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Digital Object Memory Based Monitoring Solutions in Manufacturing Processes

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Abstract

Manufacturing processes monitoring is more than conventional machinery monitoring, it covers also a part quality monitoring and manual working processes monitoring. To explain it, a novel Digital Object Memory (DOMe) based model in automated surface roughness monitoring and data storage in turning is proposed. The model allows automated interaction between workpiece (WP) and machine tool using RFID based smart environment. As a result, WP on-board g-code for turning and machine tool based real time cutting signals are combined into algorithm to measure indirect surface roughness of WP. Moreover, surface roughness value for every cut can be stored on-board of WP to detect the WP history and quality all over the product life cycle. Also framework for DOMe based hand work station monitoring and assistance system is proposed. Smart environment creates compatibility between parts and products on working area to double check workers attentions and to give assistance to workers for avoiding mistakes.

Keywords: Digital Object Memory; quality monitoring; human-machine interaction; Cyber Physical Production System

1. Introduction

Conventional machinery monitoring gives the utility only in narrow field in the whole manufacturing process. More advanced approach is needed to merge different processes and specific products dynamically with monitoring sensors and assisting environment to achieve maximum productivity all over the manufacturing process. Cyber Physical Production System (CPPS) concept [1,2] introduces the application of Digital Object Memory (DOMe)

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[3,4] that paves the way into augmented reality. Mechatronics and information technology have been the main drivers of monitoring development in manufacturing. Information technology new solutions together with more accurate sensors have given the option to collect data about processes, to follow state of processes over the Internet and to take fast real time decisions. Machining seems to be always close to production managers, wherever they are located.

Manual work can be improved using state of the art monitoring solutions. Machine tool monitoring concentrates mainly to the parts quality and machine tool components condition. Machining quality is influenced by several components (gears, bearings, cutting tool, machine tool rigidity, machining environment), but all in all cutting tool – workpiece (WP) contact point carries the most sensitive data [5] in part quality point of view, which can be monitored visually [6].

Machining quality is slowly changing compared to human action. Workers tend to make mistakes in monotonous work, but in changing working situation they need extra time for adaptation. The bigger is batch sizes, the more automated machining processes are required. But in last decade one-offs and small batches started to pave the way. It means a company can produce thousands of products, which are all different, but only slightly. It makes easier to change parts and to produce scrap. Moreover, manual work sections need monitoring as protective equipment usage reminder. It is easy to forget protective mask in gluing, protective glasses in laser working or ear protection in cutting. Nowadays, collecting of historical statistics is not the main idea of monitoring; instead, it is a tool for quality assurance. Its functions are rather to avoid reworking and wrong movements by giving real time feedback. Automatic assistance system with monitoring doubles the efficiency. Reminders and instructions, which are context sensitive, are the main force of increasing human work productivity and seamless work flow in shop floor.

In CPPS the physical work flow is combined with digital information flow that is both, machine and human readable. CPPS application, Digital Object Memory (DOMe) is the element that improves interoperability in shop floor environment. It is like a diary that in one hand conserves an object related historical and provenance information, but in other hand, it keeps collecting new information. Maximum effect rises, if a smart environment allows to communicate these objects to each other and to assist machines and humans to act in more efficient way. DOMe with supporting intelligent environment and sensors form an environment called augmented reality.

The aim of the paper is to introduce and discuss CPPS application DOMe based novel monitoring and assistance system solutions in machining output quality monitoring and in manual work section seamless workflow assurance and in human protection. The paper is organized as follows. Section 2 introduces the concept of CPPS and its application DOMe. Section 3 proposes a novel solution for DOMe based automated surface roughness monitoring and storage in turning. Fourth section describes DOMe based manual work station monitoring and assistance system.

