The initial considerations and tests on the use of real time locating system in manufacturing processes improvement

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Abstract. Contemporary enterprises forced to compete on the global market actively seek methods that allow improving production processes. This demand resulted in the emergence of RTLS (Real-Time Locating Systems). RTLSs are considered an effective way to identify and track the location of objects in both indoor and outdoor environments. There is no established standard in indoor localisation, thus the selection of an existing system needs to be done based on the type of environment being tracked, the speed, the cost and the accuracy required. The RTLSs differs in terms of the type of technology used, positioning algorithm, accuracy and precision, complexity, scalability, number of tracked objects and costs. The article presents comparison of the most commonly used technologies of indoor real-time location, taking into account its possible applications in production engineering and process improvement. An example of RTLS, based on the UWB technology was also presented. The principles of the system operation, its main features as well as hardware and software components have been described. Preliminary tests of RTLS were also carried out.

1. Introduction

Nowadays, companies are still looking for methods to improve efficiency and reduce manufacturing costs due to globalization and increasing competition on the market. A vision of industrial development, according to which we are now at the start of the next, the fourth industrial revolution, referred to as the Industry 4.0 is currently promoted [1]. The earlier industrial revolutions were connected with mechanization (steam engine powered factories in the 19-th century), electrification leading to mass production in the early years of the 20-th century, and automation of the industry in the 1970s [2]. The European concept of Industry 4.0 means further development stage in the field of the organisation and management of the entire value chain process involved in manufacturing industry, similar concepts were proposed also in other parts of the world, under different names, like Asian concept of Intelligent Factory [3]. One of the main elements of Industry 4.0 is to ensure the flow of data to enable vertical and horizontal integration across the enterprise [4]. Transport and logistics systems in a company, often going beyond its borders, are a key enabler for acquisition of data on flow of all kinds of objects (materials, components, WIP, products, machines, means of transport, workers), within the company and outside its borders [5]. The companies strive to reduce operating costs and optimize their operations through intensive automation and robotisation [6][7], implementation of modern materials and production technologies [8], use of advanced design methods [9][10].
streamlining production planning and scheduling [11][12], as well as extensive application of modelling [13], risk assessment [14] and simulation methods before introducing changes [15].

The works dedicated to issues of arrangement of data acquisition in the industry were previously conducted [16], but did not take account sufficiently the issues of real time location of objects in production and logistics subsystems of enterprises.

The factor that can facilitate the optimization of various processes taking place in enterprises is the access to the real-time information on the location of various entities, e.g. mobile assets, workers, products, WIP, materials, key components, means of transportation, containers, etc. Location estimation is a crucial component in numerous applications. This demand resulted in the emergence of a new class of systems, referred to as RTLS (Real-time Location / Locating Systems). RTLSs are considered an effective way to identify and track the location of objects in both indoor and outdoor environments. The problem of outdoors location is solved for the majority of applications thanks to the availability of the GPS system and its European and Asian counterparts (GLONASS, Galileo, Beidou) [17]. Also many indoor RTLSs have been developed and made commercially available in recent years. There is no established standard in indoor localisation, thus the selection of an existing system needs to be done based on the type of environment being tracked, the speed, the cost and the accuracy required [18]. The majority of the localisation techniques can be classified as the active systems, due to the necessity of electronic devices (tags) carried by the person being tracked or mounted on objects in order to estimate their position, whilst passive localization stands for the locating of objects without the use of any devices [19].

The RTLSs differs in terms of the type of wireless technology used, positioning algorithm, accuracy and precision, complexity, scalability, number of tracked objects and costs. The article presents comparison of the most commonly used technologies of indoor real-time location, taking into account its possible applications in production processes improvement, also presenting their advantages and disadvantages.

An example of RTLS, based on the UWB technology, obtained for testing at the Integrated Manufacturing Systems Laboratory in the New Technologies Centre of the Silesian University of Technology was also presented. The principles of the system operation, its main features as well as hardware and software components are described. Preliminary tests of the accuracy of determining the position of objects in various conditions were also carried out.

