GO0DMAN

AGENT ORIENTED ZERO DEFECT
MULTI-STAGE MANUFACTURING

Deliverable 3.2

Self-adaptive quality control systems

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Executive Summary

The WP3 of GO0DMAN project is focussed on the development of laboratory prototypes of smart inspection tools, i.e. quality control systems which exhibit smart behaviours, aimed to keep measurement uncertainty under control and to improve system performance in the complex factory environment typical of multi-stage manufacturing, also taking into account the presence of man-in-the-loop.

In WP3 a total of 7 prototypes have been developed, for the 3 industrial use cases provided by the partners Volkswagen Autoeuropa, Zannini Poland and Electrolux Professional; their structure was presented in D3.1-" Quality inspection systems".

This D3.2- "Self-adaptive quality control systems" describes the smart behaviours implemented in the prototypes; the two documents together provide an overview of the smart quality control systems developed. Altogether, they represent a representative set of smart modes of operation: self-adaptivity to compensate external disturbances as well as self-diagnosis and self-calibration, together with specific features designed to keep the man-in-the-loop. For each case this is made possible by suitable hardware, which includes sensors and actuators and specific algorithms and software providing the system the capacity to perform strategies aimed to improve its performance. This D3.2 puts in light how the self-X strategies have been implemented for each smart quality control system, providing block-diagrams and schemes and results obtained in laboratory conditions.

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Acronyms

ZDM	Zero Defect Manufacturing
SIT	Smart Inspection Tool
CPS	Cyber Physical System
FoF	Factory of the Future
QCS	Quality Control station
DoA	Description of the Action
SPC	Statistical Process control

MAS	Multi Agent System
DOF	Degree Of Freedom
RA	Resource Agent
ICT	Information Communication Technology
DA	Data Analytics
KM	Knowledge Management
CNN	Convolutional Neural Network
CCS	Confocal Chromatic Sensor
WR	Working Range
SMR	Start of Measuring Range
CMM	Coordinate Measuring Machine
RGB	Red Green Blue
ROI	Region of Interest
US	Ultrasound

1 Introduction

1.1 Objective of the deliverable

The GO0DMAN project has developed a number of smart inspection tools which have been described in GO0D MAN Deliverable D3.1 [1]. These systems are designed to perform quality control tests in-line; their main feature consists in exhibiting smart behaviours, aiming to manage measurement uncertainty at the desired level in the complex environment of production lines.

In order to address a set of industrial cases representative of the variety of multi-stage manufacturing systems operating in Europe, within the GO0DMAN project the following test cases have been selected (Figure 1):

a) a test case from the automotive industry (Volkswagen Autoeuropa), where a serial production of vehicles takes place in a very structured and traceable production system, with automatic and manual processes;
b) two test cases in a batch production system (Zannini), where parts are not traceable to the single unit and are produced by automatic machine-tools in medium size batches;
c) four test cases in a production system of professional ovens Electrolux) where each product is highly customized, and production is mainly manual.

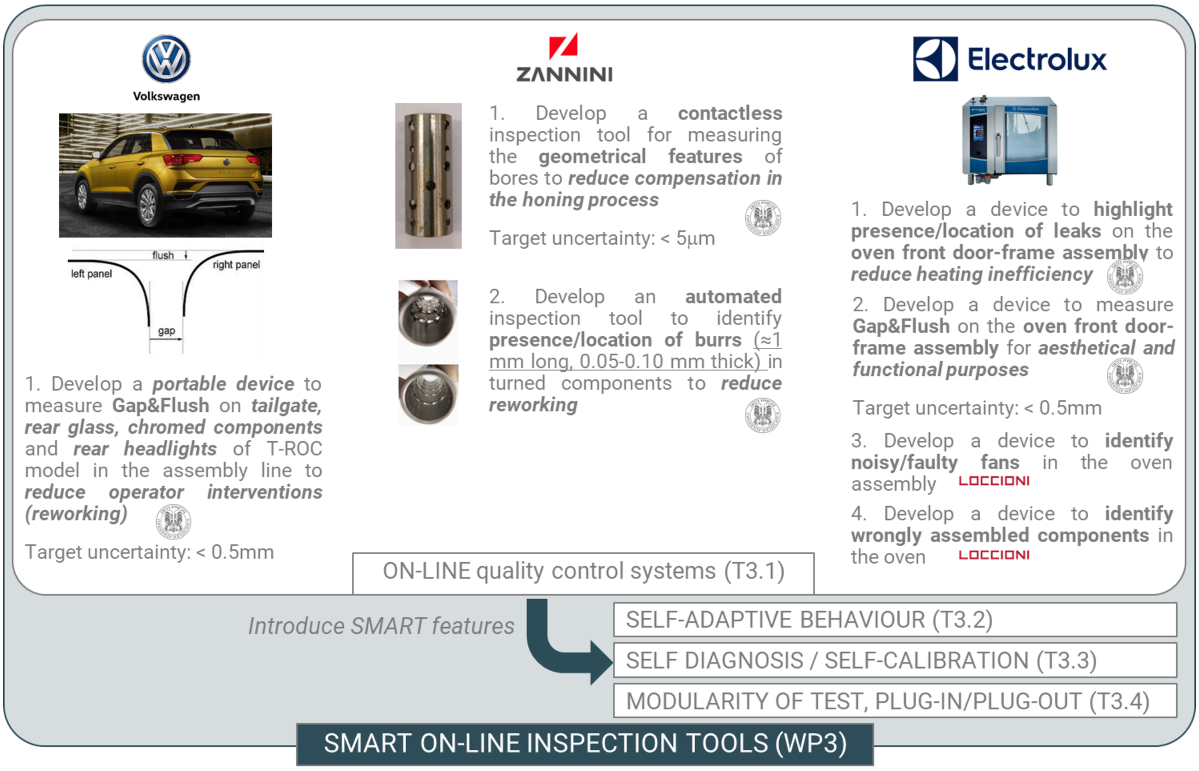


Figure 1 – The smart inspection tools developed in the three industrial scenarios considered in GO0DMAN project

The architecture of the 7 smart inspection tools was detailed in D3.1, while in this D3.2 it is discussed how smart features have been implemented in each case. These smart behaviors fall into the categories of self-adaptivity (developed in Task 3.2) and self-diagnosis and self-calibration (developed in Task 3.3). Each tool does not exhibit all kinds of behaviors, however the systems presented in this document altogether cover a large variety of smart features that enable these systems to operate in the complex industrial environments considered.

Particularly relevant is that two of the tools developed are designed to keep the man-in-the-loop, a theme of large importance in the debate on the future of automated systems. Keeping the man-in-the-loop, especially when the man is in charge of taking measurements which would then support decision making processes, is a challenge that can be addressed if the quality control systems effectively support the operator in the complex task of measurement, with attention to the quality of measured data and allowing a safe and reliable operation.

Another innovative characteristic of the GO0DMAN smart inspection tools is their tight integration with the Multi-Agent System (MAS). The MAS supports the collection of data in a distributed manner, as well as data processing and correlation for the early detection of problems and the optimization of inspection and processing operations. Each smart inspection tool is designed as a Cyber-Physical System (CPS) where the cyber part is a software agent, called Resource Agent (RA), connected to the quality control station (QCS) acting as the physical counterpart.

Objective of the D3.2 is therefore to provide an insight into each smart inspection tool developed, providing a description of its specific smart behaviors in the context of the industrial application considered.

1.2 Structure of the deliverable

The following chapters from 2 to 7 provide each the description of a specific smart inspection tool, focusing on its smart behaviors. Even if measurement uncertainty is the quantity to be managed, these chapters do not deal specifically with a quantitative estimate of measurement uncertainty. This is done because the evaluation of measurement uncertainty in operation requires tests to be conducted in an industrial environment, where all sources of uncertainty, as well as the effect of human operators, will manifest itself. This D3.2 rather concentrates on the design and implementation of smart behaviors which will allow managing uncertainty in a production environment. The scope is not to provide a metrologic analysis of performance neither to calibrate instruments in laboratory conditions, where the complexity of the production line could not be simulated. Later in the project, during the in-line validation of the prototype systems, an evaluation of uncertainty really achievable in a production environment will be provided in quantitative form.

All chapters share a common structure: the first paragraph reports for each quality control system a block diagram describing the measurement procedure, as well as some screen shots of the user interfaces developed for management of the process. The block diagram shows the self-X behaviors, in particular self-adaptation and self-diagnosis which are detailed in paragraph 2 and 3 of each chapter and, where implemented, also self-calibration. Concerning self-adaptivity, information on interfering and disturbing inputs which affect the measurement process are recalled. Finally, each chapter concludes with paragraph 4 where a comparison of the performance of each smart inspection tool with and without self-X behaviors is provided.

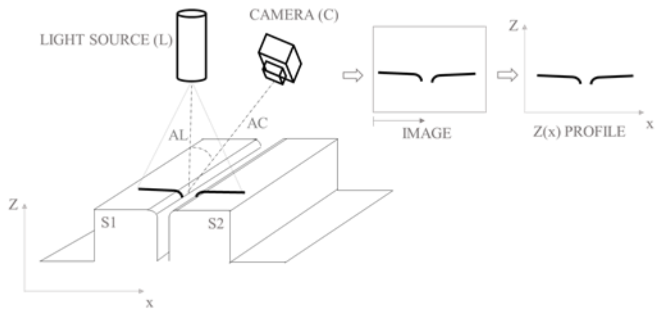
2 Quality Control System for Gap&Flush (VWAE+ELUX)

The goal of the QCS to be developed for the VWAE as well for the ELUX use case is the assessment of Gap&Flush values (Figure 2a) on the tailgate-to-body assembly of VW T-ROC model (Figure 2b) or, on the professional oven, front-panel door with respect to the oven frame (Figure 2c). As discussed in D3.1, in VWAE this inspection is currently performed using a feeler gauge tool by the operator, hence no data are available at the end of the inspection but a compliant/not-compliant tag. The inspection takes place at both the tailgate pre-fit (i.e. before rear lights assembly) and during the tailgate-rear lights fit operations. In ELUX this inspection is not performed at present.

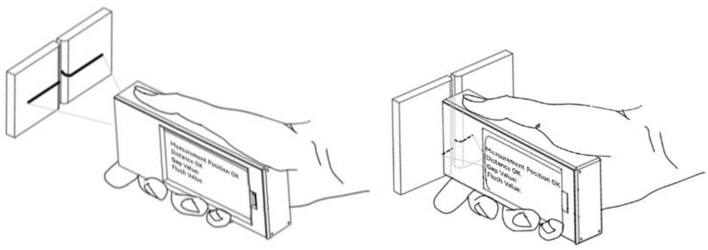
(a) *(b)*

Figure 2 – QCS for Gap&Flush: gap&flush definition (a); T-ROC model (b); professional oven model

The tool developed within GO0D MAN exploits the laser line triangulation principle (Figure 3a) on a portable device (Figure 3b) that aims at keeping the operator in the measurement loop.



(a)



(b)

Figure 3 - QCS for Gap&Flush: laser line triangulation principle for Gap&Flush measurement

Even though some portable systems are present in the market, none of them are able to always provide accurate results when measuring on different materials like metal, plastic, glass because of the different optical characteristics of these materials. The device developed for the GO0D MAN project embeds a series of smart features that make possible to:

a) Handle operator safety issues due to the presence of laser light;
b) Handle operator mistakes in defining the measurement point by cross-checking operator's will through a measurement point recognition procedure;
c) Manage different target materials to optimize measurement accuracy.

2.1 Measurement procedure

Being a hand-held device, the tool needs to manage the interaction with its operator. For this reason, the measurement procedure involves the operator at different levels (Figure 4). There is a continuous interaction loop between the operator and the QCS. Indeed, the QCS checks operator decisions by comparing them with its own strategies. If and only if the results of these checks comply with operator decisions, then the green light to perform a measurement is provided. To make an example, at the beginning of the inspection the operator is asked to select the measurement point. The operator is asked to point the device towards the measurement point he/she selected. A picture of the part is then automatically performed by the device and algorithms for classifying the framed part are run. If the result of this classification states that the measurement point selected by the operator is really the one he/she pointed the device at, then the procedure can proceed, otherwise the operator is asked to check the right position of the device. This cross-check has a twofold implication: on the one hand it makes possible to reduce the assignation of gap&flush values to wrong measurement points, on the other hand, as it will be better explained in Section 2.2, it makes possible to optimize the measurement conditions (i.e. optimize the exposure time of the camera with respect to materials/colours characterizing the part under inspection) to guarantee a lower uncertainty on result of the measurement.

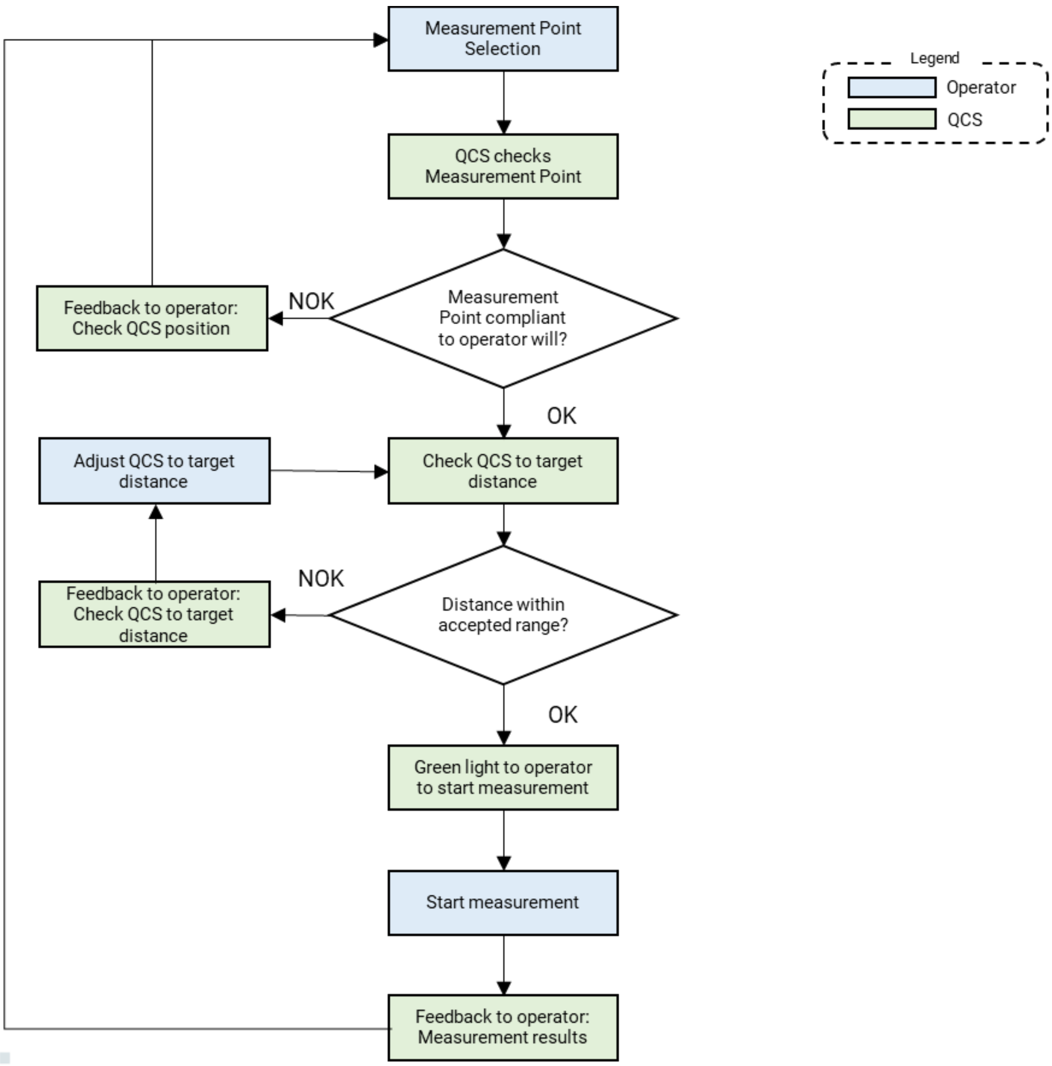


Figure 4 - QCS for Gap&Flush: measurement procedure

Since the QCS is asked to work in a multi-stage production line, it might be possible that the number of inspection points changes, depending on the results of the upstream assembly process, managed through the MAS. For these reasons, a strong cooperation with the Resource Agent (RA) associated to the QCS is required. For instance, the RA can suggest whether the inspection points have to be modified with respect to the nominal ones. Indeed, the RA can suggest an optimized configuration to the QCS. This talk between the QCS and its RA takes place as schematized in Figure 5. The communication between the QCS and its RA is checked at first by the QCS. If the communication is down the QCS runs the measurement procedure using its default configuration, otherwise the RA can suggest whether to load a default or an optimized configuration. Once the measurement is performed, the QCS-RA communication is checked again: if communication is up, data measured are both pushed to the RA and stored in a local database of the device; if communication is down data are stored in the local database of the QCS and hold (not yet transferred) and current data are pushed to the RA once communication is established. In this way the possibility to lose data is reduced.