2. Concept of DOMe in CPPS

2.1. CPPS

The idea of DOMe has grown up from German government national program Industry 4.0 [7,8]. The goal of the program is to pave the way for fourth manufacturing revolution. The first manufacturing revolution took place at the end of 18th century, when the steam and fluids found their way as energy carriers. The source of the second revolution was electricity as energy carrier and mass production as result. The third revolution took place in 1970-s, it was carried by developments in electronics and information technology that lead to manufacturing automation. Today, CPPS is on focus of this program as next revolutionary phenomena in production environment that helps to reduce the cost of production.

CPPS outlook is to integrate physical production system with cyber (digital) production system in the level, where distinguishing one or another is fuzzy. It means they are merged together as fully functioning flexible system. The production system develops towards concepts of Internet of Things (IoT) and All-IP. IoT main idea is that soon 90% of computers are embedded computers, also in production environment. They are integrated into products and parts that seem unnatural today. All-IP carries the same idea that everything around have IP address and Internet access capability. It goes beyond a manual human leveraged simple unilateral control, where information flow goes through human as center of everything. Conventionally, a human starts interaction, but according the idea, the things could communicate with each other to improve the result.

CPPS needs intelligent environment for communication. For instance, according to IoT a package of milk can communicate with transportation truck air conditioner to regulate the temperature, if needed [9]. Later, in store, a customer can get access to the milk temperature history and can evaluate, if he wants this milk or not. In the same way, also in production environment drives, components and parts can communicate with each other to plan production in optimal way, ensure the quality, reduce reworking and save production information for possible recalls.

CPPS can be naturally built on service oriented architectures [10]. It means, in shop floor planning, the focus is on services and hardware is secondary. Services library would work as app-s in smart phones. One of the main challenges utilizing above described environment is compatibility between different machine tool components, parts, tools and products. Potentiality lies on open standards and semantic information presentation. Semantic programming languages like Web Ontology Language or RDF [11] can be used, which bases to provenance of objects and object groups mutual relationships [9].

2.2. Concept of DOMe

Concept of DOMe was first mentioned by W. Wahlster in 2007 [12]. DOMe is the fruit of CPPS development. It supports the idea of communication between products, machine tools and humans. DOMe has a structured storage place for object related information that supports information usage over the object life time. DOM comprises hardware and software components, which together provide an open and universal platform for capturing and interacting with the digital information of connected objects - including storage, documentation and provision of information concerning actions an object is or might be involved in [13]. It is defined as follows: DOMe denotes of repository of digital data, which is linked with a physical artifact, and which is continuously enriched with data from entities that interact virtually of physically with the artifact [14].

DOMe is sometimes also called Digital product memory, but the expression Digital Object Memory is more correct if the memory is attached already in raw material or WP phase, when it cannot be called product yet. The main developer of DOMe has been J. Haupert [15] from German Research Center for Artificial Intelligence.

DOMe focuses to the product service oriented automation in manufacturing environment. Conventionally, a process have been the most important to optimize production. DOMe changes every product unique, every product from batch can be recognized personally. That is actually true, for instance cutting tools are in continuous wearing situation and every next part have probably lower surface roughness quality, until next cutting tool change. Also material heterogeneous structure, human interaction and storage conditions play an important role in part behavior and life time.

Semantic DOMe bases on Extensible Markup Language, which is both- human and machine readable language. Object Memory Model (OMM) defines DOMe structure and it is W3C open standard [16]. The fastest and the most convenient solution is to store a memory directly on object integrated device, usually on radio frequency identification (RFID) tag. As RFID tags memory is limited, therefore large data sets need to be saved outside of the object, to the back-end system, which can be accessed by link. Back-end system can be hold in Object Memory Server (OMS) [17]. OMS manages many different objects memories. For access to the server, URL address is used that starts with object ID and ends with specific memory name. Fast access information as working parameters are recommended to hold on object and monitoring larger data sets, which are not so critical, in back-end system [18]. Since, some input information (like g-code of the part) is confidential for a company; it can be encrypted for other users.