1.1. The Industry 4.0 concept

The main goals of Industry 4.0 are to increase competitiveness, utilise opportunities and reduce risks, adjust talent and IT resources, develop potential for individual business segments and use impetus from exponential technologies [2]. These goals should be fulfilled through the transformation, based on nine foundational technology advances: Big Data i analytics (business intelligence), autonomous robots, modelling and simulation, horizontal and vertical system integration, The Industrial Internet of Things, cybersecurity, the cloud, additive manufacturing and augmented reality [20]. During this transformation, sensors, machines, workpieces, transport, logistics and IT systems should be connected along the value chain beyond a single enterprise. These integrated systems (also referred to as cyber-physical production systems, CPPSs) should be able to communicate with one another using standard Internet-based protocols and analyze data in order to predict failures and adapt to changes. Industry 4.0 should make possible gathering and analyzing data across machines and systems, enabling more flexible, faster and more efficient processes to manufacture higher-quality goods at reduced costs. Smart machines are able to continuously share information about current stock levels, problems or faults, and changes in orders or demand levels [21]. All modern solutions used in industry should create smart network of machines, ICT systems, smart products across entire value chain and the full product life cycle, forming entity called Smart Factory, cooperating with other CPPSs in its neighbourhood.
2. Real-Time Localisation Systems

In the context of Industry 4.0 the development of services based on location and rapid advancement in area of communication services has increased the researcher’s effort in a development of the localization systems. Location determination is one of the key features in the context-aware computing [22]. Real-time Locating (or Localisation) System (RTLS) is defined as combination of software and hardware used to automatically determine the coordinates of an object in real time within an instrumented area (e.g. person, materials, or equipment), allowing tracking and management. The data on location collected by RTLSs may be used not only for real-time purposes but also for further analysis and optimisation. First applications of RTLS allowed only outdoor positioning [23], but demand from potential users, requirements of industry and recent developments in RTLS have extended its application to indoor location tracking.

The GPS and other systems (e.g. GLONASS) are widely used for outdoor position determination, however it cannot estimate location in indoor environments due to the technology request for Line-of-Sight (LoS) when connecting to satellites, that can be difficult indoors. Accuracy of location systems based on another outdoor technology, GSM signal strength measuring, is insufficient for many applications. Thus various systems has been developed based on the proprieties of phenomena which can be used indoors. This class of localisation systems is the focus of this paper, because theory and applications of outdoor RTLS in transport and logistics systems are common, widely used and well described, while indoor RTLS are in the stage of development.

RTLSs can be used to obtain one of three categories of physical location: descriptive locations (sometimes referred to as location at choke or characteristic points), spatial locations and network locations [19]. A descriptive location is a location related to some geographic objects (e.g. mountains, lakes, cities, roads, buildings), that have a description such as name, identifier. The spatial location represents a point expressed by two- or three-dimensional coordinates in a Euclidean space, it is in applications where a descriptive location is not accurate enough. Network location is a type of location based on the topology of a communications network, where a client’s device position in a network is detected based on its Internet Protocol (IP) address or (in mobile networks) from the base stations used by the mobile terminal. In that case accuracy is also not sufficient for many applications in production engineering.

2.1. Classification of RTLS

Despite the fact that indoor location detection has become a crucial component in many applications, a common standard for indoor localisation does not exist yet. Systems based on many different phenomenon can estimate the position of an object with various accuracy. The choice of the technique to estimate location depend on application. It is necessary to choose the type of system which offers the accuracy required for a specific application. Location detection systems are a very important component for many applications such as asset tracking, health care, location based network access, games, manufacturing, government, logistics, industry, shopping, security, tour guides, and conference guides. Indoor RTLS can be classified into two categories [19]:

- **Active systems** – require tracked objects to participate actively. Active participation means that an object (e.g. person, mean of transport, package) is equipped with an electronic device (e.g. tag, transceiver) that sends information to a positioning system allowing detection of that object’s position. In some cases, these electronic devices can process data obtained from beacons installed in fixed positions, calculate its own relative position and send the results for further processing to an server application using this data in higher-level algorithms.
- **Passive systems** (using passive localisation) – the tracked object is not equipped with any electronic devices facilitating its position detection. The position (or presence) of object is estimated based on the variance of a measured signal or video analysis.