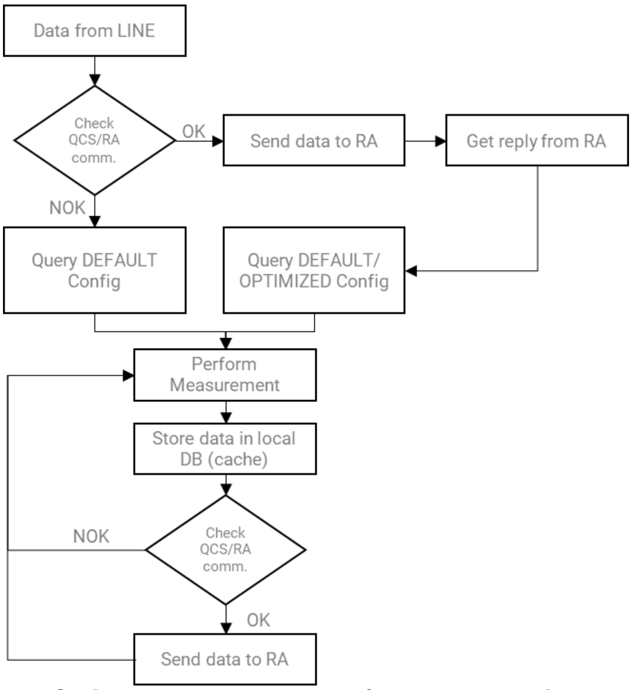


Figure 5 - QCS for Gap&Flush: QCS-RA interaction for optimizing the measurement procedure

2.2 Self-adaptive behaviour to keep uncertainty under control

To guarantee a correct analysis by the GO0D MAN actors working at the higher layers (Data Analytics – DA - tool and Knowledge Management – KM - tool), data provided by the QCS have to be as accurate as possible. This translates in reducing the uncertainty of the measurement. In GO0D MAN, this concept is applied by embedding each QCS with self-adaptive behaviour that aims to minimize effects of different measurement conditions that could somehow badly influence the whole measurement chain.

The measurement principle characterizing the QCS for Gap&Flush is laser triangulation. This implies that a picture of the part under inspection is taken once it has been illuminated by a laser line. However, since different materials/colours of the same materials behave differently to the same laser wavelength illumination, it is important to optimize the camera exposure time to guarantee the best image result. To perform this operation in an automated way it is fundamental to somehow recognize the measurement point on which the measurement is taking place. Indeed, once the measurement point is recognized, a recall of materials/colours characterizing that measurement point can be performed and the best camera exposure time for that combination of materials/colours can be set.

The recognition of the measurement position is performed on the QCS by running a Convolutional Neural Network (CNN) named Alexnet [2]. This is a pre-trained CNN that takes the image of the part (with laser source switched off) under inspection as input and classifies the image according to the classes defined during the learning phase. Each class embeds an optimized exposure time. As a consequence, once a label is assigned to the part under inspection (classification result), the camera exposure time can be set accordingly, this ensuring the best result in terms of image quality, laser line profile extraction and gap&flush calculation. Figure 6 reports some results from a set of 62 images of different parts of different T-ROC samples. As it can be seen, the CNN correctly classifies 75% of the images. The CNN fails in classifying the image received in the 13% of the whole population. Left to right inversion (LT/RT) represents the main source of classification error. This is quite straightforward, since the CNN is invariant to image scaling and rotation.

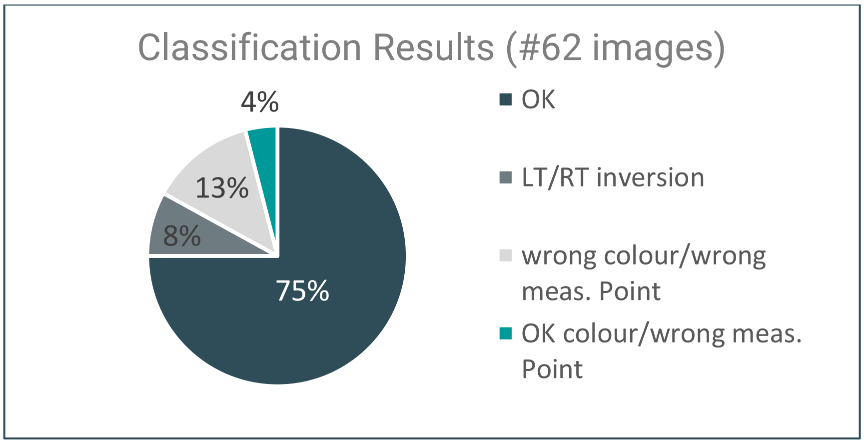


Figure 6 - QCS for Gap&Flush: CNN classification results for labelling the part under inspection

Given the few images that were used for training the network, these results are quite remarkable. Some mis-classifications are still present. However, it is expected that, once the QCS runs in the production line and more images are available, the behaviour of the CNN becomes more and more stable, thus providing more accurate classification results.

As a triangulation system deriving quantitative information from an image, it is important to ensure data are acquired within the calibration range of the device. The QCS hosts a distance sensor having a twofold purpose: ensure the operator safety (laser is switched on only if the measurement point is recognized as valid and target-to-sensor distance is within the measuring range) and enable the measurement to be consistent with the calibration range of the device. This latter aspect should ensure more accuracy in the estimation of gap&flush.

2.3 Self-diagnosis and Self-calibration strategies

The possibility to check whether the device is pointed towards the correct position and within the correct working target-to-sensor distance range is an enabler for an embedded self-diagnosis feature of the device. Indeed, since the device provides a feedback to the operator for both the two phases, this can be seen as a way to auto-diagnose whether the measurement conditions for which it was designed are respected or not. This is an innovative feature for a gap&flush measurement device. Indeed, commercial systems do not have this capability: they typically provide a feedback about the working range as in-out information, since this check is performed directly on the image (if the laser line is captured in the image then the device is operating within its working range). The device developed within GO0D MAN exploits a different strategy. The distance sensor is used to limit the working range of the device to the one that ensures the most accurate results in terms of gap&flush measurement.

As a measurement system, the QCS for gap&flush has to be calibrated periodically. This calibration involves three features of the device:

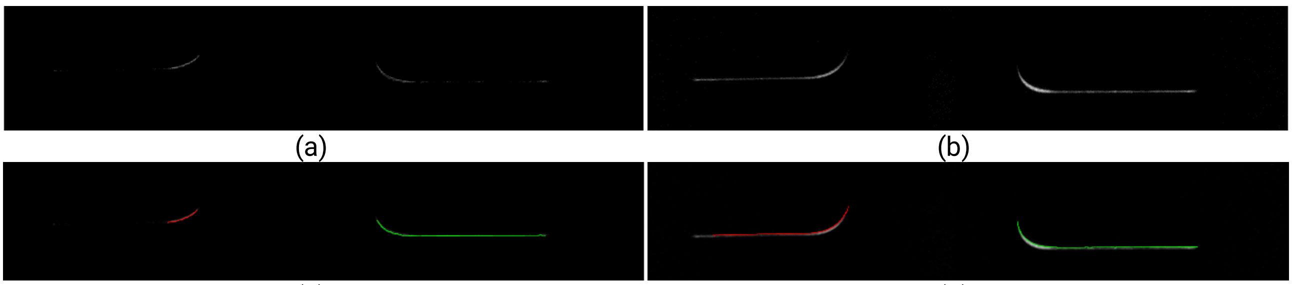
i. Ability to correctly identify the measurement position;
ii. Correct functioning of the distance sensor;
iii. Correct evaluation of gap&flush values.

The first task of the list is faced by pointing the device towards a series of known positions and checking whether the classification is running correctly or not, e.g. correct identification of materials/colours. In case the procedure fails, the device should go to maintenance.

The second and the third items of the list above can be addressed together. Indeed, by placing the device on a tool comprising a target of known gaps and flushes, and a slide moving perpendicularly with respect to the target it is possible to check the correct functioning of the gap&flush measurement part and the distance sensor.

2.4 Results

This paragraph reports some results to show the benefit of the self-adaptive behavior (namely the measurement point recognition by the CNN) characterizing the QCS. Figure 7 shows, on the top part, two images framing the same component. The one in the right is taken optimizing the exposure time through the self-adaptive behavior that characterize the QCS. It is well evident that, when the exposure time is not optimized for that particular material/color, the laser line is only partially detected on the image (Figure 7a) and therefore roughly recognized by the line profile extraction algorithm (Figure 7c). On the contrary, when the self-adaptive behavior is enabled, the laser is entirely present on the raw image (Figure 7b) and the profile extraction algorithm works much better (Figure 7d).



(a) (b) (c) (d)

Figure 7 - QCS for Gap&Flush: (a) and (b) - raw images, (c) and (d) corresponding laser profile recognition with self-adaptive behaviour disabled and enabled respectively

This has a great impact on the accuracy of gap&flush measurement, as demonstrated quantitatively in Table 1, in which deviations from nominal values of a reference tool of known gap and flushes are reported. It is well evident that deviation of gap values decreases of one order in magnitude. Flush values are stable in both cases.

Table 1 QCS for Gap&Flush: Gap & Flush deviations with respect to nominal values measured with self-adaptive behaviour disabled/enabled

	Deviations to nominal values	
	No exposure optimization	**Exposure Optimization**
Gap Value (mm)	-2.4	0.3
Flush Value (mm)	-0.1	0.1

3 Quality Control System for measuring geometrical features of bores (ZANNINI)

The QCS for measuring the geometrical features of cylindrical parts developed for the ZANNINI use case (Figure 8) targets an overall uncertainty of less than/equal to 10 μm over the bore diameter. This is quite a challenge, given the in-line installation of the whole system. Indeed, it is expected, for instance, a greater variability in terms of environmental temperature with respect to a metrological room, in which temperature is highly stabilized. All these factors pushed the necessity to develop a series of smart-behaviors that could ensure accuracy and repeatability of measured data. In particular, the following two main self-adaptive behaviors have been developed for this QCS:

- Sensor-to-part centering;
- Temperature self-compensation.

These aspects will be deepened in the following sections.

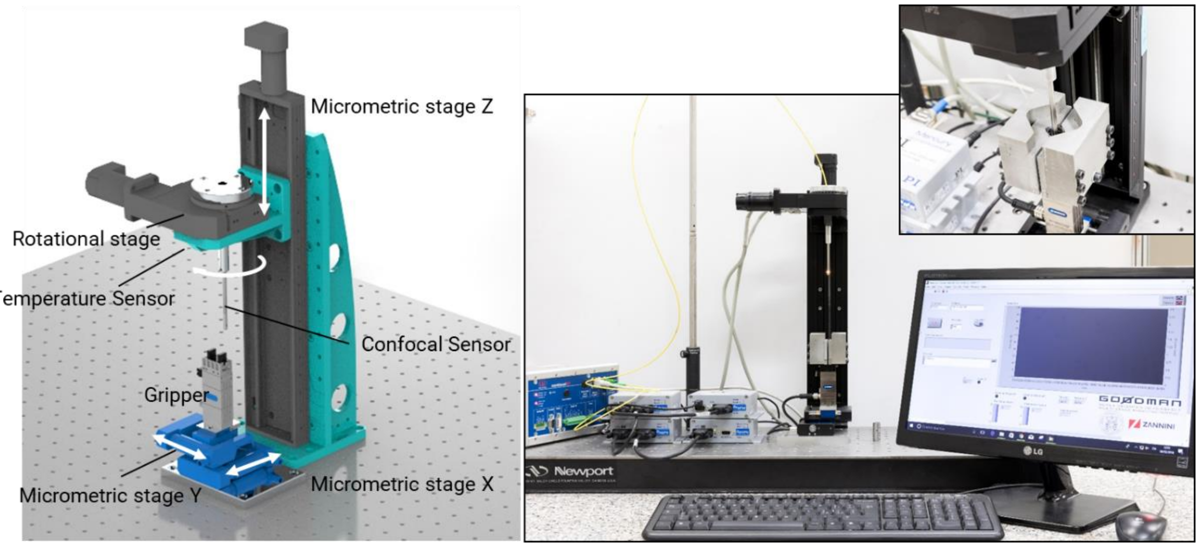


Figure 8 - QCS for measuring geometrical features of bores: the schematic drawing (left) and pictures of the prototype (right)

3.1 Measurement procedure

The measurement procedure characterizing this QCS is illustrated in the flow chart reported in Figure 9. The QCS is in an idle state until it receives a trigger event (e.g. from a robot or from a software event triggered by the operator) that the cylindrical part to be inspected is ready to be measured. This event triggers a first data exchange between the QCS and its RA and the closing of the gripping system, in order to fix the position of the cylindrical part. The vertical stage carrying the Confocal Chromatic Sensor (CCS) inserts the sensor axially and brings it to the first section to be inspected. The correct positioning of the CCS with respect to part is then checked. If the CCS actual position is compliant with the desired position the measurement starts: data from CCS and temperature sensor are acquired during one revolution of CCS. The availability of local temperature data makes it possible to perform temperature compensation (see Section 3.2.2 for further details) and then to extract current geometrical data about the section inspected. If necessary, further sections along the cylindrical part are tested. Finally all these data are stored in a local database and pushed to the RA to be transmitted along the GO0D MAN architecture.

The QCS/RA data exchange strategy is reported in Figure 10. The QCS loops the measurement of the part diameter at different sections until the target number of sections to be inspected (information provided by its RA after the QCS passes tags of the sample) is reached. During this loop, to avoid loss of measured data, the measured data are stored in a local database. Once the connection between the QCS and its RA is established, data related to the measured part are pushed by the QCS to its RA and then moved to the top layers through the GO0D MAN MAS architecture.

