Total quality control of the cyber-physical production using machine vision technologies

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Abstract. The total control is made for each separate unit of the item being manufactured to prevent any scrap. The automatic control tools are a part of information, measurement and controlling sub-systems, which use the machine vision technology. The information sub-system is done with the cyber-physical production calculation potency. The measurement sub-system is a set of digital cameras (optical detectors) and the artificial illumination semiconductor sources. The controlling sub-system regulates the item position with turning mechanisms inside the closed cyber-physical system technological chamber. A set of sub-systems performs a non-destructible item quality control with the item surface photographic images and stereo-maps program analysis, which should not contain non-homogeneous sections like scars, fissures, inclusions and other and any deviations of geometrical dimensions. The calculator three-dimensional item image is formed with reconstruction algorithms of two-dimension photographs received in different views and illumination conditions and the means of laser scanning. The item surface quality requirements in the enlightened areas and obscured ones are defined with rendering equation, which are permitted for the item digital twin with calculator numerous methods. The quality control requires to compare with the reference energy and color measurement item surface characteristics, which are defined with mathematical calculations and optical measurement means. There is a scheme given of information, measurement and controlling cyber-physical system channels, which engage the machine vision technologies to control the item quality.

1. Introduction

In the Industry 4.0 paradigm the quality provision politics of the items being manufactured in a cyber-physical production (CPP) requires a process approach to organize the technological processes control system where the operation control covers the entire chain of the industrial item creation [1, 2]. The total
operation control where each item unit will be checked may monitor in real time the technological processes results done with particular cyber-physical systems (CPSs) united as conveyor lines [3]. The item quality uninterrupted check as the technological processes general control system is one of the CPS production relations element, which keeps the operation results connection, which are controlled in the inter-machine interaction processes joint [4, 5].

The production item quality control is to prevent the scrap and that non-condition item transmission through the conveyor line transmission [6]. A complex approach to provide the CPP item quality is done with measuring and controlling sub-systems tools influencing the CPS processes, which create the item. The item total quality control is done with automatic visualization system, which functionality is based on the machine vision technology [7, 8].

The item quality as the machine vision technology attention object is being controlled with CPS autonomous sub-systems, which engages the measuring optical means, which gives the CPS controlling sub-systems the accurate or interval parameters evaluation of the item appearance (item lines, flanges, edges and other) [9, 10]. The sensitive and highly productive CPS optics for the machine vision technology is the non-destructible control detector component of the CPS technological processes, which transmit to the calculator the item surfaces photo images taken in different views with digital cameras and interfaces technical means [11, 12].

The item reference correspondence evaluation, which shows that there is no scrap and all CPS equipment technological modes are observed and the machine vision technology confirms with the cyber-physical modelling results, which include the image structure analysis and being detected objects classification in defects categories [13]. The item surface properties minimal deviations detection from the required project documentation standard (the item digital twin) shows that there are some product defects, which require some technological processes correction measures or the CPS functionality environment conditions must be corrected [14, 15].

The item manufacturing process normalizing could be of private character and require repairing or some CPS units settings re-settlement or could be of system character, which researches the functionality parameters influence of some CPSs on the processes being completed quality in other CPSs, which form together a conveyor line [16]. In the industrial environment to stop a production line if a scrap is detected is a radical measure so that why they collect the possible CPS functionality break-downs data as a preventive measure. The quality control measures volume depends on the quality level, which maintaining is dictated by the company politics [17].

The quality control traditional forms accepted in the Industry 3.0 done within the production sections, which require the product test of some indications in given requirements correspondence. The quick reaction quality control for the process stability violation is a CPS function and an Industry 4.0 innovation to provide the serial items being manufactured parameter stability [18]. The item parameters acceptable range must depend on the CPP raw material and the machine vision technology technical and program and algorithms capabilities acceptable range [19, 20].

2. The CPS machine vision

The technological processes control component is the item being manufactured quality operation control. In a fully automatic production, the CPS evaluate the item quality, which apply the machine vision technology (samples recognition, digital images affine transformations, the volume items 3D scanning, X-ray check and other). The quality inspection is done with video monitoring technical means of program and algorithm processing in a video sequence of digital frames and mathematical formalities registering and analyzing the item photo pixel structure for some defects (micro-fissures, inclusions, scars, geometrical dimension deviations and other).

Each product sample image processing control creates some specific problems of highly-accurate measurement related to the items 3D-photos quantum in the level of light intensity by calculating the color difference in frame elements in different spectral lines and color measurement models organizing the parallel functionality of multi-core calculation environment, which is used to restore the item volume structure by uniting the video samples registered in different views and other. One of the most effective
systems to control a CPP engaging machine vision technologies so they unite the image detectors and CPS regulators closed through the video tide data processing loop in the reverse connection channel.

To integrate video detectors, video processors and control nets to support the technological process they provide the measurement repeatability with necessary metrology characteristics in the automatic production conditions sufficient to control the item being manufactured quality in mass. The item parameters CPS visual control is done to detect and isolate any piece of scrap — items, which properties are different from the established in the design documentation. The machine vision technology requires to compare in each production process step the photos registered with digital (colored) cameras with reference item images stored in a database by means described in the industrial object knowledge base. Being rendered as a scrap with the given quality criteria such item is taken away with manipulators from the bunch, which is moving through the conveyor line and is given to the sort-out. The CPS information, measurement and controlling channels scheme engaged with machine vision means is given in figure 1.

The item representation to be inspected is formed by combining different image parts received in real time from the digital cameras focused on the product being manufactured. The volume shape geometrical model restoration is done with the item angle positions in comparison to stationed cameras. The necessary for increased photo accuracy specter of the item external illumination is done with a system of semiconductor providers, which form in the being researched surface the artificial illumination (a pulse of light) with the required energy characteristics. The photos sequence with the angle image content relation forms a two-dimensional (multi-measured) video signal to be processed. The items position and orientation change by the CPS cameras position is done with the electromechanical actuator controlled with the calculation core.

