

THE „IN-LINE” REAL-TIME MONITORING STATION FOR PRODUCTION SYSTEMS

1. Introduction

Monitoring of materials flow, partially-completed and completed products during production process is necessary practice for every modern company because of need for operation optimisation and requirements of ISO 9000 series quality assurance standards. It is required to identify technological operations, parts, products and crew members responsible for any production stage.

Knowledge about state of production system is also necessary for proper management of company. Typically there is an ERP (Enterprise Resources Planning) software present in modern company, but still there is a gap between business and manufacturing layers of company. Usually there is no direct connection between production system and ERP software. There is a need to provide solutions allowing to acquire data directly from production system, analyse this data and display it in convenient form. On production system level in a modern company there is a HMI (Human-Machine Interface) and SCADA (Supervisory Control And Data Acquisition) software used, that can be accessed as a source of data for higher-level software.

In order to provide production transparency, improve quality and decrease product lead times, an appropriate integration of enterprise IT systems is necessary. Manufacturing Execution Systems (MES) bridge the crucial gap between the business processes (ERP) and shop floor (Production Control System). Some of MES functionalities were originally introduced by legal provisions (Tracking and Tracing in food industry) or by specific company needs. Because of common needs standard tools were developed. ANSI/ISA-95 is an important standard for enterprise integration [5]. It provides numerous object oriented models and terminology. It also serves as common model of integration, a standard terminology to define system requirements and integration between different software systems. Integration between enterprise's software systems should be vertical as well as horizontal (Fig. 1). ANSI/ISA-95 standard can be used as a tool to analyse manufacturing companies. By checking the integration needs, considering information flows, mapping the existing manufacturing systems and tools on the models and filling the blanks with new system,

ANSI/ISA-95 can be used as a roadmap for a well structured analysis.

MES software can be used as a joint between HMI/SCADA and ERP systems, furthermore it can be used as a stand-alone management information tool.

There are many types of objects and events in production system so there are different methods needed to acquire data and identify process state and products. Because of the variety of objects and conditions each type requires different approach to collect data.

The “in-line” monitoring station has been designed for testing different real-time production monitoring methods, such as RFID, bar codes and vision systems. It allows scientific research as well as teaching of students. Production system model or small production system is a subject of monitoring. Data acquired from the “in-line” monitoring station can be stored in a database, processed using MES software and relayed to ERP systems.

2. Manufacturing data acquisition technologies

There are many methods of process data acquisition available. The choice of the method depends on type of data and production system automation level.