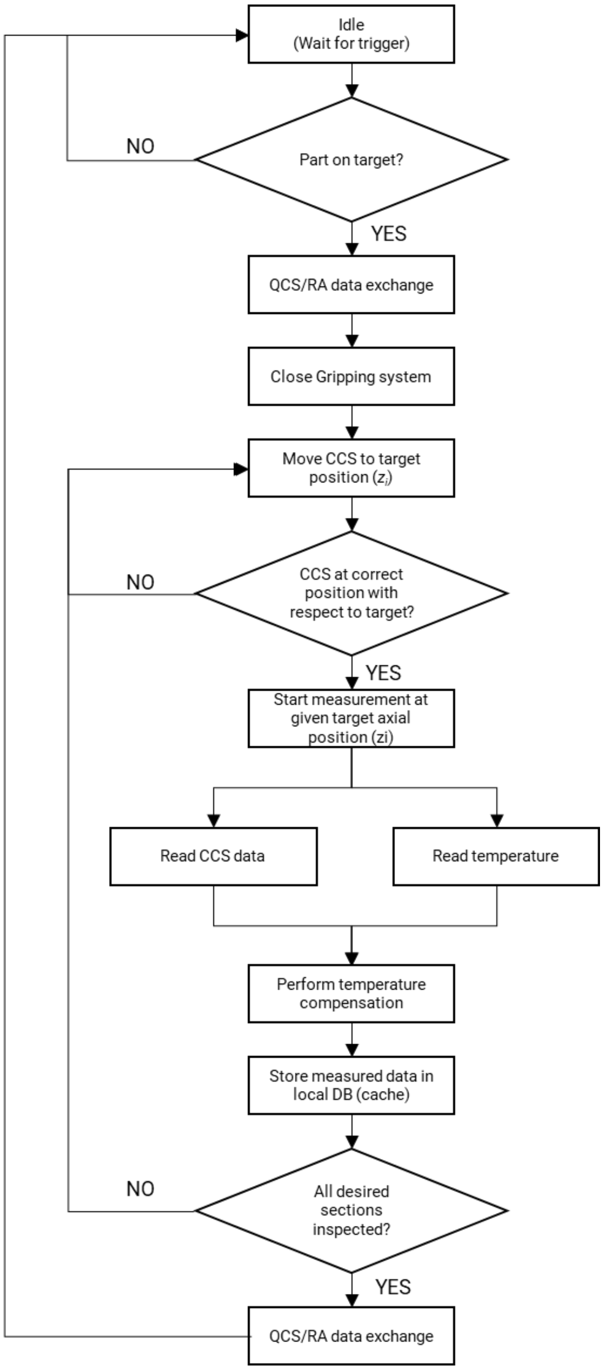


Figure 9- QCS for measuring geometrical features of bores: flow chart describing the measurement procedure

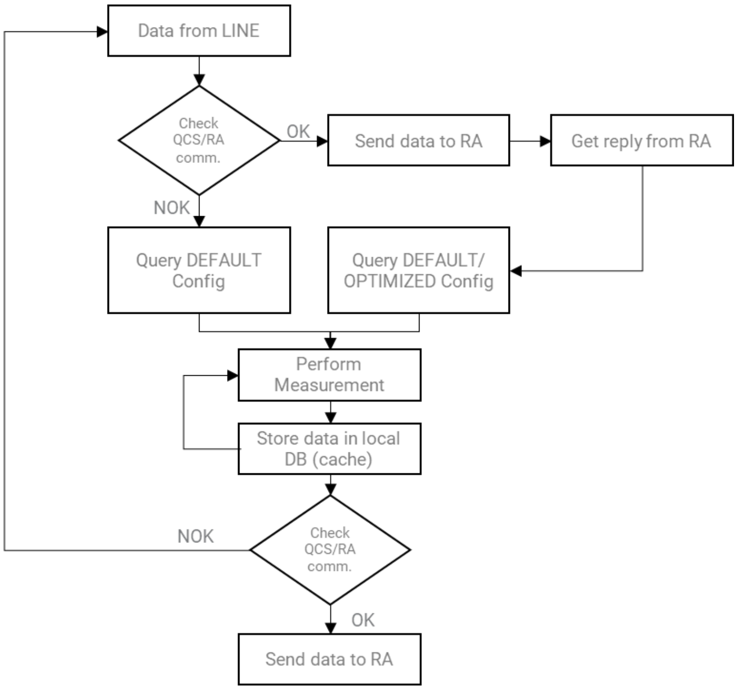


Figure 10 - QCS for measuring geometrical features of bores: QCS-RA interaction for optimizing the measurement procedure

3.2 Self-adaptive behaviour to keep uncertainty under control

3.2.1 Sensor to part centring

A correct alignment of the sensor axis with respect to the sample longitudinal axis is of extreme importance to ensure an accurate measurement of sample inner diameter during the sensor revolution. If eccentricity is present, the sample diameter is assessed wrongly. To ensure a centering as much correct as possible, the system performs a preliminary distance evaluation, at the same vertical position, on four points located every 90° along the same circumference. An optimization procedure where the sample is moved by the XY traversing axes, which means changing the relative position of the sample longitudinal axis and the sensor vertical axis, runs to make these distances equal within a certain tolerance. The centering procedure is terminated when the stop criterion is reached. After this preliminary eccentricity correction, a circle fitting is carried out and finally an analysis of residuals with respect to the circle is performed, so to refine the centering of the sensor with respect to the sample.

3.2.2 Temperature Self-compensation

Ambient temperature represents a modifying effect for the chromatic confocal sensor and therefore it is necessary to compensate the erroneous distance value provided by the sensor [3]. Indeed, temperature variations causes a twofold effect on the CCS, i.e.:

- Onset of spurious displacement Δz

$$n(\lambda_0, T_0) = n(\lambda_0 + \Delta\lambda, T_0 + \Delta T) \quad (1)$$

$$\Delta\lambda = -\Delta T \cdot \left(\frac{\partial n}{\partial T} / \frac{\partial n}{\partial \lambda}\right) \quad (2)$$

$$\Delta z = -\Delta\lambda \left(\frac{z_{max}-z_{min}}{B}\right) \quad (3)$$

Where n is the refraction index of the optics, λ_0 is the dominant wavelength recorded for an object at distance z at the standard temperature T_0

- Variation of sensor working range $|dz_{max} - dz_{min}|$

$$dz_{min} = \frac{y^2}{(y-f_{min})^2}, dz_{max} = \frac{y^2}{(y-f_{max})^2} \quad (4)$$

where *f* represents the effective focal length of the optics and *y* stands for the distance (fixed) from the confocal fiber tip to the optics.

A natural consequence is that the working range increases while decreasing temperature and the sensor undergoes temperature drift. A dedicated measurement campaign was performed to experimentally characterize the correlation between ambient temperature and measured distance. The CCS was installed inside a temperature controlled chamber, together with a reference micrometer, arranged in a way to measure the distance to the moving plate of the micrometer (Figure 11). Since it is expected that temperature variations cause different effects at different sensor-to-target distances (*z*), the measurement campaign consisted in measuring five different sensor-to-target distances at different temperatures (Figure 11). The nominal distances (D_n) were evaluated by the micrometer, whose readout was also monitored by a custom-made vision-based system. The temperature range investigated ranged between 10°C and 40°C.

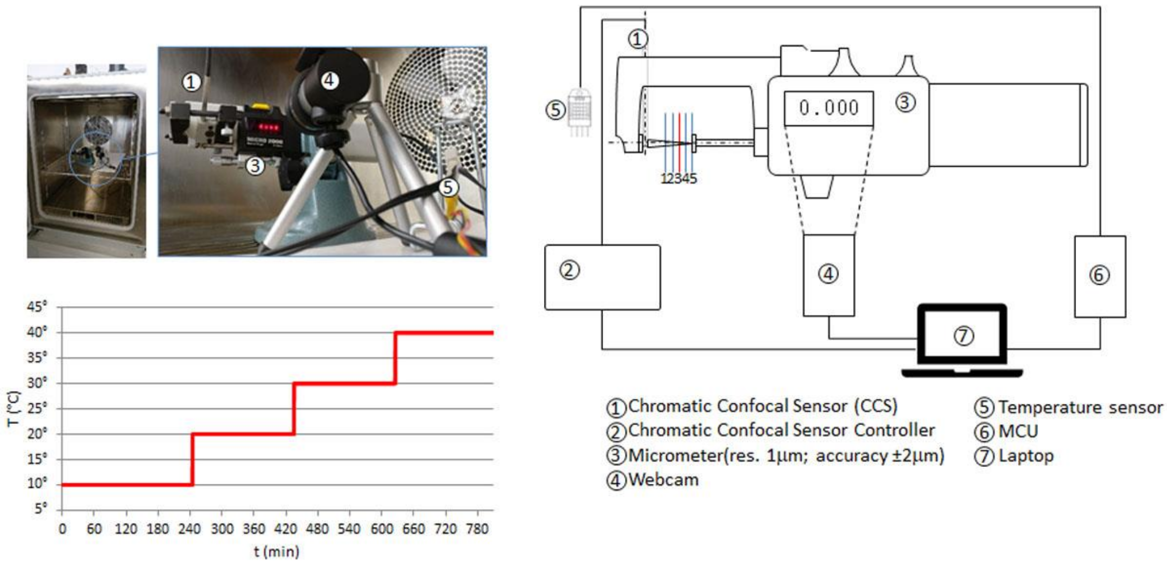


Figure 11 - QCS for measuring geometrical features of bores: Test setup for temperature compensation - arrangement of the monitoring set-up (top-left), measurement chain (top-right) and temperature ranges investigated (bottom-left)

Data obtained made it possible to characterize the temperature drift of the sensor. Figure 12 shows the dependence of the CCS sensor readout (*d*) vs. the ambient temperature (*T*). It is interesting to notice that an average drift of approximately 8 µm/°C characterizes the CCS used in the test.

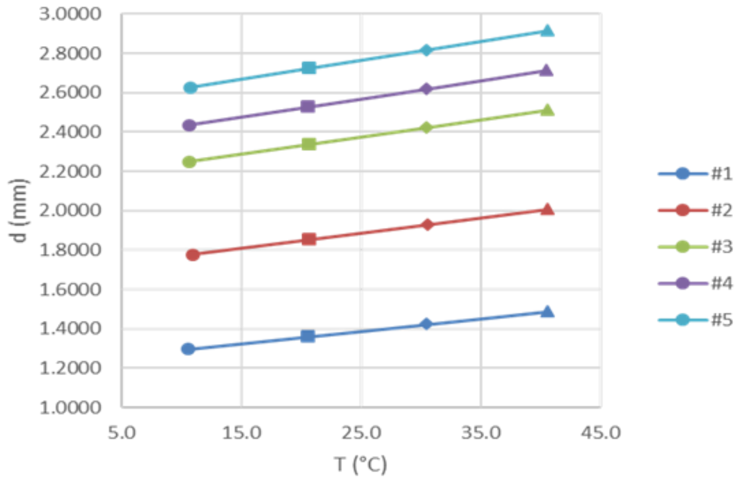


Figure 12 - QCS for measuring geometrical features of bores: CCS readout (*d*) vs. ambient temperature (*T*) at different sensor-to-target nominal distances

Figure 13 shows the relation between the nominal sensor-to-target distances (*Dv*) and the CCS readout at different ambient temperatures. The decrease of the slope of the interpolating line with an increase in temperature is a further proof that the CCS working range (WR) is decreasing.

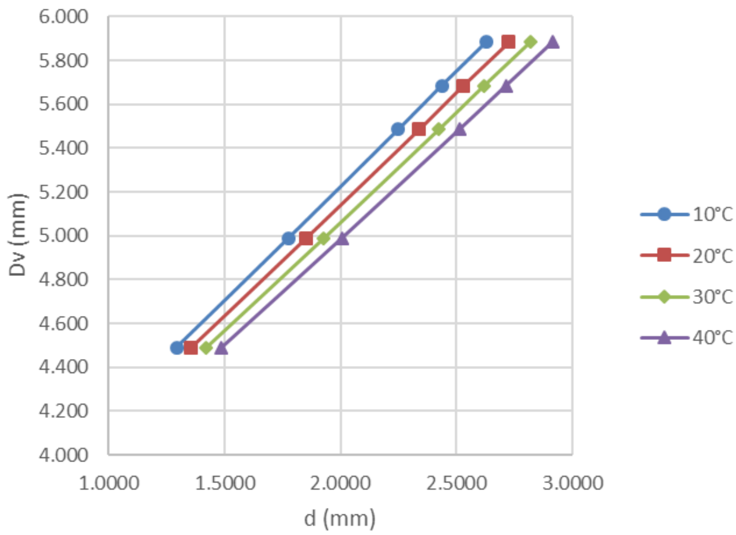


Figure 13 - QCS for measuring geometrical features of bores: Nominal sensor-to-target distance (Dv) vs. CCS readout (d) at different ambient temperatures

The average temperature drift of the sensor was estimated in approximately 8 μm/°C

By exploiting a surface fitting of the data collected during the tests (Figure 14), it was possible to get the sensor-to-target distance value (D_v) given the distance value (*d*) provided by the sensor and the ambient temperature (*T*) measured close to the sensor. This allows temperature compensation.

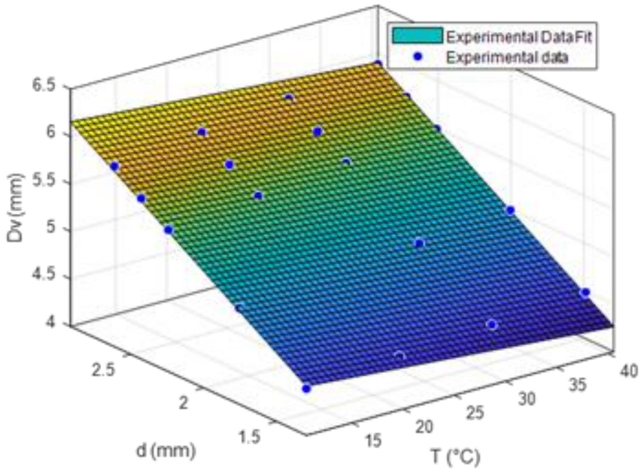


Figure 14 - QCS for measuring geometrical features of bores: Surface fitting to extract absolute sensor-to-distance values (Dv) given sensor readings (d) and ambient temperature (T) values

3.3 Self-diagnosis and Self-calibration strategies

It is important to periodically check the performance of the system so to ensure an uncertainty lower than 10 μm; indeed, dimensional measurements at this level of uncertainty are subject to many disturbances. Periodic check has therefore been implemented by testing the correctness of both the temperature compensation and the self-centering approaches through the sequence of operations reported in the flow diagram of Fig. 15. In case any of the two steps fail, it becomes possible to perform eventual interventions on the system (e.g. check of the screwing torques of mechanical parts) so to bring back performance at the desired levels.

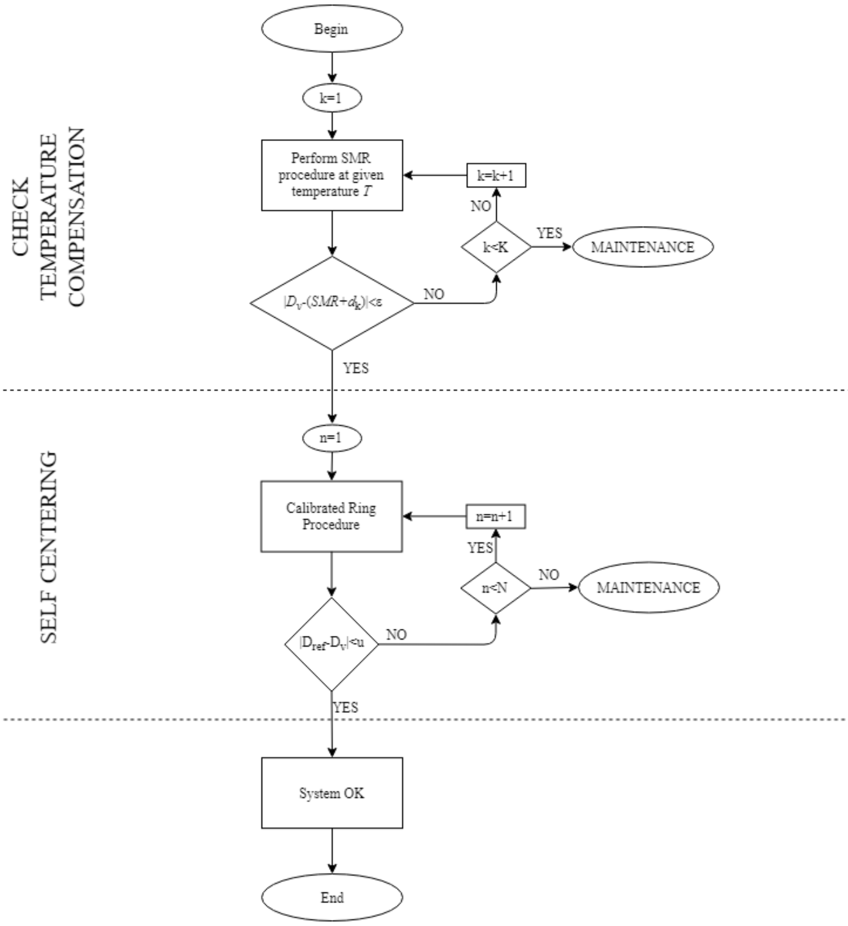


Figure 15 - QCS for measuring geometrical features of bores: Self-calibration check procedure

The Start of Measuring Range (SMR) value at a known temperature can be calculated by running a dedicated two-steps procedure (Fig. 15) in which the sensor-to-target distance (d_i) is evaluated on the opposite sides of a target of known thickness (b) after moving the target by a known displacement value (A) (e.g. by exploiting micrometric stages). A reference gauge block (thickness accurate up to micrometric values) can be exploited for the purpose. The SMR can then be extracted using Eq. (5)

$$SMR = \frac{A-b-d_1-d_2}{2} \quad . \quad (5)$$

The SMR value thus obtained is used to test the validity of the temperature compensation procedure. If data extracted by the distance-temperature fitting (D_v) differs from the absolute value obtained as the summation of the SMR and the distance value provided by the sensor at k^{th} step by more than a fixed threshold ε, the procedure has to be repeated until a maximum iteration number is reached. If the latter condition takes place, a maintenance operation is performed.

