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# Real Time Locating Systems for Human Centered Production Planning and Monitoring

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**Abstract**: Production companies often operate in a dynamic and volatile environment. This leads to an increasing demand for continuous changes in their production systems and processes. Furthermore, decreasing product life cycle times and rising market demand for product variety and individualized products is bringing about the necessity for the monitoring and coordination of processes in the operations phase. As a result of these developments production management is facing new challenges in decision making for the optimal settings of the production system design and the related coordination of production. All of this demands enormous efforts to maintain a consistent and reliable database for the ongoing configuration and coordination of the production system. It is thus a remarkable challenge for industrial companies. Real time locating systems (RTLS) with their ability to continuously monitor the current position and parameters (speed, direction, etc.) of process resources (operators, equipment, products, etc.) offer several potential benefits for the manufacturing industry. The potential areas of application can be identified in different layers of production management. They range from data acquisition on shop floor level through reconfiguration of production systems to providing real time feedback for the blue collars. Furthermore, it allows dynamic coordination of production orders for industrial plants via appropriate digital twin (DT) technologies. This paper proposes an original framework for RTLS in industrial environments and presents a case study for framework application at the TU Graz Learning Factory.



*Keywords*: Production planning & control, human centered design; digital twin, real-time feedback; RTLS;

## 1. INTRODUCTION

Manufacturing companies face the challenge of continuously improving and adapting their production systems in planning and operation due to the evolving context conditions (Mourtzis 2016). The isolated search for local optima at factory level is currently the dominant approach in manufacturing system optimization (Friedli *et al*. 2014, Ferdows 2014, Schuh *et al.* 2014). This trend is mainly related to high degrees of processes' complexity, the number of variants involved and the tremendous interconnectivity of processes and sites in existing industrial networks (Ulsrein 2016). However, a suitable data base for manufacturing system optimization and control is frequently considered solely on a highly aggregated level. Since time related data about process levels are frequently either not available or only considered in process design, several planning premises and assumptions have to be integrated in the decision making for production reconfiguration (Auberger *et al.* 2021). A basic requirement to be able to select the right option in complex manufacturing networks or systems is the transparency of factory processes (Lanza & Treber 2019). Providing data of this kind is a particularly difficult challenge especially for those manufacturing systems where the human still plays a pivotal role (manual assembly systems, discrete logistics, high product variety, low standardization etc.). In this case the optimization and control of manufacturing systems is a challenging task which should consider high complexity and uncertainty of human behavior (Ruppert & Abonyi 2020). Where full automation is not feasible or economically viable, human workers still remain central actors in industrial environments (DeLooze *et al.* 2016). However, most production planning and control models do not consider the human operator factor in production system design and coordination (Frazzon et al 2020). To include such factors into these models, human centered key performance indicators (KPI) are of extreme importance to be measured. The Human Resource Efficiency (HRE) as KPI represents the percentage of time in which a qualified worker (operator, technician, support) performs value adding activities. In this context, the primary modelling tasks are related to the analytic measurement of the working times that contain all the relevant work steps as e.g. material handling and assembly. (Ruppert & Abonyi 2020) To provide a suitable database for planning and decision making in such production systems the implementation of technologies for collecting real-time data is crucial (Schäfers *et al.* 2019, Mundt *et al.* 2019). The recent technological improvements in the sector of real-time locating systems (RTLS) offer new possibilities to gather and leverage such data fostering transparent manufacturing system design and control. Since in literature there are few applications RTLS-based aimed to digitalize a production process where

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the mutual collaboration between automated resources and workers is strategic, this paper proposes an original framework to better integrate these two entities and thus achieve higher in-plant performances. On one hand, by feeding structured and reliable dataset collected by the RTLS into digital twins (DT), automated processes may be optimized through closed feedback loops. On the other hand, early warnings may adequately notify to human operators their inefficiencies and potential changes on the monitored process. Finally, the prosed framework is validated in a real case study at the IIM Learning Factory (TU Graz).