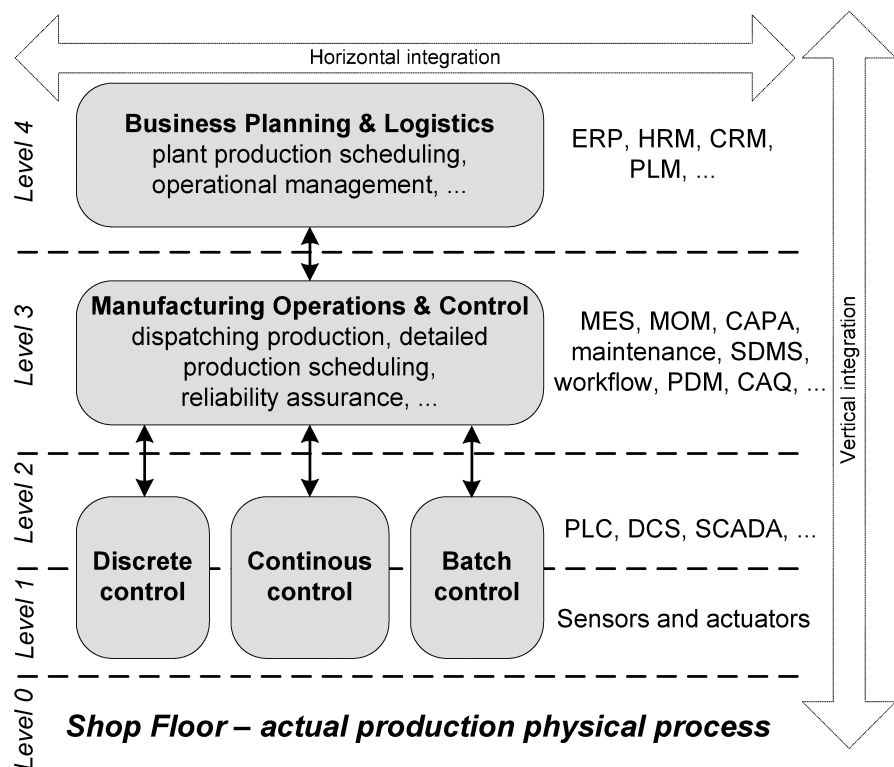


Fig. 1. Functional hierarchy model defined by ANSI/ISA-95, allowing vertical and horizontal integration of the enterprise levels

Level of production system automation determines the ability to acquire data automatically. Highly-automated production system is usually equipped with sensors monitoring process state for control of production process. Production data is available through PLC (Programmable Logical Controller) controlling production process on level of machines and equipment. In some cases it is only necessary to change or upgrade older PLCs to new versions, equipped with data transmission interface. There is a variety of sensors (induction, capacity, temperature, pressure, optical etc.) working on the lowest level of production system control hierarchy, that can be connected to PLC. Data from sensors is used for low-level production control and can be accessed through PLC. It is a main source of data from automated production systems, especially data describing state of production process and single machines or equipment. In case of highly-automated system there is need to provide a method to identify objects and products during manufacturing process.

In case of non-automated or partially automated manufacturing systems data acquisition is more difficult. It requires installation of sensors and other hardware or direct acquisition of data from machine operators. Data can be entered manually into special application or using custom designed devices. This solution is less reliable and it is subject of research to conveniently acquire data in such situation, eliminating possibility of mistakes and requirement of human action.

Next chapters present different methods of automatic objects identification, used in industrial practice.

2.1. Barcode technology

A barcode technology is based on patterns of parallel lines (1D) or two dimensional geometric patterns (2D) that are optical, machine-readable representations of data relating to the object to which it is attached. 1D barcode represents data by varying the widths and spacing of parallel lines. Data capacity of 2D barcode is higher but it requires more sophisticated equipment to read. Barcodes can be printed using many types of universal or special printers on paper, plastic and other material labels or on the object itself. In the past barcodes were scanned by special optical scanners, now scanners and barcode reading software became available on many devices like PDAs, tablets and smartphones [14].

In a production system each technological operation, semi-finished or finished product, machine and staff member can be labelled with a unique barcode label.

There are many advantages of a barcode technology: codes can be read without participation of human, it is non-contact

technology, barcode etiquettes are cheap to print and can be printed on practically any printer and any material, it is commonly used – most of products are labelled with barcodes. Barcode technology is used since many years so it is dependable in most situations [15].

There are also disadvantages of barcode technology: it is optical technology so barcode has to be in reader’s head field of sight (sometimes objects have to be manually re-oriented), there is no possibility to write/change data in barcode, codes printed on paper are not resistant to humidity, high temperatures and mechanical damage. Data capacity of 1D barcode is low and cannot be improved without enlarging of a label. 2D barcodes offers higher capacity and data reading error correction mechanisms (that allows to read partially damaged labels) but require more advanced scanners [4].

2.2. RFID technology

Radio-frequency identification (RFID) technology is a wireless non-contact automated identification system and uses radio-frequency electromagnetic fields to transfer data from a tag (transponder) attached to an object, for the purposes of automatic identification and tracking of wide range of objects (Fig. 2). Tag communicates with radio waves when placed in electromagnetic field of a reader’s antenna. There are many types and forms of RFID tags:

- *active tags* require power source (battery), *passive tags* are powered by the electromagnetic fields used to read them.
- data in *read-only tags* is written during it’s production process, *WORM tags* can be written only once by user and read many times, data in *RW tags* can be changed many times,
- tag size, shape and data capacity depends on application; tags can be water-, pressure- or temperature-resistant if it is required.