In projects carried on so far, mostly passive RFID tags are used as information storage place [19] but also more expensive WSN (wireless sensor network) based solution has been proposed [20]. WSN gives more options as attached sensors can measure the product related parameters and activate alarms or switch lights in certain conditions. Also some RFID tags are already equipped with sensors, but they also need extra energy source that changes them more expensive and massive.

A passive ultra high frequency RFID system consists of a transponder, also called a tag, and an interrogator, also called a reader. The reader provides power via RF energy, commands via protocol, and timing. The tag consists of an IC (integrated circuit) and an antenna. The tag communicates by modulating the IC impedance, which changes the scattering characteristics of the antenna, which can be detected by the reader. For an RFID tag to operate, the IC must receive sufficient power to run the circuitry and provide enough backscatter signal strength for the reader to detect the response. Regarding several systems it can be assumed that the system is limited in the forward channel (reader to tag), and if the tag responds, then the reader will detect the response. As is common with many antennas, the bandwidth of an RFID tag is typically limited by the impedance of the antenna. The reactive IC impedance can further aggravate this problem [21].

DOMe can be used over entire product life cycle; sample has been brought about pizza life cycle [22]. In manufacturing environment, DOMe equipped object is capable to order its own working according to previously saved specification, to collect monitoring information during its working about physical parameters, time and used machine tools and equipment. After production it can monitor its stock and transportation conditions. In store or in customer hands, it has ability to introduce its provenance and quality. Finally, it can be helpful if it is need to manage recalls or development of production process.

3. DOMe based surface roughness detection model in turning

According to the concept of DOMe, it should hold the information related with product processing and should collect information in time of processing. One of the first DOMe based prototype solution was presented in Hannover Messe Industrie 2010 fair by Stephan et al. [23]. It describes the processing of dietary supplements. In this prototype, a product is basically complemented from limited number of modules. WP owns on-product information about its modules by stored codes and after processing it is complemented with production time stamp. There is also mentioned that after milling, all relevant information regarding the successful processing is transferred to the on-product DOMe and available to the following manufacturing steps. But what information is needed and how to collect it, is not mentioned.

In CNC machining, feedback about correct geometry according tolerances is important. But also many of the physical characteristics (vibration, temperature, acoustics, current consumption) can be classified as useful quality descriptive monitoring information. One option is to compare for instance temperature in working zone and try to find irregularity. Since temperature is relatively slow changing characteristic, it cannot detect sudden impacts, but only the trend. On the contrary, vibration and acoustics are influenced immediately, if an impact appears. But usually temperature, vibration and acoustics threshold values are not specified and it is hard to define them during small batches. Much more informative is surface roughness value that is always comparable.

Surface roughness can be indirectly measured by evaluating in-process signal, cutting parameters, insert radius and machine tool stability coefficient [24]. According the concept, WP DOMe contains its working information. If the storage capacity is sufficient, instead of special codes for modular CNC machining, full machine readable code (G-code) can be stored in DOMe. G-code comprises the information about cutting parameters and treatable surfaces with their geometry. In-process signal can be measured by sensors, but placing sensors with energy consumption into every WP, is inconceivable. Cheaper solution is to merge sensors to CNC machine tool or cutting tool and change information between sensors, WP, machine tool and cutting tool. Read/write passive RFID tags or chips in above mentioned things and RFID transponder with antenna in near field create an intelligent environment for data transfer.

3.1. Sample case with model

As follows, sample DOMe based CNC turning case is described and analyzed. A WP needs to be cut according to the drawing (Fig. 1). Bold line presents the part; dash lines present the cuts and WP geometry change. Four cuts are needed to achieve the part with required surface roughness. Cuts no 1 and 2 are rough cuts and their surface roughness is not important. Cut 3 must give 10 point average surface roughness (Ra) at least 3.2 and cut 4 accordingly Ra 1.6.