Location technologies can be classified according to the location positioning algorithm, the physical layer or location sensor infrastructure. Location sensing approaches can be classified into
main categories: triangulation, trilateration, hyperbolic lateration, proximity, location fingerprinting (scene analysis), and dead reckoning [19]. The metrics typically used in most of these approaches are: Received Signal Strength Indicator (RSSI), Time of Arrival (TOA)/Time Difference of Arrival (TDOA), and Angle of Arrival (AOA) or Direction of Arrival (DOA). Most of positioning technologies is based on radio frequencies communication, that can be used in standard network communication (wireless local area networks – WLANs, Bluetooth) or adopted to performing positioning tasks (Ultra-wideband – UWB, Radio Frequency Identification RFID). A few methods are based on other technologies and phenomena, e.g. ultrasonic, infrared. Figure 1 presents technologies that can be used in the active and passive tracking systems.

![Figure 1. Localisation techniques taxonomy [22].](image)

Because of many problems with obtaining precise indoor location in complicated environment (buildings with a lot of obstacles, e.g. machines, storage racks), causing signal interferences or masking of beacons in a Line-of-Sight requiring methods, and high number of located objects, hybrid location systems combining two or more techniques in order to improve the accuracy of the location estimation has become popular.

2.2. **Example RTLS applications in production engineering and management**

RTLS systems can be used in many different fields, such as transport and logistics, warehousing, production, construction (civil engineering) [23], health care [24], agriculture, animal breeding and many more. Numerous tasks descriptions are available in the literature, which can be implemented better thanks to RTLS support. In healthcare, RTLS allows to obtain information about the location of patients, medical staff and medical equipment, which, in turn, allows to quickly find them or conduct use analyzes [25]. RTLS can also support navigation in public buildings - offices, museums, company headquarters, and also enable access control.
In the transport and logistics systems, it is possible to track objects in warehouses and transport network, and in this case it is generally necessary to use the combination of systems operating indoors and outdoors (usually GPS) [26]. Another example - Animal Welfare System built on RTLS allows cows to be tracked around barns, movement can be analyzed for health information, RTLS improves animal health and farm productivity.

For production systems RTLS applications, the following options provided by RTLS can be listed:

- Provides central overview and control of process state [27], example 1: in car assembly system RTLS tracks both vehicles being assembled and tools, detecting when a power tool is brought close to the vehicle; the required tool program is obtained from the MES using the VIN and sent directly to the IBS Tool Controller to program and enable the tool;
- Ensures correct pacing of component work items for final assembly; example 2: system tracks the vehicles as they come ‘off-line’ and move through specific process stages (rolling road, wheel alignment, paint inspection, etc.); defined rules specify the process order and dwell time thresholds (time spent in a step); exceptions trigger alerts visible to shop-floor operators and reported on intranet [28]
- Allows Process monitoring across multiple factory sites, automatically updates ERP system, scheduling tools or any other IT systems [28]
- Allows creating dynamic spaghetti diagrams [29]
- Records time spent in maintenance, provides real-time asset management [26]
- Health and safety - access control to hazard areas, even in metallic, highly-obstructed environment; automatic check-in and check-out, last known position assists rescue teams [17]

Also the expected accuracy of the system, the need for direct visibility between the transmitter and the receiver (Line of Sight), the speed of getting the location, the ability to locate objects moving at different speeds and resistance to interferences and other inconveniences in the environment in which the system will be used, depends on the specific application. If RTLS is used to support production management or asset management, an accuracy of 0.1 - 1 m is sufficient, which is, however, insufficient to control autonomous robots or vehicles.

It should also be decided whether it is sufficient to determine the location in the choke points (in this case, there is no information about the location of objects that are not in the range of sensors or the system has only information in which room or section of the production line the object sought without exact knowledge of coordinates) whether there is a need to determine the coordinates of the object in the local coordinates system [22]. In the case of location in choke points and the need for high accuracy, it is necessary to install a large number of sensors (or RFID tags if the sensor moves along with the object whose location is determined). RTLS operating in local coordinates usually require fewer sensors (or anchors), but tags attached to objects being localized are usually more expensive.