The tag contains processor circuit and memory cells that can be read from distance up to several meters. Unlike a barcode, the tag does not need to be within line of sight of the reader and may be embedded in the tracked object [2, 8].

RFID tag can be attached to a product at the beginning of production line and be used to track its progress through the assembly line. Animals, pets and humans may have miniature tags attached or injected into the body, allowing its identification.

RFID technology offers many advantages over manual identification and barcode technology. Tag can be read if

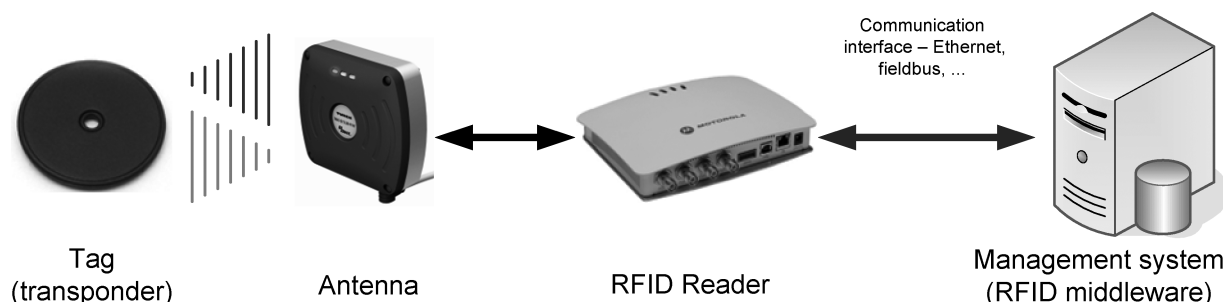


Fig. 2. RFID devices technology scheme

passed near a reader, even if it is covered by the other object or not visible - inside a case, carton box or other container, and it is possible to read multiple RFID tags at the same time. Tags can be environment-resistant and allow to change or add data. Tag integrated circuit and antenna can be a layer of paper label and written using a barcode label printer with RFID head. RFID can be used in asset management, inventory systems, product tracking, access control, transportation and logistics, passports, identification of people and animals, etc.

There are also some disadvantages of RFID technology. Most important and limiting one is that RFID tags are much more expensive than barcode labels. RFID technology and standards are still in phase of development, there are many incompatible systems available on market. Simultaneous reading of too many tags can be difficult and lead to transmission errors and data loss.

2.3. Vision systems

Next method used in object identification applications are vision systems, basing on computer vision and machine vision (MV) terms. Computer vision means methods for acquiring, processing, analysing and understanding images in order to produce numerical or symbolic information. Machine vision usually means process of combining automated image analysis with other methods and technologies to provide automated inspection in industrial applications [6]. In this method image acquired by camera is digitized and analysed by special algorithms. Usually processed image is compared with previously defined patterns. This method allows to identify object by its features (like shape, size, colour and other properties) instead of labels, that can be damaged during manufacturing process. Main application fields of vision systems and machine vision are quality control, sorting, processes control, navigation, detection of events, etc [7].

Typical vision system consists of 3 elements: camera, light source and computer with image processing software (Fig. 3). In some applications computer can be integrated with camera (smart camera, smart sensor). Type of camera and lightning have to be adjusted to local conditions and application. MV software uses digital image processing techniques to extract the required information and make decisions based on the extracted information.

Available machine vision image processing methods include: pixel counting, segmentation, blob discovery & manipulation, pattern recognition (finding, matching, counting specific patterns), barcode, data matrix and 2D code reading, optical character recognition (OCR), measurement of object dimensions, edge detection.

Conventional MV systems use visible light, camera can be monochromatic or colour, alternatively MV can detect various infrared bands or X-ray. Sometimes vision system have to be triggered by other sensors. Thanks to optical character recognition and ability to read 1D and 2D bar codes, MV systems are more flexible than barcodes technology, but it is still a much more expensive solution.