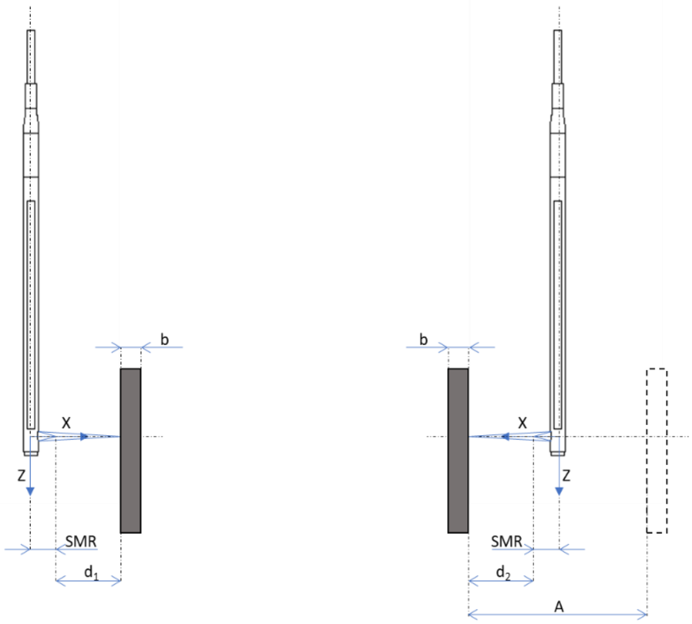


Figure 16 - QCS for measuring geometrical features of bores: SMR evaluation procedure: (i) sensor-to-target distance measured on the first side of the reference target of known thickness (left); (ii) target moved by a known displacement value (A) and sensor-to-target distance measured on the opposite side of the target (right) with respect to (i)

In case the temperature compensation procedure succeeds, the efficacy of the self-centering approach is checked. To do so, a calibrated reference ring (micrometric accuracy) has to be used. The known radius value of the calibrated ring is compared to the radius estimated through the confocal sensor. If these two radii differ more than the target uncertainty, the self-centering procedure has to be repeated. This process iterates until either the former condition is verified or a maximum number of iteration (*N*) is reached. If the self-centering verification process stops because the maximum number of iterations is reached, a maintenance operation has to be performed, otherwise the whole system is intended to be verified up to the desired uncertainty.

3.4 Results

This section reports some preliminary results related to the QCS for assessing the geometrical features of ZANNINI sleeves. It should be clarified, however, that a final evaluation of the effective uncertainty associated to the QCS will be performed only during the in-line installation and testing of the test station. Indeed, it was not possible to reproduce in laboratory all the events (temperature changes, vibrations, etc.) that might influence the measurement during an in-line inspection. Anyway, results obtained so far demonstrate the need for the self-adaptive behaviors developed for this QCS.

All data reported hereafter will be presented as deviations with respect to nominal values. For confidentiality issues, these nominal values, referred to the sleeve shown in Figure 17 and previously obtained by a dedicated measurement campaign on a CMM (Coordinate Measuring Machine), cannot be reported in this document, given its public nature.

Figure 18 shows the effect of the centering operation on measured data. It is well evident that an initial deviation of approximately 0.1mm (Figure 18a) is exclusively due to an out of center position of the sensor with respect to the sleeve axis. During the centering operation, this deviation from the nominal value (Figure 18b) progressively decreases down to less than ± 10 μm.

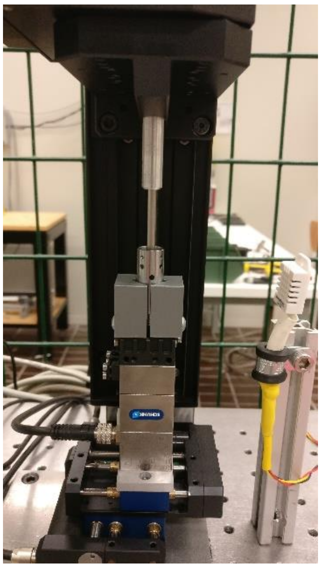


Figure 17 - QCS for measuring geometrical features of bores: example of a sleeve during an inspection

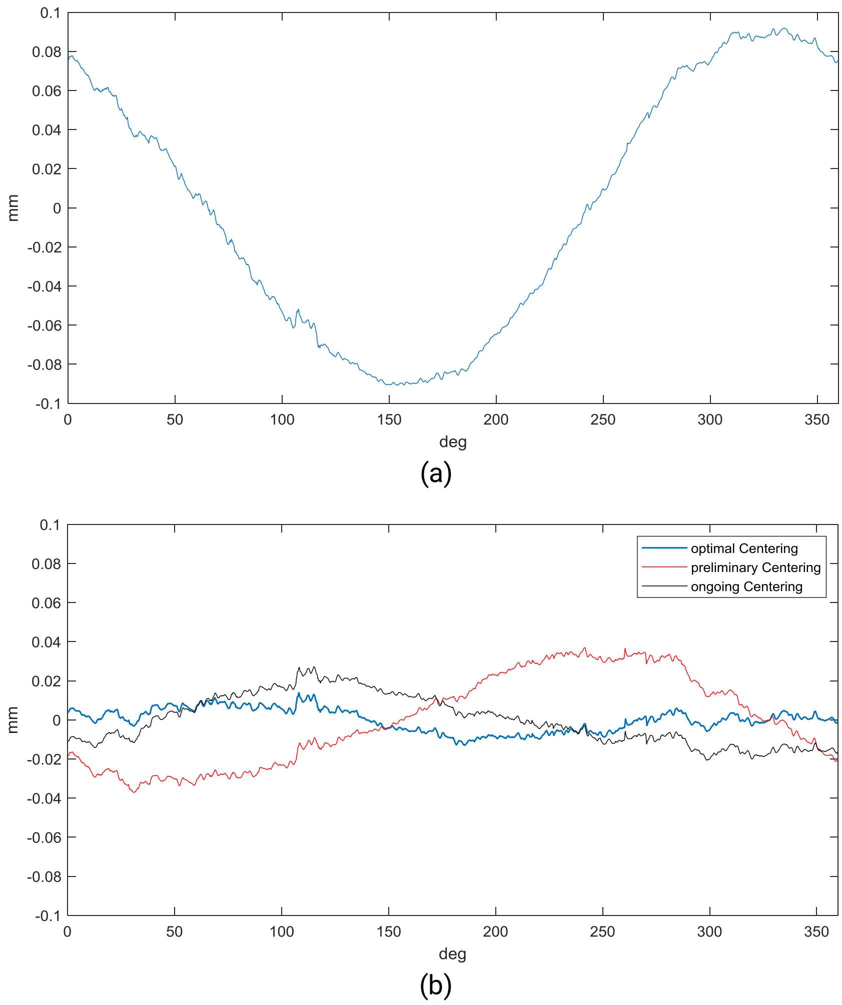


Figure 18 - QCS for measuring geometrical features of bores: effects of centring on measured data

Effects of temperature compensation on measured data are reported in Figure 19. Here, temperature offsets data (blue curve), is creating false deviations from nominal values. On the contrary, once temperature is compensated by exploiting the procedure described in Section 3.2.2 (black curve), deviations are highly limited and residuals refer to deviation with respect to circular shape.

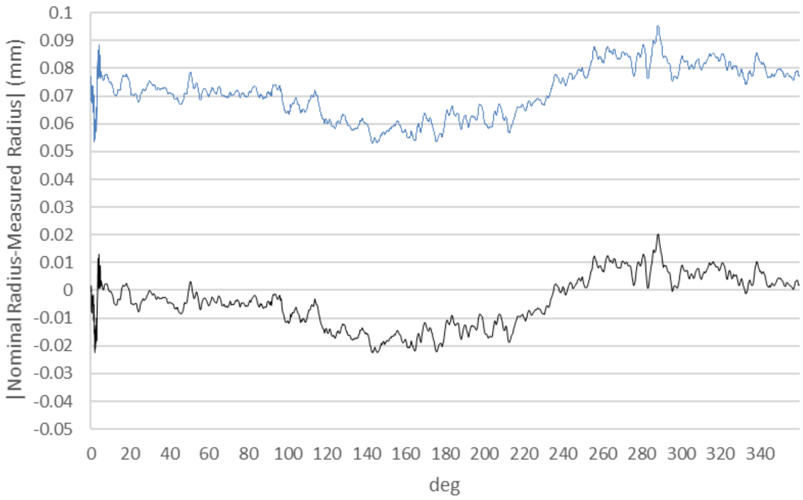


Figure 19- QCS for measuring geometrical features of bores: effects of temperature compensation on measured data – not compensated data (blue curve) vs compensated data (black curve)

The average diameter value on the section scanned differs 0.001mm with respect to the one measured with a CMM. with a standard deviation of 0.009mm. The standard deviation was evaluated assuming data acquired over a whole rotation as constituting the statistical population. This value is compatible with the nominal expected diameter of the reference sample at that section height, thus proving that the QCS, by exploiting its smart capabilities, i.e. self-centering and temperature self-compensation, is able to provide highly accurate dimensional data.

4 Quality Control System for detecting Burrs (ZANNINI)

The QCS for detecting burrs targeted to the ZANNINI use case aims at substituting visual inspection performed by operators. However, as detailed in D3.1 [1], the idea underlying the system is to somehow reproduce, in an automated way, the operations that an operator would do in checking a part, i.e. rotating it and observing the circular shape of each hole since the whole part is inspected under backlighting; backlit illumination is generated by a light stick inserted into the cylindrical part. The QCS does not measure the geometry of eventual burrs it detects; therefore, it would not be, strictly speaking, correct to talk about uncertainty associated to the QCS. We should rather talk about confidence on the diagnostic output (burr detected or not). However, the two self-adaptive behaviours that have been developed do increase the accuracy of the system in detecting burrs and therefore they will be described in this document.

4.1 Measurement procedure

The measurement procedure of the system is reported in Figure 20. The QCS waits for an external trigger event (e.g. a software trigger given by the operator via the QCS Human Machine Interface – HMI – or a hardware trigger provided by a robot) defining the placement of the part on the system. Once this trigger has been received, the first QCS/RA data communication starts. The part is then closed by the gripping system and the internal illuminator inserted accordingly. The colour of the illuminator light is adjusted depending on environmental light and/or the part finishing. After this adjustment the part is brought to rotation and the measurement starts. If data are not consistent to predefined confidence level after one rotation (e.g. clockwise), rotation direction is inverted (e.g. counter clockwise) and inspection is performed again. Results of inspection are then transferred to the RA associated to the QCS.

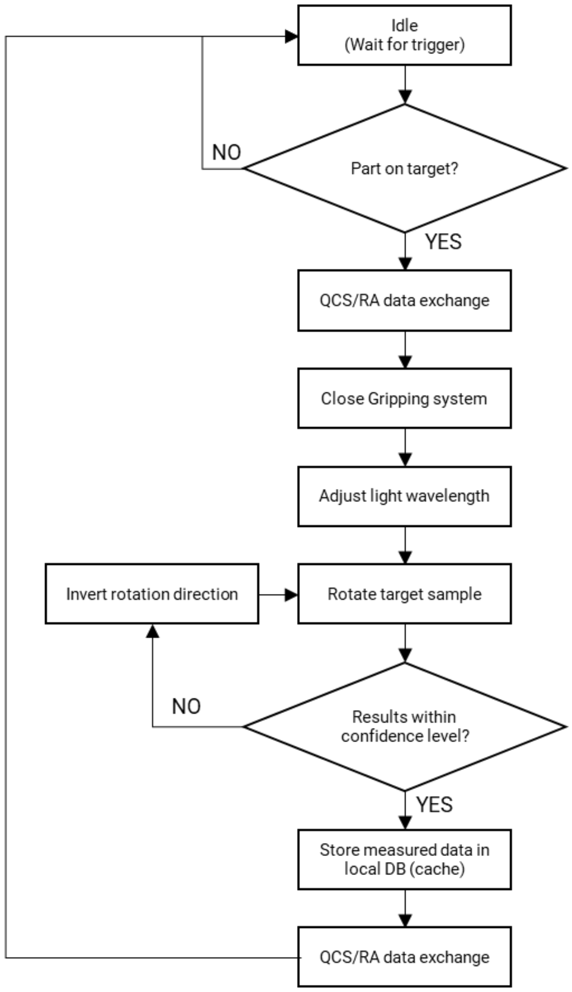


Figure 20- QCS for detecting Burrs: flow chart describing the measurement procedure

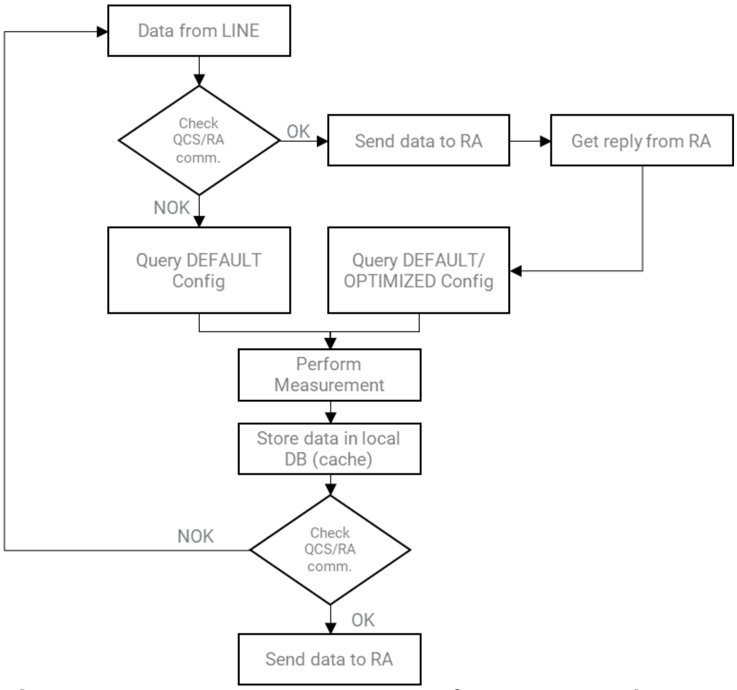


Figure 21 - QCS for detecting Burrs: QCS-RA interaction for optimizing the measurement procedure

The QCS/RA data exchange strategy is reported in Figure 21. The QCS performs a full inspection on the part and then tries to communicate to its RA the results of the test. If communication is down, the QCS is set again in an idle state (wait for an external trigger event) and send results of the previous inspections when QCS-RA communication is established again.

