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An overview of robot applications in automotive industry

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Abstract

The paper deals with an overview of industrial robot usage possibility in automotive industry which nowadays is the most important customer of industrial robotic market. The first part of paper describes the situation of industrial robot usage and offers an overview of application of robots in world industry. Later we deal with the most common applications of robots, especially in the automotive industry, as well as trends and perspectives on the future of automotive robotics. Finally, there was presented a model task from real industrial practice in form of specific project overview about robotized tightening of screws on the production line of car seats at the end of the article.

Keywords: industrial robot; robotics in automotive; production of passenger cars; transport and production; automated assembly line

1. Introduction

Robotics is one of the key branches of automation in general, and not only in the mechanical engineering industry. Industrial robots and manipulators have found their application in a wide range of tasks that can perform and where can replace human operators. In searching for a suitable and generally valid definition of "what exactly the industrial robot is", we encounter several specific complications, mainly based on differences resulting from the differences between the Euro-American and Asian (especially Japanese) markets. Robot is any mechanical / mechatronic device equipped with kinematic pairs (joints) with a certain resulting degree of freedom of movement, which is intended for

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manipulation of objects for "eastern markets". In contrast, the "western markets" are significantly stricter and they define the complex set of requirements for their control system performances as well as overall robot capabilities.

In addition, the evolution of robotics has been forcing different updates to its definition as well, Gonzales, (2003). For the purposes of our article, we can adhere to the definition derived from the International Organization for Standardization, which specifies the term robot as follows: *"Robot is any automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications."* (ISO 8373: 2012) This definition covers all key features of any industrial robot, such as ability to reprogramming - quickly changing the performed processes and desired motion trajectory via only a program change; multipurpose - versatility for different applications; three or more axes – capability of complex spatial motion in three dimensional space (in most cases also orientation around up to three axes); mobile - the possibility to extend the workspace via mobile robotic platform or at least so-called 7^{th} axis control, Uríček, (2014).

According to the main application possibilities, industrial robots can be divided into: Malega, (2012)

- manipulation robot - is the most common type of robot designed to perform operations related to changing position and orientation of objects (production machines tending, palletizing, transport of objects, etc.
- technological robot – is designed to perform certain technological operation (painting, welding, etc.).
- universal robots - is industrial robots that are able to perform several different kinds of tasks.
- special robots - is designed to perform one special task, Utsch, (2009).

Since the first industrial robot was installed into production in 1967, more than 2,800,000 of these devices have been sold worldwide up to this day. The range of these machines was later replaced by modern-generation robots. Contrary to the older-generation, they are more efficient, highly-capable (e.g. up to 10-times higher payload-to-weight ratio, nowadays coming closer to 1:1) and complex handling/technological devices, usually equipped by various cognitive and "intelligent" sensors which can help to navigate robots in difficult environment conditions or processes and avoid potential damage of manipulated items or robot itself.