3. Analysis of RTLS requirements for manufacturing management support and production engineering

Based on previous works and applications, it is possible to specify the features that RTLS for production engineering should possess. When considering the RTLS requirements for management support and production engineering, the characteristics of the needs in this application class should be taken into account. Features that should be considered are listed below:

- the type of objects whose location will be determined
- the required positioning accuracy
- the ability to identify and differentiate identical objects
- frequency of refreshing location information, locating objects moving with different speeds
- the need for continuity of location determination
- the need to provide a line of sight, immunity to interferences
- the cost of the system
3.1. The type of objects whose location will be determined

The location system should make it possible to determine the location of, among others [30]:

- people (e.g. employees, clients, patients, guests) in order to determine what work they do, establish a quick contact, navigate to a specific point, enable or disable access to specific areas (zones dangerous to people or prohibited for various groups),
- vehicles and mobile devices (cars, trucks, forklifts, robots, transport trolleys, conveyors, AGVs),
- high-value devices that can be moved and lost in large buildings (they are not permanently associated with a specific location), e.g. welding machines, ultrasound machines and other advanced medical equipment, advanced power tools,
- containers or pallets containing components, materials, raw materials, WIP, finished products; these facilities may be on the line or near the production line or in warehouses,
- products, work in progress or components,
- animals in farms.

3.2. The required positioning accuracy

As a result of literature analysis, it can be concluded that the accuracy of location in applications in production engineering should be within a range of several centimetres to several meters. Of course, positioning systems with higher accuracy are better, because they allow for more reliable results, but further increase in accuracy (below the range of centimetre) does not make sense, because the location information is not used for direct control of accurate positioning (e.g. robots). In turn, systems operating with low accuracy (allowing to determine the location within a dozen meters or the presence of the object in a room or zone) may not be sufficiently accurate for some applications in production engineering, e.g. detailed analysis of objects moving to optimise traffic [26].

3.3. The ability to identify and differentiate identical objects

In production engineering applications, it is almost always necessary to distinguish between specific, identical or similar objects, the distinction between object classes only is rarely sufficient. This feature eliminates the majority of passive RTLSs, including vision-based systems (limited use of vision systems can be made possible by marking objects with special labels) [19].

3.4. Frequency of refreshing location information, locating objects moving with different speeds

In applications related to the optimization of object movement, the speed of some objects (e.g. means of transport, forklifts) and their location during the movement should be determined in near real time (though there is no requirement for continuity, some data can be interpolated), so RTLS should be able to determine the position of objects moving with a frequency of seconds or fractions of a second (however, it can still be a much lower frequency than in applications related to object control). This requirement usually does not apply to all objects covered by RTLS. It is advisable to be able to determine the position of objects with a frequency depending on the object class - in the case of objects moving at low speed or occasionally the refresh rate may be low, while objects moving at higher speed or continuously should be located at a higher frequency. Such a distinction also allows to increase the maximum number of objects that are tracked by the system (which can be very large in complex production systems) based e.g. on radio transmission, and to extend the life of batteries supplying active tags, which affects the cost of maintenance, as well as reliability of the system.

3.5. The need for continuity of location determination

In case of RTLSs used in production engineering, there is rarely a need to have fully continuous information about the location of the object with very high accuracy, since it is possible to approximate intermediate points, and in some applications intermediate points are not relevant if the path between the characteristic points is known. In some applications, there may be sufficient systems to determine the presence of objects only at characteristic points, but having only such partial
information usually does not usually allow conducting some analyzes and excludes certain applications. An examples of systems that determine the location in characteristic points are:

- production lines with a strictly defined track or conveyors; objects on them must pass through subsequent points or segments that detect their presence (based on e.g. RFID tags),
- access control systems for objects or zones that allow to determine the presence of an object in a room - sensors detecting objects are located on any entrances from a room or area; additionally, it is usually necessary to detect the direction of movement (inbound or outbound, whether the object enters and it leaves the room/zone),
- the most advanced systems based on a matrix of characteristic points (eg RFID tags) arranged usually in an array with a specific density depending on the required positioning accuracy, in the form of a matrix, in the floor of the room; the object whose location is determined is equipped with sensors detecting these tags, and, based on tag's unique identifier and location information of individual tags, it is possible specify the location of the object; such a system can be additionally supported by other technologies and sensors, e.g. encoders, acceleration sensors, etc.

