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On line control of optimal setup of a laser sheet system for real time monitoring of welding

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***Abstract* – A methodology is presented able to continuously check the settings of a vision system for automatic geometrical measurement of welding, having a complicated shape. The simple optical measurement system is based on a laser sheet. The set calibration methodology 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 effect of varying the lighting conditions has been carefully studied, that is a relevant cause of uncertainty. The method appears very sensitive to little deviations from optimum setting in many operating conditions. The effects of process variability on the method are also studied and quantitatively evaluated; practical solutions for on line use of the proposed methodology are finally discussed.**

I. INTRODUCTION

No contact optical systems are widely used for on line monitoring of quality, geometry and position of welding, based on different optical measurement methods, like spectroscopic studies of the welding plasma plume [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 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 [6] [7] [8], especially for the control of complicated geometries, as it is requested in some industrial scenarios.

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 case untreated metal surfaces should be investigated. In fact, at the intersection of the laser sheet with the object to be analyzed the laser line appears to be well contrasted with respect to the object surface. In this way, the intersection points (circled in red in Fig. 1) between different surfaces of an object are easily identified.

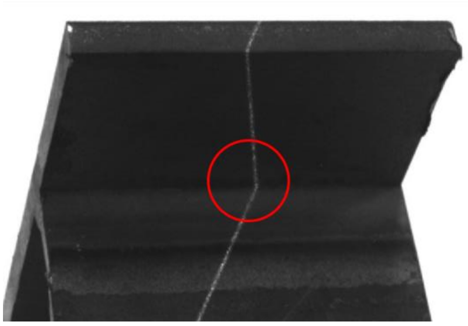

Fig. 1. Example of identification of the intersection point between two lines generated by the laser sheet.

For uncertainty reduction a further important issue, that must be satisfied, is to find a simple method for on line assessment that the best quality level for measurements [6] [7] [8] 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.

Furthermore, an experimental methodology is presented, in order to improve the possibility of using this simple measuring solution also in difficult situations, aiming to automatically check and maintain conditions of good setting of the vision system, with particular attention to the variations of the lighting level and characteristics.

The main parameters affecting uncertainty are individuated and their effect evaluated from both a theoretical and experimental point of view.

The p-value parameter [9] was used to automatically identify the best settings for the vision system, taking into account the main causes of uncertainty. The method demonstrated to be able to detect the effects of a little variation of settings, so strongly supporting the setup of the vision system.

The effect of process variability was also studied, in particular dimensional variability of pieces to be welded together, showing that the method is very sensitive to it.

In this paper the methodology has been applied to other operating situations, in order to check its validity even though different operating conditions for the measuring system are set.

Enlarging the range of cases being taken into account it will be used to also update the methodology in order to make it more robust and reliable in practical applications.

To reach this goal, after a short description of the procedure, for better understanding of the theoretical and experimental motivations of it, the experimental results will be described and the way the data have been processed, in order to validate the methodology for a class of practical applications.

In particular, besides the effect of geometrical and dimensional effects, the lighting influence will be studied, taking into account the influence of process parameters and their stability.

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

II. DESCRIPTION

The system used for the control of position and of dimensional correctness of welding is a vision system based on a laser sheet, whose architecture is shown in (Fig. 2 and Fig. 3). A detailed description of components and the complete procedure for the setup of the system is illustrate in a previous work [10].

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 a characteristic point from a reference. 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; validation of the position and of the dimensional parameters of the realized welding bead will also be possible.

It’s 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 [11].

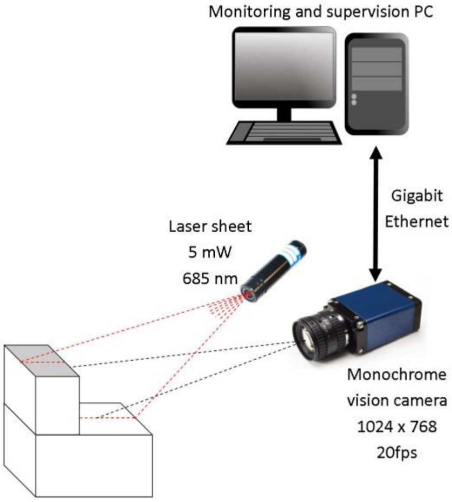

Fig. 2. Scheme of the system for the welding control.