WP has on-board DOMe that is structured to header, table of contents and blocks (Fig. 2). Header contains specific order related ID for every product. Table of contents makes the structure understandable for human and recognizable for objects. Blocks are divided to metadata and block payload data. According to OMM, metadata is ID, name, format, creator, contributor, title, description, type, subject and link. All the metadata blanks do not need to be filled. Every block payload contains information about specific processing operation. In this case, block 1 contains information about WP geometry, material and physical properties. Block 2 is divided into two parts. Part A contains instructions for processing (turning) and part B will be stored after the processing with monitoring information. Compared with open standard OMM, blocks are divided into two parts, to separate original DOMe data and collected information in the course of lifecycle. The rest of the structure remains the same.

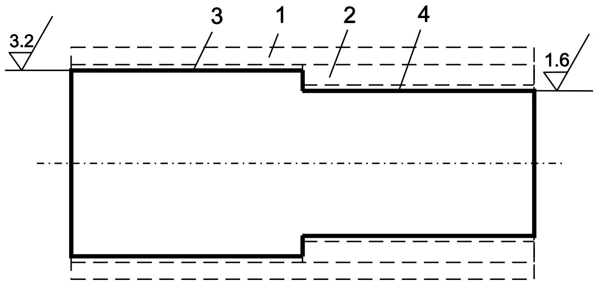

Fig. 1. Sample part cutting steps.

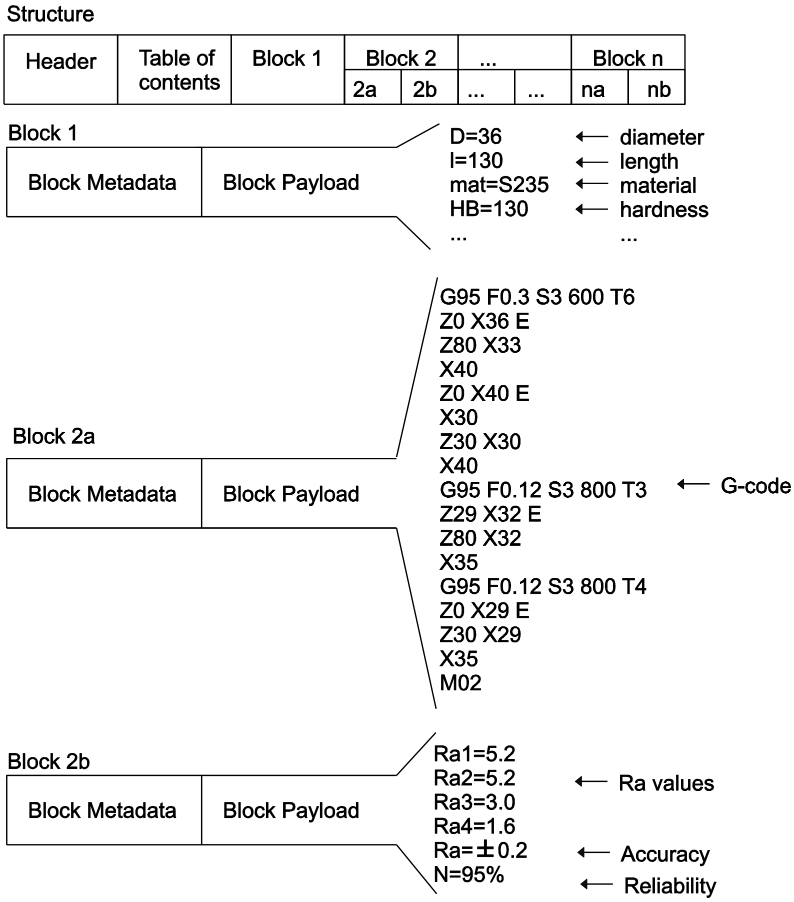

Fig. 2. WP DOMe structure.

In this case, block 2A contains g-code for the part turning. G-code shows that three different cutting tools are used to optimize tool inserts life time. First two cuts are rough cuts and their surface roughness result is not so important than removing enough material to be prepared for finishing cuts. For those cuts, fast and high productive tool is used. Subsequently, for cuts 3 and 4, two different finishing tools are used to achieve Ra 3.2 and Ra 1.6 accordingly.

