improvement was the change from 14.5 seconds without segmentation to 1.25 seconds with the background erasing.

H. *Accuracy*

The accuracy obtained was measured using specific points of the nozzle, and moving the robot to those points. The distance difference between the points provided by the localization system and the real points had a maximum of 20 mm, so the error was around ±20mm.

The parameter optimization allows achieve a better accuracy, as show in Figure . In this figure it can be appreciated that the matching is better in the second image.

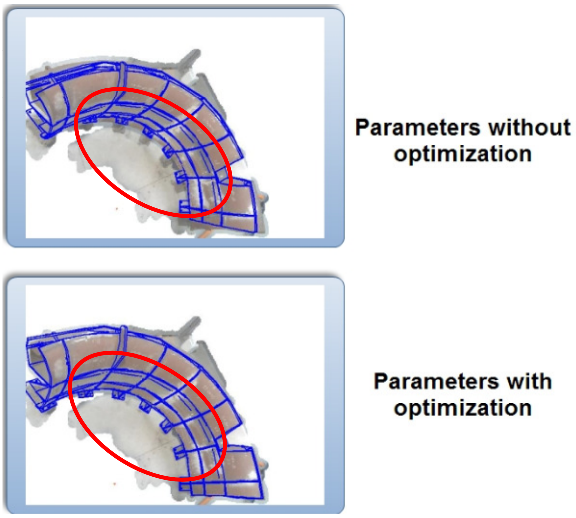

Figure 10. Effect of parameters optimization.

The accuracy obtained may not seem very important but must be taken into account, not only the big size of the nozzle, but also that the requirements of processes like grinding, deburring and polishing are not very demanding.

Besides, due to the deformations produced by welding, the real shape of the nozzle is very dissimilar to the theoretical CAD, so the robot trajectories created from the CAD environment should be readapted due to the geometric deviations. In fact, in SONIA project there is a further step that involves a 3D vision system based on laser triangulation [20] to correct the position of the robot.

The error obtained can be perfectly corrected by the posterior location system used to readjust the robot trajectory.

I. Algorithm segmentation

The Figure 11 shows the segmentation algorithm implemented and the subsequent localization. The same picture shows clearly the improvement introduced by the algorithm in the localization results.

In this last example, the algorithm cannot locate properly the marine nozzle using only localization algorithm because of the dirty and noisy background, requiring an additional step provided by the segmentation function developed.

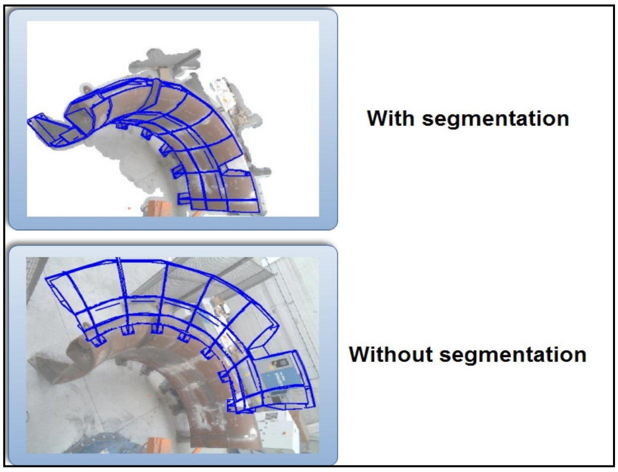

Figure 11. Improvement produced by segmentation.

J. Low cost system.

In addition to the tests performed to verify the result of the project, and with the objective focused on reducing cost, localization tests were made with a webcam, specifically a low cost Logitech 920 HD USB camera, with a resolution of 1920 x 1080, and a capture rate of 30fps. See Fig. 12.

The virtual model created is different because of the different position of the webcam, but the parameters are the same acquired in previous steps. The high accuracy demonstrates the feasibility of use the development with a very low cost machine vision system without lose the flexibility searched in a hyper-flexible cell.

Tests with different nozzles were made, however, for confidentiality issues regarding the design of the parts, have not been able to show more images.

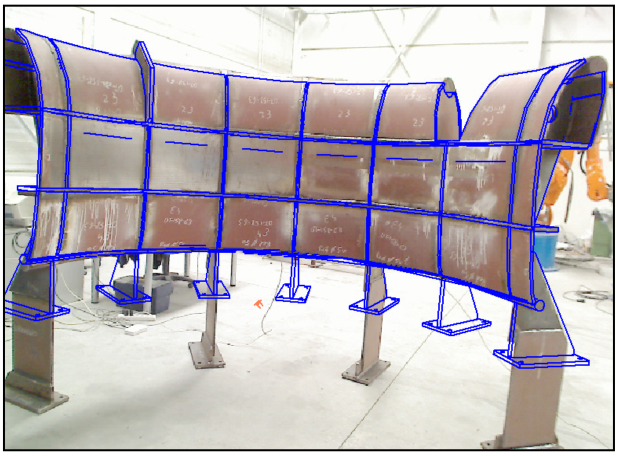

Figure 12. Localization with webcam.

VI. Discussion

A monocular CAD-based localization system has been applied to a real industrial environment. It allows a quickly location of the object and can deal with manufacturing changes, enabling the use of industrial robots in an example of small batch manufacturing

The developed location system is easy to use. An operator can initiate the entire process in few seconds, by simply selecting the CAD design without specific training on robotics and acquire the image from the camera by means of the application programmed.