4.2 Self-adaptive behaviour to keep uncertainty under control

As discussed in the introductory part of Section 4, the QCSS for detecting burrs does not perform any quantitative measurement; however, it has been equipped with two self-behaviours targeted to ease the identification of burrs during the vision-based inspection, namely:

a) Capability to rotate the part;
b) Capability to change light colour of the internal illuminator.

Regarding the self-behaviour a), the need to rotate the sample during the inspection was understood by observing the operator movements during a visual inspection. Indeed, by changing the viewpoint of the system with respect to the part, inner (directing inwards the part - Figure 22a) and outer (directing outwards the part - Figure 22b) burrs can be detected more accurately. To mimic the operator and automate this process, the gripping system was customized with an external motor for enabling the rotation of the part once it is grasped between the fingers of the gripper (Figure 23). The motor enables both clockwise and counter-clockwise rotation directions. A change in the rotation direction is needed to increase the level of accuracy in the inspection. Indeed, when rotation changes, the way a burr is located with respect to the optical axis of the imaging system changes as well, therefore the probability to locate it increases as well. To further improve localization probability, three different Region of Interest (ROIs) are set on the image recorded by the camera (Figure 24). The top (red) and bottom (yellow) regions are functional to the identification of burrs lying on the inner surface of the sample in case the central ROI (green) does not provide results reliable enough. It is worth recalling that, in the central ROI, burrs are identified as deviations from a circular shape given by each hole, while for the top and bottom ROIs deviations are considered with respect to elliptic shapes.

(a) (b)

Figure 22- QCS for detecting Burrs: burrs pointing inwards (a) and outwards (b) the part

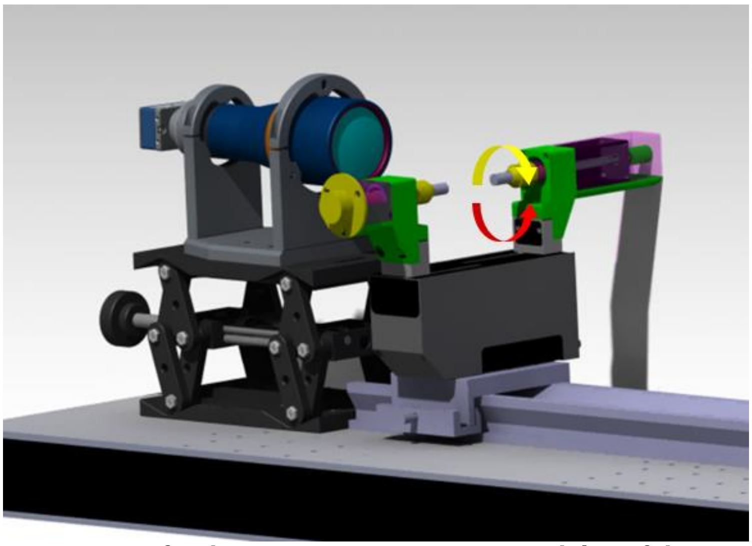


Figure 23 - QCS for detecting Burrs: rotation capability of the system

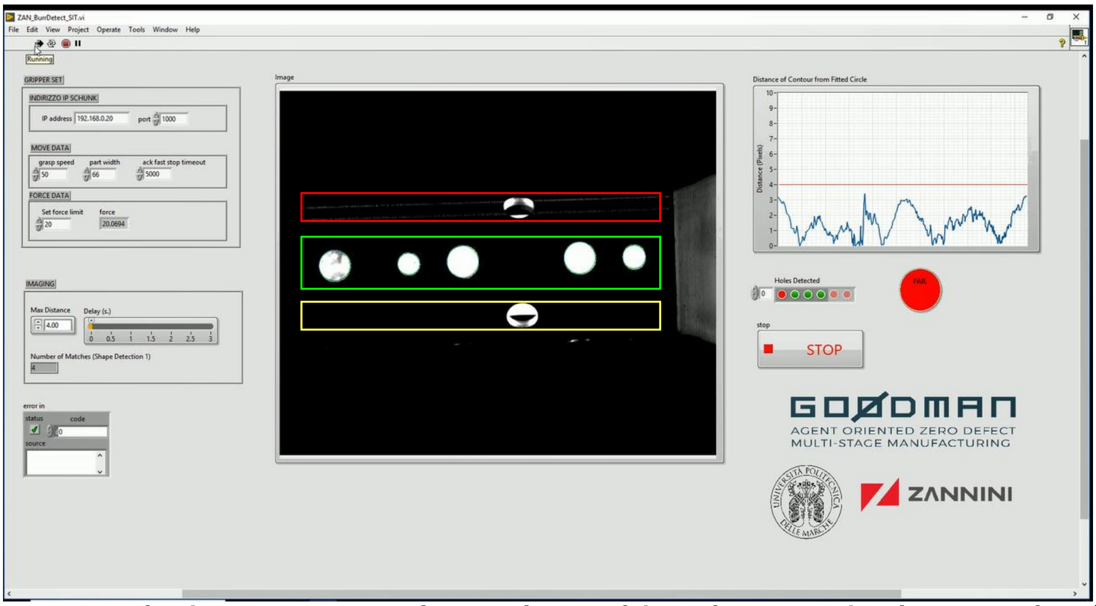
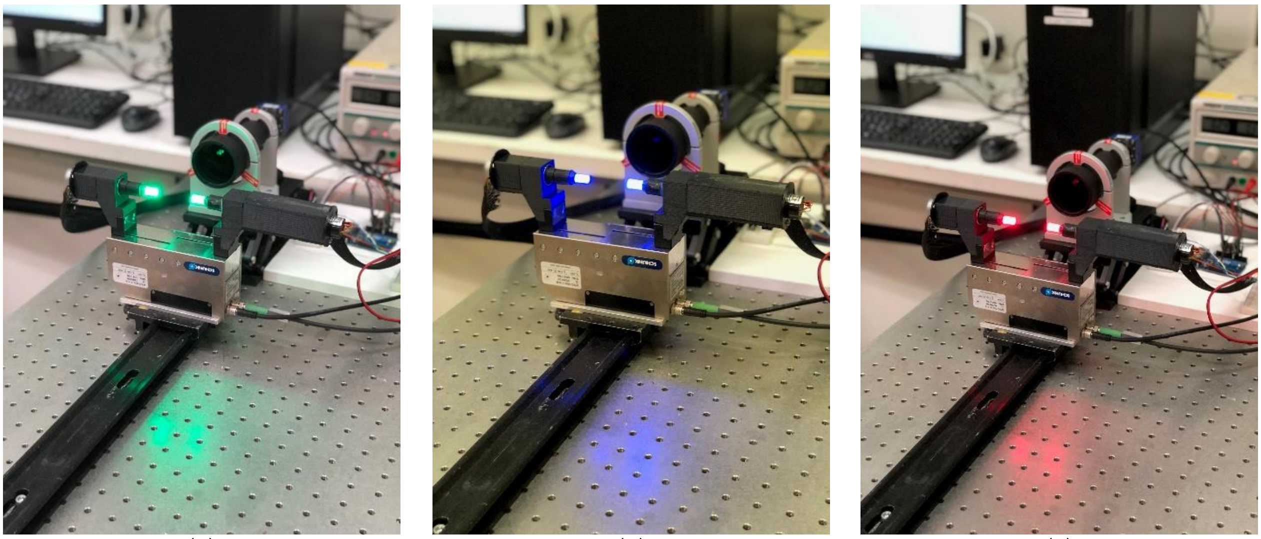


Figure 24 - QCS for detecting Burrs: preliminary layout of the software Graphical User Interface (GUI)

With respect the self-behaviour b), the internal illuminator is equipped with RGB+W leds that makes possible to change illuminator's light colour. This capability enables image optimization (contrast enhancement) with respect to environmental light and the optical characteristics of the part.

Figure 25 shows example of this behavior. The diffuse light stick illuminator is visible in the pictures; it allows illumination of the cylindrical part from the interior.



(a) (b) (c)

Figure 25 - QCS for detecting Burrs: change in illumination wavelenght to enhance image contrast

4.3 Self-diagnosis and Self-calibration strategies

Burrs recognition is based on a geometric pattern matching algorithm [4]. Indeed, this algorithm is exploited to highlight dissimilarity with respect to known geometric shapes (circles in the central ROI; ellipses in the top and bottom ROIs). With respect to standard pattern matching approaches, in which pixel intensity levels in the template image are used for matching on the final image, the algorithm exploits geometric information present in the template image as primary features (e.g. low-level features, like edges or curves, or higher-level features, such as the geometric shapes made by the curves in the image) for matching. Deviations from known geometric features are then compared to a threshold: if some data falls above the threshold, these data, very likely, correspond to burrs on the hole.

Being a system in which detection of burrs relies on a comparison with a threshold, it is important to periodically check/update this threshold. This can be done by using a reference part with burrs of known extensions in known locations. Once the reference part is mounted on the system, the capability of the QCS to correctly detect and locate the burrs can be checked. Since the part is a reference tool, it has to be worked to have a reference hole (e.g. smaller hole) easily detectable, from which the nominal location of holes with burrs can be recovered (Figure 26).

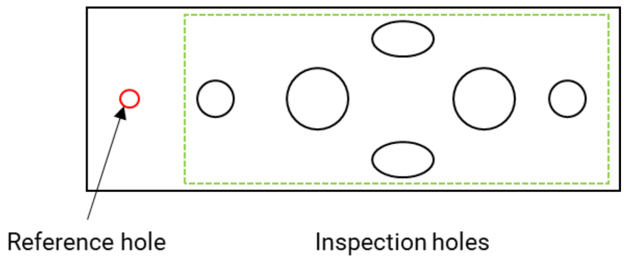
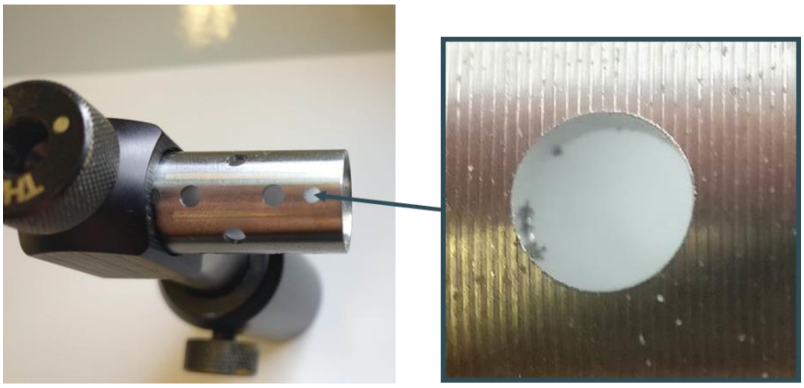


Figure 26 - QCS for detecting Burrs: reference part to check threshold values

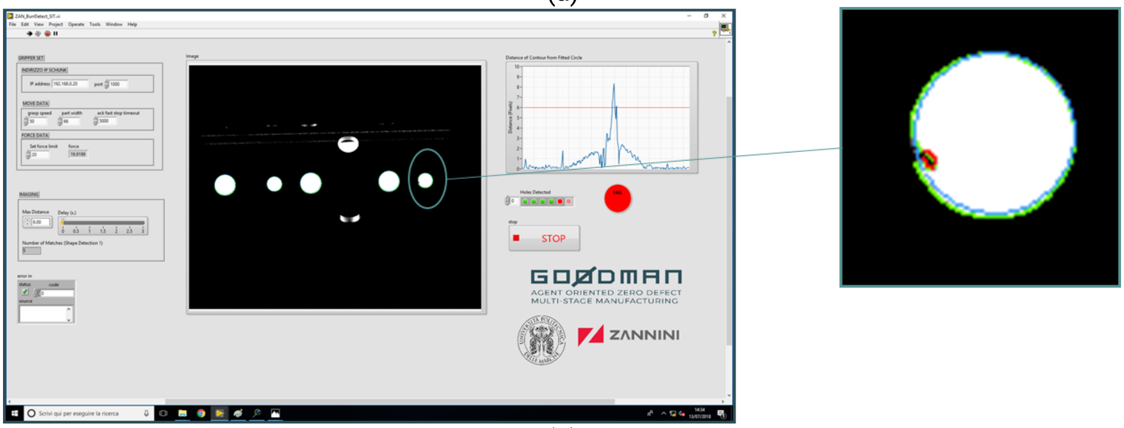
If the system, for instance, does not detect any burr then the threshold can be modified accordingly, i.e. by decreasing the threshold value. On the contrary, if too many burrs are located with respect to those effectively present, the threshold value should be increased. This operation can be performed in an automated way by a dedicated software procedure that cross-checks inspection results and nominal data.

4.4 Results

Figure 27 shows some results obtained on parts delivered by ZANNINI as damaged parts. The presence of burrs on the external hole (the one close to the edge with respect to the fixation system) is well evident (Figure 27a). From Figure 27b is clear that, once deviations from circular shape on the last hole fall above the pre-defined threshold, burrs are correctly identified.



(a)



(b)

Figure 27 - QCS for detecting Burrs: example results of an inspection

Since the population of damaged parts provided so far is small, it is expected that the threshold value already identified will be modified in the future. The first part of the measuring campaign during the integration phase in ZANNINI will be dedicated to the refinement of this threshold value.

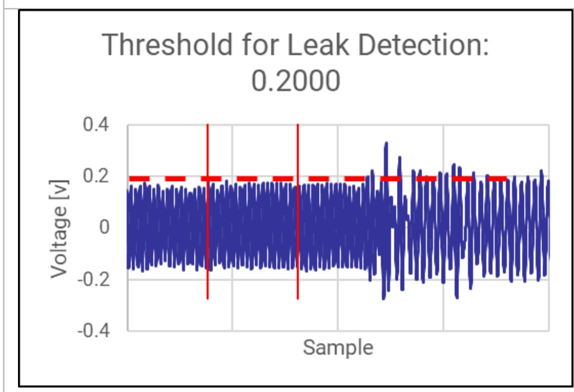
5 Quality control system for highlighting presence/location of leaks on oven front door-frame assembly (ELUX)

Leakage detection from door seals is a relevant problem for quality control of a variety of appliances which have a door. In the case of ovens, as it is brought to relevance from ELUX, leaks from the internal cavity consist in a localized air or steam flow exiting from the cavity, through the faulty seal, towards the external air. The flow rate can be very small and depends on the size of the defect on the seal. If the oven is operating, this flow has a temperature higher than the external ambient and is a flow exiting the cavity, due to the slight overpressure in ventilated ovens and to convective motion. If the oven is not operating, the leaking flow has the same temperature of the external environment and the direction of flow through the seal is not established; this flow could also be zero if no pressure difference between internal cavity and external environment exists.

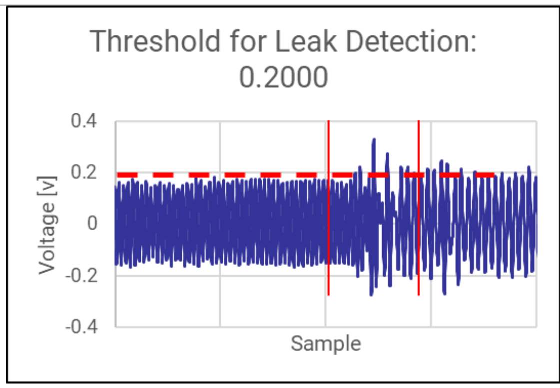
The QCS developed to detect presence of leaks is based on ultrasound (US) inspection. An US emitter (Figure 28) is placed inside the oven internal cavity and switched on. The front door is then closed. An US receiver probe is used to scan along the space between the hinged oven door and the case. Whenever a defect in the seal allows for a leak of gases then the external microphone detects the acoustic emission from the internal microphone which reaches the microphone through an aerial path. Therefore, when a leak exists, the US signal received by the scanning probe shows higher amplitude. By tracking the positions of the probe, the leak locations can be identified on the oven.