3.6. The need to provide a line of sight
Production halls, office rooms and warehouses are an environment in which one should expect a large number of objects interfering, damping or being an obstacle between transmitters and receivers of signals of various types on which RTLS is based. This type of environment virtually eliminates many of the technologies listed in section 2.1 from production engineering applications - virtually all methods requiring direct visibility (line of sight) between the transmitter and the receiver, i.e. using visible and invisible (infrared) light and ultrasound. There are no technologies that are completely resistant to electromagnetic interference (electromagnetic noise, caused by industrial devices) and obstacles such as walls of rooms made of various materials, structural elements, large devices, and storage shelves. This necessitates the use of advanced algorithms allowing the interpretation of signals coming directly and reflected or suppressed, as well as the use of separate sets of sensors (base stations) or anchors, in individual rooms or groups of rooms covered by RTLS. In this case, the interferences between the system sections operating in different rooms should also be taken into account. Hybrid systems using different measurement techniques and different positioning algorithms (TDOA, AOA) are better suited for industrial environments and buildings.

3.7. The cost of the system
The savings from RTLS should cover the (often significant) cost of the system in a reasonable amount of time, so the need for investment in base stations, tags and software should be justified [31]. In order to minimize costs, it is possible to use location technologies that are based on existing infrastructure and already available devices, which ideally allows users to be located without the need to invest in equipment (usually software and location server purchase is enough). The object itself (e.g. a smartphone) can be equipped with appropriate software and determine its location relative to the base stations. An example can be RTLS based on wireless networks (Wi-Fi) and Bluetooth.

In the case of Wi-Fi, it is possible to use the typical access points of the existing network (which can be additionally expanded with access points specialised only for the location tasks) and mobile devices (e.g. smartphones, that are usually equipped with Wi-Fi modules) as tags (i.e. there is no need to use additional tags in the case of people's location, only other objects should be equipped with a Wi-Fi module with the appropriate software).

The situation is similar in the case of Bluetooth technology, but the range is smaller (~10 m) and it is necessary to install base stations (access points) or beacons, which, in the case of this technology usually are not present previously. Bluetooth can be used to locate in characteristic points (not in local coordinates), i.e. to detect the appearance of certain objects near the access point, as in iBeacon technology, used mainly for marketing purposes (e.g. providing users with personalized information and advertisements when they are within the reach of a specific base station [32]).
Such solutions, built on existing systems (Wi-Fi access points), usually provide the less accurate location (or only information about presence of an object in a small specific zone) than systems specialized for determining the location, but in many cases they are accurate enough to perform the tasks in the field of production engineering.

4. RTLS in the Integrated Manufacturing Systems Laboratory

Demand for the development of the RTLS concept and application resulted in adding another functionality to the existing Integrated Manufacturing Systems Laboratory in the New Technologies Centre of the Silesian University of Technology, created to carry-on research on data acquisition and integration of manufacturing systems with a business area in order to improve the management of processes taking place in companies. The laboratory was equipped with modern automation devices and advanced software, allowing research and development on the field of the acquisition of production data and integration of production systems with the business area of companies [33]. It allows the conducting of research, as well as lectures and workshops for students specialising in production engineering and management, systems integration, Industry 4.0 concept or industrial automation [34]. The problem of the integration of the production system with the business area of a company plays a significant role in the Industry 4.0 concept [35][36], demanding i.a. interconnectivity of machines, systems, processes and products in "smart" networks [37][38].

The initial phase of RTLS implementation in the Laboratory includes installation and configuration, followed by tests and development of applications for the commercial Ubisense RTLS system.

4.1. Ubisense RTLS as an example of Real Time Location System

Ubisense RTLS [39] is a commercial 3D location estimation system, using both Time Difference of Arrival (TDoA) and Angle of Arrival (AoA) of the the UWB (6–8 GHz) pulse transmission in order to estimate the location of a specific active tag (Ubitag), that use RF signal (2.4 GHz) to coordinate transmission time (figure 2).

