SENSOR SYSTEMS FOR AUTOMATION IN INDUSTRY 4.0

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Abstract

The paper presents a basic analysis of applicable active sensing systems for use in automated manufacturing equipment and robotics. The paper is divided into sensor and vision solutions and briefly describes inductive sensors, magnetic sensors, ultrasonic sensors and optical sensors (conventional optical sensors, 2D Vision and 3D Vision). The basic objective is to present the principles on which each system works.

Key words: Industry 4.0, Automation, Robotics, Sensors, Vision System

INTRODUCTION

The fact that today's industrial production cannot do without automation is known to everyone. The current state of automation is due to the triumphant drive of computer technology, that enables control systems, programmable automates, etc. At the same time, few outsiders know that all automation technology would be powerless without sensors. These sensors give the system information about the state of the entire process environment, e.g. pressure, temperature, distance or the answer to a Boolean yes or no question. [1], [2]

Sensors use different methods and principles to operate. Among the most commonly used are inductive, magnetic, ultrasonic, optical, mechanical, etc.

During the development of electronics and electronic signal processing circuits, intelligent sensors were developed (see Fig. 1). By combining sensors with downstream integrated circuits on a silicon chip, these smart sensors are created. They incorporate a sensor, electrical signal conditioning circuitry, an analog-to-digital converter, a microprocessor and circuitry for bidirectional communication. [3]

INDUCTIVE SENSORS

Inductive sensors (see Fig. 2) are one of the most widely used proximity or presence sensing solutions. They are resistant to the effects of the operating environment thanks to their sealed housing. They operate without contact and without backlash. Inductive sensors are completely solid-state elements that operate at a high switching frequency. They have an almost unlimited lifetime, unless they are mechanically damaged. They are typically used to replace mechanical limit switches or as detectors of actuator (drive, valve) position, part presence, part count, and position or speed control. [1]

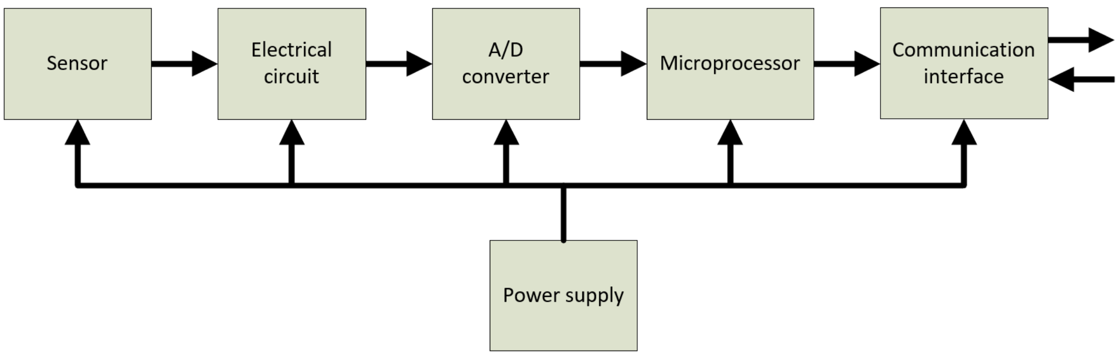

Fig. 1 The principle of intelligent sensors [1]

Fig. 2 Inductive sensors [4]

The principle of operation is based on a coil and an oscillator that generates an electromagnetic field in the vicinity of the sensing surface. If a metallic object is present in this operating area, the sensor is able to assess, by damping the amplitude of the oscillation, that a metallic object is indeed present in the area. The working distance of the sensor depends on the shape and size of the actuator and also depends on the nature of the material. [1]

Inductive sensors can be further classified into several categories, such as.:

- Cylindrical and block
- Notched
- Circular
- Magnetic field resistant
- Selective
- With built-in speed evaluation
- Analog

MAGNETIC SENSORS

Magnetic sensors detect changes and disturbances in the magnetic field such as flow, force and direction. Magnetic sensors are divided into two groups, those that measure the entire magnetic field and those that measure vector components of the field. The vector components are the individual points of the magnetic field. The techniques used to create these sensors involve various combinations of physics and electronics. [1]

The source of the magnetic field can be either a permanent magnet that is placed on the object to be sensed or, less commonly, on a sensor under the front surface. In the latter case, the condition is that the sensed object is ferromagnetic. [5] The most common applications include sensing liquid and bulk material levels, sensing the position of pneumatic cylinders or simple identification.