3. The “in-line” monitoring station for production systems

Growing number of advanced control systems, industrial networks, automated devices and product identification methods used in modern production systems results in the need for research in this area from the management methods point of view. Also teaching students how to successfully apply these techniques in their practice require developing of test laboratory stations and didactical exercises.

There are modular, didactic production systems available on the market [3, 12], but these products are usually expensive, limited only to specific applications and do not allow full flexibility in configuration [13]. More advanced versions can be equipped with barcode readers, RFID systems, HMI devices, SCADA and even MES software.

In this situation decision was made to design laboratory-scale station for monitoring of production systems, equipped with different production monitoring subsystems. It should cover scientific and educational needs and allow flexible development in the future.

The “in-line” monitoring station for production systems (Fig. 4) is an integrated modular system designed for real-time monitoring of production system using vision, RFID and barcode subsystems. Skeletal structure of the “In-line” monitoring station can be moved and placed over any small production system available in laboratory of Institute of Engineering Processes Automation and Integrated Manufacturing Systems.

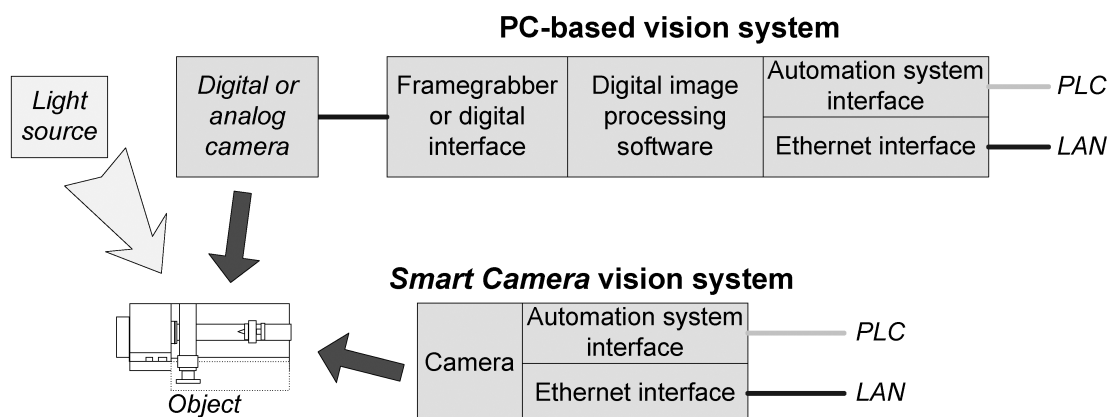


Fig. 3. Machine vision systems – PC-based and “smart camera”

