Photo provided by Brain Corp

3D sensors for robot applications

Robotics is currently undergoing a boom. The reason: Robots allow more and more interactions with humans and are less and less impaired by the restrictions of safety barriers. If we will soon see more and more robots in everyday situations, this will mainly be due to the sensors used. If robots are to interact with humans, sensors play an important role as the equivalent to human organs of perception. This White Paper illustrates the importance of 3D image sensors that allow robots to perceive their environment.

The history of robots begins in literature, in 1920. In the science fiction play „R.U.R." by the Czech writer Karel Čapek, artificial humans – the robots – are used as cheap workforce before they change the entire economy and, in the end, eradicate the human race. Especially in science fiction literature that became popular during the first half of the 20th century, robots would soon be everywhere. The Three Laws of Robotics that Isaac Asimov introduced in a short story written in 1941 illustrate mankind's fear of artificial beings. In literature, robots are in most cases, humanoid – i.e. similar to humans.

Advanced technical development in robotics only became possible when semiconductor technology became more widespread. The dream of humanoid robots, however, did not yet come true. Robots usually have a fixed mounting position and fulfil specific tasks. Upright walking, mobility in general and communication by means of language are technically very demanding and not required in most applications. Especially in the manufacturing industry, in particular in the automotive industry, the use of robots is rapidly increasing. Handling loads, welding car bodies and gluing parts are among ▸

In the past, robots have worked in separate areas to exclude any danger to persons – safety barriers like mechanical protective fences or light curtains are prescribed to ensure sufficient safety.

the most important work steps done by robots. Robots' greatest strengths are moving heavy loads or doing repetitive monotonous activities. The advantages are obvious: Robots know no fatigue, they operate day and night and are very strong.

No protection fence required

The rebellion of the robots that leads to the extinction of mankind as described in Čapek's play has not yet taken place. A danger that is far more realistic is the great strength, the high speed and the dynamics of robotic movements. Moreover, robots execute highly specific programmed movements. The possibilities of interaction with the environment are highly restricted. In the past, robots have worked in separate areas to exclude any danger to persons – safety barriers like mechanical protective fences or light curtains are prescribed to ensure sufficient safety.

The strict separation of robots and people, however, makes collaboration difficult and restricts possible applications. For example, it is not possible for human colleagues to work on a heavy workpiece held by their robot colleagues. How can this restriction be overcome? This is one of the most urgent questions that need to be solved to widen up the possibilities of robot applications outside the industry. The areas where robots can fulfil important tasks are very versatile: simple logistic transport activities in hospitals and homes for the elderly, in hotels or office buildings. Everywhere where comparatively simple and repetitive works need to be done, robots can replace humans. To benefit from the potentials offered by the use of robots, it is important to consider the essential differences between humans and robots with regard to specific work processes.

Sensors as key technology

There are many tasks where robots are better than humans. They are faster, stronger and more accurate – depending on the requirements. There are, however, many tasks where they are not fit to hold a candle to their human colleagues. Not only where creativity and abstract thinking are required. Visuomotor skills are one of our strengths. In more colloquial terms, this is also referred to as eye-hand coordination or as eye-foot coordination. It is hard to imagine today that a robot could handle a football with Christiano Ronaldo's virtuosity. Simulating the complex interaction of our highly developed organs of perception with our brain will still require a lot of development work on all levels. One of the most important areas that require development is sensor technology.

It is hard to imagine today that a robot could handle a football with Christiano Ronaldo's virtuosity.

The operating principle of robots – or automated machines in general – is based on the combination of sensors, actuators and the controller. In simplified terms, this combination is equivalent to a human with organs of perception (sensors), muscles (actuators) and the brain (controller). Sensor development is very versatile and has brought about useful sensors for all kinds of tasks. Sensors can also detect measurement categories or measuring ranges that are not accessible to humans senses. Typical examples for this are very high temperatures, radioactivity, ultrasonics or infra-red radiation.

Special case: image-producing sensors

The most important of the human senses is visual perception, which in technology is replaced by cameras and photoelectric sensors. Image recognition and processing, however, plays a ▸

special role in sensor technology. While other sensors merely only detect individual values to be measured, for example temperature, the data volume produced by image-producing sensors can be very high. This data must be processed to generate information from it that can be used by the controller. Depending on the image processing concept, this requires additional computing capacity. This can either be provided by the central controller or the use of several sensors to process the collected data directly or at least pre-process it.