![Ubisense RTLS Diagram](image)

**Figure 2.** Ubisense Dimension4 RTLS [39].

Precision of Ubisense is high enough for most transport, storage and logistics applications, approximately 15 cm (6") for 95% of the readings due to the use of the active tags signal triangulation. The main components of a Ubisense systems are: sensors, tags and the software platform. The 3D location of an Ubitag does not require Line-of-Sight due to the UWB technology – the signal is filtered and processed in order to minimise the multipath effect. Ubisense can cover large areas and offers the possibility of tracking a large number of objects in real-time. The system works similarly to
a cellular network, where the covered area is organised into cells with at least four sensors. Ubitags are designed for use in harsh industrial environments, optionally comes with a GPS option, allowing hybrid outdoors location. Range of available tags includes asset tags, personal tags (for workers, visitors, patients), tags for dangerous environments, industrial rugged tags, modular tags (small tool tags, designed to fit on industrial tools, can be powered from the tool). Battery of a typical tag should last up to 5-8 years at a 1 Hz update rate.

4.2. Installation and initial tests

The main components of the system installed in the Laboratory are (figure 3):

- a set of 4 RTLS Series 7000 Ubisense sensors, allowing determination of the position of tags in the area of maximum 100 x 100 m (in the absence of obstacles blocking or deflecting UWB radio signals) using AOA and TDOA methods; any of the sensors can be configured as a master,
- 15 RTLS tags with their own power sources,
- communication infrastructure based on PoE switch, ensuring communication and powering of sensors, each sensor is connected to the switch and additionally the Master sensor is connected directly to all Slave sensors with wires ensuring synchronization of signals (timing),
- server with the Ubisense software suite installed.

![UWB RTLS block diagram](image)

After installing the software, it is necessary to carry out its configuration, including adding sensors to the cell, defining their relative placement (measurements should be taken with the required accuracy) and determining the configuration and role (master, slave) of individual sensors. It is also necessary to declare ranges of numbers of used tags and to specify time parameters of the frequency of the location, which allows declaring which tags can be refreshed with low and which ones with high frequency. After uploading the software to the sensors and their restart, RTLS platform should be calibrated in automatic or manual mode, which allows to tune system components to obtain the required accuracy. After the calibration procedure, RTLS system tests can be carried out - the Location Engine Config window with visible tag ID 250-000-013-066 located at coordinates X3,55 Y1,30 Z1,09 is shown in figure 4.

Initial tests showed the accuracy and repeatability of the system at a level consistent with the manufacturer's declarations (15-30 cm). In the future, more in-depth tests will be carried out to determine the possibilities of locating moving objects and the impact of obstacles and disturbances in the laboratory environment.
5. Conclusion and further research directions

Wireless indoor localisation has recently become an important research subject because of significance of data acquisition in a context of Industry 4.0, filling an informational gap between workfloor, transport or logistic systems and management of the company. RTLSs allow to obtain data automatically from previously non-automated parts of a company, that are crucial for proper operation optimisation and management.

Many researchers and developers have focused on hybrid location systems combining two or more techniques in order to improve the accuracy and precision of the location estimation, allowing more precise and error-free location indoors and, in some cases, integrating indoor and outdoor location information that is very important in logistics applications.

Thanks to RTLSs user is able to know the location (and in some cases status) of every product, mean of transport, worker, critical production asset, etc. It is possible to easily find the specific objects needed to meet current objectives, make objective decisions based on real-time or processed data, eliminate manual production status checks, automatically identify and locate process performance issues, enable managers to proactively maintain production flow, prioritize tasks and optimize asset utilization. RTLSs can reduce risk of errors and rework, enable total traceability and compliance and increase efficiency.

The cost of solutions offering insufficient accuracy of location is high because these systems are still in development stage and there are no established standards, that could increase competition in the RTLSs market. For applications that do not require very high location accuracy, systems working partly on the basis of existing infrastructure (e.g. WiFi, Bluetooth, RFID) can be used, which will significantly reduce the cost of implementation due to reduced hardware needs and the use of standard solutions, often pre-existing or used for other applications (e.g. Internet access through WiFi). The selection of a localisation system depends on the accuracy and granularity required for a specific type of environment.