## 2. FUNDAMENTALS OF PRODUCTION SYSTEM DESIGN AND CONTROL WITH RTLS

Production system design includes the design of the production network and planning of manufacturing, assembly, logistics and the necessary support processes by leveraging a limited set of resources (Mütze *et al.* 2021). Relevant tasks comprise, on the one hand, the manufacturing system and plant design and, on the other hand, the ongoing production control (monitoring and coordination).

### *2.1 Production system design*

In Production system design, to address on a daily basis a performing decision-making process several managerial tools such as flow charts, spaghetti diagrams, Sankey diagrams, transport intensity matrixes or value stream maps are of crucial importance. All these tasks mostly exploit the time-dependent geometrical location of products, materials, employees, and equipment. However, during the design stages the gathering of the related data is generally quite effort-intense and time consuming and involves several challenges (data accuracy, estimations, etc.) especially considering low standardized or variable processes (cf. Grundig 2016).

### *2.2 Production system control & monitoring*

Production system control comprises all short- and medium-term activities (e.g. product scheduling, capacity adjustment) aimed to optimize the production system with regard to high capacity utilization, short lead times, low inventories and high delivery reliability. A continuous monitoring of such complex systems may provide structured data upon which identify possible deviations from planned states and optimize processes. (cf. Slack 2019)

Solving problems related to control and monitoring of production systems is a traditional research area where several computer-based approaches are proposed. The detailed and dynamic complexity of production systems increasingly requires the application of sophisticated tools and methods such as discrete event simulation (DES), which is based on a set of variables and events that determine the movement of objects, the use of resources, and the state of machines. DES plays a central role in production system planning and control as it provides high precision representations of production processes. (Ruppert & Abonyi 2020) This precise and real-time representation of the production processes subsequently is the basis for the introduction of DT, which allow real-time control and adaptation of production systems. DT can be defined as simulation models that digitally reflect, the state of a corresponding physical model based on real-time sensor data. DT thus enable an adaptive optimization under a socio-cyber-physical perspective (Frazzon *et al.* 2020).

In the control phase, major challenges can be related to the monitoring of ongoing operations with a privileged focus on integrating human operator's interactions i.e. human centered production planning (Rácz-Szabó *et al.* 2020). This is particularly important where the human role in production is strategic, since human influence on process execution is often unpredictable and may lead to deviations from the planned process. Considering the pivotal role human operators will have in selected production and logistic systems during different phases (e.g. executing, coordinating etc.), they must be involved in closed feedbacks loops. Based on these loops early warnings can be generated by a DT approach as a targeted and straightforward information input for achieving this purpose (Gil *et al.* 2020). This approach may provide several benefits for the operator and the production system setup. At first, reconfigurations of processes are displayed in real time. This means shorter reaction times and thus reduced downtimes to comply with such modifications. Secondly, workers have continuous feedbacks on their performances, eventually, along with tailored instructions to enhance the execution of tasks. For instance, guidelines for a better positioning of components in the working station may be required to speed up the assembly process. Third, the continuous flow of feedbacks may reduce the impact of high turnovers of the qualified personnel. One hardware technology to display targeted feedbacks are smartwatches due to, among others, their adaptability (sounds, vibrations, etc.), ease of set-up and adoption rate. Considering these discrepancies and disruptions that may arise, system design and coordination is heavily relying on real-time data that serves as a facilitator for continuous updates of the planned states according to the performed closed loops. However, a requirement to implement such approaches is the collection of real time data on the shop floor which can be realized, among others, by using RLTS described in the subsequent section.

### *2.3 Real Time Locating Systems*

According to the trends described above, manufacturing companies have to smoothly redesign their processes and, best practices in order to face a volatile and competitive market. To achieve this purpose, the key challenge is to digitally interconnect automated processes between each other and also involve the dedicated human operators. RTLS offers a viable path to deal with such complexity and variability keeping in-plant performances constantly updated and reinforced at target levels. In the case of indoor environments, RTLS can determine the position bundled with the respective timestamp of any industrial entity equipped with a transponder (TN). TNs emit localizations signals with a given blink rate to the anchors (ANs) displaced in known positions of the monitored industrial layout. The signal received by ANs is thus transmitted by the gateways (GWs) through the LAN to the locating manager responsible for localizing entities (e.g. components, forklifts, human resources, etc.), responsible for localizing entities generally in two steps through tailored methods and algorithms (Siemens 2020). Moreover, indoor environments typically rely on non-line of sight (NLOS) propagation in which the signal transmitted cannot travel in a straight path from the TNs to the ANs. While over the years several technologies have been proposed, Table 1 lists a subset of them along with different distinctive features. The UWB represents the most performing technology due to its effective multipath resolution which protects signals from fading and jamming. This results in a very accurate estimate of the real-time location of any TNs (Mazhar et al. 2017, Gladysz & Santarek 2017).

