The Principle of 3D Sensors

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***Abstract* - Gradual development of modern trends with more emphasis on visualization and measurement accuracy have resulted in the continuous improvement of measuring instruments, which are very closely linked to Personal Computers and/or Programmable Logic Controllers to the displaying unit and leads to greater utilization of 3D technology. 3D technology is used in security, biometrics, and in many other fields. This contribution is focused on understanding the issues of scanning and its advantages and disadvantages. It serves as a complete overview of the structure of the 3D sensors.**

Keywords – 3D sensors; sensors; CCD; CMOS.

I. INTRODUCTION

The greater emphasis on accuracy, versatility, speed, and price is the result of the continual development of production, automation, and research of 3-dimensional measurements of objects. These 3D technologies became more important with the development of integrated computer technologies.

The binary system is a numbering system which is used to express a value using only characters 0 and 1. The binary system belongs to a group of positional number systems with base 2, which is a specific number as expressed by the power of 2. The numbers registered in the binary system are called binary numbers. Record of numbers in the binary system is complemented by a 'B' or 'b', which is used as a subscript on the last digit or acronym BIN. [1]

Thus, the control input/output information becomes only the values “YES” or “NO” because that specifies whether the previous cycle is performed correctly, satisfies the specified tolerances, but it does not describe the influences, facts and events that preceded the input. Since the control input/output is mainly done visually, it is necessary to adapt the technique using geometry [2]. This path is very appealing, but it may happen that our elected sensing principle is imperfect and must subsequently find a new algorithm for image processing. The main representative of 3D shooting is CCD (Charge-Coupled Device) [3] and/or CMOS (Complementary Metal–Oxide–Semiconductor) [3] camera. The separation of signals may be difficult in practice, because there are plenty of influencing factors. Quality can be affected by the most essential settings, such as the arrangement of cameras, illuminators and environment. This setting is applied in film and art photography as well. A big part is affected by lighting or suitable arrangement of illuminators - object - cameras. If we have neglected these factors, we put programmers in a position where they spend most of their time creating and optimizing algorithms for finding the proper results in the image. Some problems and disruptive factors can be eliminated by polarization and absorption filters, semi-permeable mirrors, light reflectors and diffusers [4].

Photometric systems can be difficult to connect with the PCs and their operation systems but, generally, they use simple methods of image processing. Scanning is performed using surface or line CCD camera with a greater emphasis on minimization of measurement errors [2].

The rest of the paper is structured as follows. Section II serves as an introduction to optical radiation and the principle of its operation. Section III describes two construction types for scanning device and their advantages and disadvantages. The last section describes the types of methods used for 3D scanning.

II. OPTICAL RADIATION

A 3D sensor utilizes electromagnetic waves radiated by the scanned object to obtain information on shape, position and object properties. The object may be an active source of optical radiation, or passive, which only reflects or modifies the incident radiation from another source. The most significant properties are light rays, straight lines, independence of each other and no interaction with each other. The law of reflection and refraction is applied. Optical radiation has the same properties as the electromagnetic wave [2].

For the velocity (in $m \cdot s^{-1}$) we have the relation:

$$v = \frac{1}{\sqrt{\varepsilon\mu}} \tag{1}$$

Permittivity (ε) is a physical quantity describing the relationship between the vectors of the electric field intensity and electric induction in a material or vacuum. Permeability (μ) expresses the influence of the material or environment on a magnetic field [5].

Since it is a very small probability that the scanning takes place in vacuum, we extend this pattern for the environment where the scanning is performed. The relation to calculate the diverse environment is given below:

$$v = \frac{c}{\sqrt{\varepsilon_r}} \qquad (2)$$

where c = 2,998·10^8 m·s^-1 is the speed of light in vacuum and ε_r the relative permittivity environment.
The speed of light is also affected by refractive index. Maxwell explains the relation between the absolute refractive index n_0 and the dielectric constant ε_r:

$$\varepsilon_r = n_0^2 \qquad (3)$$

Radiation can also be characterized by wavelength (λ), which is always smaller than in vacuum. The relation between λ and n is expressed by:

$$\lambda_n = \frac{\lambda_0}{n_0} \qquad (4)$$

III. Principle of Video Camera

The principle of the video camera is the same as the digital camera. Reflected electromagnetic waves (visible light) from the object pass through the objective and fall onto the photosensitive sensor. Consequently, the input image is converted to an electronical signal by the sensor and then it is saved using the internal electronics.