It is planned to conduct further RTLS tests, e.g. to determine the possibilities of locating moving objects and the impact of obstacles and disturbances in the laboratory environment. Software will also
be developed, allowing to obtain data useful in production engineering and production management support from RTLS.

6. References
[1] Paszek A and Wittbrodt P 2015 The method of building a knowledge management system in a manufacturing company. *Int. J. Modern Manuf. Technologies* **VII** 1/2015
[2] Schlick J, Stephan P and Zühlke D 2012 Auf dem Weg zur 4. Industriellen Revolution. *IM - Fachzeitschrift für Information Management und Consulting*
[3] Sękala A, Kost G, Dobrzanińska-Danikiewicz A, Banaś W and Foit K 2015 The distributed agent-based approach in the e-manufacturing environment. *Mater. Sci. Eng. 95* 012134
[4] Kempa W M, Paprocka I, Kalinowski K, Grabowik C and Krenczyk D 2016 *Communications in Computer and Information Science* **639** 464-475
[5] Gwiazda A, Sękala A, Monica Z and Banaś W 2014 Integrated approach to the designing process of complex technical systems. *Advanced Materials Research* **1036** 1023-1027
[6] Banaś W, Sękala A, Gwiazda A, Foit K, Hryniewicz P and Kost G 2015 *IOP Conference Series: Materials Science and Engineering* **95** 012099
[7] Foit K 2014 Controlling the Movement of the Robot’s Effector on the Plane Using the SVG Markup Language. *Adv. Mater. Res.* **837** 577–81
[8] Adamiak M, Czupryński A, Kopyś A, Monica Z, Oleneder M and Gwiazda A 2018 The properties of arc-sprayed aluminum coatings on armor-grade. *Metals steel* **8** 142
[9] Ociepka P and Herbuś K 2016 Application of the CBR method for adding the technological process designing. *IOP Conf. Ser.: Mater. Sci. Eng.* **145** 022030
[10] Ociepka P and Herbuś K 2016 Application of CBR method for adding the process of cutting tools and parameters selection. *IOP Conf. Ser.: Mater. Sci.* **145** 022029
[11] Krenczyk D and Skołud B 2014 *Applied Mechanics and Materials* **657** 961-965
[12] Paprocka I and Skołud B 2016 *J. of Scheduling* doi:10.1007/s10951-016-0494-9
[13] Kampa A, Golda G and Paprocka I 2017 *Computers* **6**(1) **10** 6010010
[14] Burduk A 2015 *Advances in Intelligent Systems and Computing* **368** 427-437
[15] Foit K and Świder J 2005 The use of networked IPC techniques in hybrid description of a simulation model. *J. Mater. Process. Technol.* **164**–**165** 1336–42
[16] Ćwikła G 2016 Manufacturing information acquisition system methodology as a tool supporting data acquisition for production management, *IV International Scientific Technical Conference PRODUCING 2014*, 8-10 December 2014, Poznan, Poland. Selected Conference Proceedings Poznan Univ Technol (Springer) 44-56
[17] Lin C-Y, Hung M-T, Huang W-H 2012 A Location-Based Personal Task Management Application for Indoor and Outdoor Environments. *Network-Based Information Systems (NBiS), 2012 15th International Conference on* DOI: 10.1109/NBiS.2012.108
[18] Adler S, Schmitt S, Wolker K, Kyas M 2015 A survey of experimental evaluation in indoor localization research. *Indoor Positioning and Indoor Navigation (IPIN), 2015 International Conference on*, DOI: 10.1109/IPIN.2015.7346749
[19] Deak G, Curran K, Condell J 2012 A survey of active and passive indoor localisation systems. *Computer Communications* **35** 1939–1954
[20] Rüßmann M, Lorenz M, Gerbert P, Waldner M, Justus J, Engel P and Harmisch M 2015 Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. https://www.beperspectives.com/content/articles/engineered_products_project_business_in industry_40_future_productivity_growth_manufacturing_industries (acc. 10 November 2015)