(a)

(b)



(c)



(d)

Figure 28 - QCS for highlighting presence of leaks: US probe emitter inside oven (a); US receiver scanning probe (b); US signal far from a leak (between the red cursors) (c); US signal

The main limitation of the proposed method is that the ultrasonic emitter inside the cavity cannot withstand the temperature of the cavity; therefore, the ultrasonic detection of the leaks can be applied only in cold conditions, i.e. after door assembly or at the final test station, before the oven is powered on.

5.1 Measurement procedure

The measurement procedure characterizing the QCS is described in Figure 29. As it can be seen, the "man-in-the-loop" nature of the inspection method is very well highlighted by the procedure. Indeed, the operator should perform a series of actions before and during the measurement. To prepare the test, he/she should place the US emitter inside the oven and close the door to avoid any possible further leaks from those eventually present between the front-door/frame assembly. Once the operator receives green light from the QCS, which has already exchanged data from the production line (e.g. model of the oven) with its associated RA, he/she starts scanning the oven over the front-door/seal/frame assembly. Feedback is continuous and provided both graphically and acoustically (tone whose level increases as a leak is approached). If a leak is detected the operator highlight its position on the GUI of the QCS. These operations repeat as long as the whole front-side of the oven is scanned. An overall report about the test is then provided by the QCS to the operator; significant data (test results) are then transferred to the RA. The operator can then remove the US emitter from the oven cavity.

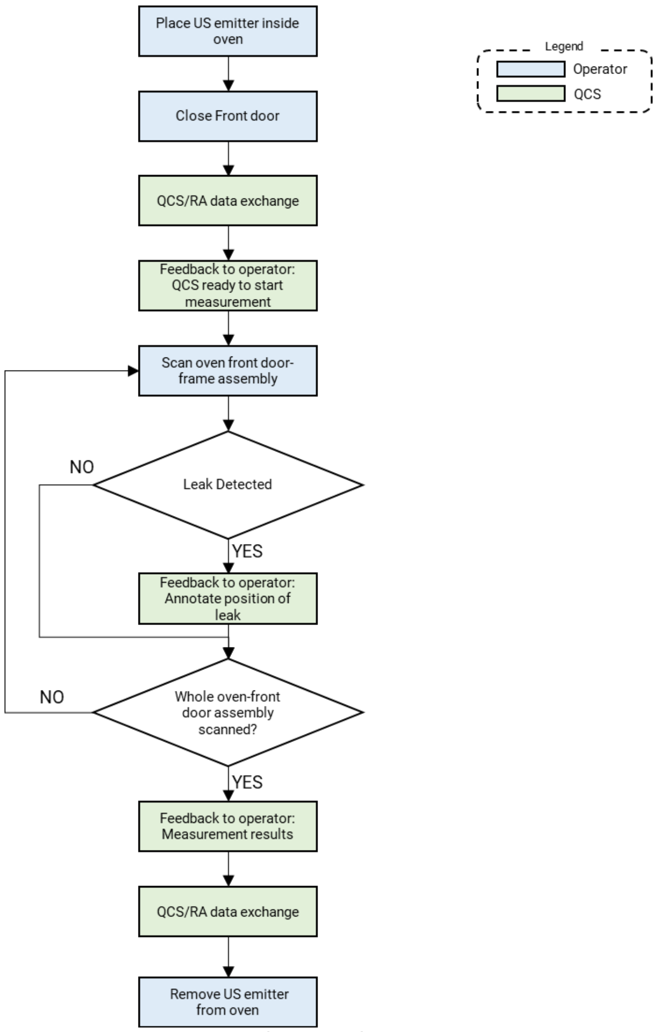


Figure 29 - QCS for highlighting presence of leaks: flow chart describing the measurement procedure

The QCS/RA communication strategy is sketched in Figure 30. As it happens for other QCSs, if a first communication check is positive, the QCS waits for the RA to send a configuration file containing test information, otherwise a default configuration file is loaded by the QCS. After measurement is performed, a preliminary storage on a local DB is performed by the QCS. Communication is then checked again. If this is still active, test data are sent to the RA, if communication is down, data related to the oven just inspected are sent to the RA after another oven is tested.

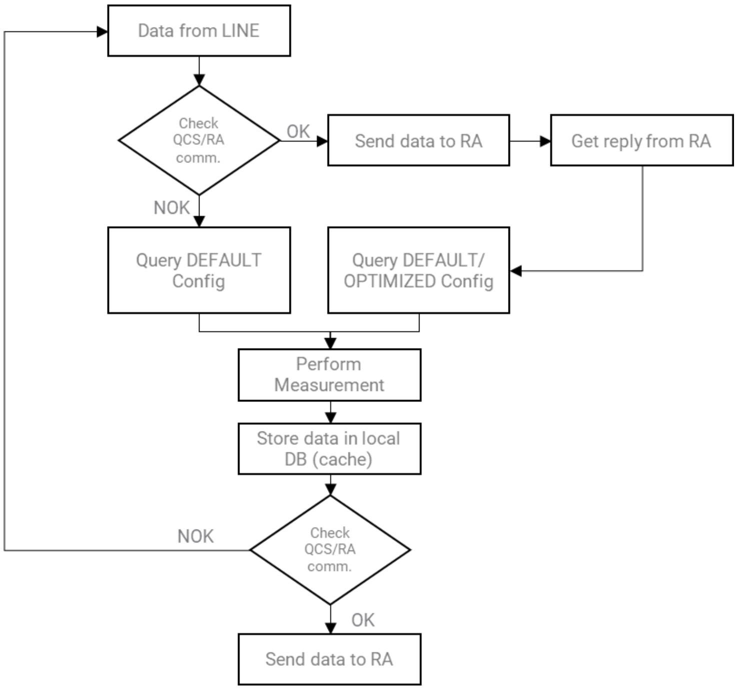


Figure 30 - QCS for highlighting presence of leaks: QCS-RA interaction for optimizing the measurement procedure

5.2 Self-adaptive behaviour to keep uncertainty under control

Leaks on the oven front-door/frame assembly can depend on a series of causes, among which a wrong assembly, a wrong placement of the seal on the oven frame, or even the use of damaged seals. This makes quantitative inspection highly difficult, especially if leaks are characterized by extremely low air flow rate. The QCS, consequently, does not perform any quantitative measurement, but detects anomalies with respect to a reference situation (e.g. no leaks). In this context, no self-adaptive behaviours to keep uncertainty under control have been developed for this system.

During the integration phase, as long as measurement data are collected, the strategy to detect presence of leaks will be updated accordingly. Indeed, being a measured based on a comparison with a reference threshold (US magnitude above threshold indicates presence of leak at a certain location), it will be necessary to refine the threshold value with respect to the one identified so far, which was obtained placing an insert of known diameter between the seal and the oven front-door.

5.3 Self-diagnosis and Self-calibration strategies

To ensure a correct detection of leaks it is fundamental that an US signal is correctly received by the QCS. Indeed, the hardware circuitry of the device downshifts the US signal to audible range (2-3 kHz). This operation has twofold benefits: an acquisition board with lower sample frequency can be exploited; the received signal can eventually be transformed in an audible tone as a feedback to the operator. The consistency of signal received has to be verified anyhow. Indeed, this can be performed by calculating the FFT (Fast Fourier Transform) of the signal recorded by the US receiver and checking whether the spectrum in the 2-3 kHz range (analysis range) has the highest magnitude with respect to the other ranges of the frequency spectrum. Indeed, it is expected that, if an US signal is correctly received by the QCS, the downshifting operation that moves the signal to the 2-3 kHz frequency range and the associated band-pass filtering (band-pass frequency range coinciding with the analysis range) that lowers to -20dB the magnitude outside the analysis range, result in a signal showing frequency component in the analysis range characterized by a Signal to Noise Ratio (SNR) of 20dB at least. If this is not the case, something is not working properly, and the QCS/US emitter need to be checked by the operator. This self-diagnosis capability is important to ensure that the threshold operation is performed on a signal that carries meaningful data.

Another aspect to be considered to ensure a proper working of the whole system is the definition of a periodic calibration strategy. An approach that can be exploited for this QCS relies on the use of a tool of known dimension that can be used to reproduce a leak. This can be, for instance, a needle of known dimensions that is placed between the seal and the front-door.

5.4 Results

Figure 31 shows an example of the testing procedure discussed in Section 5.1. Pictures refer to a measurement campaign performed at ELUX in M20. All components of the QCS are visible in the sequence: US emitter (Figure 31a), simulated leak (not used in a real inspection, but usable for a calibration phase - Figure 31b), portable tool (Figure 31c) and GUI (Figure 31d) on which the operator can annotate the positions of leaks detected. The procedure is fast, and leaks are well identified. A training phase during the integration in ELUX line will be required to optimize the threshold value needed to judge the eventual presence of leaks.

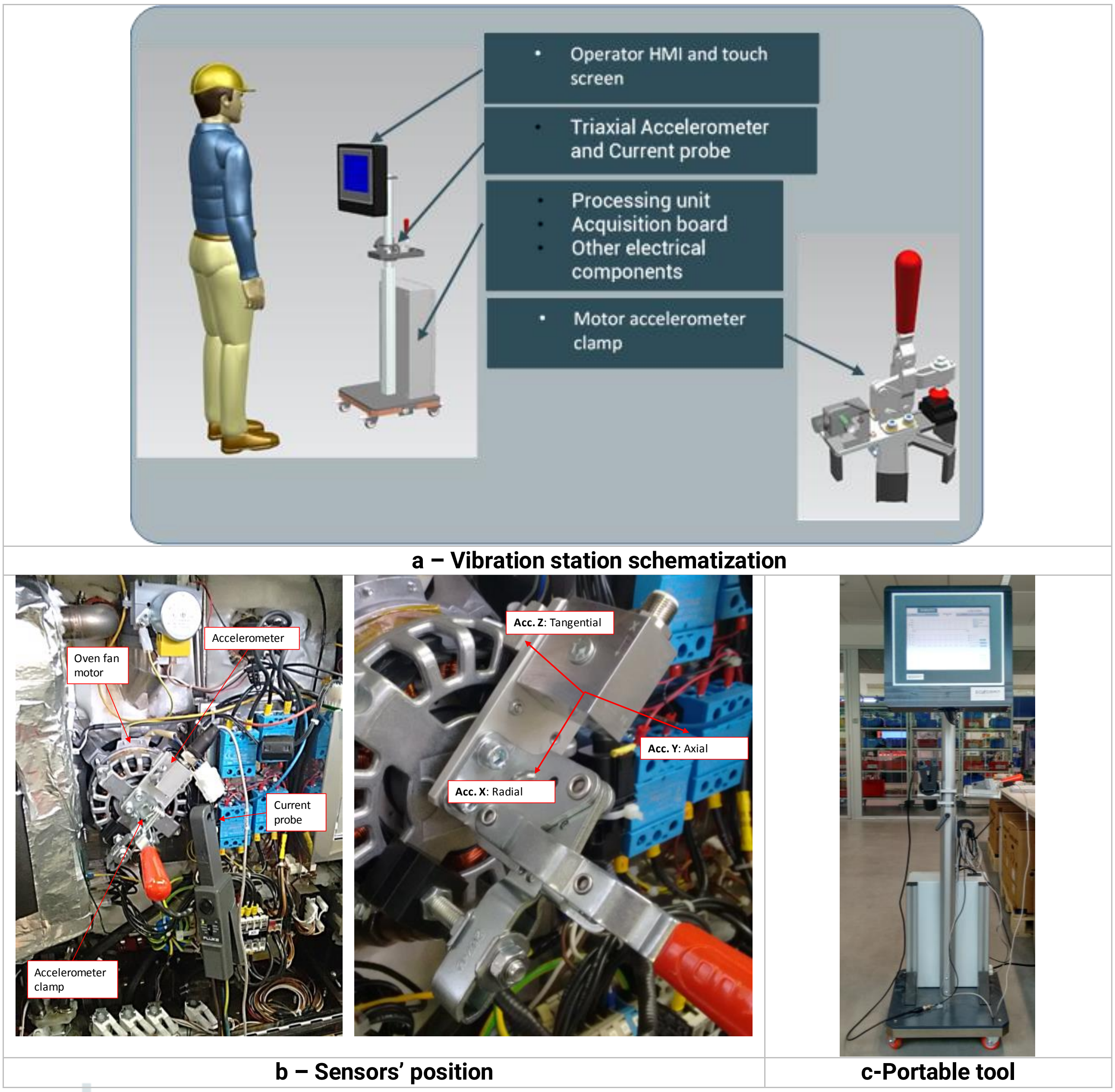
Figure 31 - QCS for highlighting presence of leaks: example of measurement procedure and detection of leaks

6 Quality control system for motor-fan assembly vibration analysis (ELUX)

As detailed in D3.1, in order to check the correct assembly of one of the critical sub-group of the oven, i.e. the motor and the fan, a quality control based on vibration analysis is necessary. This check should be done as soon as the assembly of the motor and the fan is completed, in order to detect immediately any possible malfunctioning due to incorrect assembly of the components or even if the components are not working properly.

6.1 Measurement procedure

In this paragraph, the measurement procedure is depicted, starting from the description of the QCS developed (Figure 32) and the methodology to follow in order to classify the motor-fan subgroup under tes.



a – Vibration station schematization

b – Sensors' position **c-Portable tool**

Figure 32 – QCS for motor-fan assembly vibration analysis: Measurement set-up

The QCS consists of:

- A mobile base on 4 adjustable wheels, in order to have a system easily transportable inside the plant and to ensure the stability of the HMI touch screen
- An industrial touch screen for operator who can decide if the test should be repeated or the result achieved by the SIT can be accepted;
- An industrial triaxial accelerometer with an armored cable, mounted on a fixture designed to be handled by the operator with only one hand and able to clamp the bottom of the motor case in a repeatable way;
- A current probe, to hook one of the motor power supply phases and have a reference of motor dynamic current absorption (and consequently of RPM).

As depicted in Figure 32b, the sensors are positioned on the back of the motor (Left); in particular the triaxial accelerometer is mounted through a clamping system (Right), where “x” axis detects the vibration of the motor along its radial direction, “y” is on its axial direction and “z” on its tangential direction.

Once the oven arrives in the testing area, the vibration station is ready to be used to perform the vibration quality inspection, following the steps illustrated in Figure 33. Also in this case, the “man-in-the-loop” nature of the inspection method is very well highlighted by the procedure. After the operator places the accelerometer and the current probe on the oven, he/she receives green light from the QCS, which has already exchanged data from the production line (e.g. model of the oven) with its associated RA. The motor is activated and the procedure automatically checks if it reaches the speed of 1000 rpm. The complete test lasts around 12 seconds to cover 8 seconds in steady state and 4 seconds for initial and final ramps. The acceleration signals are acquired at 50 kHz and then are analyzed. When the test finishes, an automatic system based on Neural Network is taking the decision on the quality of the motor-fan sub-group analyzed and an overall report about the test is then provided by the QCS to the operator. Significant data (test results) are then transferred to the RA. The operator can then remove the accelerometer and the current probe from the oven and based on the results of the vibration analysis moves the oven to the assembly line or to the repair station.

The QCS/RA communication strategy is the same as described for the other QCS. As it happens for other QCSs, if a first communication check is positive, the QCS waits for the RA to send a configuration file containing test information, otherwise a default configuration file is loaded by the QCS. After measurement is performed, a preliminary storage on a local DB is performed by the QCS. Communication is then checked again. If this is still active, test data are sent to the RA, if communication is down, data related to the oven just inspected are sent to the RA after another oven is tested.