A. Objective

The camera uses the lens optical system for imaging. Lenses are divided into two basic groups: lens (refractors) and mirrors (reflectors). Reflectors create an image of direct, apparent and the same as the subject. Two types of mirrors are used - concave and convex. Concave mirrors create a mirror image that is direct, apparent and reduced. Convex are dependent on the distance from the focus and the mirror. If we show the object positioned between the focal point and highlight of mirrors, it creates a picture of the direct and virtual object located further from the focus. On the other hand, it appears as an image inverted and real. The size of the result image can be dependent on the position of the lenses as well as reduction or enlargement. The main advantages include the absence of reflectors chromatic aberration and it is easier to manufacture large mirrors. Figure 1 shows the main representatives of mirror telescopes which are Cassegrain [6] and Newtonian [6] telescopes.

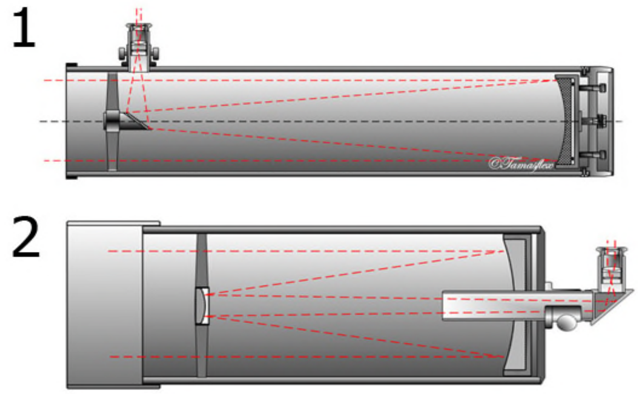

Figure 1. Principle of the reflector (1 - Newton's principle 2 - Cassegrain principle) [6]

Refractors use an optically isotropic medium which is bounded by two spheres (or one spherical and one plane). It is called the lens (spherical lens). Lenses limited by non-spherical surfaces (e.g. part of the cylinder, ellipsoid, etc.) are called aspherical lenses. The lens has a different refractive index than its surroundings. The emerging picture when viewing the lens depends on the type of lens (converging, diverging) and the position of the object against the lens. A diffusing lens creates an image directly. The size of the resulting image may be larger or smaller against to original image [6].

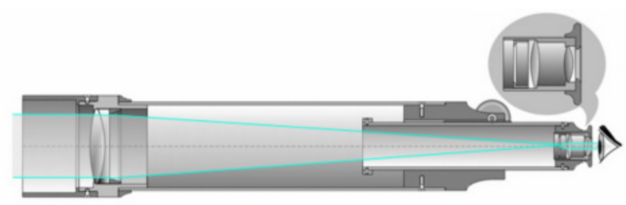

Figure 2. Principle refractor [6]

B. CCD vs CMOS

Nowadays, technologies are dominated by two data recorders.

CCD is the most frequently used imaging chip in compact cameras. Its manufacture is relatively simple, but costly. The output information from the CCD chip is not a digital, but an analog, and must be digitized. The utilization of the Analog / Digital converter (A/D) means higher power consumption and slowing down the flow of data. Light-sensitive cells on CCD have a square shape and the output from the CCD is via bus. The individual rows or columns of photosensitive cells are connected to the bus. Data is sent to the bus row by row. Simpler embodiments but slower data read. That arrangement of the CCD chip is called progressive CCD chip. In contrast, the chip known as an interlaced CCD chip is easier to manufacture.
The principle is very simple. First to third column is on its own register (subtraction for mini sort memory), fourth to sixth also have their own pair. They are deducted gradually in these values of individual registers, which leads to higher

speed retrieval of data from the chip (in this case, it would be 2-3 times).

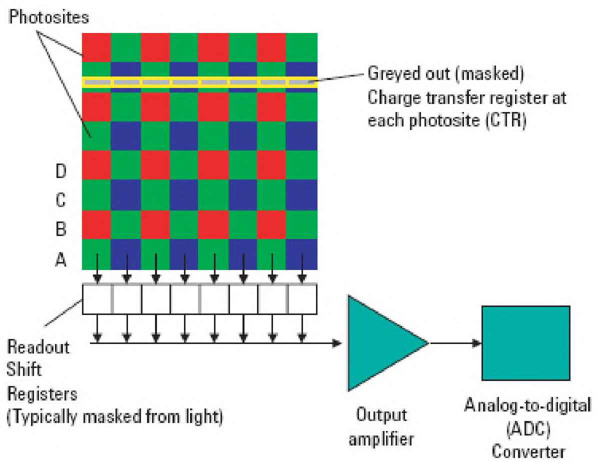

Figure 3. Principle CCD [4]

