A simple and accurate solution based on a laser sheet system for on line position monitoring of welding

G D'Emilia, D Di Gasbarro, E Natale
Dipartimento di Ingegneria Industriale e dell’Informazione e di Economia, University of L’Aquila, 67100 L’Aquila, Italy
E-mail: giulio.demilia@univaq.it

Abstract. A methodology is presented able to check on line that optimal settings of a vision system are reached and maintained for automatic geometrical measurement welding having a complicated shape. The simple optical measurement system is based on a laser sheet. The set calibration methodology appears very sensitive to little deviations from optimum setting and allows the measurement system to reach level of uncertainty adequate for automatic dimensional checking of welding, even though a simple measurement system is used. The effects of process variability on the method are also studied and quantitatively evaluated; practical solutions for on line use of the methodology are finally discussed.

1. Introduction
No contact optical systems are widely used for on line monitoring of both geometry and position of welding, based on different optical measurement methods, like CCD camera vision systems [1], triangulation systems [2] and other types of solutions [3]; remarkable measuring performances could be achieved in terms of measurement uncertainty, even though the cost of these solutions is often high, so that their use is limited to specific applications. Measurement systems based on a laser sheet, as depicted in figure 1, are a simple and economical way to carry on no contact geometrical measurements in different types of applications [2] [3] [4] [5]; usually their accuracy has to be optimized in order to achieve satisfactory uncertainty level [7] [8] [9], especially for the control of complicated geometries, as it is requested in some industrial scenarios.

Another important issue that must be satisfied is to find a method for on line assessment that the best quality level for measurements [7] [8] [9] is maintained; it should be not too onerous from the point of view of time, operations and data processing requirements.

Therefore, it is important to both develop a vision system that works well under certain environmental conditions and a methodology to automatically maintain good metrological characteristics, also in complex applications and varying operating conditions.

In this paper the measurement capability of a measurement system based on a laser sheet is described with reference to the monitoring of welding having a complicated geometry, for realization of motorbike frames.

The proposed system uses the same hardware components of the triangulation systems [2], but it provides a different software elaboration; in fact, the aim of this approach is not to identify the geometrical surface of the analyzed object, but to evaluate, in a simple manner, the distance of some characteristic points from a reference.
Furthermore, an experimental methodology is presented, in order to improve the possibility of using this simple measuring solution in a difficult situation, aiming to automatically check and maintain conditions of good setting of the vision system.

To reach this goal, the effects on uncertainty of many parameters should be taken into account, like environmental conditions, surface characteristics, variable positioning of the optical system with respect to the target, in order to limit the uncertainty and to guarantee suitable production tolerances. Therefore, the main parameters affecting uncertainty will be individuated and their effect evaluated from both a theoretical and experimental point of view.

A procedure to automatically check that good measuring conditions are set and maintained will be described, with the purpose of identifying quantitative indicators for this purpose and threshold limits suitable for on line use of this procedure.

The effect of geometrical and dimensional effects will be studied taking also into account the influence of process parameters and their stability.

Some discussions will be finally carried out with reference to the use in field.

2. Materials and methodology
The system used for the control of position and of dimensional correctness of welding is a vision system based on a laser sheet.

In particular, it is composed of the following main components (figures 1 and 2):

- A compact GigE Vision camera, model Genie M1024, produced by Teledyne Dalsa, that uses a Sony CCD, a monochrome sensor with a resolution of 1024 x 768. The camera operates at 20 frames per second at full resolution.
- A Laser line generator, LasirisTM SNF, diode power 5 mW, wavelength 685 nm.
- A supervision Axiomtek industrial PC, with a processor Intel (R) Atom (TM) CPU D525, 1.80 GHz, RAM 2 GB.
- Software LinceoONE, produced by Vision Device s.r.l., for image acquisition and elaboration.

