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IN PROCESS IDENTIFICATION OF WORKPIECE/SYSTEM GEOMETRICAL DEVIATIONS BASED ON GENERAL PURPOSE ROBOTS AND LASER TRIANGULATION SENSORS – PART 2: EVALUATION

Abstract: *This paper gives a conceptual framework of a new class of metrological systems based on integration of general purpose industrial robot with laser triangulation sensor for contactless dimensional metrology. The paper has two parts. Part one considers conceptual framework where the system architecture is given, key aspects of the interface between two subsystems are considered, as well as a new methodology frames for signal processing and generation of partial or complete 3D digital model of scanned object with complex spatial geometry. For verification of practical applicability, laboratory installation is developed and experiments and practical functional testings are carried out. This paper also gives recapitulation of two feasibility studies: huge assemblies welding process robotization and forging press serving in the scope of flexible manufacturing cell for forging on MAXI presses. Evaluation and practical implementation are in the second part of this paper.*
Key words: *Industrial robot, laser triangulation sensor, 3D digitalization*

1. INTRODUCTION

For illustration of practical applicability of the concept of robotized scanning of objects with complex geometry directly on production lines and with application of commercially available general purpose industrial robots, the results of evaluation activities carried out in laboratory conditions and in the form of feasibility studies for concrete application in industrial manufacturing are given. The evaluation procedure is carried out within the research project INTOSA[1] [1] where the conceptual bases for one robotized system for 3d digitalization of objects with complex geometry based on CCD laser sensor with spot optical triangulation are developed and practically realized. Practical applicability of this concept is verified and demonstrated in laboratory conditions in Center for New Technologies at Faculty of Mechanical Engineering, University of Belgrade. This paper should be seen in continuity with the first part [2] where the conceptual framework is given.

2. MAPPING OF THE ROBOT ERROR

Figure 1 shows the installation for experimental verification of robotized scanning concept which is realized within Center for New Technologies (CeNT) at Faculty of Mechanical Engineering in Belgrade. System consists of 1)robot with anthropomorphic configuration with 6 DOF, payload of 10 kg and reach of 1650mm, made by Kawasaki, Japan, model JS10, 2)laser triangulation sensor made by Micro Epsilon, Germany, model optoNCDT 1700-100 (characteristics are given in Table 1), 3)PC acquisition system with corresponding interfaces and software, and 4)worktable.

Table 1: Technical performances of laser triangulation sensor ME optoNCDT 1700-100

Measuring range (MR):	100 mm
Stand-off distance:	70 mm
Linearity:	±0.08% MR
Resolution:	6 μm
Maximal mesuring rate:	2.5 kHz
Light source:	
Wave length: 100 mm	670nm, red
Max. power:	1mW
Laser class:	2(II)
Allowed ambiental light intensity:	10.000lx
Spot diameter at the middle of MR:	60μm
Temperature stability:	0.01 %FSO/K
Operating temperature:	0...+50 °C
Vibration resistance (IEC 68-2-6):	2g/20...500Hz
Shock resistance (IEC 68-2-29):	15g / 6ms
Weight:	550g

For the purpose of improvement of metrology performances of robotized measurement system the identification of positioning error of robot end point in a part of its workspace is carried out. Quantitative indexes are derived by generation of a sequence of equidistant calibration curves (vectors) which are positioned in one vertical plane perpendicular to y axis at position y=1000mm. Calibration curves are generated for straight line nominal trajectory, by scanning an etalon ruler with length of 500mm.

Figure 2 shows one of 5 calibration curves. One can observe the existence of error caused by imperfections of manipulation robot which come up from: 1) mechanics of the robot kinematic chain, 2) actuation system and 3) robot control system. In the given case this error is ± 0.142 which is for 40% greater then error specified by manufacturer (±0.1 mm in the complete workspace). Calibration curve is derived using

[1] Project MA14035: **Application of Intelligent Sensor Systems in Development of Integrated Automation of Real and Virtual Processes in Manufacturing Enterprises - INTOSA**, financed by the Government of the Republic of Serbia, Ministry of Science and Technological Development, Grant 14035, (2008-2010)

Fig 1: Instalation for experimental verification of the proposed concept within CeNT