The measurement process control system includes a set of digital cameras pre-calibrated for different spectral consistency of the external illumination source. To make the item surface defective structures be more detectable they use the semiconductor emitters, which light characteristics are given in warm, neutral and cold specters. The external illumination different consistency let search for the image properties anomalies (in comparison to the reference) received from the item surface with different proper color (gold, silver, aluminum, bronze, copper and other), which participates in the being registered photo color measurement coordinates formation.

3. The machine vision rendering

The item surface optical inspection is done in a closed volume of the CPS work chamber by photo visual
control received from a system of front and angle photodetectors in the condition of artificial illumination. A set of measured surface characteristics must be checked defined in the item circle view stipulated in speed characteristics with the machine vision tools solution capabilities. The technological chamber item rotation is done with servo actuator mechanisms and CPS control device, which let the visual control system make the volume shapes geometry 3D reconstruction with views of hardly accessible areas. The item being manufactured given points related to the CPS technological chamber coordinates system.

The item photo views are obscured and covered surface points received after multi time second reflection (distortion) of the light tide from the located in the CPS technological chamber perimeter semiconductors artificial illumination sources. The item local illumination visual model in the CPS technological chamber closed volume approximating the influence optical effects on the surface illuminations sums from all light sources, which is described with the rendering mathematical equation:

\[
L_o(x,\omega,\lambda,t) = L_e(x,\omega,\lambda,t) + \int f_i(x,\omega',\omega,\lambda,t)L_f(x,\omega',\lambda,t)(-\omega' n)\,d\omega',
\]

where \( \lambda \) - light wave length; \( t \) - time; \( L_o(x,\omega,\lambda,t) \) - emission amount of the necessary wave length \( \lambda \), coming alongside in the direction of \( \omega \) in the time of \( t \) from a given point \( x \); \( L_e(x,\omega,\lambda,t) \) - emitted light; \[...\,d\omega' \] - incoming directions semi-sphere integral; \( f_i(x,\omega',\omega,\lambda,t) \) - two-direction reflection distribution function (amount of emission reflected from the direction of \( \omega' \) to the direction of \( \omega \) in the point \( x \) in the time of \( t \) for a wavelength \( \lambda \); \( L_f(x,\omega',\lambda,t) \) - emission in the incoming direction in the wavelength \( \lambda \), to the point \( x \) in the time of \( t \); \(-\omega' n \) - the incoming emission absorption in the given angle.

The rendering model applies mirror and diffuse item surface reflection capabilities and CPS technological chamber construction walls, which can be seen in different angles of the optical monitoring views, which are obscured or turned to the light sources. Item rotation with changing of the reciprocal light source angle positions and surfaces being analyzed, which let include in the model the illumination background component and construction elements, which obstacle the view required for the analysis. The reflected light tides directed intensity character is formed and according to its position and optical properties the semiconductor light sources and being manufactured items surfaces are seen.

The rendering equation has no a fixed analytical solution. They use number methods and simplifications available for calculations in the CPS multi-core processor platforms. The light tide color measurement and energy characteristics are to be analyzed and calculated, which are reflected from the item surfaces placed in different distances from the semiconductor artificial illumination sources and the CPS technological chamber walls.

4. Conclusion
The results of the application of machine vision technologies associated with solving industrial problems are aimed at monitoring production equipment and quality control of the product manufacturing processes performed in CPS. Prompt corrective action is formed as a result of detecting areas of defective surfaces and eliminates the technological causes of defects.

The industrial CPSs with the machine vision function have an applicable task to control the item quality made in a CPP. The accurate item representation in a multi-process CPS environment is formed with photographic images reception technologies tools, which reflect the technological processes results. The photographing object information (details) are represented as dynamic scenes with shadowed and enlightened surfaces areas taken with 2D frames. The stereo-maps of the item profile geometry profoundness is synthesized after synchronization of several 2D parts of the general image with the laser scanning machine and program means and the item 3D images machine building.

The images taken with the CPS integrated industrial design digital cameras on a high photographic speed are to be analyzed in a tide. The machine vision system activation is done after each technological
operation is ended and it is an element of the item non-destructible control. A set of photoelectrical detectors transmit the surface video tide to the calculator without data compression, which through an algorithm evaluates and forms the item different characteristics. The surface photo taking process is accompanied with a flash of light created with an optical subsystem of the image grasping with the necessary level of illumination in the CPS chamber closed volume.

The combination of digital cameras and laser scanning in a single measurement sub-system connected to the servo control of the angle item rotation, which provides the best CPP item quality control with machine vision technologies. Reverse connection signals from a servo driver closing the processor loop, lateral vision sensors and turning mechanisms synchronize the item photographing process with an illumination flash generated with semiconductor emitters. The reverse connection channel unites the CPS technological chamber control system and the CPS optical measurement sub-system into a general automatic system.

The item photo images and stereo-maps analysis is done to detect in a random place some non-homogeneous surface sections corresponding to any calculated before technological defect property (in color, texture or a defective part surface illumination). The part defects in automatic CPP may appear after random events (failures) of the equipment functionality (during the technological operations completion), which unexpected change the item external appearance or its inner structure rendered as a scrap. Important for the product quality control in a CPS are the following elements of the machine technological vision:

- the item surface image energy characteristics improvement with a digital filtering of optical signals to increase the signal-noise ratio;
- the object contour edges marking (segmentation of semi-tonic images) with small sections of defective surfaces;
- the defective structure identifying given for the plot image fragmenting with general visual characteristics, which are different from the acceptable ones shown in the electronic design documents (item digital twin).

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