Magnetic sensors can be further divided into:

- Sensors with Hall probe
- Magnetoresistive probes
- Sensors with saturating coil core

ULTRASONIC SENSORS

Ultrasonic sensors measure distance using ultrasonic waves. The sensor head emits an ultrasonic wave and receives the wave reflected back from the target (see Fig. 3). The way sensors work is that they measure the distance to the target by measuring the time between emission and reception. In an ultrasonic transducer with a reflection model, a single oscillator emits and receives alternating ultrasonic waves. This allows for miniaturization of the transducer head. At the same time, they are used as barriers, where the point of transmitter and receiver is fixed and any disturbance of this field is evaluated as an error or unwanted object in the barrier area. [6], [7]

Ultrasonic sensors are mainly used for distance measurement. An example is the installation of a sensor on the end element of a robotic gripper in palletizing and handling applications. Thanks to the sensor, the robot is able to move to a certain height above the piece without the need for complex calculations of the height position of the individual pieces.

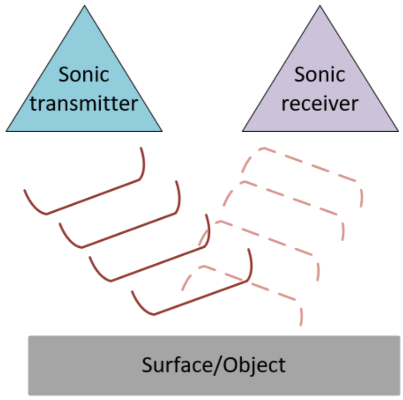

Fig. 3 Ultrasonic sensors principle

OPTICAL SENSORS

Photoelectric sensors detect objects, changes in surface conditions and other items through various optical properties. A photoelectric sensor mainly consists of an emitter to emit light and a receiver to receive light. When the emitted light is interrupted or reflected by the sensing object, the amount of light that arrives at the receiver changes. (see Fig. 4) The receiver detects this change and converts it into an electrical output. The light source for most photoelectric sensors is infrared or visible light, most commonly infrared light. [1]

Conventional optics

Optical sensors can be divided into three basic groups:

- Reflective sensors
- Reflective sensors with reflection (reflective barrier)

- Sensors containing a separate transmitter and receiver (one-way barrier)

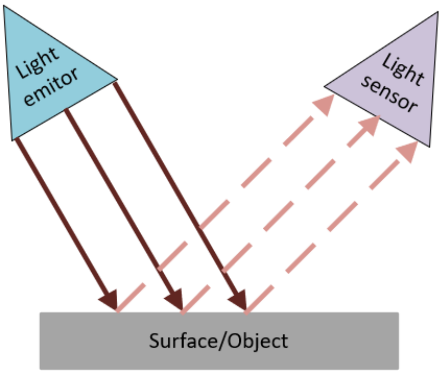

Fig. 4 Optical sensors principle

Reflex sensors

They are a direct alternative to inductive proximity sensors. Their purpose is to detect the presence of an object that is intended for the technology. Unlike inductive sensors, they are able to accurately measure distance and process other optical parameters such as colour and contrast. [1]

An example of this sensor usage in a robotic manufacturing system is given in the article: "Implementation of Simulation in the Design of Robotic Production Systems" [8], [9]

Reflex sensors with reflector

Their purpose is similar to that of ultrasonic sensors. They are mainly used as optical barriers, where light emanates from the transmitter towards the reflector. From the reflector, the light signal is reflected back to the transmitter. If this signal is interrupted by any object, the sensor output is activated. Sensors operating on this principle have a range of up to 10 metres. [1], [10]

One-way barriers

The simplest optical sensor principle, where the beam emitted from the transmitter is captured by the receiver. They can be used to sense distances up to 200 metres, subject to guaranteed mutual stability between the two elements. Perfect alignment can be demonstrated by an alignment indication on the receiver, which is able to evaluate whether the maximum light output of the transmitter has reached it. [1], [11]

2D VISION

This system uses the cooperation of a robot with a black and white or colour camera. It is able to recognize and locate products or workpieces regardless of their size, shape or position. It can also read barcodes, sort by colour and support the handling of flexible parts (see Fig. 5). The goal of 2D Vision is to eliminate the need for jigs and speed up classically designed processes. It can also be used in quality control processes where it can locate features and determine the correctness of their position, etc.

Fig. 5 Delta robots with 2D Vision system [12]

The principle of this system is the recognition of predefined shapes. If a shape is recognized, the coordinate position of a piece of that shape is returned to the robot. In the case of the color version, its position in the RGB spectrum is also recognized according to its color. Due to the impossibility of providing ideal lighting conditions, the camera will never evaluate one and the same color perfectly accurately, so tolerances such as 5% are used to ensure color recognition even in adverse conditions.