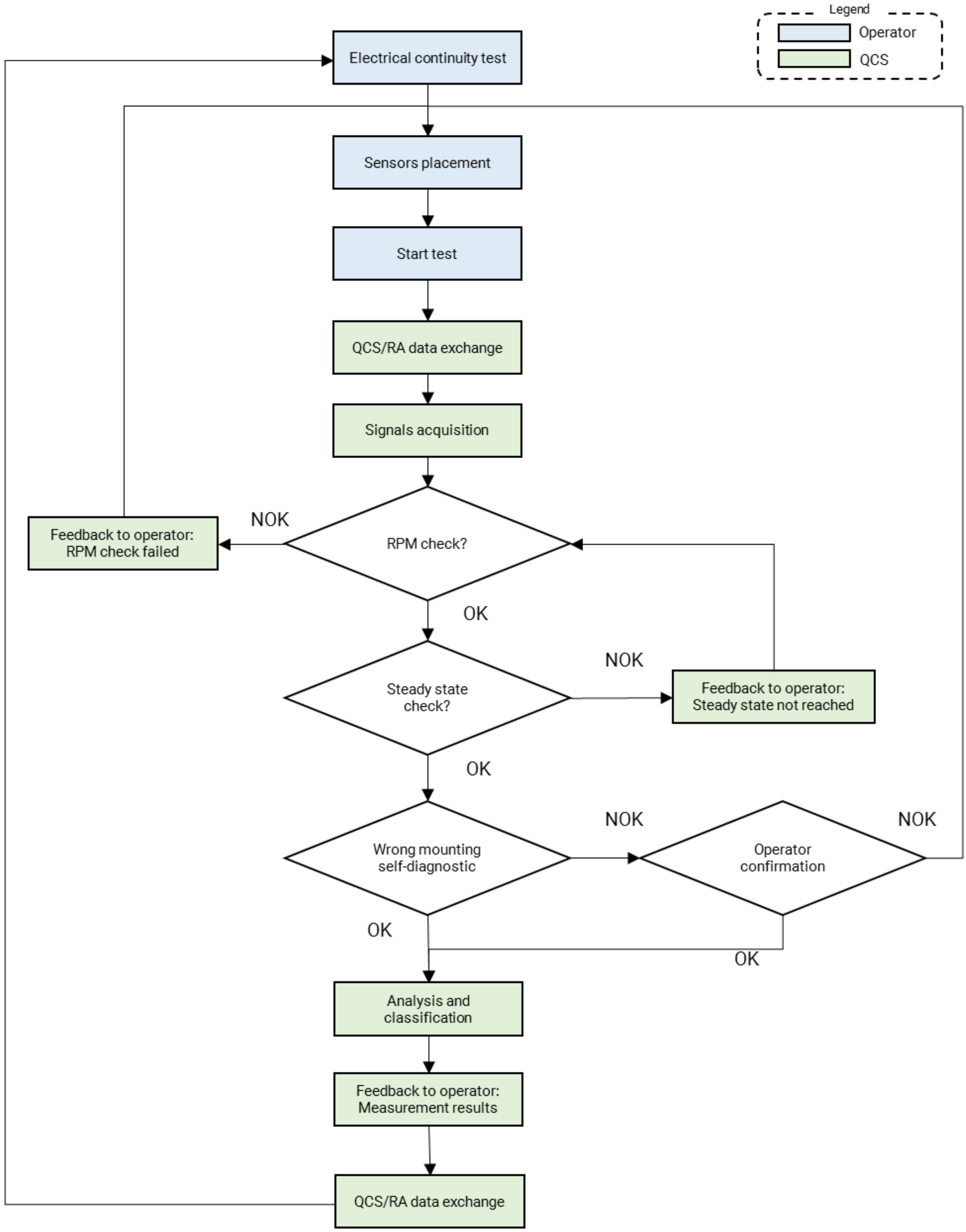
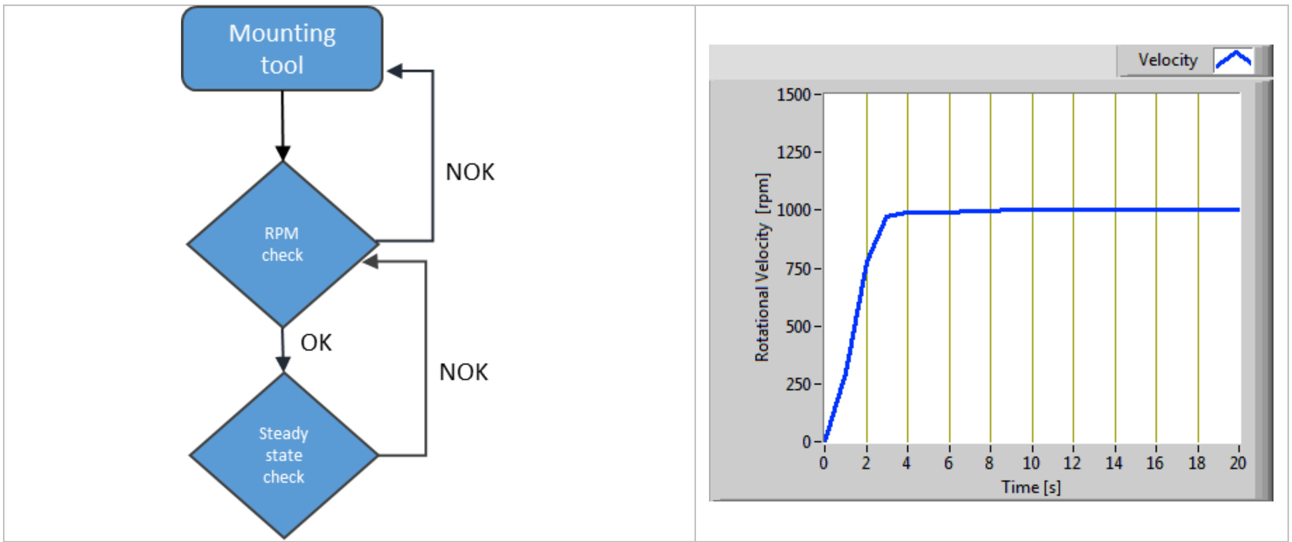


Figure 33 - QCS for motor-fan assembly vibration analysis: flow chart describing the measurement procedure

6.2 Self-adaptive behaviour to keep uncertainty under control

In order to keep uncertainty under control, before starting the test, it is important to understand if the measurement conditions are suitable to guarantee stability and repeatability.

The QCS has to perform the control of the rpm value because for the vibration analysis, it is important to guarantee that the conditions of the motor under test are the same, i.e. the QCS has to check if the steady state is reached and the rpm values are stable. Once the tool is mounted, as the motor is powered on, the QCS automatically reads the rpm value and gives a feedback to the operator if the acquisition started or not. After this first check, the QCS continues to check the rpm and only when the pre-fixed value has been reached (i.e. 1000 rpm) and it is stable, it starts the acquisition. In Figure 34, this procedure is described.



a – Self-adaptation loop | **b – Starting speed ramp**

Figure 34 - QCS for motor-fan assembly vibration analysis: Self-adaptation flow chart

6.3 Self-diagnosis and Self-calibration strategies

The vibration analysis QCS is able to perform self-diagnosis and self-calibration procedures.

The self-diagnosis procedure is performed in order to provide to the operator a feedback on the correct mounting of the accelerometer on the motor and it is based on the signals acquired from the accelerometer as soon as the steady state has been reached. The self-diagnosis procedure is based on a Neural Network that, after the signals are acquired, decided if the accelerometer is properly mounted. In order to work in automatic, the neural Network has to be trained and an off-line study has been carried out. This preliminary study has the following objectives:

- to select among all the features extracted the most efficient features for the classification of the correct/uncorrect mounting;

- to train the Radial Basis Function Neural Network (RBF NN) with the previously selected subset of features and to create the respective knowledge.

For the study, a data set of 120 signals acquired both with correct and uncorrect mounted accelerometer (80 correct and 40 uncorrect) have been used for the features selection and the training phase.

The signals acquired from the three axes of the accelerometer are processed by extracting a set of features (15 features for each axis).

In particular, going deeply in details of the analysis, the features extracted from the dataset used for the mounting diagnosis classification are the following:

- 75^{th} percentile
- Crest factor
- Crosscorrelation
- Logarithm entropy
- Shannon entropy
- Filtered Crosscorrelation
- Spectrum amplitude arithmetical average
- Spectrum amplitude geometrical average
- First harmonic amplitude peak
- Amplitude peaks' sum between 1480 and 1830 Hz
- Kurtosis
- Peak to peak value
- Maximum Peak (absolute value)
- RMS on the whole signal
- Skewness

Among these features, the most relevant have been selected using Bhattacharyya distance method, as reported in Figure 35.

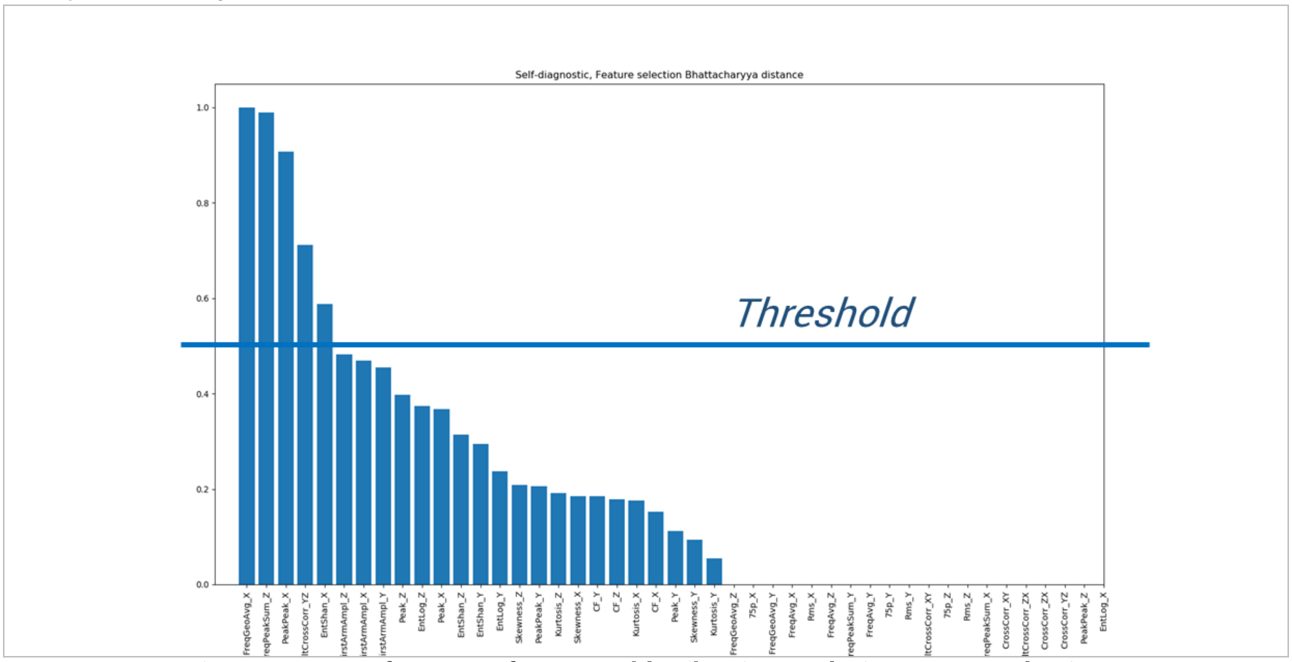


Figure 35 - QCS for motor-fan assembly vibration analysis: Feature selection

The best selected feature (Spectrum amplitude geometrical average) separates the decisional space in a very precise way, as illustrated in Figure 36.

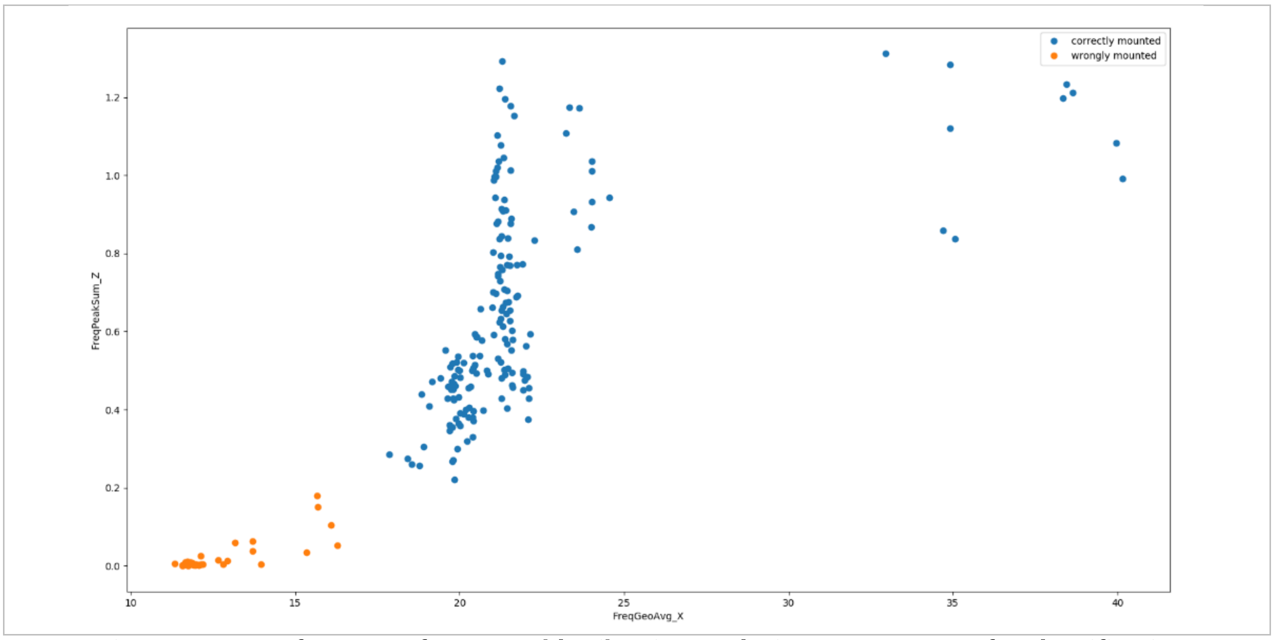


Figure 36 - QCS for motor-fan assembly vibration analysis: Feature space for classification.

During the automatic measurement procedure, the Radial Basis Function Neural Network receives as input the subset of the selected features and, based on the knowledge created during the training phase for the specific model of the oven under test, gives a feedback on the correct/uncorrect tool mounting.

Every time a new model of oven is tested the aforementioned procedure has to be repeated and the respective knowledge has to be generated.

A calibration procedure for the vibration analysis QCS has been defined. A standard accelerometer calibrator can be used to calibrate the sensor through a software wizard procedure.

For this procedure, the accelerometer has to be removed from the motor clamp and fastened on the calibrator head with wax or using a magnet. As the industrial accelerometer chosen for this project MTN /1330 has a nominal weight of 100g, the most common B&K 4294 accelerometer calibrator, with a 0-79g load range, cannot be used. It is suggested to use a portable PCB handheld shaker model 394C06, as it accepts sensors weighing up to 210 grams. The calibrator delivers a controlled 1g (9.81m/s^2) RMS mechanical excitation, at 159.2 Hz (1000 rad/s).