**Table 1. RTLS and distinctive features (Sullivan *et al.* 2021)**

| Technology | Initial cost | Coverage area | Interference potential | Accuracy [m] |
|---|---|---|---|---|
| Wi-Fi | Medium/ High | High | High | Medium [3-4] |
| Bluetooth | Medium | Low/Medium | Medium/High | Medium [0.5-1] |
| Infrared | Medium | Low | Low/Medium | Low/Medium |
| UWB | Medium/ High | Medium/High | Low | Very high [0.15] |
| RFID | Medium/ Low | High | | Medium [0,5-3] |
| GPS | High | Outdoor | Not suited for indoors | Low [15] |

Digitalizing an industrial environment with RTLS strengthens three main aspects. On the one hand, benefitting from the dynamism and scalability of the presented technology different lean and management tools from value stream mapping to the production schedule (e.g. MRP) may be improved and constantly updated by structured and reliable data (Sullivan *et al.* 2021). Simultaneously, by leveraging data acquired by RTLS, factories enhance the traceability of industrial assets as a means of promptly reacting to unexpected plunges of efficiency in processes. This unique and innovative approach is enabled by simulating the processed raw data into digital environments (DES, DT). Relevant comparisons between physical and digital environments may exploit each unforeseen root cause. Third, travelling times and in more general terms, manual non-added value operations may be detected and reduced by in-plant navigation systems and early warnings (Sbaragli *et al.* 2021, Slovák *et al.* 2019).

### *2.4 RTLS industrial use cases*

RLTS has been used ever more frequently in recent years for supply chain management, healthcare and also for military, retail, postal and courier services (Ruppert & Abonyi 2020). For industrial use cases Rácz-Szabó *et al.* 2020 identified several areas of application for RTLS. They name (1) cycle time reduction through production control, (2) lead time reduction in logistics, (3) loss identification and worker guidance in quality management, (4) collision avoidance, real time warnings and contact tracing for safety management, and (5) efficiency monitoring and improvement (e.g. tracking of non-value adding times, overall equipment efficiency (OEE), individual human resource efficiency (HRE). Further potential is seen in RTLS as basis for IoT technologies, DT and efficient human machine interaction. Furthermore, Mütze *et al.* 2021. specified different use cases for RTLS in factory planning and operations consisting of (1) tracking products within a factory in real-time, (2) real-time material flow analysis for layout planning, (3) automatic recording of an existing factory layout, (4) tracking of moving objects, fleet control and contact tracing, (5) orders and material location and (6) real-time order tracking and monitoring. Concrete use-cases reported for the ultra-wide band (UWB)-based RTLS technology in the manufacturing domain include real time tracking of resource (workers, materials, key components, forklifts, pallets), automation of logistics work such as stock-taking, storage positioning and checking, improvement of picking accuracy and efficiency, automatic tool adjustment on assembly lines, and emergency evacuation planning and management (Rácz-Szabó *et al.* 2020, Umer & Mohsin 2020, Löckin *et al.* 2020). Moreover, RTLS has been used in other domains for e.g. tracking humans to improve patient care management, or in construction for theft, or collision prevention as well as ergonomic improvements (Umer & Mohsin 2020, Cheng *et al.* 2013). So far, however, only few researchers considered the potential benefits of RTLS for uncertain activities of human operators in production systems (cf. Ruppert *et al.* 2020). A further research need is thus reported for the area of human-centered production planning with RTLS (Rácz-Szabó *et al.* 2020).