CMOS chip is predominantly used in digital cameras and gradually expands into digital compacts. CMOS chip is structurally a very complex matter, but it is cheaper to produce because it is produced in the same way as computer processors. Circuits that digitize an image at the CCD for all pixels gradually are directly part of the CMOS chip - each photoreceptor cell has these circuits directly at each other. Digitalization of the image is thus, performed in each photosensitive cell at the same time. This reduces the time required for reading the image of the CMOS chip and reduces power consumption. On the other hand, the area sensitive to light is only a tiny part of the overall chip because the other areas are digitizing circuitry. This is solved by color filters. These filters use Red – Green – Blue – additive color model (RGB) or Cyan – Magenta – Yellow – Key (CMYK). Filter miniature lens which focuses the rays illuminating the surface of photoreceptor cell only to place, which is the light-sensitive. The number of cells per micrometer rises up to tens of million. Another advantage is the data output from the CMOS chip goes suddenly as matrix. This increases the speed of a collection of data from the CMOS chip. In particular, this property is desirable for high speed filming. Older and cheaper CMOS chips cause undesired spreading to nearby hubs light-sensitive cells. Overall, this phenomenon manifested itself as lighter or darker bands on the scene known as the effect of striped shirt - a man in a one color shirt looks like he is wearing striped one. This undesirable phenomenon of "leakage" of electrons can sometimes be observed on the CCD chip as well. A new generation of CMOS does not suffer from this defect anymore [4].

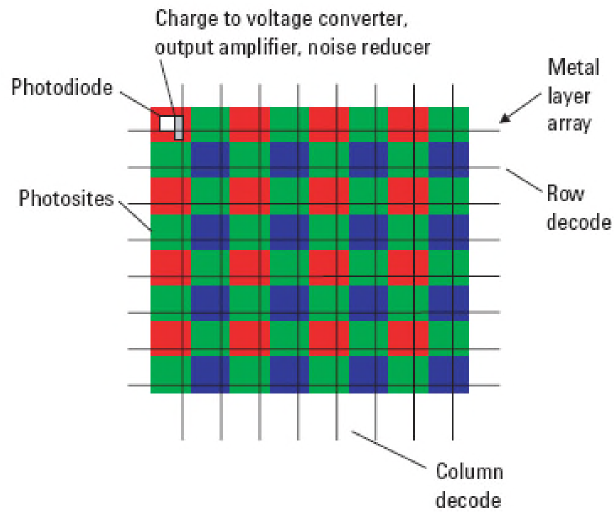

Figure 4. Principle CMOS [4]

IV. PRINCIPLES 3D SCANNING

3D sensors are coming to the forefront and are more and more commonly used in all possible sectors because of the development of technology and the increasing demand and popularity of virtual reality. Some examples include construction, architecture, industrial machinery, navigation, etc. Perhaps in all applications, it is necessary to have coordinates in a 3D space. The scanning is dependent on the position of the object, its speed, color, shape, and angle of rotation. The advent of modern technology and optics, which is still used for 2D scanning, expanded to methods for measuring the third dimension. Today, there are mainly two methods of measuring. The first one is a triangulation and the second is a light interference. The gradual development of technologies brings about the third method. This method is called Time of Light (TOF) and uses the knowledge of the speed of light.

A. Triangulation

Triangulation is very often used as a method which requires a very complicated structure of the measuring sensor. It is divided into two categories: active triangulation and passive triangulation.

The principle of the active triangulation involves photogrammetric reconstruction of the scanned object. The surface of scanned object is illuminated by the light source and simultaneously scanned by the CCD sensor [7].

The principle of passive triangulation involves photogrammetric reconstruction of the scanned object on the basis of its projection on the sensor surface device. One dimension is lost during projection and it is needed to renew on the basis of a common information from multiple sources [7].

The principle can be seen in Figure 5. The light signal is transmitted from the laser source to the object. The object reflects the light ray to the camera. The angle of the

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transmitted ray from the source is constant, but the CCD sensor depending on the spend ray of the dimmed sensor. The connector between the light source and the CCD sensor is called triangulation base (baseline). Thanks to the knowledge of two angles and the length of the triangular base, we can calculate the distance of a point, and then save the coordinates for later calculations and rendering [8].

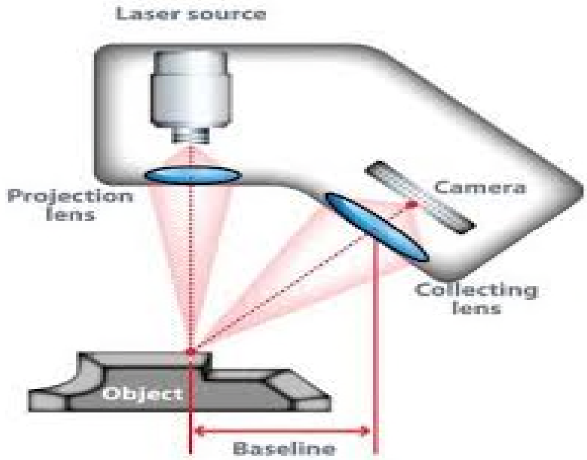

Figure 5. Principle triangulation [5]

To mark the surface, the following are used:

- the light beam (1D triangulation),
- light (2D triangulation),
- Structured light beam (3D triangulation).