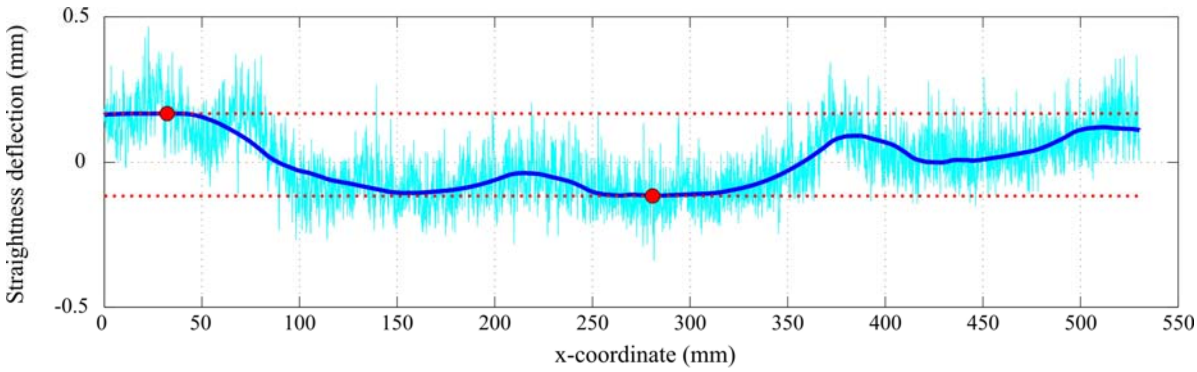

Fig. 2: Identified robot error in horizontal plane at the worktable level – straightness deflection for the nominal trajectory: y=1000; z=100; x=t.

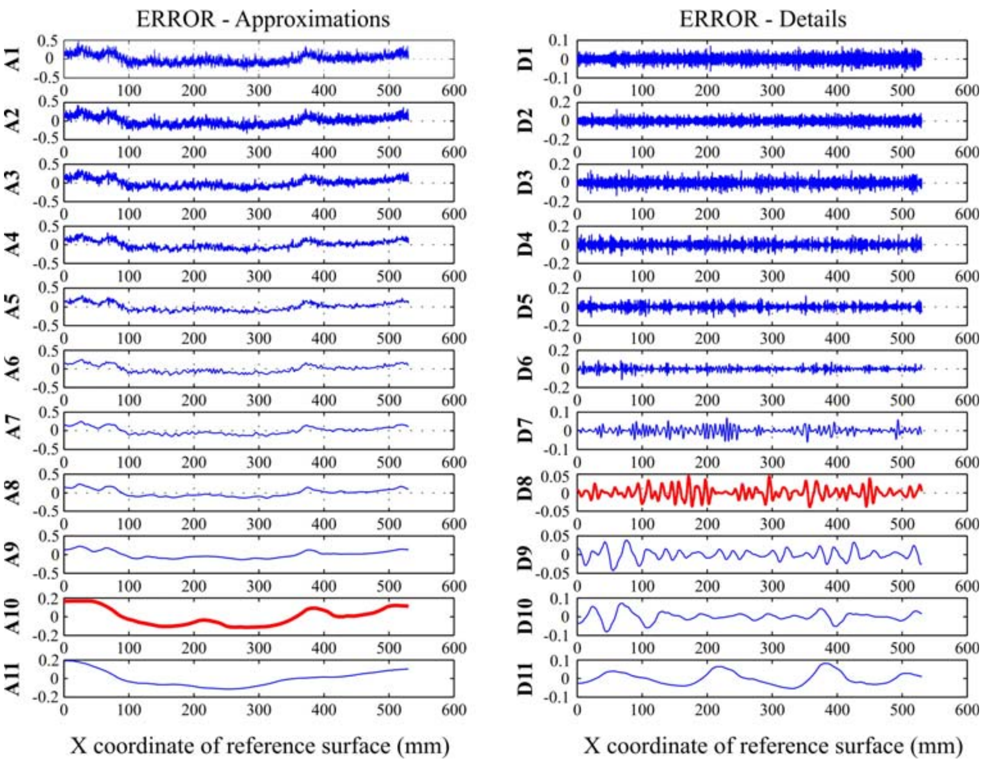

Fig. 3: Decomposed robot end point error signal given in Fig. 2 using db4 DWT at 11 levels