[21] Deloitte 2014 Industry 4.0. Challenges and solutions for the digital transformation and use of exponential technologies, http://www2.deloitte.com/content/dam/Deloitte/ch/Documents/manufacturing/ch-en-manufacturing-industry-4-0-24102014.pdf (acc. 25 January 2016)
[22] Pirzada N, Yunus Nayan M, Subhane F M, Fadzil Hassan and Khan M A 2013 Comparative Analysis of Active and Passive Indoor Localization Systems. *AASRI Procedia* **5** 92 – 97
[23] Li H, Chan G, KwokWaiWong J and Skitmore M 2016 Real-time locating systems applications in construction Automation in Construction 63 37–47
[24] Liu C, Xiong H, Papadimitriou S, Ge Y and Xiao K 2017 A Proactive Workflow Model for Healthcare Operation and Management. IEEE Transactions on Knowledge and Data Engineering Vol.29, Iss. 3, March 1 2017
[25] Pancham J, Millham R and Fong S J 2017 Evaluation of Real Time Location System technologies in the health care sector Computational Science and Its Applications (ICCSA), 2017 17th International Conference on
[26] Kelepours T and McFarlane D 2010 Determining the value of asset location information systems in a manufacturing environment. Int. J. Production Economics 126 324–334, doi.org/10.1016/j.ijpe.2010.04.009
[27] Um J, Srinivasan R, Thorne A and McFarlane D 2015 Smart tracking to enable disturbance tolerant manufacturing through enhanced product intelligence. Industrial Informatics (INDIN), 2015 IEEE 13th International Conference on, DOI: 10.1109/INDIN.2015.7281932
[28] Jiang J, Guo Y, Liao W, Li S, Xie X, Yuan L and Nian L 2014 Research on RTLS-Based Coordinate Guided Vehicle (CGV) for Material Distribution in Discrete Manufacturing Workshop. Internet of Things(iThings) 2014 IEEE International Conference on and Green Computing and Communications (GreenCom) IEEE and Cyber Physical and Social Computing(CPSCom) IEEE
[29] Gladysz B, Santarek K and Lysiak C 2018 A case study of pilot RTLS implementation. Advances in Intelligent Systems and Computing Dynamic Spaghetti diagrams. 637, DOI 10.1007/978-3-319-64465-3_24
[30] Ma X, Liu T 2011 The application of Wi-Fi RTLS in automatic warehouse management system, IEEE Proceeding of the IEEE International Conference on Automation and Logistics (ICAL) Chongqing China, August 2011 64-69
[31] Mohebbi P, Strouila E and Nikolaidis I 2017 Indoor Localization: A Cost-Effectiveness vs. Accuracy Study. Computer-Based Medical Systems (CBMS), 2017 IEEE 30th International Symposium on, DOI: 10.1109/CBMS.2017.126
[32] Posdorfer W, Maalej W 2016 Towards context-aware surveys using Bluetooth beacons. Procedia Computer Science 83 42-49, doi.org/10.1016/j.procs.2016.04.097
[33] Ćwikla G and Foit K 2017 Problems of integration of a manufacturing system with the business area of a company on the example of the Integrated Manufacturing Systems Laboratory. MATEC Web of Conferences 94 UNSP 06004
[34] Skołud B, Krenczuk D, Kalinowski K, Ćwikla G and Grabowik C 2016 Integration of manufacturing functions for SME. Holonic based approach. Advances in Intelligent Systems and Computing 527 464-473
[35] Sękala A, Ćwikla G and Kost G 2015 The role of multi-agent systems in improving performance of manufacturing robotized cells. IOP Conf. Ser.: Mater. Sci. Eng. 95 012097
[36] Sękala A, Gwiazda A, Foit K, Banaś W, Hryniewicz P and Kost G 2015 Agent-based models in robotized manufacturing cells designing. IOP Conf. Ser.: Mater. Sci. Eng. 95 012106
[37] Hozdić E and Jurković Z 2016 Cyber structures for network production systems. Int. J. Modern Manuf. Technologies Vol. VIII 1/2016
[38] Hozdić E 2015 Smart factory for Industry 4.0: a review. Int. J. Modern Manuf. Technologies Vol. VII 1/2015
[39] Ubisense. Industrial Real-Time precision 3D location, https://ubisense.net/en/products/rtls-platform (accessed 25 January 2016)