Conventional cameras or other image-producing sensors generate a two-dimensional picture. Humans, however, have three-dimensional visual perception. The interaction of the human eye with the visual centre in the brain creates a three-dimensional image of the environment. In robotics, such a three-dimensional image is important to enable robots to act independently and without causing any danger outside of safety barriers. 3D image sensors and corresponding three-dimensional image processing, however, are significantly more complex than conventional two-dimensional image processing.

The interaction of the human eye with the visual centre in the brain creates a three-dimensional image of the environment. In robotics, such a three-dimensional image is important to enable robots to act independently and without causing any danger outside of safety barriers.

3D image sensor technology

3D information about the environment can be detected using different kinds of technology. One of the most promising methods is the ToF technology (Time-of-Flight), which measures the time of flight of the light travelling from the light source to the object and back to the sensor. The echolocation used by bats or radar measurement used to monitor air traffic are based on the same principle – the measurement of the time of flight. pmdtechnologies AG – a 100% subsidiary of ifm electronic gmbh – has developed a camera technology that is based on this ToF technology. The object is illuminated by an infrared light source, which is invisible to the human eye. The light source is modulated in a way that a phase shift between the sent and the received signal can be determined. This phase shift is used to determine the light's time of flight from which the distance is calculated. The 3D image sensor operates with an integrated active suppression of background illumination and guarantees high reliability even in difficult light conditions. What makes this development special is the fact that the sensors are designed on the basis of the CMOS technology. This standard technology has many advantages, such as miniaturisation and easy integration into existing systems. Distance measurement and the corresponding generation of a 3D image are independent of the object's colour and its illumination. The sensors' robust technology is tried and tested and very reliable.

The image of 3D image sensors consists – like with conventional image sensors – of individual pixels. Instead of defining a colour or brightness value, a 3D image sensor, however, measures a distance value between the sensor and the object for each pixel. Creating a three-dimensional image of the environment based on these distance values, however, requires a lot of computing power. To ensure that the central controller of a robot will not be overloaded by these calculations, direct processing inside the sensor is advantageous. Thereby, objects can be recognised in the environment and transmitted to the central controller. ▸

Creating a three-dimensional image of the environment based on these distance values, however, requires a lot of computing power. To ensure that the central controller of a robot will not be overloaded by these calculations, direct processing inside the sensor is advantageous.

Humans and robots in the same room

Modern sensor technology makes it possible to implement new concepts of cooperation between humans and robots including direct interaction. A robot can operate in the same room as humans, provided that the robot recognises its environment reliably, so that any risk can be excluded. At the same time, this prevents collisions with obstacles and between different robots. Such robots also allow applications where robots and humans work „hand in hand". A very important aspect are sensors that detect the environment three-dimensionally and that identify objects and persons reliably. The 3D image sensors provide an ideal basis for this. The 3D sensor O3D from ifm electronic is such a sensor that works according to the illustrated ToF principle. The sensor has 23,000 pixels and for each pixel it determines a separate distance value between the sensor and the object. This allows reliable identification of different objects and also persons in the environment of an autonomous robot.

Wide range of applications

The new possibilities open up countless new applications for robots. Many activities that must still be done by a human could be taken over by robots in the future. A typical example is floor cleaning. First units for domestic use are already available, which, however, only require comparatively simple sensor technology since their movements are neither very fast nor powerful. If we think of larger surfaces, e.g. in public areas, floor cleaning machines still require human operators. Last year, Deutsche Bahn AG had invited to a competition for this precise application. The challenge is to clean larger surfaces with a driverless cleaning robot. Autonomous cleaning robots from four international manufacturers participated in the competition. Each robot had to clean a surface of 200 square metres while both the cleaning performance and the reliable avoidance of collisions with people or obstacles were evaluated. The cleaning robot CR700 from Adlatus was the winner of this competition and will now have to pass a test period of two years at Ulm main station. More stations will follow, among them Berlin. After a successful test phase of two years with Adlatus Robotics, stations all over Germany will be polished using robots. The goal of Deutsche Bahn is to improve the tidiness of the stations. Every year, cleaning train stations costs Deutsche Bahn an eight-figure sum. Inside the CR700 cleaning robots, O3D type 3D sensors from ifm detect the environment.