## 3. FRAMEWORK FOR RTLS IN HUMAN CENTRERED FACTORY PLANING AND COORDINATION

The goal of this research is to exploit the role of RTLS where the role of human operators is strategic. This targets the design phases of a complex production system and an accurate monitoring and control of ongoing manufacturing processes

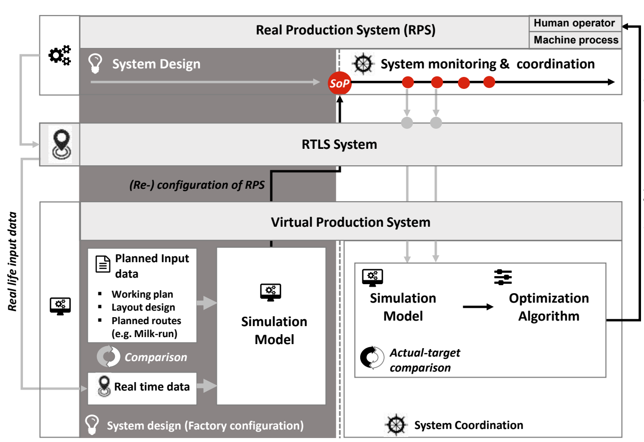


Fig. 1. Proposed RTLS Framework for human centered feedback

The developed framework (Fig. 1) structured around two distinctive conceptual paths outlines an original approach to feeds into a DT the structured data acquired by the UWB-based RTLS. Moreover, it targets any term of production from the short to long one.

The concept is built along the idea of designing an adequate RTLS technology (middle layer) as a link between a real (top layer) and a virtual (lower layer) production system. This configuration provides two distinctive functions. While it fosters real time, data based (re)configuration of the production system (system design, dark grey), it can supervise and assist human operators during task execution and system coordination (white). On the other hand, the system coordination track focuses on production monitoring and control in standard operation. In this stage, structured and reliable data acquired from RTLS continuously feed a tailored DT technology. Here, the engineered virtual environment replicates with high degrees of detail the monitored process. For this purpose, the aforementioned data are simulated into a simulation model in order to analytically compare the actual state of the monitored process with the scheduled/target one. Whichever unexpected deviation from the target state may be easily identified along with its respective root cause. This could for example be the case, if disruptions e.g. re-work or unplanned longer set-up or takt times occur during the process in the real production system which affect the performance for the following products. The continuously updated simulation model can be combined with an optimization module where different adaptions (e.g. process order, lot sizes, production schedule, etc.) can be developed and thus validated in a virtual environment. At this point, benefitting from the automated-data flow provided by the DT technology the most performing solution may be effectively implemented in the monitored manufacturing environment. However, any entity affected by such targeted modifications may be adequately updated or informed. While fully automated ongoing resources can be re-configured by the mentioned closed feedbacks loops, human operators have to be part of the centralized and automated decision-making process in a different manner. For this purpose, early warning may show the blue collars in real-time (e.g. via smart watches) any plunge of efficiency, or enhance the visibility of any issues occurring in the system according to performed closed feedback loops.

This straightforward information serves the purpose to suggest future reconfigurations of the process based on the mined and optimized real time data. In doing this, the plant workers are provided with all the information needed to perform their task with the highest efficiency. In the case of major deviations between actual and the target state, or a new product has to be integrated in the running production, benefitting from the factory configuration track the manufacturing setting can be re-designed multiple times in the virtual space using the new planned data merged and validated with data acquired from the RTLS system. The outlined approach to exploit an adequate DT technology provides different competitive advantages under different viewpoints. At first, feeding real data into simulations models disruptively increase the consistency of the decision-making process due to the possibility to either validate or forecast different scenarios. This result in lower costs to implement novel system configurations and in consistently reduced reaction time to unexpected and underperforming deviations. Secondly, through closed feedback loops and early warning the aforementioned industrial entities works in perfect synergy avoid any kind of disruptions driven by lack of information.