multuiresolution analysis of original signal transformed from time to spatial domain. Signal is decomposed at 11 levels using Discrete Wavelet Transform (DWT) with db4 wavelet [3]. Decomposed signal, that is, the sequence of its approximations and corresponding details is given in Figure 3. Elimination of high-frequency contents which come from robot and noise in sensor readings gives calibration curve. By thorough analysis of detail signals at all 11 levels, approximation level A_{10} is chosen as dominant level at which the error that comes from imperfection of mechanics and robot control is located. Error components that come from robot end-point vibrations are grouped around D_8 detail level. High frequency error components that come from sensor system are located at the level D_1 and higher levels. The error of metrological system as a whole is determined by error generated by manipulation robot.

Since the error map is derived applying DWT it is possible to reduce the amount of data to be stored in the look-up table. Instead of memorizing raw data, or approximations A_{10} it is more convenient to memorize approximation coefficients a_n^{10}. These approximation coefficients carry the complete information contents of A_{10}. A_{10} can be computed from a_n^{10} using IDWT (Inverse Discrete Wavelet Transform). Having in mind that there are 2^{10} less approximation coefficients a_n^{10} than samples in A_{10}, significant reduction of memory is feasible. Besides, since DWT is additive, it is possible to subtract the approximation coefficients of error directly from the db4 10th level approximation coefficients of signal measured during scanning.

3. SCANNING THE GEOMETRY OF FORGING

The first example of practical implementation relates to the area of forging process automation. Contemporary trends in market impose very high demands when the geometry of forgings is considered. This imposes the need for in-process inspection of key geometry parameters. For the needs of Zastava Kovacnica Company, Kragujevac, during year 2008 the feasibility study [4] for the automation of existing forging technology based on MAXI presses is carried out. In the given case the manufacturing cell consists of two presses, one for shaping with capacity of 2500 tons and the other one for flash trimming. For the purpose of forging process quality surveillance, besides two manipulation robots that serve both presses and system for inductive heating, the third robot is added. The task of the third robot is to continuously inspect key geometry parameters. The layout of given cell is shown in Figure 4. For the purpose of validation of practical applicability of suggested concept of robotized manufacturing cell, test scanning of chosen example of forging – the housing of the bearing unit of the automobile front wheel is carried out in laboratory conditions. Contour of one of the scanned cross sections of forging is shown in Figure 5.

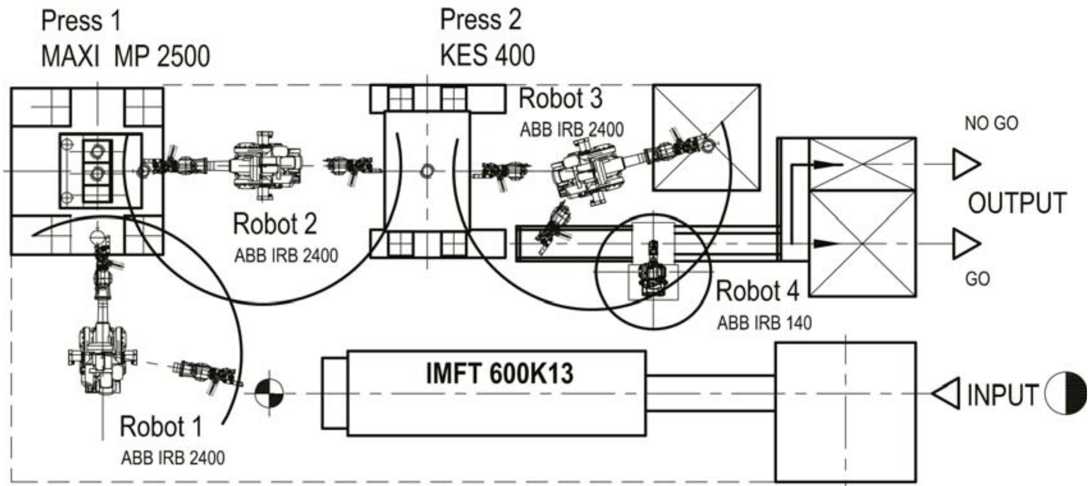

Fig. 4: Layout of robotized manufacturing cell for forging in Zastava Kovacnica Company. A variant version with integrated final forging geometry control system using universal manipulation robot IRB 1400, mfd. by ABB