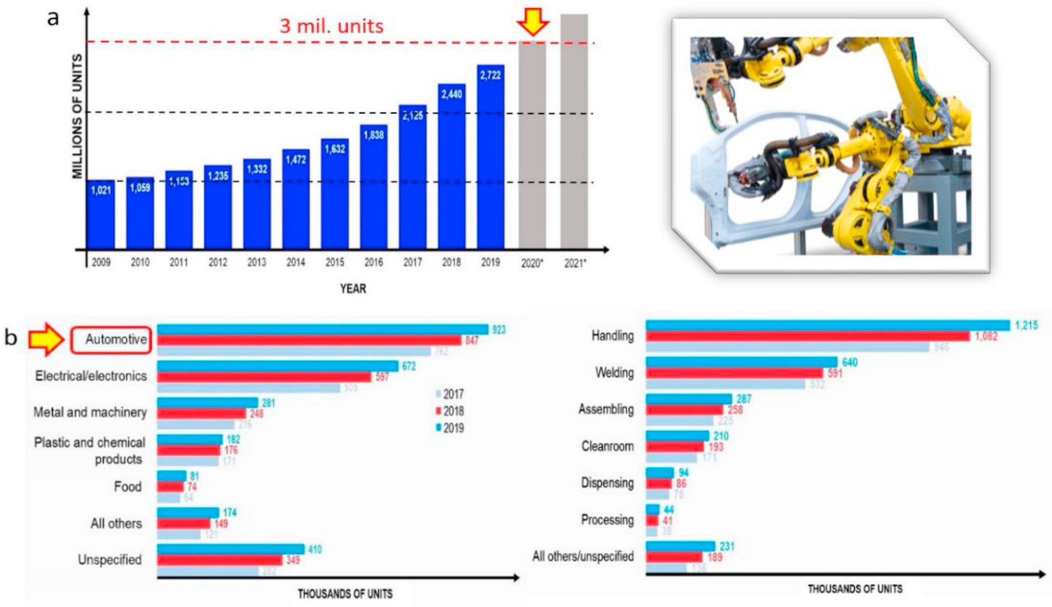

Fig. 1. (a) trend of worldwide operational stock of industrial robots in last decade / prediction to 2021 (based on data: IFR. 2020); (b) worldwide operational stock divided by industry (based on data: IFR. 2020); (c) distribution of robots in automotive / processes (based on data: IFR. 2020)

Here we can mention especially tactile sensors, integrated force-torque sensors, accelerometers, scanners, high performance cameras with fast pattern recognition algorithms and other cognitive sensors often equipped with deep learning functions for advanced decision-making as an example. It was assumed that by the year 2020 their number should have exceeded three million units (Fig. 1a). The number of robots has recently increased by an average of 26% per year. Assembling is one of the fields where automation and robotics are developing at a high pace.

Robots have become established in common engineering and consumer products assembly, however robotics in electronics is now experiencing probably the greatest expansion. The International Federation of Robotics (IFR) states that global production and sales in this area have increased by 114 percent in the last six years. According to published data (IFR, 2020), by 2021, the robot market is expected to grow by 14 percent annually, bringing production to 600,000 robots produced annually. In contrast, there were about 80,000 of them produced annually at the beginning of the millennium. In 2018, there were on average 106 robots per 10,000 industrial workers in Europe, 91 robots in the USA and 75 robots per 10,000 industrial workers in Asia.

2. Present state and trends in applications of industrial robots in automotive industry

It is well known that industry sector with one of the largest implementation of robots into production is automotive industry, for instance in 2019 with 33% of total supply of robots (see Fig. 1b). Production of transport vehicles and cars for passengers, whether with a conventional internal combustion engine, or increasingly widespread vehicles with hybrid drive and electric drive system respectively, has become more and more complex nowadays. A major part of all production processes currently requires automation based on two key production equipment - CNC machine tools and industrial robots. In addition to call for the climate changes, the 2030-year targets will require low or zero-emission vehicles, which will need even faster and massive automation of new generation based on so-called "intelligent sensors", cognitive and collaborative robots or other "smart technologies" (with respect to so-called “Nine basic blocks of concept Industry 4.0”) Kuhlmann, (2016).

2.1. The current state of robotics in the automotive industry

According to several sources, e.g. IFR (IFR, 2020), there have been demands for new investment projects aimed at the development, modernization or creation of new production facilities for modern cars during the last decade. As new materials and new technologies are constantly being used in automotive production, these projects have created a demand for the supply of the latest generation robots capable of meeting high technical requirements. This trend continues today and despite the difficult situation in 2020, it is assumed that it is not going to change significantly even with regard to the requirements of newly opened emerging markets. It is very likely that the application of robotics will become even more desirable also due to the effects of the global pandemic of COVID-19. The situation has also confirmed that one of the weakest links in the production chain is a human operator. Therefore, it would be appropriate to increase the robustness of the production system to such circumstances, e.g. even with a wider application of robots. Of course, not all of the processes can be fully automated from the technical point of view, or this is not economically advantageous. However, also based on our experience (new project requirements for additional robotic cells to existing lines), we can say that the trend to automate more and more processes is already established.