If a cutting tool is placed to cutting position, intelligent environment activates a monitoring information transfer algorithm (Fig. 3). First, data is requested from WP and machine DOMe-s. According to received data, pattern is selected for surface roughness calculation. In the same time, in-process signal is sensed by sensors. If the signal is higher than specified silence level, it saves 0.25 sec signal for further analysis. Subsequently, analogue signal is converted to digital and Fast Fourier Transform is performed to make the analysis in frequency domain. Based on the signal and selected pattern, surface roughness is calculated continuously and saved to environment memory. Concurrently, calculated value is also displayed on screen to operator that has the biggest and fastest influence to the working process. If signal is measured as specified silence or lower, system asks if any surface roughness value has been already saved. If not, it means working is not started yet and loop is repeated. If yes, working is over, surface roughness values can be sent to WP DOMe into block 2B and loop can be stopped. To ensure the data flow, response from WP DOMe is asked about received data. Finally surface roughness values are deleted from environment memory. After turning operation, block 2B contains average Ra values for every cut, its calculation accuracy and reliability.

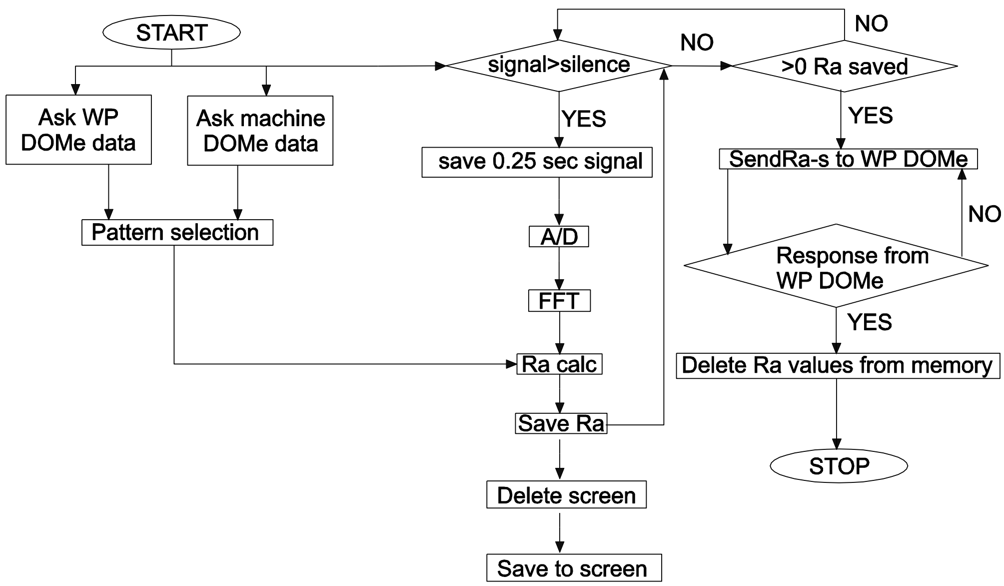

Fig. 3. Algorithm for interaction in surface roughness monitoring in turning.

3.2. Discussion

This solution helps to reduce the time of manual surface roughness measurement and save the quality values into the WP for the whole lifetime. It makes every part unique by its quality parameters. For instance in case of recalls, every part can be evaluated separately by customer according the manufacturer instructions and only potentially defective products are replaced, instead of full manufacturing set. Proposed model has potential in case of development of Flexible Manufacturing Systems, where introduction a new system to market still takes a time due to its complexity.

The solution was described theoretically, but implementation in shop floor needs further experimentation and deeper analyzes. For instance, G-code based solution is complicated to implement as it has more than 5000 different dialects. It means, basically every machine tool - CAM pair has different code. Hence, these codes do not differ completely. The most important, G and M code numbers still activate the same tasks, but one dialect adds row numbers, the other adds zero before one digit numbers etc. Important information as feed to estimate every cut time and theoretical surface roughness; rotation speed to choose the calculation pattern; and movement coordinates for cut counting and length are recognizable.