## 4 APPLICATION AT TU GRAZ LEAD FACTORY

The Learning Factory of Graz University of Technology has been operated by the Institute of Innovation and Industrial Management (IIM) since 2014 (Fig. 2). The didactic approach is performed in different setup states. First, participants work in the initial state where a customized scooter is assembled under sub optimal conditions (e.g. material flow, layout, production schedule, ergonomics, information and feedback for workers). Secondly, in the optimized state, the layout and setup of the factory is improved implementing corrections according to the lean principles (VSM, 5S, Flow, Kanban, etc.). Since 2016 many digital technologies such as augmented reality glasses, digital work orders, process control with RFID, human and process simulation etc. have been introduced to achieve an optimal factory design and control. Recently, a UWB-based RTLS system was adopted to validate the proposed framework for human centered work design. The mentioned locating system involves four ANs which cover an area of approximately 64 $m^2$ (see Fig. 3). In the defined coverage area, relevant industrial assets are equipped with a TN and thus tracked in real time. According to the aforedescribed industrial use cases, Accuracy and scalability were the important selection criteria for the localization technology used. The system thus makes use of UWB technology for several reasons. On the one hand, UWB technology enables real-time localization on centimeter-level precision. On the other hand, it allows a large-scale integration of TNs depending on their set update rates. The RTLS itself is built upon the hard- and software of Decawave's Module Development & Evaluation Kit. Moreover, a Linux host is setup as a gateway to route location data from these units to other connected devices. The RTLS operates with an application for network setup and node configuration and a developed application for collecting, processing and visualizing the data provided (Fig. 3 and Fig. 4). The pre-testing stage of TNs resulted in an overall positioning accuracy of 18.3 cm on average at best conditions under 11000 measurements. According to the suggested framework, both use cases targets the measurement of production data in which human operators are properly tagged.

Fig. 4: Initial state IIM LEAD Factory

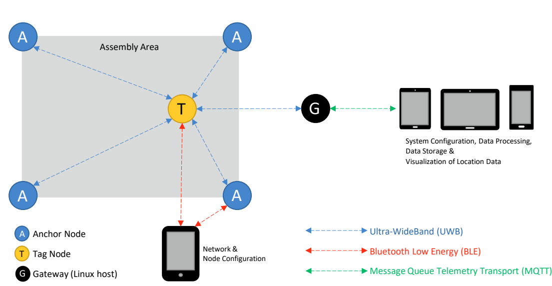


Fig. 2: RTLS system at IIM LEAD Factory

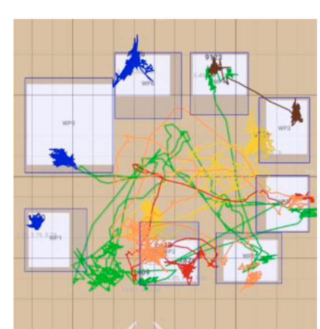

Fig. 3: RTLS based spaghetti diagram

Considering the first application, 8 candidates participated where the 3 of them were assigned to working fixed working station (blue TNs) while the others according to the planned productive cycle assembled the product in different spots (green, red, brown, yellow and orange TN). Fig. 4 represent the dynamic position assumed by the tagged workers during an assembly process of 17 minutes. Therefore, participants can feed into an adequate DES the structured data acquired by the proposed framework. Here, analytic and detailed comparisons between the actual and the planned stated are performed to optimize the material flow. According to the simulation results, a re-layout of the geofenced working station is required to slash production times and hence improve the productivity of the process.

In the following application, the RTLS monitors the takt times at the detail level of each working station per worker in order to derive improvement suggestions on the current assembly process (Fig. 5). Based on the different measurements a Gantt chart of the 17-minute production process is created based on the RTLS data. It visualizes the chronological sequence of production steps for each worker and workstation throughout the assembly run. In this context, each bar defines the exact time a tag was detected inside a marked region from entering until leaving. All relevant information for creating this chart were gathered from the app's exported history file. The chart provides relevant insights into the wasted resources on both, workload, and workflow of the production process. While the faster workstation can be finished in about 2:10 minutes (purple bars), assembly processes at WP2 accumulate for roughly 8 minutes on average. The empty spaces between the colored bars further represent inefficiencies within the workflow caused by waiting times for workers. For example, Worker 1 had to wait over seven minutes after leaving WP7 until WP2 became available. However, the initial testing also revealed some potential improvements of the developed application in terms of human influences (false measurements caused by unintended TN handling e.g. worker 3), influences of the work environment (movements caused by moving the tag on the workstation, inaccurate measurements caused by vibrations from tools e.g. work station 6) and filter settings (e.g. calculating the walking distance per worker based on comparing 2 consecutive positions of the tag with different 10 or 20 cm deviation).