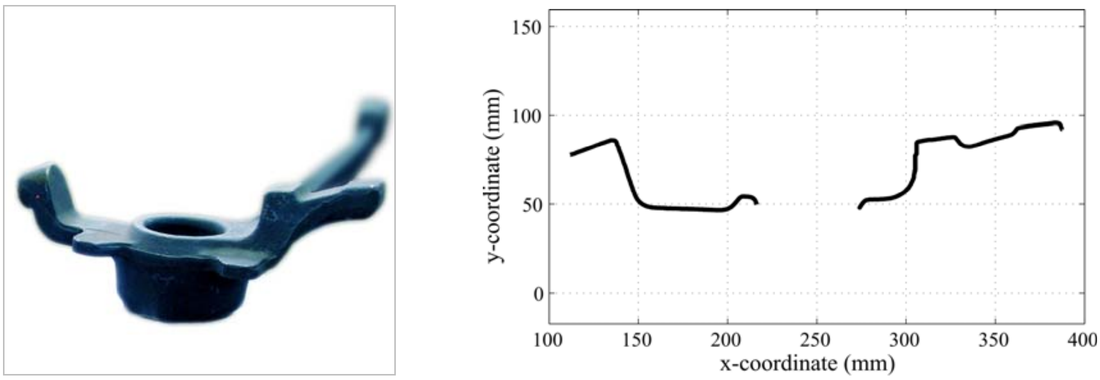

Fig. 5: An example of scanned contour of forging cross section in vertical plane transformed into spatial domain. In the left corner a photo of scanned forging in the angle showing the scanned cross section is shown