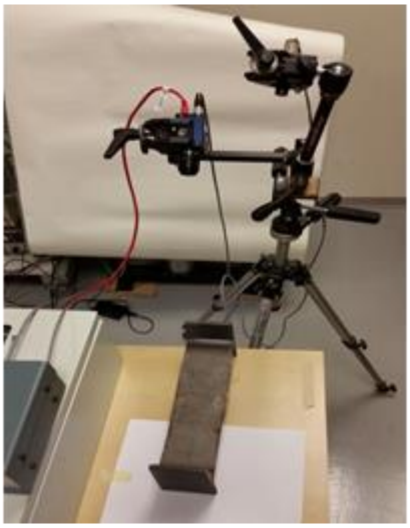

Fig. 3. Picture of the system for the welding control.

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.

Based on literature indications [12] and on the previous work [10], the p-value has been chosen as the indicator of the correctness of the system setup.

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

Based on the above considerations and on the previous work [10], 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 and spatial calibration:

this phase is needed for the correct focusing and exposure setting of the camera [13]. It can be carried out using a simple 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. A gauge block of known size is used for the evaluation of the ratio pixels/mm.

2. 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.

3. Test “on line monitoring”:

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.

4. P-value estimate to be compared with a threshold value:

the measurements acquired in working conditions should be used to calculate the p-value and then to check 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 the next section the methodology will be discussed with reference to some practical applications concerning pieces to be welded for motorcycles.

III. RESULTS

In this section the effects are evaluated of varying the setting of the vision system with respect to the best one in different lighting conditions 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 (Fig. 1). The positioning tolerance due to the design size of the welding bead is set equal to ± 1 mm. Grey threshold has been identified as the most relevant setting parameter, to be studied, together with the lighting conditions.

The change of setting of the vision system, by varying the grey thresholds (variation of the grey level in the transition from dark area to the light one) modifies the two boundaries of the laser line, which is a broken line because of the object shape (Fig. 1). The threshold values are given with respect to the whole interval of values, ranging from 0 to 255. These data should be processed in order to find the position and the dimensional parameters of the welding bead.

Three different typologies of illumination have been compared. For each lighting situation, different settings of the grey threshold have been examined.

The test plan described in Table 1, it is composed by 9 different cases. Illumination condition 1 is based on neon light system at a 2 m distance from the object. Illumination condition 2 is based on the same neon system of condition 1 but is added a led lamp at a 0.3 m distance. Illumination condition 3 is based on the same system of condition 2 but the led lamp is placed at a 0.5 m distance. The system setting conditions can be optimal or not. This is dependent of the gray threshold values selected. 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.

As for process influence, pieces have been considered with a variable distance to be controlled for each chassis with respect to a reference one: differences of the reference distance, d0, in the order of ± 0.10 mm have been examined.

A. Effect of gray level

The results of this test are shown in figures 4 and 5.

Table 1. Tests plan.

Case	Illumination Condition	Gray threshold 1	Gray threshold 2	Optimal settings
1	1	40	80	Optimal
2	1	37	67	
3	1	35	65	
4	1	33	60	
5	1	40	80	Optimal
6	2	40	70	Optimal
7	2	40	80	
8	3	53	70	Optimal
9	3	40	80	

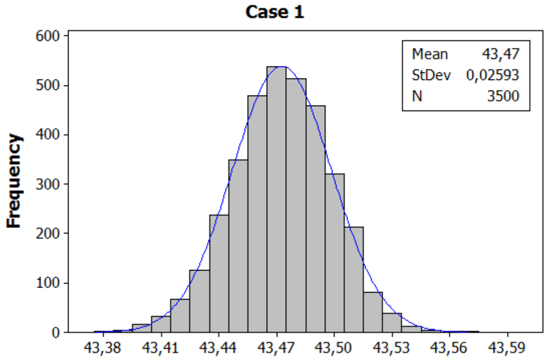

Fig. 4. Frequency distribution of measurements in Case 1.