Automotive robotics can be defined as the area of industrial robotics that has its focus and application in automotive industry - directly in main assembly line of the car factory or in whole supply chain (plants of suppliers). Their application in the entire production process allows to achieve a significant volume of process automation, reducing the need for human operators in monotonous processes, increasing safety and reliability. The most common “robotized processes” in automotive industry are (Fig. 1c): general handling, arc and spot welding, automated assembly, paint spraying, joint sealing, visual inspection, and quality check, as well as various additional tasks such as cleaning activities. Nowadays, engineers in automotive industry are exploring the new tasks for robotics, while robots are more accurate, efficient, capable to perform increasingly complex and even more flexible tasks, Dodok, (2017). Therefore, automotive industry still remains one of the most automated supply chains globally, and one of the largest users of robots (Robotics Business Review, 2021). Automotive robotics is the area that generates the largest incorporation of industrial robots worldwide, currently covering 30% of total investments in the industry sector. The applications of robotics in the automotive industry that we could point out are, Kuric (2019):

- increase process accuracy and annual production rates in the automotive industry,
- some tasks are automated and elaborated with limited human intervention,
- health is guaranteed and possible occupational risks are reduced for workers,

- effective activities and operations are generated for the handling of heavy and oversized materials.

2.2. Future of automotive robotics

Modern robots cooperate side-by-side with their human operators, replacing them in monotonous and sometimes physically arduous operations. It is expected that angular (also known as articulated, anthropomorphic) types of robots will continue to be a key element of robotics in the automotive industry, especially for their versatility, performance and efficiency. They are equipped by five or six independent axes (DOF – degrees of freedom) arranged in the so-called serial kinematics. This kinematics is suitable for activities such as: handling, machining, painting, transport and assembly, Hrušková (2010). Its advantages are flexible mounting possibilities and the possibility of obtaining any orientation of the end-effector (working head – gripper, spot gun, arc-welding torch, etc.) while they have a bit less stiffness, Kopas (2017). Despite the success of robots with conventional kinematics, one of the main emerging trends is the wider application of collaborative robots, also known as "cobots" (collaborative robot can be defined as robot that collaborate with a human operator)(Tlach,2017), application of so-called robots with parallel kinematic structure capable of achieving enormous speeds and accelerations (up to 15 times gravitational acceleration),Poppeová (2013) that work in very short cycle times, as well as the "smart sensors" usage and possibilities of data exchange between devices, offered by Industry 4.0, Bulej (2018). Another emerging trend is visible where the automated process requires more than one arm. In such cases the dual arm robots perform multi-axial movements and various high-precision tasks by its redundant axes Kelemen (2018). The development of robotization is heading towards an autonomous factory, which will run production entirely on its own, however, as experts emphasize, there is still a long way to go, Knauf Industries (2020).

3. An example of robotized application with integrated vision system for automotive industry

Furthermore, we present the cell of robotic tightening of screws on the car seats as an example of robot applications in the automotive industry in the next chapter. This is a task that we solved for an industrial partner from automotive in frame of cooperation with the company *AI engineers crowd, Ltd.* located in Slovakia, Ai-ec, (2020). The integration of so-called VGR (Vision Guided Robot) system in its control will be presented in addition as well.

The main aim is to design a robotic cell, the task of which will be to replace a human operator at the workplace of bolts tightening on the car seat assembly line at an external supplier of the car factory. Specifically, it is a process of tightening 4 screws that connect the lower part (seat part) and the rear part (backrest) of the front seats of passenger car, always a pair of seats - left (marked as LH) and right (marked as RH). The average production capacity of the line is around one thousand pairs of seats, which represents approximately eight thousand tightening cycles per day.

Fig. 2. View on solved bolting station – overall view (left), detailed view on bolts' location (right down), bolts pre-assembled by previous human operator (middle) and required order of tightening process (right up) (Sága, 2020)

According to the original task assignment, there was defined the total cycle time of the robotized cell as 45 seconds (time between two consecutive seats entering the tightening position) or 35 seconds of the robot's cycle time respectively (the period between the robot leaving the HOME position and will return to it again). After the first test period (approximately 4 months), this requirement was changed by the customer, specifically to a maximum of 35 seconds and 25 seconds, respectively. With regard to the analysis of the requirements set by the customer, we decided for following configuration and equipment of the robotized work-cell. The basis of the whole cell is angular industrial robot with serial kinematic structure and 6 DOF (degrees of freedom) FANUC M-20iA/20M33, Fanuc (2020). The robot is placed on a base - a welded steel frame, which helps to align the robot workspace with the places it must reach with respect to the position of the conveyor. The conveyor has been preserved in its original way, which passes through the entire production line. However, it was necessary to change the position of the "stoppers", due to the location of the safety cage. The robot is equipped with a multifunctional effector, which contains:

- spindle Desoutter EFDE 51-70 (tightening unit) / Desoutter CVI3 module (Desoutter, 2019) (Fig. 3),
- monochrome camera Sony XC-56 (Sony, 2021), the key element of 2D optical visual system,
- additional ring light, which is placed around the camera,
- hollow screw attachment for hexagon screw heads.