An example of this sensor usage in a manufacturing system is given in the article: " Application of Innovative Methods of Predictive Control in Projects Involving Intelligent Steel Processing Production Systems" [13]

3D VISION

This system allows robots to recognize and pick up randomly placed objects directly from a stack of blanks, workpieces and other loose material into predefined containers (see Fig. 6). Process automation using this object recognition technology is an effective way to increase productivity and reduce costs in a wide range of general material handling applications. Whether it's loose, mixed and irregular objects or bags for palletizing, 3D Vision's solution provides an efficient handling solution that can be quickly customized to manage a variety of products to suit any order. With grippers suitable for handling, depalletizing, picking and sorting, it ranks among the top products in the industrial automation industry.

The 3D spatial sensor uses structured light projection to create 3D maps. It uses these to identify and select a part based on what the integrated part manager decides is the fastest possible option.

Fig. 6 3D area sensor [12]

CONCLUSION

The article describes the basic sensors and principles of sensing systems that form the cornerstone of any automation system. It is divided into sensor and vision solutions and briefly describes inductive sensors, magnetic sensors, ultrasonic sensors and optical sensors (conventional optical sensors, 2D Vision and 3D Vision). This survey of sensing systems and their principles will serve to orient the reader to the issues. Based on this, further work will be carried out to select suitable sensors for the collaborative robot workplace in the Industry 4.0 laboratory at the Faculty of Mechanical Engineering of the University of West Bohemia in Pilsen. Based on the use of the selected sensors, a program will then be developed for the manipulation of coloured work pieces by the collaborative robot and verification of the reliability of colour recognition for the selected sensing system.

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References

[1] Martinek, R.: Senzory v průmyslové praxi, Praha: BEN - technická literatura, 2011. ISBN 978-80-7300-354-8.
[2] Pollák, M., Kočiško, M., Baron, P.: Measurement of unidirectional pose accuracy and repeatability of the collaborative robot UR5. Advances in Mechanical Engineering, Volume: 12, Issue: 12, DOI:10.1177/1687814020972893, 2020. ISSN: 1687-8132.
[3] https://coptkm.cz/portal/?action=2&doc=7943&instance=1 (Accessed 21.11.2021).
[4] https://www.sick.com/cz/cs/ (Accessed 3.12 2022).
[5] Kočiško, M., Pollák, M., Töröková, M., Baron, P., Paulišin, D., Kundrík, J.: Determination of Methodology and Research of the Influence of the Trial Run of High-Precision Reducers on the Change of Their Characterizing Properties. Applied Sciences, Volume: 11, Issue: 9, Article Number: 3859, DOI: 10.3390/app11093859, 2021. eISSN: 2076-3417
[6] Buchholz, D.: Bin-picking: new approaches for a classical problem, Cham: Springer, 2015. ISBN 978-3-319-26498-1.
[7] Takpara, R., Duquennoy, M., Ouaftouh, M., Courtois, C., Jenot, F., Rguiti, M.: Optimization of SAW-type Surface Wave Ultrasonic Sensors for Ultrasonic SHM. RESEARCH IN NONDESTRUCTIVE EVALUATION. Volume: 29, Issue: 2, Page: 61-77, DOI: 10.1080/09349847.2016.1252870, 2018. ISSN: 0934-9847.
[8] Daneshjo, N., Malega, P., Hlubeňová, J., Štuller, P.: Implementation of Simulation in the Design of Robotic Production Systems. TEM Journal. Volume 11, Issue 1, pages 179-188, DOI: 10.18421/TEM111-22, February 2022. ISSN 2217-8309.
[9] Martirosov, S., Bureš, M., Zítka, T.: Cyber sickness in low immersive, semi immersive, and fully immersive virtual reality. Virtual Reality, Volume 26, Issue 1, pages 15-32. DOI: 10.1007/s10055-021-00507-4, 2022. ISSN: 1359-4338
[10] Kačerová, I., Kubr, J., Hořejší, P., Kleinová, J.: Ergonomic Design of a Workplace Using Virtual Reality and a Motion Capture Suit. Applied Sciences, Volume 12, Issue 4, DOI: 10.3390/app12042150, 2022. ISSN: 2076-3417
[11] Kubr, J., Novikov, K., Hořejší, P., Kleinová, J., Krákora, D.: Connecting a virtual production and a PLC. MM Science Journal, Volume 2021, pages 4452-4462. DOI: 10.17973/MMSJ.2021_6_2021007, 2021. ISSN: 1803-1269
[12] https://www.fanuc.eu/cz/en. (Accessed 3.12 2022).
[13] Svetlík, J., Malega, P., Rudy, V., Rusnák, J., Kováč, J.: Application of Innovative Methods of Predictive Control in Projects Involving Intelligent Steel Processing Production Systems. Materials, Volume:14, Issue: 7, Article Number: 1641, DOI: 10.3390/ma14071641, 2021. eISSN: 1996-1944.