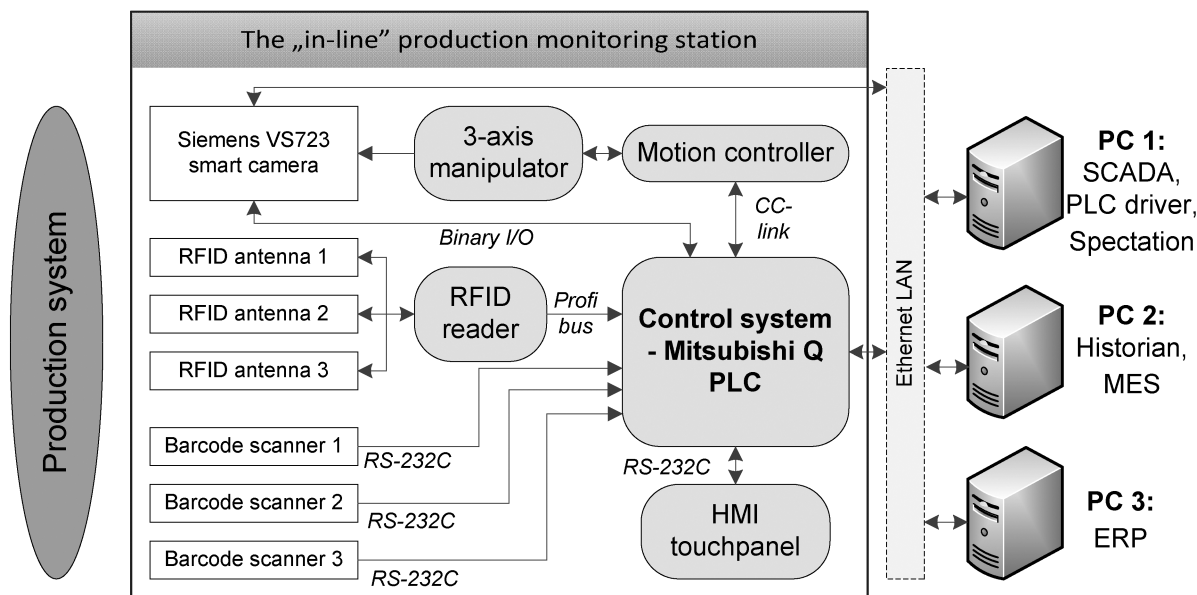


Fig. 4. Block scheme of the “in-line” monitoring station

The “in-line” monitoring station consists of data acquisition subsystems, mechanical structure with XYZ manipulator, drives and control subsystems with interfaces. Control over the monitoring station is possible through operator console or using HMI/SCADA application.

3.1. Mechanical structure and 3-axis manipulator

Mechanical structure of “in-line” monitoring station is designed as a frame (chassis) made of light alloy rigid profiles, standing over production system model being monitored. Chassis is equipped with wheels and can be moved, whole construction is modular. Data acquisition subsystems element can be easily installed on this skeletal structure. The vision system (smart camera) is installed on the manipulator and can move in 2000x1000x500 mm (XYZ) workspace. Manipulator electrical linear drives accuracy is 0,05 mm. Drives are powered and controlled by motion controller unit in the control system cabinet.

3.2. The control system

The main part of the control system is advanced Mitsubishi Melsec Q series PLC controller. It is responsible for processing signals from sensors and subsystems, data presentation and control over whole monitoring station. The control system construction is modular, allowing later upgrades. At present motion controller (Mitsubishi Q-motion), network interface (Ethernet), three In-Out modules, RS-232 and Profibus DP interfaces are installed.

Available network interfaces list includes ETHERNET (100BASE-TX), PROFIBUS DP, MELSECNET, CC-LINK, ASI, RS, SSCNET III. Direct communication with SQL and ORACLE databases through hardware MES module is also possible. There are also 32 binary inputs and 16 outputs installed. Control system programming of is possible with Mitsubishi MT Developer and GT Developer IEC1131 compatible software.

3.3. Vision subsystem

Vision subsystem is based on Siemens VS723 smart camera combined with LED lighting panel (Fig. 5). CCD Camera sensor is monochrome 1024*768 pixels resolution and 0,6 mm optical resolution. Integrated vision system controller is connected to monitoring station with Ethernet and 4 IN/OUT binary lines.

Siemens smart camera programming is possible using *Spectation* software, installed on a PC. *Spectation* is used to define vision system operation. After programming smart camera can operate without connection to a PC. Object and features detection is based on so called SoftSensors. The main groups of SoftSensors are Presence/Absence SoftSensors, Positioning SoftSensors and Specific Inspection SoftSensors. Positioning SoftSensors help