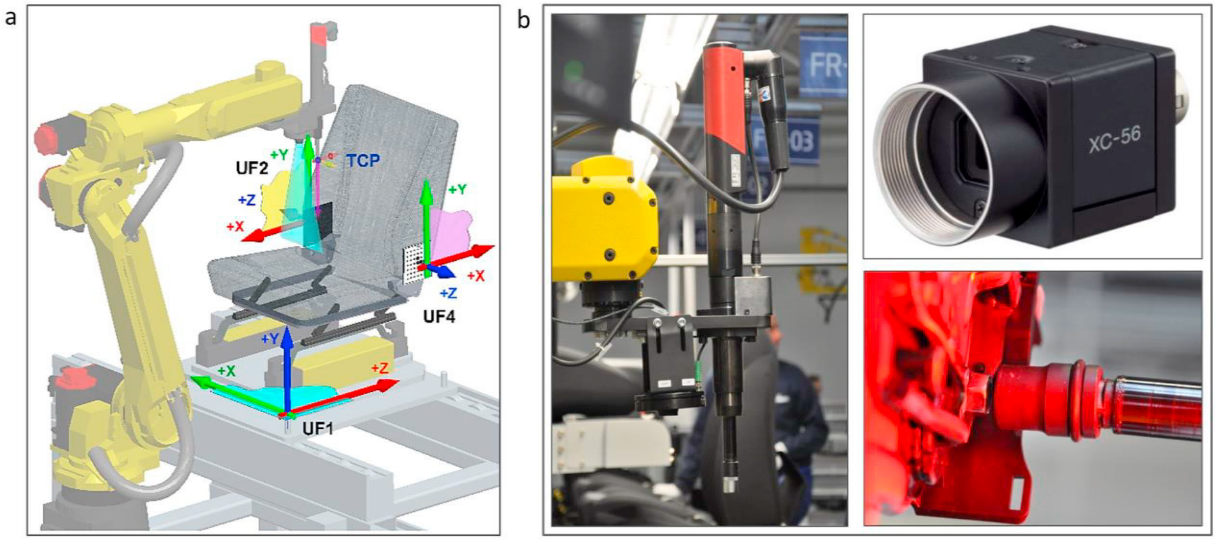

Fig. 3. (a) Schema of bolting-tightening station - defined User Frames: palette coordination system (UF1), plane for bolts 1 and 4 (UF2), plane for bolts 2-3 (UF4) (Sága, 2020); (b) tools mounted on end-effector (Authors): view on entire end-effector (left), camera (upper right) and detailed view on screwing process (bottom right).

The main reasons for designing such a workplace configuration were the following. We chose the robot with regard to the range needed to operate the workspace and achieve all positions (with the space limitations of existing production line), as well as with regard to restraining torques from the Dessouter tightening head. We chose the screw-driver with regard to the required torque for tightening the screws and space limitations (in-line version fits better). We also took into account compatibility with other tightening heads on the line (communication with the MES system). The camera and lighting were chosen based on the required image output needed to find the position of the screws with adequate precision and also with regard to the results of experimental tests (testing of different types of lighting and filters) for the given lighting and material conditions.

The robot communicates with the MES (Manufacturing Execution System) system of the production line via its inputs / outputs and subsequently also with the control unit of the tightening head. From it, the robot also receives information about which type of seat came to the mounting position (manual / driven and LH / RH).

The safety of the workplace is ensured by the SICK Flexi Soft system, Sick, (2021) – entire system composed of software-programmable safety controller and wide variety of peripheral hardware components. The main hardware components are safety sensors / light optical barriers at both entrances to the line (cell inlet and also the outlet), muting sensors that block the function of optical gates when passing the pallet. The unit is complemented by a safety fence equipped with an entrance door with safety lock for operator entry. Entry is signaled by the request button, but is allowed only after the end running task (robot return to the HOME position). Robot controller R-30iB was integrated into the fence due to easy access and other space limits as well.