A robot can operate in the same room as humans, provided that the robot recognises its environment reliably, so that any risk can be excluded.

Optimised logistics in the supermarket

Using robots can be useful in many other areas. As in the example with the cleaning robots, autonomous machines are being developed to fulfil specific tasks. With Tally, Simbe Robotics have put a robot on the market that has been developed for use in supermarkets. It can check the stock level of individual products on the shelves and ▸

© DB AG / Pablo Castagnola

send out a notification if a shelf position is almost empty, so that the shelves can be refilled in time. Tally can identify the products either by using cameras or RFID technology. Bossanova offers a similar product.

The data of the autonomously operating robots are transmitted to a control centre, so that the current statuses of the shelves in the supermarket can be verified at any time. The autonomous robots can do the time-consuming checking task a lot faster and more efficiently than the supermarket staff. To ensure that all data is always up to date and available, the robots must operate during the opening hours of the supermarket. Also in this case, sophisticated sensor technology ensures that collisions with customers or supermarket staff are avoided. The autonomously operating robots in the supermarkets open up new paths for trade logistics. If the data is directly available in the supermarket's or the chain's logistics system, the digitisation of processes has made a giant step.

The rise of the service robot

With the Relay, Savioke have presented a new generation of service robots. They collaborate with humans in the same environments as well; and also here, safety is top priority. Sensors must recognise objects and persons at close range. The service robot can avoid obstacles or will stand still if it is not possible. The autonomous robots transport objects weighing up to four kilograms in a closed container. The first application of the Relay was the room service at a hotel. Guests will enjoy fast and automated deliveries of drinks, towels or bathroom articles directly in their room. The service robot can navigate through the hotel and even operate the lifts. Since the container is closed, reliable and safe delivery to the right guest is guaranteed. The Relay has a touch screen that can be used as a user interface, for example, to request a code to open the container. The service robot can be used to transport and deliver different objects ranging from ordered food from the delivery service to documents in offices and components in a production environment or prescription drugs at a hospital. Annoying errands can be replaced by an autonomously working robot.

Transforming standard machines into autonomous solutions

Creating an autonomously operating robot does not necessarily mean you need to start from scratch. There are already solutions for many of the above-mentioned applications, for example, for cleaning machines that are conventionally operated by a driver. Instead of developing a completely autonomous machine from scratch, the controller can be provided with additional sensors that transform the machine into an autonomous one. The technology company Brain Corp from San Diego, USA, offers ▸

Photo provided by Brain Corp

adequate solutions for this approach. With their proprietary operating system BrainOS, they provide the foundation to transform conventional machines into autonomous solutions. This is the basis for the development of intelligent controllers for self-driving machines that can safely navigate environments with pedestrian circulation.

Robots will belong to everyday life

Robots are booming and will soon be everywhere, and it will be perfectly natural that they will work in our immediate environment. After they have been used almost exclusively in the manufacturing industry for many years, developments in sensor technology and control systems make it possible that, today, robots work more and more often in direct contact with humans. These human robots, however, do not have a lot in common with the humanoid robots that populated the science fiction literature of the 20th century. Instead, autonomously working machines are put on the market that have been developed for specific tasks. In all situations where humans must fulfil simple and monotonous tasks, using robots might be possible. The new generation of robots must be able to cope with their environment. They must be able to navigate and to perceive their immediate surroundings. This is the only way to ensure safe cooperation between humans and robots. Modern sensor technology, such as 3D image sensor technology, is an important key to solving these issues. ■

After they have been used almost exclusively in the manufacturing industry for many years, developments in sensor technology and control systems make it possible that, today, robots work more and more often in direct contact with humans.

Author: Jörg Lantzsch

What does it mean …?

Time-of-Flight (ToF)
By measuring the time of flight of the light, distance values between the individual image points and the object can be established at pixel level, generating 3D information directly and in real-time (in addition, the grey values are recorded at the same time). The most frequent ToF technology is known as PMD (photonic mixer device).

CMOS sensor
Image sensor in complementary metal-oxide semiconductor technology. Originally used in low cost cameras with lower resolution they were further developed to become more powerful and have already overtaken the CCD technology. Special feature: Small areas to be defined (see 'area of interest') in the image sensor can be read out at an extremely high frame rate.

Source:
VDMA
Key Technology for Automation Solutions
Machine Vision 2018/19
Applications – Products – Suppliers
www.vdma.com/vision