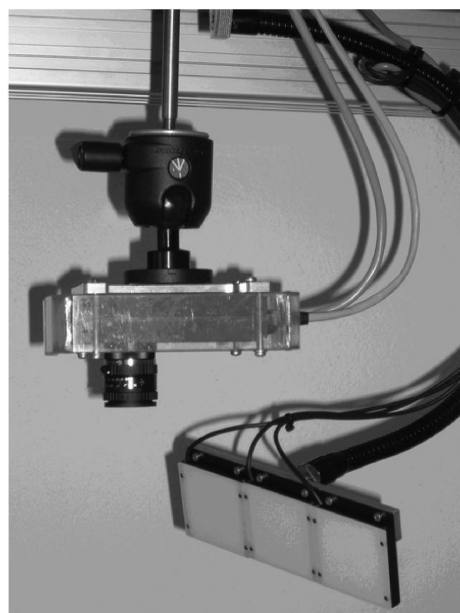


Fig. 5. Vision subsystem – Siemens VS723 and LED lighting panel

locate parts to be inspected. Presence/Absence SoftSensors perform basic checks for detection of features. Specific Inspection SoftSensors include 1D and 2D code readers, OCR readers, measurement sensors, math tools, colour sensors, pattern matching sensors, geometry finding sensors and programmable sensors [11].

Red LED lighting panel is used to improve lighting conditions to get the most contrast picture required for proper operation of vision system.

3.4. The RFID subsystem

RFID subsystem installed in “In-line” monitoring station is based on Turck BL-ident hardware – the controller unit and 3 antennas (Fig. 6) [1]. Antennas can be used to read and write data in passive tags (TW-R50-K2, each tag has own ID number and 2 kilobytes data capacity). Suggested distance between tag and antenna is 50 mm, error-free operation is possible up to 120 mm distance. Distance between antennas should exceed 500 mm to avoid interferences. Antennas can be fixed to chassis of the “in-line” monitoring station in required points. Data throughput depends on distance between tag and antenna and varies between 20 to 200 bytes/s.

The RFID subsystem is connected to control system through the Profibus DP interface.

3.5. The barcode subsystem

Barcode labels are presently the most popular method of object identification. Barcode subsystem consists of barcode printer Zebra, connected to a PC, and three barcode readers (Fig. 7) connected to control system via serial RS-232 interface. Barcode readers can read any 1D standard barcodes. Two industrial Metrologic „Quantum T” readers can be installed on chassis of monitoring station, while third (Symbol LS 2208) is a handheld scanner.

3.6. HMI and SCADA subsystems

The main device of the control panel is touch screen module Mitsubishi GOT-1000, allowing presentation of system state and operational control.

Control panel application software is organised into several screens. It allows programming and control over manipulator (homing, position programming and positioning in

automatic and manual mode), vision subsystem (camera triggering, lighting control), RFiD subsystem (reading and writing of RFiD tags) and barcode subsystem (barcode reading). Alternative to GOT-1000 method of controlling the monitoring station is HMI/SCADA CITECT SCADA software application, installed on a PC. At present it offers the same operations as hardware HMI GOT interface but in the future its functionality will be extended.

3.7. Physical model of production system

The only limitation concerning model of production system is that it should fit under the structure of manipulator frame, at least in part that should be inspected by vision system, RFiD heads and barcode scanners can be installed in remote positions limited only by length of the cables. For example Festo MPS (Modular Production System) can be used [3]. At present a plate conveyor is installed as a model of production system. It is configured as a closed loop, identified objects can be placed on conveyor. Currently monitored objects are differently shaped (for tests of vision system) and sized boxes with printed barcode labels and/or RFiD tags attached. Vision system is programmed independently using Spectation software installed on PC, it communicates with the “in-line” monitoring station control system using 3 binary inputs.

Currently 16 steps (positions) of manipulator with attached vision system can be programmed using on-line programming method. Positions are programmed manually, it is possible to set the speed of positioning. Programmed positions can be activated or deactivated.

3.8. Test of barcodes and RFID tags reading

“In-line” real-time monitoring station allows to carry many different tests of automated identification devices, for example comparison of reliability of identification systems. In order to test reliability of barcode reading with barcode scanner and vision system, as well as RFiD tags reading, test station has been set up with all identification subsystems over the surface of the conveyor in the same place. A set of objects with barcode printed label and RFiD tag attached was prepared. Linear velocity of conveyor can be controlled with frequency inverter, it is possible to set speed in range from 0 to 0,5 m/s.