The setup of the visual system took place in three basic steps, Saga, (2020):

- Basic camera setup within the WEB-Server platform,
- Calibration of the camera with respect to specific User Frame and robot position to achieve desired scanning distance from the screw-head,
- Definition of so-called Vision Process Tools – tool for pattern recognition and position data extraction.

The basic settings of the FANUC iRVision system can also be performed directly on the robot's touch control panel (Teach Pendant). However, it is significantly more efficient to implement this using the WEB server interface running on a computer. Two-way communication between the robot controller and the PC is provided by an Ethernet cable. In the first step, the camera is set up with regard to the application, the method of mounting (in our case it is carried on the robot end effector) and the lighting conditions. This is followed by calibration using a two-dimensional grid with a precisely defined spacing of calibration points (Fig. 4a). It connects the coordinates obtained from the camera with the coordinates against the defined UF (user frame). The calibration process contains several steps that must be performed in a defined sequence and with the highest possible accuracy. The accuracy of object identification and the resulting coordinate error will depend on how precisely this step was done. As an example of such procedure: robot arm positioning to the required distance (so-called reference position, Fig. 4b), turn on the lighting, scan the calibration grid (ideally in two different levels) and set the coordinate system. Subsequent filtering / correction of scanned points makes a significant benefit.

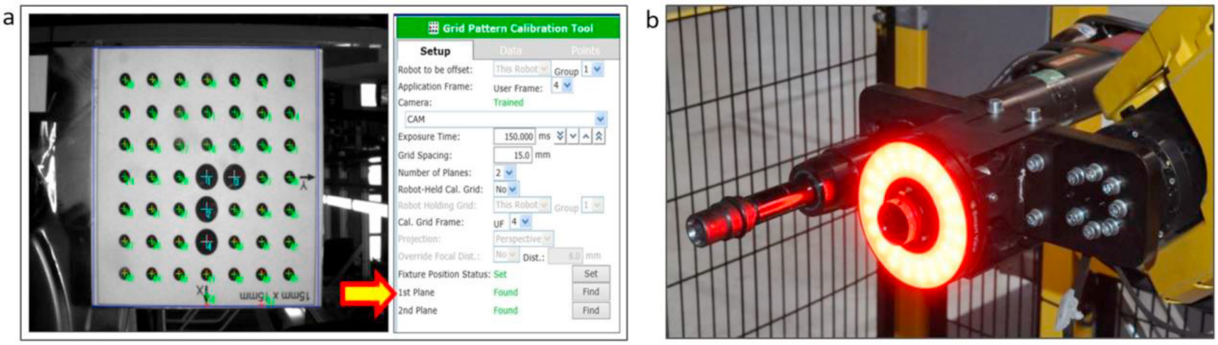

Fig. 4. (a) Calibration procedure for *i*RVision system; (b) common tool holder carrying screwdriver, monochrome camera and light (Authors)

Final step is creation of the "tools" for each scanned object, in our case for each of the four screws separately, for both seats LH and RH - 8 identification tools in total. The basic element of each vision tool is the so-called GPM Locator Tool, in which there is a precisely defined pattern, shape, text, or other significant element, the identification of which we perform by a camera system. Among other things, we can influence the quality of outputs by setting the proper value for parameters threshold, contrast, elasticity when processing image information. It has proved very useful to delimit the area where the shape can be located (e.g. screw head) using the "Search Window" function. How demanding the setup process was, is illustrated in Fig. 5, where you can see not only the procedure itself and the set parameters, but also changes in the image output under different conditions and with subtle changes in the position of the camera relative to the component. Whole design process consisted of gradual improvements, adjustments and changes in the program, the technical means used to meet the requirements of the customer. The complexity of this process was also due to the changings of input requirements during the development phase, as the required maximum cycle time (reduced from 45 to less than 35 s), or space conditions (e.g. shifting the whole robotic cell by about 0.5 m along the line axis).