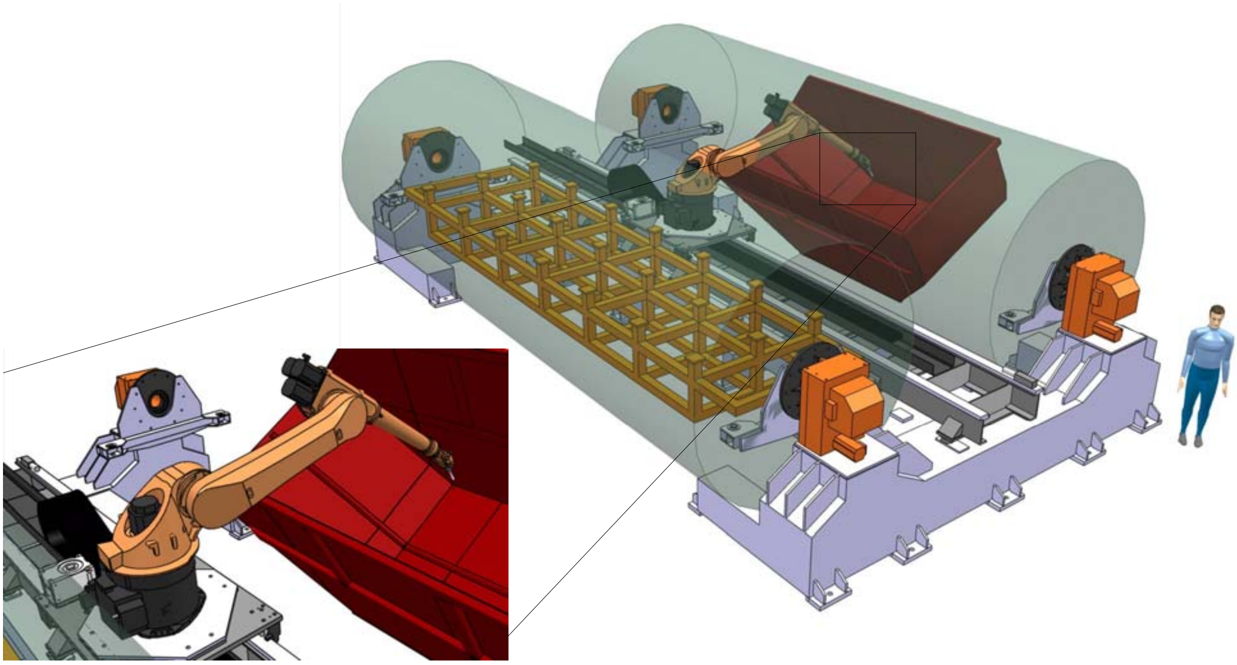

Fig. 6: Layout of robotized manufacturing cell for final assembly of family of containers. The cell is based on robot KR 30 L16, mfd. by KUKA which besides welding carries out identification of geometry and assembly location

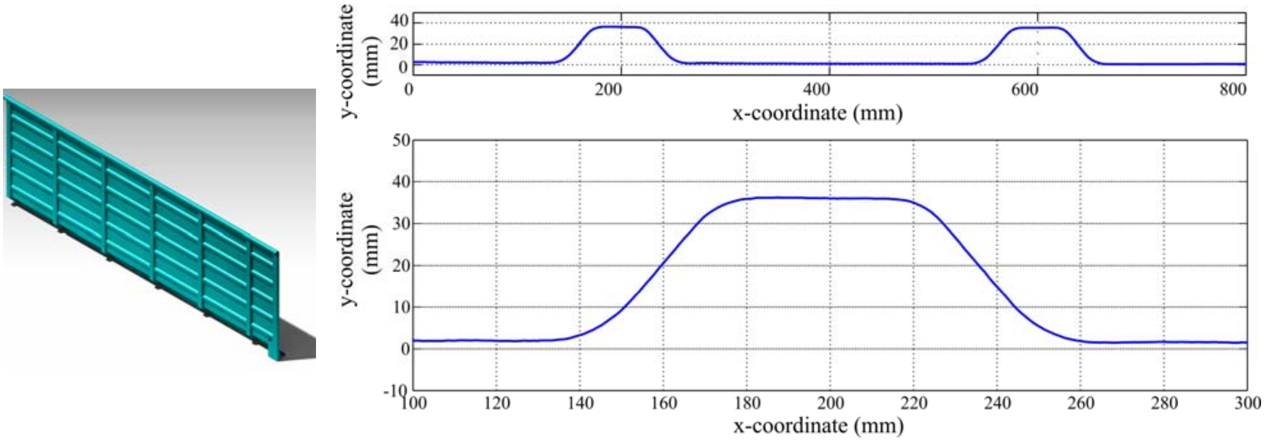

Fig 7: 3d CAD model of huge size container lateral side and an example of scanned profile geometry of ribbed sheet metal filling; Scanning is carried out in laboratory conditions in CeNT

Contour is scanned with the speed of 100mm/s which gives spatial resolution of 40µm. Only those points that are visible in the horizontal plane of orthogonal projection are shown. In this case, by applying measuring system, it is possible to realize the control of forging process directly on the manufacturing line. This approach enables fast reaction at the deflection occurrence, which guaranties the high quality and the stability of manufacturing process.

4. SCANNING THE GEOMETRY OF WELDED ASSEMBLY

The other example of practical implementation relates to the robotized system for arc welding of metal assemblies with huge size. The feasibility study [5] is carried out for the Velpan Company, Kikinda, which is specialized for manufacturing of containers for the diffuse load transport. Manufacturing system is designed in such a way that it consists of two manufacturing subsystems. The first subsystem consists of manual work places where the pre-assembly of subassemblies and final container assemblies is carried out. Pre-assembly is done on palettes which are equipped with specialized jigs and fixtures and which can be transported using bridge crane. The other subsystem consists of fully automated robotized manufacturing cell which has two rotary tables for the pickup of palettes with pre-assembled assemblies and manipulation robot KUKA KR 30 L16 with anthropomorphic configuration, reach of 3100 mm, equipped with seventh linear axis with the length of 10000mm. The layout of proposed system is given in Figure 6. The key demand for practical applicability of proposed concept is the complete information about