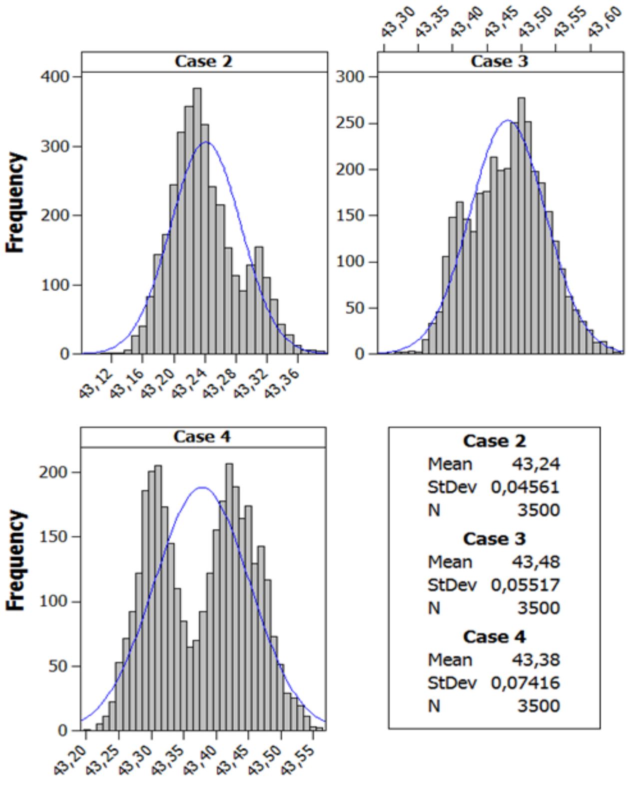

Fig. 5. Frequency distribution of measurements in Case 2, Case 3, Case 4.

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 6 to 8. 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 Fig. 6 show the behavior 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 analyzing 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 Fig. 6 show that separated p-value ranges occur, between settings optimal or not, if a reduced standard uncertainty of the assessment normal distribution is considered (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, d0. 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 8, as a function of the distance deviation from the reference distance d0, for different work-pieces.

The Fig. 7 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

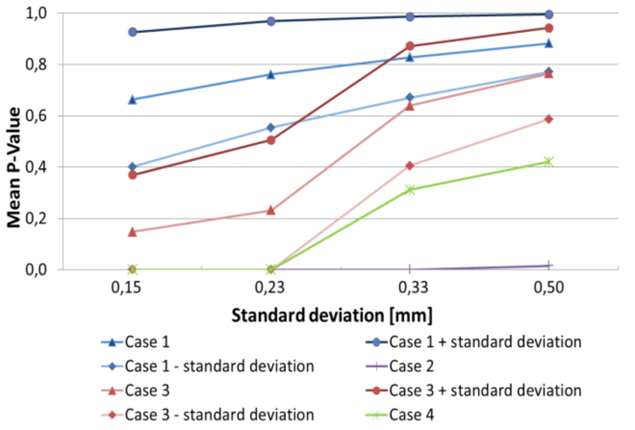

Fig. 6. Mean p-values and their standard deviation ranges (Case 1 and Case 3) vs. standard uncertainty.

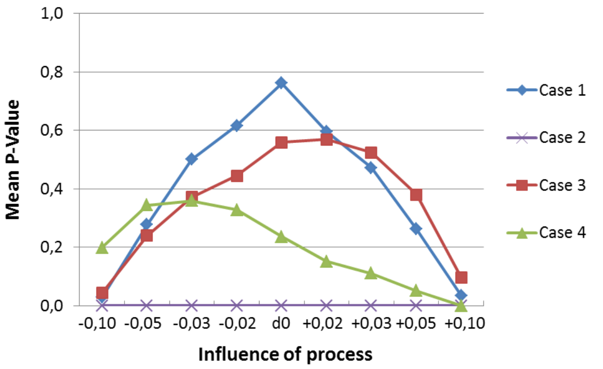

Fig. 7. Mean p-values vs. difference of distances from d0 in all analyzed cases.