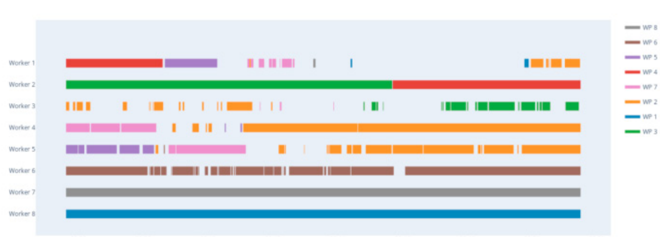


Figure 5: Gantt chart of work time per worker and workstation

Moreover, a comprehensive application of the framework is not now applicable, as at the current state there is no DT application for the assembly process and workers are not in the loop through early warnings. Nevertheless, the real-time data can be used to further optimize both, workflow and safety aspects within the production cycle, by providing targeted feedback and warnings or instructions based on a constant comparison between actual and target state. For this purpose, the current system already enables regions of interest to be marked on the virtual model. When operators stay inside a region for longer than the set cycle time, or the maximum person capacity of a workstation has been reached, the system gives haptic and auditive warnings to the operators on the shop floor. Further, waiting times and workflow congestion can be reduced by assigning workers to free working areas, instead of waiting for occupied workstations to become available. Furthermore, as safety measure, dangerous areas with e.g. heavy machinery can immediately give warnings in the event of entry attempts by unauthorized workers, as a safety mechanism. In addition, in case of a near accident logged relevant information can be post-analyzed for future improvements.

## 5. SUMMARY AND OUTLOOK

This paper proposes an original framework to optimize modern and complex production systems. The enabling technology is represented by UWB-based RTLS. This is designed to track any dynamic industrial entity in real-time. The unique possibility for equipping industrial layouts with the RTLS components results in a more accurate and structured dataset upon triggering a performing decision-making process. While RTLS technology is already used in industry the novelty is based on enabling mutual collaboration between workers and automation as a strategic element for ensuring long-term competitive operation in dynamic and volatile markets. Therefore, the RTLS is paired with DES models of real factories and connected to a DT simulation of the production processes to enable human centered closed loop feedback. Considering that discrepancies and disruptions may arise, a DT enabled closed feedback loop can set the target operative conditions from the viewpoint of automated processes and enables enhanced system design, control and monitoring. Furthermore, the role of workers is emphasized by collecting real time data about their locations and movements (system coordination). The usage of a RTLS system is particularly important here since human influence on process execution is often unpredictable and may lead to deviations from the planned process. Therefore, the framework defines a system coordination and monitoring track, where dedicated early warnings serve the purpose of constantly updating blue collars about the process performance and potential corrective actions for addressing inefficiencies. The corresponding simulation model can then be used to plan e.g., the factory layout or material flow routes or optimize workflow and safety within the production cycle. After the initial application and integration of the RTLS in the LEAD factory, next steps regarding this research will focus on the implementation of the DT to provide real time optimization assistance and human in the loop feedback. Further research should validate the outlined framework in real industrial case studies for two main issues. At first, identified challenges (see chapter 4) which might be present in real life use cases must be managed. Secondly, real production processes generally operate with a higher flow of products which have consistent interdependencies with each other. Moreover, to test the scalability and the dynamism of the framework different applications (e.g., production scheduling, material replenishment, etc.) and process configurations (e.g. assembly line, job shop, etc.) may be necessary to further validate its structure. However, in operating manufacturing processes to achieve a consistent commitment and thus a performing decision-making, the TNs assignment to human operators must be random to preserve their privacy. According to this, mined data serve solely the purpose to ease workers daily tasks and optimize processes strictly avoiding non-related working activities (e.g., time spent outside the coverage area during the shift).

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