Fig. 6. RFID subsystem – antennas, passive tags and RFID controller



Fig. 7. Barcode subsystem – scanners and Zebra barcode label printer

In order to carry on test a set of 100 objects has been put on the conveyor, test was repeated with different speeds 3 times. Vision system has been programmed to read barcodes. Lighting conditions were the same during 3 runs of tests, which is significant because reliability of optical methods of identification depends on it. Distances of barcode scanner, smart camera and RFID head from recognized objects on conveyor were set according to values described in operation manuals of devices.

Knowing labels strings and data written in RFID tags, it is possible to assess accuracy of barcode reading using scanners and vision system, RFID subsystem reliability can be assessed as well. Number of successfully recognized objects is shown in Table 1. Average results are presented in a form of chart (Fig. 8).

Obtained result shows that up to 0,2 m/s conveyor speed every method of object recognition is reliable enough to use in industrial applications. Optical objects recognition methods, using hardware currently available in “in-line” production

monitoring station configuration, appears to be worse than RFID technology in moving objects recognition applications. Proper RFID object recognition is possible up to 0,35 m/s conveyor speed using Turck BL-ident heads and TW-R50-K2 (tag identifier UID + 2kB Flash RAM memory) tags. Recognition of faster moving objects can be improved in applications where is no need for RW tags – read only tags can be read faster then read-write tags because of time insufficient to transmit longer data strings.

Reliability of barcodes reading using vision system can be improved in two ways – better lighting conditions (in limited range) or change of vision system architecture to system designed for moving objects recognition [6]. Also optimisation of recognition algorithms can improve recognition results [7, 9]. Smart camera Siemens VS723 is not designed for fast moving object recognition, another system prepared for that type of objects should be used, for example Point Grey Gazelle GZL-CL-22C5M-C camera [10] with frame grabber and computer.

Conveyor speed [m/s]	0,05	0,10	0,15	0,20	0,25	0,30	0,35	0,40	0,45	0,50
Identification method	Number of successfully read labels/RFID tags (out of 100 objects)									
Barcodes - scanner - run_1	100	100	99	98	100	90	96	85	80	65
Barcodes - scanner - run_2	100	99	100	100	98	96	95	94	85	61
Barcodes - scanner - run_3	100	100	100	98	95	98	92	90	87	74
Barcodes – vision system - run_1	100	100	100	99	98	94	80	71	64	48
Barcodes – vision system - run_2	100	100	100	98	95	97	82	65	61	39
Barcodes – vision system - run_3	100	100	100	100	98	90	85	73	53	42
RFID tag – run_1	100	100	100	100	100	99	100	97	65	32
RFID tag – run_2	100	100	100	99	98	98	100	99	58	41
RFID tag – run_3	100	100	100	98	100	100	97	95	48	37