The use of a sheet of laser light allows to overcome the problem of low contrast images and to obtain, in a simple manner, information on the shape of surfaces. This is particularly important in this specific application, where it is necessary to inspect untreated metal surfaces. In fact, at the intersection of the laser sheet with the object to be analyzed the laser line appears to be very contrasted with respect to the object surface (effect white on black background). In this way, the intersection points (circled in red in figure 3) between different surfaces of an object are easily identified.

![Figure 1. Scheme of the system for the welding control.](image1)

![Figure 2. Picture of the system used for the welding control.](image2)
This possibility can be useful in two phases of a welding process:

- to identify the line of contact of two pieces that have to be welded and to drive the robotic arm, that deposits the welding bead;
- to verify the correctness of the position and of the dimensional parameters of the realized welding bead.

In any case, it is important to ensure that characteristics of correct setting of the system are set over all the time, so that the measurement results are reliable. Having a correct setting physically means that all variability causes act in a random and reduced way, so that no systematic and remarkable effects of any specific variability cause could be individuated. Therefore, if the system is properly set, measurements should be characterized by a Gaussian variability with fixed mean and reduced standard deviation.

The methodology described hereinafter is based on this assumption.

This condition should be guaranteed both at the installation time of vision system and during the on line working.

Of course, before the production activity begins, the time available for checking that the measurement distribution is effectively Gaussian is much more than the one available during the production, due to the need of avoiding bottle necks to the production rhythms.

Therefore, automatically checking these conditions ask different requirements due to differences of time duration available for control before the start of production and during the production itself.

Due to these considerations, the correctness of the working conditions at the beginning can be evaluated by many repeated measurements; otherwise, during the production a very few measurements will be allowed to realize the checking actions. The need of assuring that the probability distributions of possible measurements are unchanged (according to the measurement performances) all along the time requires that the closeness of both distributions is evaluated.

A parameter should be evaluated, that represents the closeness of the on line real distribution of measurements to the theoretical Gaussian distribution and used as an indicator of the correctness of the system setup.

Among many possible statistical indicators proposed in literature [10], the p-value is a statistical parameter that appears to be very suitable for this purpose [10].

In fact, the p-value is a function of the observed sample results and it is used for testing a statistical hypothesis with a requested confidence level.

In general, if the p-value, ranging between 0 and 1, is greater than a predetermined threshold, Gaussian distribution of measurements and consequently optimal setup conditions are guaranteed, with the confidence level indicated in the calculation of the p-value.

Based on the above considerations, the procedure for the setup of a system for the welding control can be synthesized in the following steps:
1. "Optical" setup of the vision system: preparation of the calibration "pattern" and of the configuration program for the proper recognition of the interest areas of the "pattern" itself. This phase is needed for the correct focusing and exposure setting of the camera [11]. It can be carried out using a simple calibration pattern, which consists of white letters on a black background, to set the system so that it is able to distinguish the laser line from the background.

![Figure 4. Example of a calibration “pattern”.

The pattern has to be framed by the camera, and a program for the identification of edges and intersection points is implemented, using the software for the image processing. Focusing and exposure time are manually set, until all elements are recognized.

![Figure 5. “Optical” setup of the vision system.

To accomplish this goal, the contribution of lighting is fundamental; in particular it should be uniform and stable. The lighting in this test is by neon lamps, placed at a two meter distance from the calibration pattern. A lighting system based on LED, properly designed and positioned with respect to the pattern, could allow better performance of the system.

2. Spatial calibration of the vision system: A gauge block of known size is used for the evaluation of the ratio pixels/mm.

3. Test "start of production": it must be carried out during a few minutes (i.e. up to 15 minutes) at the illumination conditions of the environment where the system is located, with a reference work-piece mounted in front of the camera.
The measurements recorded at this stage will be the basis for the “on line” verification of the correct working of the vision system. If the system is properly set, measurement distribution should be characterized by a Gaussian variability. Otherwise, it is necessary to reset the system.