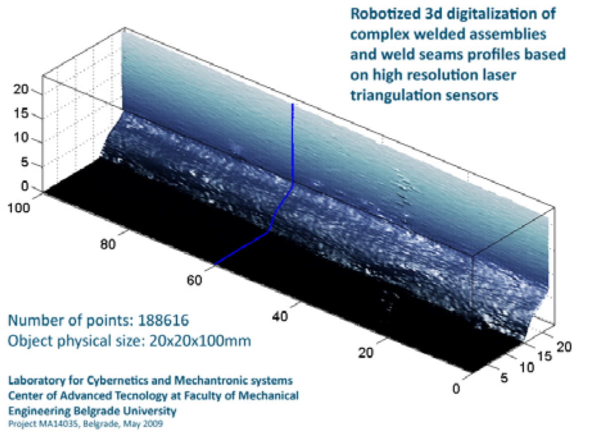

Fig. 8: 3d digitalized weld seam profile. Scanning is carried out in laboratory conditions in CeNT

geometry of pre-assembled assembly, that is, about precise location of welds to be welded. Generally, the error which occurs in this case consists of the errors of the assembly (the errors in position of assembly elements, the errors from elastic deformations and errors from thermal dilatations), the errors of geometry of assembly elements brought in during previous phases of manufacturing process and the errors of assembly positioning in jigs and fixtures, the errors of rotary table and robot positioning.

The reduction of given errors to the level acceptable for the MIG welding technology is not possible in rational way. Instead of the concept of geometric perfection, the concept of the adaptability of the system to the error is adopted. This concept is based on application of in-process robotized scanning of the assembly to be welded, starting from the initial scanning of the prepared material after the putting the pallet on the rotary table, all to the final scanning of the realized geometry after welding is finished.

Due to the complexity of subassemblies a number of successive welding and scanning operation is foreseen which enables not only the feasibility of the welding process, but also the surveillance of this process together with corrective actions on the nominal welding plan. An example of the scanned detail of lateral container side is shown in Figure 7. Based on identified profile geometry with the accuracy of ±0.15mm it is possible to continuously weld the ribbed sheet metal of the lateral container side even in the conditions when there is significant deflection in the rib profile geometry and the spatial position of the weld. Figure 8 shows the 3d visualization of the finished weld seam profile. The weld seam is scanned in laboratory conditions in CeNT.

5. CONCLUSION

Practical functionality of proposed concept of the robotized scanning is experimentally verified in laboratory conditions using anthropomorphic manipulation robot with 6 DOF and laser triangulation sensor with measuring range of 100mm and sampling rate of 2.5kHz. System has shown satisfactory behavior, and metrology performances are dominantly impressed by manipulation robot accuracy. In the given case achieved accuracy is better than ±200 μm in the comlpete work space. Developed system has general applicability at lines for assembly of products with huge or medium size, as well as on lines for manufacturing of parts made by forging and casting.

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6. REFERENCES

[1] Petrovic, P., B., Spasic, Z., Pilipovic, M., Jakovljevic, Z., *Application of Intelligent Sensor Systems in Development of Integrated Automation of Real and Virtual Processes in Manufacturing Enterprises - INTOSA*, *Annual Report,* project financed by the Government of the Republic of Serbia, Ministry of Science and Technological Development, Grant 14035, (2008-2010), Center for New Technologies, Faculty of Mechanical Engineering, University of Belgrade, 2009

[2] Petrovic, P., B., Jakovljevic, Z., Pilipovic, M., Mikovic, Dj, V., *In Process Identification of Workpiece/System Geometrical Deviations Based On General Purpose Robots and Laser Triangulation Sensors – Part 1: Conceptual Framework*, MMA, Novi Sad, 2009

[3] Daubechies,. I., *Ten lectures on wavelets*, CBMS-NSF regional conference series in applied mathematics, Philadelphia: SIAM (61), 1992

[4] Petrovic, P., B., *Flexible Manufacturing Cell For Forging Process On Maxi 2500 Press, Feasibility Study*, Center for New Technologies, Faculty of Mechanical Engineering, University of Belgrade, 2008

[5] Petrovic, P., B., Jakovljevic, Z., *Robotized Flexible Manufacturing System For Final Assembly Of Huge Dimensions Metal Assemblies, Feasibility Study*, Center for New Technologies, Faculty of Mechanical Engineering, University of Belgrade, 2009

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