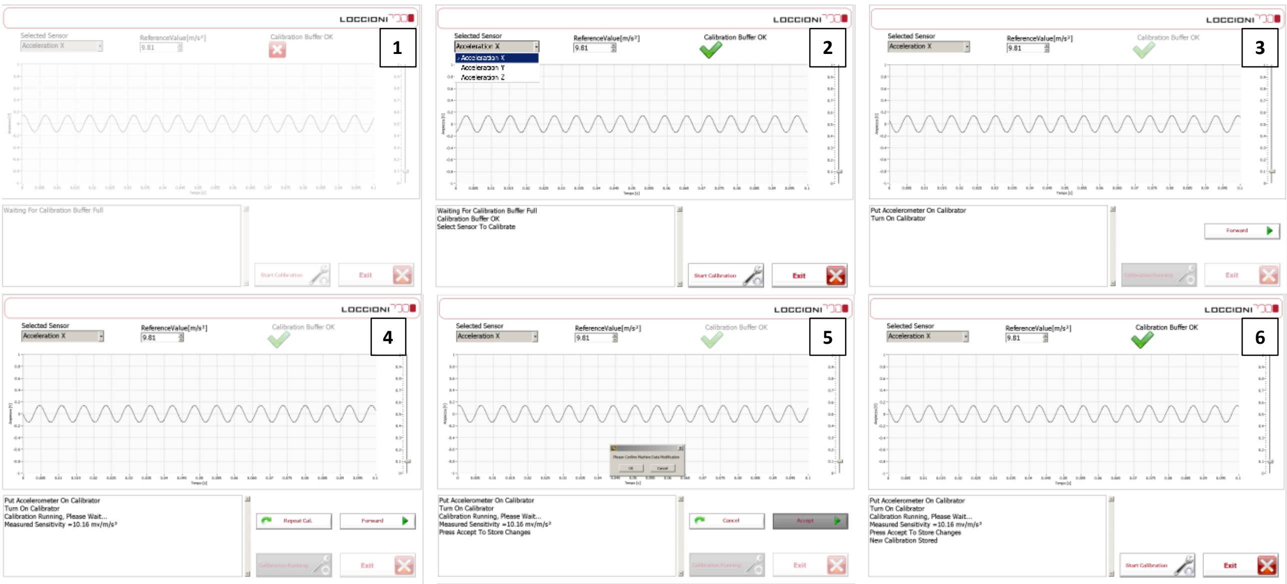


Figure 37 - QCS for motor-fan assembly vibration analysis: Calibration wizard screenshots

Figure 37 shows screenshots of the wizard software that lead the user through a series of well-defined steps for accelerometer calibration:

1. The calibration wizard is started from the software main page clicking on the “Calibrations” button, the operator is asked to wait for the buffer filling, that requires at least 2 seconds

2. After the “Calibration Buffer OK”, the operator can choose the accelerometer direction to calibrate
3. The user is asked to put the acceleration “Reference Value” (9.81m/s^2 for PCB 394C06 calibrator) and to start the calibrator
4. After few seconds of acquisition, the actual sensor sensitivity is calculated knowing reference value provided by the calibrator and actual raw voltage signal recorded
5. The operator is asked to accept calibration and to confirm the “Machine Data” modification
6. The new accelerometer sensitivity is finally stored in QCS configuration file and possibly sent to the RA.

The procedure has to be repeated for all the accelerometer directions X, Y and Z.

After calibration, the accelerometer has to be put again on the motor clamp. A torque wrench could be useful to fix the accelerometer on the probe in a repeatable way (Figure 38). According to accelerometer specifications, a fastening torque of 8-10 Nm is recommended.

Figure 38 - QCS for motor-fan assembly vibration analysis: Calibration procedure

6.4 Results

Thanks to the self-diagnosis procedure, the operator can be informed very quickly if the accelerometer is wrongly placed on the motor, in order to adjust the tool at the beginning of the test and to avoid erroneous measurements. In Figure 39, example of signals acquired from an accelerometer properly mounted on the motor-fan sub-groups and from an accelerometer not properly mounted, is reported. As it is possible to notice, there is a clear difference in the signals on all the directions. As well, the classification results are worse as reported in Figure 40, due to the fact that the Neural Network wrongly classifies good motor as unknown or faulty.

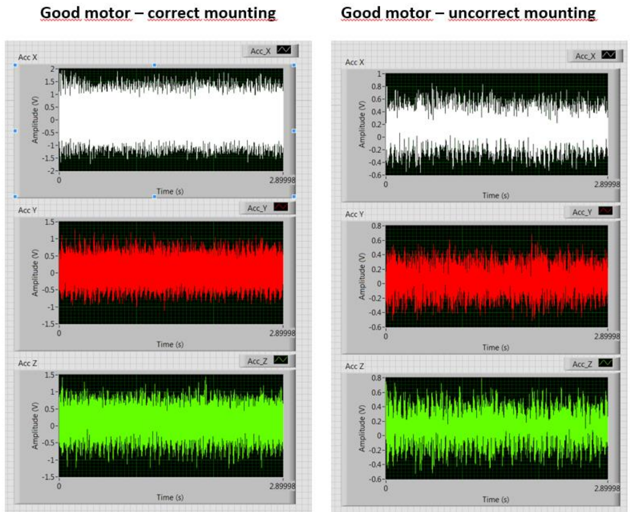


Figure 39 - QCS for motor-fan assembly vibration analysis: Acquired signals with and without the accelerometer properly mounted.

	True	Without self-diagnostic
Good	40	18
Defect 1	0	0
Defect 2	0	0
Defect 3	0	1
Unknown	0	21

Figure 40 - QCS for motor-fan assembly vibration analysis: Self-diagnosis classification results

7 Quality control system for visual inspection of components (ELUX)

When the bottom of the oven is assembled, a smart camera automated inspection is used to check if all the necessary components are present and if they are in the right position in order to allow early fault detection in the production line.

In this section, since the sensor used is a commercial solution, proprietor features to allow the self-adaptation and the self-diagnosis are presented. These features are implemented on the smart camera.

7.1 Measurement procedure

For the QCS of the visual inspection, a very easy testing procedure has to be followed, as reported in Figure 41. When the bottom of the oven is properly placed and ready to be tested, the oven model information is provided. The model of the oven is a necessary information because depending on it, the appropriate inspection must be selected. Once the image is taken, the QCS can classify the device under test.

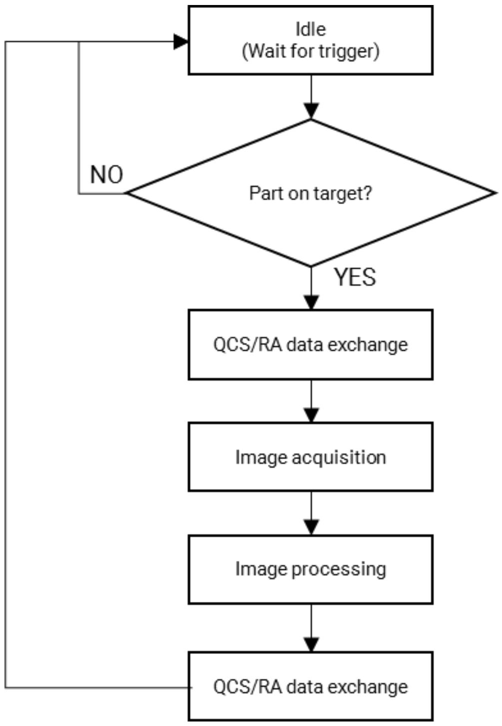


Figure 41 – QCS for visual inspection on components: flow chart describing the measurement procedure

7.2 Self-adaptive behaviour to keep uncertainty under control

In order to guarantee a self-adaptive behaviour, smart camera properties can be exploited. In particular, the exposure time can be set, as specified by Insight 5.4.0 software used to program the camera (Insight 5.4.0 Help)

Exposure

Specifies the exposure time (in milliseconds). When the sensor receives a trigger signal, light is integrated in the image sensor (CCD or CMOS) array for the specified duration. Shorter durations are better for stopping motion but may require larger lens apertures or higher amplifier gain to achieve sufficient image intensity.

Notes:

- Exposure is disabled if Automatic Exposure is enabled.
- The exposure time is rounded down to the next valid increment for the specified sensor.
- While this parameter may technically be set to 0, the Exposure time is In-Sight vision system dependent, and an Exposure value of 0 will default to the minimum exposure time (in milliseconds or microseconds) for the selected vision system.
- When calculating the exposure time, depending on the image acquisition frame rate and other job execution variables, it may be necessary to add a small amount of time to the Exposure value, to account for the warm-up time of the lights.

Automatic Exposure

Specifies whether the exposure time is automatically determined or not. When enabled, the exposure is automatically adjusted to compensate for different lighting conditions.

Mode

Specifies how the automatic exposure is determined, when enabled.

0 = Disabled

Disables the Automatic Exposure option.

1 = Continuous

Exposure time is automatically adjusted after every acquisition to compensate for different lighting conditions.

2 = Single-shot

First Acquisition: If the sensor is Offline, the first acquisition is used to determine exposure and that exposure value is stored until Single-shot is disabled. If no acquisition has occurred while the sensor is Offline, when it is put Online, the first acquisition is used to determine exposure.

Subsequent Acquisitions: The sensor will acquire the image using the exposure value that calculated at the first acquisition.

Note: Toggling the Single-shot checkbox, or selecting a different Auto Exposure Mode, will reset the exposure value. The first acquisition, after the exposure value has been reset, will be used to determine a new exposure value.

Max Exposure

Specifies the maximum exposure time used when determining the proper exposure.

Target Brightness

Specifies the desired brightness level (0 to 100; default = 10). The Target Brightness parameter governs the allowed percentage of saturated pixels (255). When Automatic Exposure is enabled, the Target Brightness setting adjusts the exposure value to return an image which has a "target brightness" of “x%” saturated pixels.

Auto Expose Region

Specifies the region to use when automatically calculating the exposure time.

X: The x-offset of the origin, in fixture coordinates.

Y: The y-offset of the origin, in fixture coordinates.

High: The dimension along the region's x-axis.

Wide: The dimension along the region's y-axis.

7.3 Self-diagnosis and Self-calibration strategies

For this particular Smart Inspection tool, self-diagnosis and self-calibration strategies are related to Insight 2000 Cognex capabilities and technical features. For example, the self-calibration can be performed exploiting “WhiteBalance” function available in the commercial solution. (Insight 5.4.0 Help)

WhiteBalance function removes color casts in a color image by calculating the image's red, green and blue (RGB) values and correcting them according to color tables stored in the In-Sight job. As a result, items that are white in the real world, for example, will appear white in the image.

The user must create the color tables by acquiring an image of a "neutral" reference (that is, one that has equal RGB values; for example, 18-18-18), while ensuring that the image does not approach saturation (255-255-255). The recommended method is to acquire an image of a blank sheet of paper.

WhiteBalance generates a histogram of each color channel (red, green and blue) and "equalizes" the color values by considering the highest value as the baseline and dividing it by each color value to produce scale factors, which are then used to create the color tables (for example, an RGB of 200-100-50 will yield scale factors of 1-2-4).

In order to achieve white balancing, the user has to remove the object from the field of view (FOV) and replace it with a blank sheet of paper. Next, simply inserting WhiteBalance function into the spreadsheet, the user has to click OK in the property sheet to confirm adding this function to the job. To create the color tables that are stored in the job file, the user acquires an image of the paper. When the object is returned to the FOV and viewed onscreen, colors are completely regulated.

7.4 Results

The right exposure time and the proper white balance are fundamental to acquire images that can be effectively analysed by machine vision algorithms: pattern matching, colour matching, edge detection, etc. ...

From the following images it is easy to understand the effect of the exposure time on the quality of the images: if the exposure time is not properly set according to the existing light conditions (Figure 42 left), the acquired image appears dark in some areas and saturated in others; the proper exposure time permits to see better all the elements of the scene enhancing the brightness and the contrast of the image (Figure 42 right).

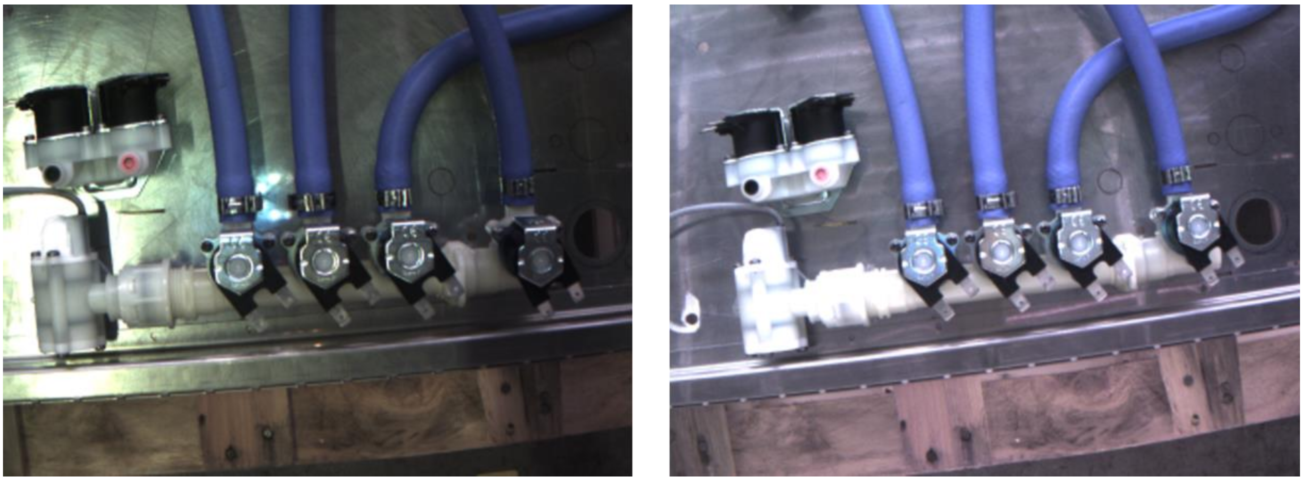


Figure 42 – Exposure Time effects: wrong setting (left), right setting (right)

Also, the white balance contributes to the quality of the acquired image and in particular to the color recognition. Figure 43 shows the effects of the white balance; if it is not properly set, the quality of the image is not good and the analysis can provide wrong results.

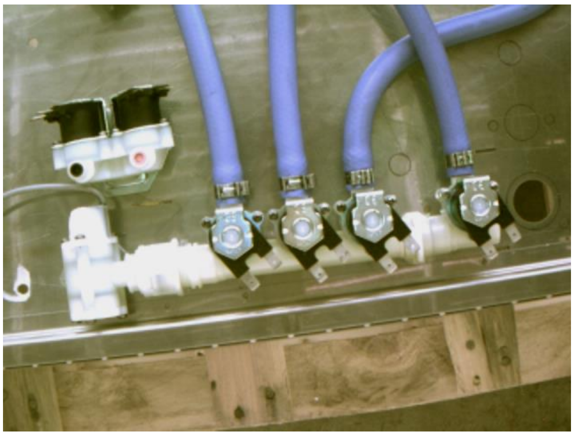


Figure 43 – White Balance effects: not correct image

8 Concluding remarks

This D3.2 complements the content of D3.1; the two deliverables, altogether provide a comprehensive description of the 7 prototypes of smart quality control systems developed in WP3. While D3.1 has presented the hardware of those systems, D3.2 puts in light the smart features and how they have been implemented for each case.

The resulting smart quality control systems exhibit self-adaptivity, self-diagnosis and self-calibration, realized through specific hardware and software which allow to implement smart strategies, all aimed to improve system performance, taking into consideration the harshness and complexity of a multi-stage manufacturing system. In three specific cases, also the presence of human operators has been considered, by realizing smart inspection tools compliant to the man-in-the-loop.

Based on the achievements of WP3, now the GO0DMAN project progresses towards the integration of those systems in a real production environment and to the following validation in-line. The smart inspection tools developed are 7, significantly more than the contractual requirement of 1 for each of the 3 use cases. In-line validation is a challenging step for a research project; however, chances of success have been maximized also by increasing the number of prototypes developed, so to be able to satisfy the contractual requirement of successfully testing at least one smart quality control system for each use case even in case of some unpredicted failure.

9 References

[1] GO0D MAN D3.1 “Quality inspection systems” - available for download at http://go0dman-project.eu/wp-content/uploads/2016/10/GO0D-MAN-DeliverableD3.1.pdf

[2] A Krizhevsky, I Sutskever, GE Hinton, ImageNet classification with deep convolutional neural networks, Advances in neural information processing systems, 1097-1105, 2012

[3] G. Berkovic, S. Zilberman, E. Shafir, Temperature Effects in Chromatic Confocal Distance Sensors, Proceedings of SENSORS, IEEE, Baltimore, MD, USA, 2013

[4] M. Gavrilov, P. Indyk, R. Motwani, S. Venkatasubramanian, Geometric Pattern Matching: A Performance Study, Proocedings of Symposium on Computational Geometry, Proceedings of the fifteenth annual symposium on Computational geometry, pp. 79-85, Miami Beach, Florida, USA — June 13 - 16, 1999