4. The system can be started up. Measurements carried out on each production work-piece will be used to check that the optimal setup conditions are maintained. Each measurement is repeated n times (typically n=30 and about 2-3 seconds depending on the acquisition and image processing rate of the system). The p-value is calculated on the basis of these n measurements. It is to be pointed out that n depends on the specific process; the requirement to be satisfied concerns the need of avoiding a bottle neck for the process.

5. The measurements acquired in working conditions should be used to calculate the p-value and then to metrologically evaluate the vision system. In particular, if the p-value is upper than a threshold level, the system is correctly set.

The threshold level can be defined in relation to the specific application and environment conditions, by means of a statistical analysis (mean and standard deviation of p-values) based on a sufficient number of p-values (at least 30 p-values) calculated on the first batch of production. In some cases, if the process variability doesn’t allow to correctly individuate the optimal setting of the system, other actions have to be provided.

In section 3, steps 3 to 5 of the methodology will be discussed with reference to a practical application.

3. Results
In this section the effects are evaluated of varying the setting of the vision system with respect to the best one and the influence of process aspects.

Measurements have been carried out on a piece, as an example, constituted by two perpendicular steel plates, welded together by a linear bead (figure 3). Grey threshold has been identified as the most relevant setting parameter, to be studied.

As for the setting of the vision system four different conditions have been considered, by varying the grey thresholds (variation of the grey level in the transition from dark area to the light one) to determine the two boundaries of the laser line, which is a broken line because of the object shape (figure 3); these data will be processed in order to find the position and the dimensional parameters of the welding bead. The threshold values are given with respect to the whole interval of values, ranging from 0 to 255.

In particular:
Case 1: grey threshold1: 40 - grey threshold2: 80 (reference case);
Case 2: grey threshold1: 37 - grey threshold2: 67
Case 3: grey threshold1: 35 - grey threshold2: 65
Case 4: grey threshold1: 33 - grey threshold2: 60

As for process influence, differences have been considered of the distance for each chassis with respect to a reference one: the reference distance, d0, was 43.47 mm and displacements in the order of + 0.10 mm have been examined.

According to the procedure described in the previous section, before the on line measurements a large number of image data has been acquired, in the order of 3500 samples for each case, with reference to the all examined settings.

The results of this test are shown in figures 6 and 7. The statistical distributions clearly show that for optimum setting (case 1) a Gaussian distribution can be obtained, confirming the hypotheses; furthermore the statistical processing of data shows that no bias exists in measurements and that the standard deviation is the lowest with respect to all cases that have been compared.

In the other cases, even though the differences in settings are little, remarkable differences can be found with respect to the standard deviation of data (case 3 and case 4); in some cases (case 2 and case 4) bias error can also been observed.
The results of applying this methodology are described in graphs of figures 8 to 11. It is to be noticed that all results refer to \( n = 30 \), being \( n \) the number of repeated on-line measurements. In particular the diagrams of figure 8 show the behaviour of the mean p-value (calculated averaging 100 p-values based on groups of 30 measurements) with respect to the set measurement uncertainty (standard deviation of the normal reference distribution of the vision system measurements) for all the examined cases. For case 1 (best setting case), even though the set uncertainty is reduced, the mean p-value remains practically unchanged, maintaining high values; for cases 2 to 4 the found p-value quickly drops when the requested uncertainty of measurements is reduced. This result is very reasonable and it also suggests that a threshold value could be set to separate the best setting case from other ones.

The possibility of defining a threshold can be further examined by analysing the possible range of p-values with their standard deviations as a function of the set standard uncertainty of the normal reference distribution.
The diagrams of figure 9 show that it is possible to separate the p-value ranges if a reduced standard uncertainty of the normal distribution is examined (standard uncertainty less than 0.23 mm). This result confirms the ability of this method of distinguishing correct setting from slightly different configurations of the vision system.

As regards the influence of process aspects, tests have been carried on work-pieces with distances varying in the field of $+0.10$ mm with respect to the reference one, around the mean value $d_0 = 43.47$ mm.