Tab. 1. Results of experiment – number of successfully recognized objects

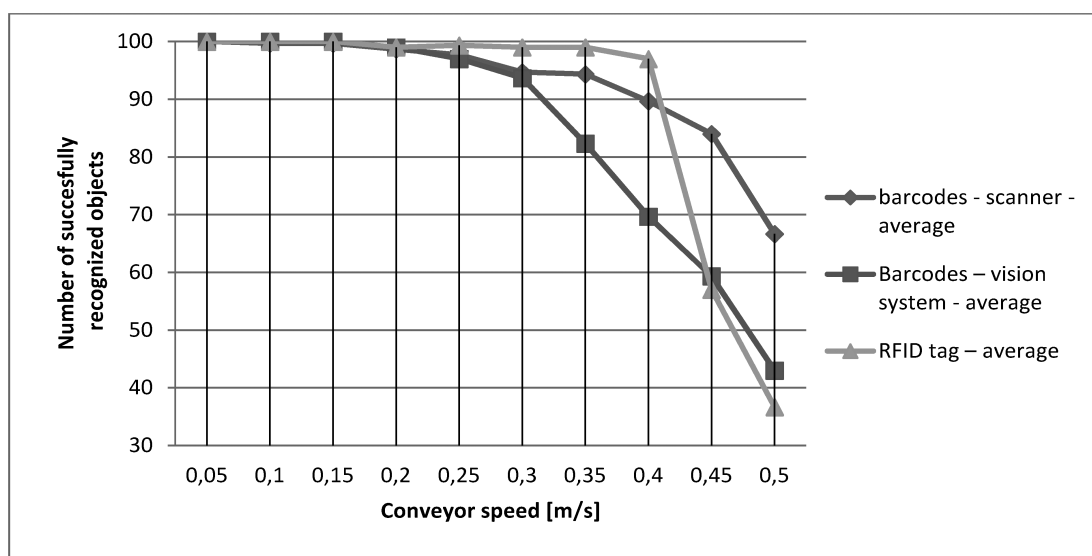


Fig. 8. Comparison of object recognition methods

4. Summary

The “in-line” real-time monitoring station for production systems described in paper allows to carry on tests of different technologies of objects identification and monitoring. There are different old (barcodes) and new, currently developed technologies, like RFID and vision systems. It is possible to compare different technologies and choose the best solution for specific application.

The monitoring station design is modular and allows configuration changes in the future. Control system is flexible thanks to modular construction of PLC controller (mainboard + standardized expansion modules).

The “in-line” monitoring station can be programmed using built-in touch panel or with HMI/SCADA software application installed on a PC. Using HMI/SCADA application after further development will allow to omit touch panel limitations (monochrome, low-resolution display) and create more sophisticated programs. Full functionality of the “in-line” monitoring station will be achieved after integration with Historian (production data archiving), MES and ERP software.

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Key words:

production monitoring, data acquisition, RFID, vision systems, barcodes, MES, SCADA, ANSI/ISA-95.

Abstract:

Paper describes the “in-line” monitoring station designed for tests of different real-time production data acquisition methods, such as RFID, bar codes, vision systems etc. Production system model or small production system can be placed under the “In-line” station as object of monitoring. Vision system camera is installed on 3-axis manipulator. RFID heads and barcode scanners can be installed at a point over production system model. Advanced PLC integrates control over subsystems and allows communication with different types of networks (Ethernet, Profibus etc.). Touchscreen display is used as a HMI interface, there is also possibility of controlling the “in-line” production monitoring station using HMI/SCADA application installed on a PC computer. Data acquired from the “in-line” research station can be stored in industrial Historian database and processed and analysed using MES software. Monitoring station allows to provide scientific research and to teach students how to apply and use modern identification systems.

STANOWISKO MONITORINGU SYSTEMÓW PRODUKCYJNYCH “IN-LINE” W CZASIE RZECZYWISTYM

Słowa kluczowe:

monitoring produkcji, akwizycja danych, RFID, systemy wizyjne, kody paskowe, MES, SCADA, ANSI/ISA-95.

Streszczenie:

Artykuł opisuje stanowisko monitoringu “*in-line*” systemów produkcyjnych, przeznaczone do badań różnych metod akwizycji danych w czasie rzeczywistym, takich jak RFID, kody paskowe, systemy wizyjne itp. Obiektem monitoringu może być laboratoryjny model systemu produkcyjnego lub niewielkie gniazdo produkcyjne. Kamera systemu wizyjnego jest zainstalowana na 3-osiowym manipulatorze, a głowice RFID i skanery kodów paskowych mogą być zainstalowane w dowolnych punktach nad obserwowanym systemem. Zaawansowany sterownik PLC umożliwia sterowanie podsystemami stanowiska i komunikację z różnymi typami sieci przemysłowych i Ethernet. Stanowisko może być nadzorowane za pomocą wyświetlacza z panelem dotykowym HMI lub aplikacji HMI/SCADA zainstalowanej na komputerze PC. Dane pozyskane z podsystemów akwizycji są przechowywane w przemysłowej bazie Historian oraz raportowane i analizowane w oprogramowaniu MES. Stanowisko monitoringu systemów produkcyjnych “*in-line*” pozwala na prowadzenie badań naukowych oraz zajęć dydaktycznych, uczących wykorzystania nowoczesnych systemów automatycznej identyfikacji.

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