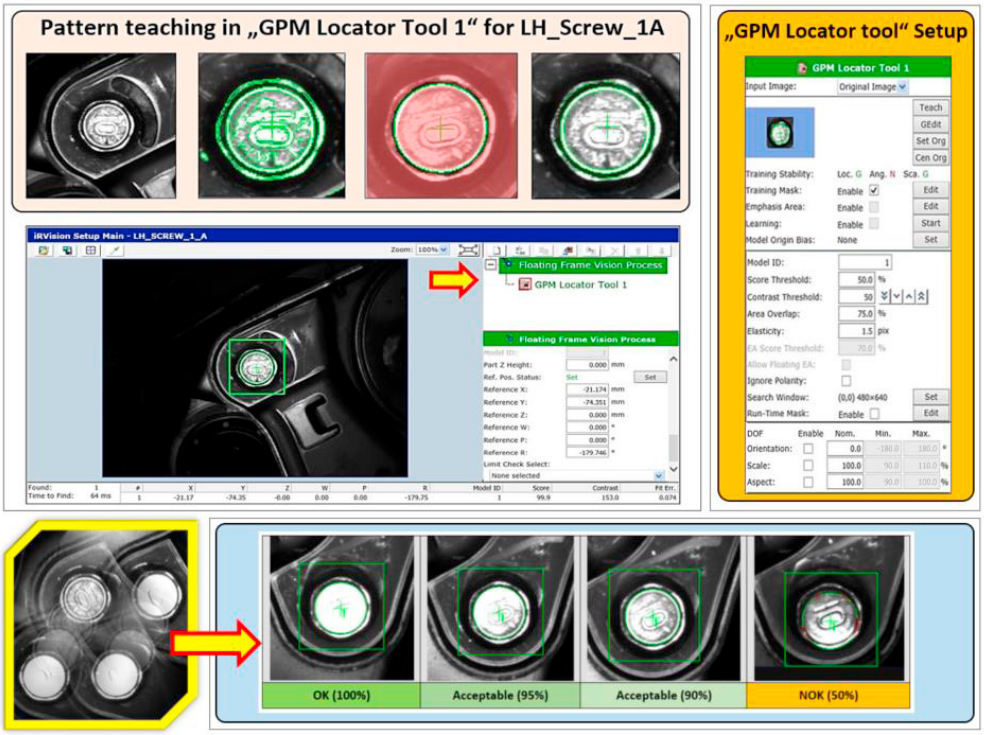

Fig. 5. Demonstration of vision tool setup for “bolt head” identification and obtaining the coordinates for robot path-planning (Authors).

4. Conclusion

Today, in the time of automation of processes and implementation of Industry 4.0, it is essential that robots be part of the production process in car production, because every day there is an increasing demand on the speed and accuracy of production and, the quality of manufactured parts. Last but not least, it is necessary to take into account meet the legislative requirements arising from combating the negative effects of climate change and apply technological processes that will shorten the total production time and reduce the harmful impact on the environment. Reducing production time and replacing some employees in monotonous processes by robots also results into lower total production costs per vehicle and maximized company profits. After general overview about industrial robotics in the first part of this paper, we focused on an overview of industrial robots’ usage in the world, especially the automation of most common processes related to automotive industry. Furthermore, there are presented the most distinguish trends in automotive robotics, such as application of “cobots”, parallel robots equipped by intelligent sensors, etc.

In the second part of the article, we introduce an example of a robotic cell applied to the assembly line of a supplier operating in automotive industry. We collaborated with the local FANUC robot integrator on the development of this line. Specifically, it is the automation of screwing / tightening of four bolts on the front seats of passenger cars. Due to the impossibility of ensuring the exact position of the bolt heads and other factors, it was necessary to integrate a machine vision system into the cell, thus creating so-called Visually Guided Robot system. Thanks to the precise setting of the optical system, the pattern recognition tools and the calibration process, we were able to achieve very good reliability as a result, which after several system improvements has reached a level higher than 99.9% (based on data from last 2 years). Rest of negative results are mostly caused by an obstacle between the screw head and the screwdriver (e.g., cables, protruding cover, etc.), a damaged screw head or threaded part in previous operations, an incorrectly pre-assembled screw, and other unspecified problems. These cases are solved manually in the next assembly position. Finally, we can conclude after real implementation that of our system for robotized bolting using VGR can results to save one worker per 1 shift, or 3 workers per a day. On the other hand, we would like to say that the successful implementation of such a comprehensive system requires proper approach, very precisely done setup process and long-period practical verification / continuous upgrading and fine tuning. The designed system has been operating to this day for almost 3 years, while in the initial phase several improvements have been made leading to the required reliability and robustness.

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