If a standard deviation of 0.23 mm is considered for the normal reference distribution, the mean p-values, calculated averaging 100 p-values based on groups of 30 measurements, are shown in figure 10, as a function of the distance deviation from the reference distance $d_0$, for different work-pieces.
The figure 10 shows that in the case 1 the trend is symmetric with respect to the zero value on the x axis. On the contrary, the curves that refer to cases 3 and 4 are not symmetric. Please note that the p-values of case 2 are constantly near zero. Furthermore, the curves intersect each other.

It appears difficult to differentiate the behaviour of case 1 with respect the other ones, if the effect of the process variability is taken into account.

This result can be easily explained, if the case 1 is further analysed (figure 11). In fact if the distance to be measured is changed with respect to the reference one, the possible ranges for the p-values drop quickly moving from the reference value. The estimated p-values are practically reduced to near zero, when the distance to be on-line measured on components is changed in the range ± 0,10 mm from the reference one. Systematic effects of the process variability mislead the method but they confirm the method itself, in the sense that the method is focused on measurements accuracy of the vision system. Due to this consideration the reference piece should be proposed to the vision system at fixed time interval among production batches for on-line measuring validation of the vision system itself.

Figure 11. Mean p-values and their standard deviation ranges vs. difference of distances from d0 in Case 1.
4. Conclusion
A method has been discussed for on line validation of position measurements of a monitoring system for welding. The device is based on a vision system and a laser sheet.

The p-value parameter has been used to automatically identify the best settings for the vision system, taking into account the main cause of uncertainty. The method is able to detect the effects of a little variation of settings, so strongly supporting the setup of the vision system. A procedure has been proposed with the purpose of applying it on line.

The effect of process variability has been also studied showing that the method is very sensitive to it. Anyway, simple solution can be found to overcome this problem and make the procedure useful for on line utilization.

Even though in a first step laboratory conditions have been realized, the obtained results encourage to pursuit this study, for on line measurement of position and size of welding in automotive applications.

5. References
[1] Bino M, Fois S, Bellandi P, Coffetti G, Sansoni G and Guerra A 2014 Tutto misure 1 17-21
[2] Acosta D, Garcia O and Aponte J 2006 Proc. of Electronics,Robotics and Automotive Mechanics Conference (Cuernavaca) vol. 2 (IEEE) p 14
[3] Kong F, Ma J, Carlson B and Kovacevic R 2012 Opt Laser Technol 44 2186–96
[4] Qing-bin T, Chao-qun J, Hui H, Gui-bin L, Zhen-liang D and Feng Y 2014 Meas Sci Technol 25 035202-11
[5] Bellandi P, Docchio F and Sansoni G 2013 Int J Adv Manuf Tech 69 1873-86
[6] Brosed F J, Santolaria J, Aguilar J J and Guillomia D Robot Com-Int Manuf 28 660-71
[7] Besic I, VanGestel N, Kruth J P, Bleys P and Hodolic J 2011 Opt Laser Eng 49 1274–80
[8] Mahmud M, Joannic D, Roy M, Isheil A and Fontaine J F 2011 Comput Aided Des 43 345–55
[9] Xi F, Liu Y and Feng H Y 2001 Int J Adv Manuf Tech 18 211–16
[10] Montgomery D C 2009 Statistical quality control (New York: McGraw-Hill)
[11] Zhang Z A 1998 Microsoft Research Technical Report MSR-TR-98-71

Acknowledgments
The courtesy of Vision Device Srl, Torrevecchia Teatina, Italy, for making available the vision system and the processing software is gratefully acknowledged.

This work has been carried out with reference to the Programmi POR FESR ABRUZZO 2007 – 2013 Attività I.1.1. Sostegno alla realizzazione di progetti di Ricerca Industriale e/o Sviluppo sperimentale – progetto “Controllo e guida dei processi relativi alle attività di saldatura – Tracking System to Weld (TSW)”, whose financial support is gratefully acknowledged.