Furthermore, this paper demonstrates the feasibility of a CAD-based algorithm developed in [11]. Besides, the developed system is easily adapted to operate in different industrial processes typical of small batch manufacturing, not only with pieces like marine nozzles but also with parts and raw material very different, the only important requirement is the possibility of a CAD file that represents the piece.

Therefore, the system is expected to have the following impact for final users:

- Increasing the manufacturing sector competitiveness: The context in which manufacturing enterprises work in the future will depend even more on flexibility and speed, as well as small-batch manufacturing.
- Increasing the technology level of the manufacturing sector.
- Decreasing to the end user the complexity of the robotic cell.
- Huge reduction of the time for object location.

The development is expected to make a significant contribution to the necessary efforts to upgrade the production infrastructures in SME and to integrate new forms of production able to benefit from the evolving automation technologies.

Therefore, this work yields a success example to encourage the development of robotics technology focused on small batch manufacturing. Further efforts in this direction are needed to allow to SME to improve cost efficiency, performance, robustness and flexibility needed to reach a more adaptive and competitive manufacturing sector.

VII. Future work

In the future, the main task will be to develop an own CAD-based localization algorithm that improves the current state of the art. This development will allow an enhanced accuracy, removing the need of a virtual model. The aim will be to delete the step of model creation, improving speed and reducing complexity.

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References

[1] http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/performance-review/files/supporting-documents/2013/annual-report-smes-2013_en.pdf

[2] Björn Johansson, Rebecca Stanworth, European Manufacturing Landscape. The Creation of a Composite Capability Index for Future Manufacturing in Europe, 2005.

[3] Pires, J.N., K. Nilson and H.G. Petersen, Industrial Robotics applications and industry-academia cooperation in Europe, IEEE Robotics & Automation, Vol.12, no.3, pp. 5-6.

[4] F.Vidal, M.Álvarez Souto, R.González, I.Iglesias. Development of a flexible and adaptive robotic cell for marine nozzles processing, Proceedings of IEEE 18th Conference on Emerging Technologies & Factory Automation (ETFA), Krakow 2012.

[5] Tadej Bajd, Matjaž Mihelj, Marko Munih. Introduction to robotics, Springer, 2013.

[6] Depenthal, C., & Schwendemann, Ji. GPS—a new system for static and kinematic measurements. In 9th Conference on Optical 3D Measurement Techniques. (2009, July).

[7] D. Torkar, G.Papa, Robot TCP positioning with vision: accuracy estimation of a robot visual control system, Proceedings of fourth International Conference on Informatics in Control, Automation and Robotics, Angers (2007), 212-215.

[8] A. Saxena, J. Driemeyer, and A.Y. Ng. Robotic grasping of novel objects using vision. The International Journal of Robotics Research, 27(2):157, 2008.

[9] F.Chaumette and S.Hutchinson, “Visual servo control, part I: Basic approaches,” IEEE Robotics and Automation Magazine, vol. 13, no. 4, pp. 82–90, dec 2006.

[10] F.Chaumette and S.Hutchinson, “Visual servo control, part I: Advanced approaches,” IEEE Robotics and Automation Magazine, vol. 14, no. 1, pp. 109–118, March 2007.

[11] Martinez, S. S., Ortega, J. G., Garcia, J. G., Garcia, A. S., & Cárdenas, J. (2013, October). Visual Predictive Control of Robot Manipulators Using a 3D ToF Camera. In Systems, Man, and Cybernetics (SMC), 2013 IEEE International Conference on (pp. 3657-3662). IEEE.

[12] Ulrich Klank, Dejan Pangercic, Radu Bogdan Rusu, Michael Beetz. Real-time CAD model matching for mobile manipulation and grasping. 9th IEEE-RAS International Conference on Humanoid Robots, 2009.

[13] Chuantao Zang; Hashimoto, K. Camera localization by CAD model matching, System Integration (SII), 2011 IEEE/SICE International Symposium on, On page(s): 30 – 35.

[14] Markus Ulrich, Christian Wiedemann, Carsten Steger. CAD-Based Recognition of 3D objects in Monocular Images. International Conference on Robotics and Automation (ICRA), 2009.

[15] Dey, V.; Zhang, Y.; Zhong, M. A review on image segmentation techniques with remote sensing perspective. En WW and B. Székely (Editors), ISPRS TC VII Symposium–100 Years ISPRS. IAPRS, Vienna, Austria, pp. Part A. 2010.

[16] Lissner, Ingmar; Urban, Philipp. Toward a unified color space for perception-based image processing. Image Processing, IEEE Transactions on, 2012, vol. 21, no 3, p. 1153-1168.

[17] Vadivel, A.; Sural, Shamik; Majumdar, A. K. Robust histogram generation from the HSV space based on visual colour perception. International Journal of Signal and Imaging Systems Engineering, 2008, vol. 1, no 3, p. 245-254.

[18] Burdescu, Dumitru Dan, et al. "A new method for segmentation of images represented in a hsv color space." Advanced Concepts for Intelligent Vision Systems. Springer Berlin Heidelberg, 2009.

[19] Verma, O.P.; Parihar, A.S.; Hanmandlu, M. "Edge Preserving Fuzzy Filter for Color Images", Computational Intelligence and Communication Networks (CICN), 2010 International Conference on, On page(s): 122 - 127

[20] François Blais, Review of 20 years of range sensor development. Journal of Electronic Imaging, 13(1): 231-240. January 2004.