The other concern is suitable and reliable in-process signal feature extraction and analysis algorithm. Based on signal analysis, researchers have successfully worked out regression [25] and artificial neural network models (ANN) [26] to evaluate surface roughness, but their compatibility must be tested. Since regression and ANN models are based on large calculation sets, their eligibility for real time system must be tested.

4. DOMe based monitoring in manual work station

Machining operations have achieved a certain constant level in manufacturing and in last years it has not changed much. It is realized that everything cannot be fully automated and that humans still have an important role next to machine tools. Especially in changed manufacturing environment, with small batches and many one-offs. The smaller a batch, the more important is human presence. Humans are still more flexible than automated machine tools, but sometimes humans forget, mixe-up or misunderstand a task. For this reason, it is important to have an automated double check.

M. Schneider has described a case where a lady who needs to take medicals, gets a warning, if she wants to take pills with unsuitable drink [27]. This is DOMe use case in end user hands. Medicals and the drink both have a smart label with necessary information and dynamic environment with rules that allow context dependent assistance (ObjectRules) [28]. Also sample SemProM browser [29] has been built for this application. Similar context aware rule based assistance in manual work section would bring new certainty level in manufacturing. Innovative design methods are needed for building and evaluating such smart products [30].

4.1. Sample solution

This solution can be used in welding or gluing section. The principle is that every part, drawing, processing chemical/material and tool is equipped with DOMe that consist semantic information about its provenance and context based rules. Additionally, intelligent environment with access point needs to exist to provide energy and to provoke interaction between objects. Here, the meaning of provenance means an object material, ingredients and its physical and chemical properties. By knowing the materials, it can be checked if the parts can be welded or glued together. Additionally, welding electrode or glue suitability for these materials can be evaluated. To make this evaluation, context based rules are needed.

A context comprises three components: a user, objects and location. In shop floor, location defines the purpose, which processing will be used. According to knowledge about worker intensions, adequate rules can be used. Objects forward the facts about them shelves. Provenance information processing needs application knowledge to assist according to rules.

If worker enters to the environment, where protective equipment should be used, but worker does not do it, automatic assistance system gives an alarm. For instance, if on a gluing table is glue that contains toxic chemicals and protective mask cannot be found in environment, assistant gives a warning message.

All these rules can be either hard-coded or declaratively represented within knowledge representations. Knowledge representations are preferred if changes will occur on a regular basis [9]. For building repositories of knowledge representations, editors such as Protégé can be used. Protégé is an open-source platform that provides a suite of tools to construct domain models and knowledge-based applications with ontology´s. Protégé can be extended by way of a plug-in architecture and a Java-based Application Programming Interface for building knowledge-based tools and applications. Ontology describes the concepts and relationships that are important in a particular domain, providing a vocabulary for that domain as well as a computerized specification of the meaning of terms used in the vocabulary. Ontology´s range from taxonomies and classifications, database schemas, to fully axiomatic theories [31]. In

Protégé, Web Ontology Language (OWL) is used to describe classes, properties and their instances in semantic presentation (Fig. 4). In OWL, everything can be called Thing (materials, workers, properties). The glue contains certain chemicals. Sub class of Chemicals is ToxicChemicals that comprises list of toxic chemicals like dichloromethane. Thing ToxicMaterial is described as follows: ToxicMaterial is any Thing that has ingredient some ToxicChemicals. Having this semantic description in knowledge base, there is no need to describe fully every Thing, but just data about provenance (ingredients). If environment founds some material with chemical that is in list of ToxicChemicals, it searches protective mask DOMe from environment. If it is not presence, assistant gives a warning.