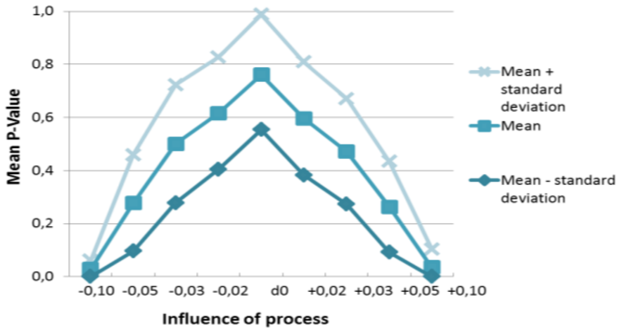

Fig. 8. Mean p-values and their standard deviation ranges vs. difference of distances from d0 in Case 1.

behavior 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 analyzed (Fig. 8). 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 intervals among production batches for on-line measuring validation of the vision system itself.

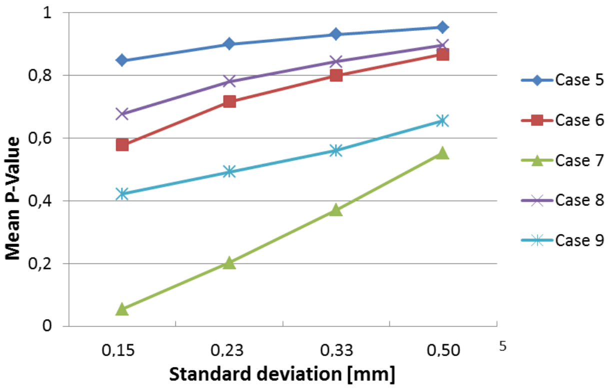

Fig. 9. Mean p-values in illumination condition 1 (case 5), illumination condition 2 (case 6 and case 7) and illumination condition 3 (case 8 and case 9) vs. standard uncertainty of normal reference

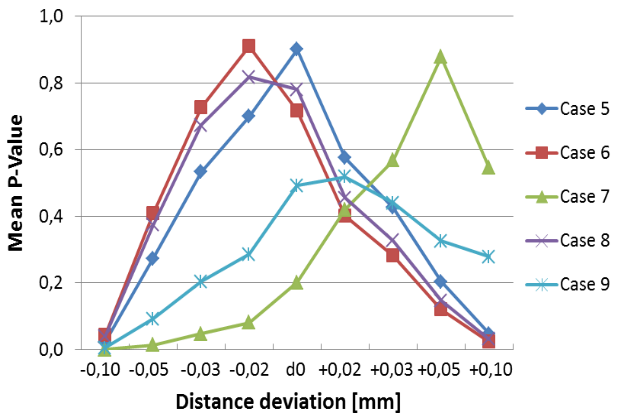

Fig. 10. Mean p-values and their standard deviation ranges vs. difference of distances from d0 in case 5, case 6, case 7, case 8 and case9.

B. Effect of lighting

Based on the tests results of cases 6 to 9 some consideration could be done.

If all the conditions of lighting are considered, in case the right setting of the grey threshold is set, the estimated distance between the reference points is in the range (43.42 ± 0.01) mm; if the grey threshold is not changed with respect to the reference case, the estimated distance between the reference points is in the range (43.42 ± 0.05) mm. Therefore the systematic error is in the range

±0.05 mm, and it is pretty negligible with respect to the expected uncertainty of the measurement, in the range 0.15-0.23 mm. This consideration suggests that the checking of the right setting by means of the measured mean value is not feasible.

If the p-value is chosen as the indicator of the right setting, a completely different situation arises. In fact, diagram of Fig. 9 show that it is strongly dependent on the grey setting for all the lighting conditions, which have been examined. Due to the found differences of p-value, even though the variability of p-value is taken into account, threshold values could be easily set, in order to quickly identify a condition of right setting.

As regards the influence of process aspects, tests were carried out for all the lighting conditions and results confirmed the previous indications (Fig. 10).

In case of the right setting negligible systematic error occurs and the graphs of p-value are symmetrical with respect to the reference value of distance. In other cases a displacement of the p-value peak could be observed, corresponding to a systematic error with respect to the distance indication. The p-value is misled by the variation of the distance between the reference points due to the dimensional variability of pieces and this effect is independent on the settings of the system. The same operating solution as at the end of previous subsection should be proposed for on line and real time monitoring of the right setting of the system.

IV. 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 and validated for different conditions of lighting. 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 use.

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.

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