Disadvantages:

- higher purchase price and better facilities,
- time demands when evaluating the Record,
- the limiting factor may be the memory size and especially the quality of the recording,
- more necessary knowledge of issues,
- treatment of subjects.

B. *Interferometry*

Interferometry is a method suitable for very precise measurements over a short distance. The principle is based on light interference. The principle can be seen in Figure 6. The light source - the laser - is transmitted through the polarization splitter - a part on the measured object. The reflected signal is combined with polarization ray splitter reference called carrier wave and they may interfere together. The resulting wave interference is given by equation (5) [8]:

$$I(x,y)=|I_1(x,y)|^2+|I_2(x,y)|^2+2|I_1(x,y)||I_2(x,y)|\cos(\varphi_1(x,y)-\varphi_2(x,y)) \quad (5)$$

Disadvantages:

- Technologically intensive production;
- Demanding quantitative interpretation of results;
- Susceptibility to interference.

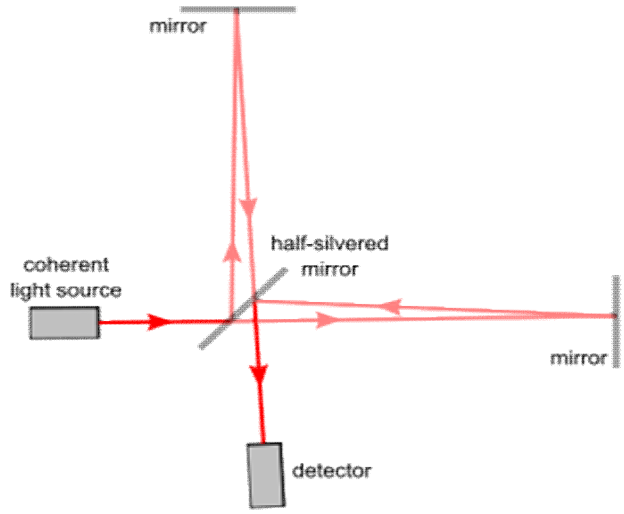

Figure 6. Principle Interferometry [8]

C. *TOF*

This is a method that uses the knowledge of the speed of modulated light signal that is emitted from the transmitter and subsequently reflected towards the receiver. The use of this method requires very precise time value. The principle can be seen in Figure 7. The distance of sensing object can be computed from formula 6, where "t" is the total time from sending a signal to the one more acceptation and "c" is the speed of light (c = 2.998 * 108 m / s) [8].

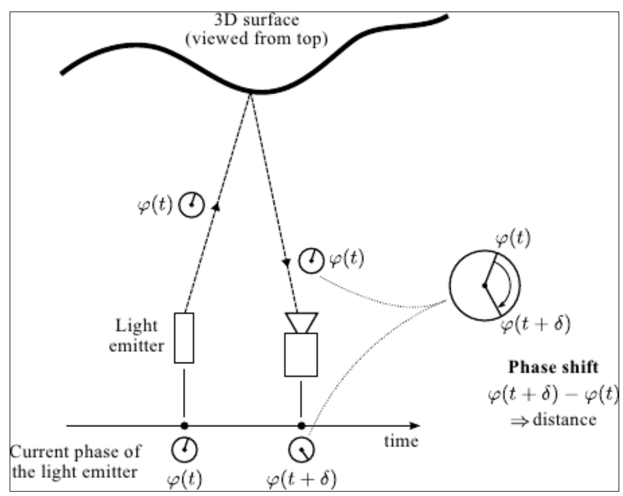

Figure 7. Principle TOF [8]

$$s=\frac{c*t}{2} \quad (6)$$

Disadvantages:

- High-accuracy time measurement required
- Measurement of light pulse return is inexact, due to light scattering
- Difficulty to generate short light pulses with fast rise and fall times

- Usable light sources (e.g. lasers) suffer low repetition rates for pulses

V. CONCLUSION

We can find a lot of potential in utilization of 3D sensors in all sectors from an overall perspective. A big boom was registered mainly in the improvement of cartography, digitization, security etc. The main objective of this article was to suggest the basic concepts, definitions, types and principles of various kinds of sensors. The summary of the information in this article suggests that the expansion of 3D scanners and 3D technologies and their general application over time will be more necessary than previously thought. The main advantage of 3D sensors is the utilization of three-dimensional space, which has been in seclusion so far and was not the main goal. The authors believe that 2D sensor will be partially or completely replaced by 3D sensors in a few years. Although we area ware that 3D sensors are more expensive because it is necessary to place greater emphasis on accuracy and designing of 3D scanners, they do provide an improved visualization.

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