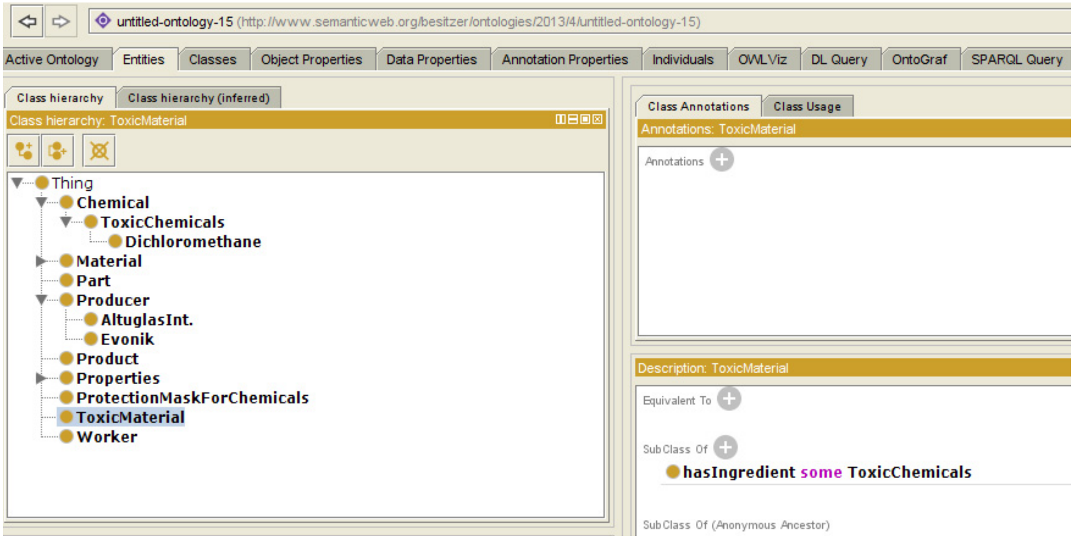

Fig. 4. OWL in Protégé platform.

In similar way, also processing suitability can be checked. If glue has knowledge about the materials that it is capable to glue and nearby parts material does not fit into the list, assistant gives a warning again to check the glue suitability.

Third hand work station possible application could be engineering drawing based. Engineering drawing memory in intelligent environment forwards the list of parts that are needed for a product. If some of the part in working environment is missing or some of them are unnecessary, automatic assistant system gives a notice. Last described application is crucial in production of one-offs, which have only slight modifications and for worker it is easy to change parts.

4.2 Discussion

This is theoretical solution, but it has great potential in CPPS. This solution facilitates production of small batches and helps to bring manual work back to developed countries. The aim is to achieve mass production like seamless work flow in small batches and one-offs.

Context, ontology and knowledge based monitoring with assisting real time feedback in manual work section provides information for fluent work flow. But implementation in shop floor needs preconditions. The broadcast area of intelligent environment is influenced by metals and it can cause noise. But this can be solved by using special Confidex Ironside™ tags that are not so sensitive with metals [21]. Implementing it in previously described way, needs uniform standard between different manufacturers and usage of DOMe on products. Also knowledge base enormous growth can damp down the idea by slowing down the interaction speed, which is essential to benefit the production. Above all, open standards are the bases for implementing such wide compatible system that across different production sectors and keeps the knowledge always up to date.

5. Conclusion

Automated communication and monitoring opportunities in shop floor are insufficient for seamless manufacturing of small batches and one-offs. Creating of RFID based intelligent environment spaces into shop floor, helps to bring the objects closer to each other by their interaction. One of the CPPS concepts, DOMe, is the tool for keeping all object related information in one compact and easy access storage place. As DOMe may also conserve the processing information, it can be used in quality monitoring in turning and for fault detection in hand work station. According to proposed model, surface roughness can be indirectly measured and stored in time of turning. In manual work station, workers mistakes can be cognitively pre detected and assistance provided to ensure seamless work flow. Proposed solutions help to save time of manual quality control and assure the process quality. So far, this is theoretical solution and experiments to support proposed models are next step of research. Proposed solutions have great potential, but there are also many obstacles that need to be solved to bring the implementation of the solution into reality.

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