Systems Engineering in Mechatronics
Midterm Exam Homework
Vision and Image Sensors

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1 Introduction

Robotic vision continues to be treated including different methods for processing, analyzing, and understanding using different kind of sensors. All these methods produce information that is translated into decisions for automated systems. From start to capture images and to the final decision of the robots, a wide range of technologies and algorithms are used like a committee of filtering and decisions.

Another object with other colors accompanied by different sizes. A robotic vision system has to make the distinction between objects and in almost all cases has to tracking these objects. Applied in the real world for robotic applications, these machine vision systems are designed to duplicate the abilities of the human vision system using programming code and electronic parts. As human eyes can detect and track many objects in the same time, robotic vision systems seem to pass the difficulty in detecting and tracking many objects at the same time.

In this article, I will make an overview of image and vision sensor types and softwares used for machine vision as well as most common vision sensors used by engineers to apply machine vision in the real world using robots. In the 3rd and 4th section I will give an information about working principles of this sensors and their applications in a real world situations.

2 Image and Vision Sensor Types

Vision sensors are quite interesting. They are sensors that are able to determine an object's dimensions, location, shape, and even vision sensororientation. They use cameras and monitors for this in most of the cases. Today, many of these types of sensors are cost effective options that are going to be able to help them with inspections and other industrial tasks.

In the industrial and automation world, machines need sensors to provide them with the required information to execute a proper operation. A lot of sensors can be added to different robots to increase their adaptability. We see a lot of collaborative robots having integrated force torque sensors and cameras in order to have a better perspective on their operations and also to provide the safest workspace. This made us think it would be a good thing to enumerate the different sensors that can be integrated into a robotic cell.

2.1 In terms of integrated circuits

Two main types of sensors are used in digital cameras today: CCD (charge-coupled device) and CMOS (complementary metal-oxide semiconductor) imagers. Although each type of sensor uses different technology to capture images, these sensors have no inherent quality difference.

Both CCD and CMOS imagers use metal-oxide semiconductors, and they have about the same degree of sensitivity to light.

CCD sensor

CCDs are manufactured using an advanced technique that enables transportation of charge across the chip without any distortion, thereby producing very high-quality sensors with reliability and light sensitivity.

Captures photons as electrical charges in each photosite (a light-sensitive area that represents a pixel). After exposure, the charges are swept off the chip to an amplifier located in one corner of the sensor. External circuitry converts the analog signal to digital form and handles storing it on your memory card.

The chip output is in the form of analog voltage. The images produced using CCD image sensors possess high quality and low noise. The processing speed is in the range of moderate to fast and the complexity of the sensor is low.

Although CCD sensors consume more power than CMOS sensors, these sensors are widely used in many applications requiring high-quality image data.

CMOS sensor

CMOS is an integrated circuit technology that has been adapted to capture images. The CMOS sensor components can be easily integrated onto a single chip using conventional manufacturing processes.

Includes solid-state circuitry at each and every photosite, and can manipulate the data for each pixel right in the sensor. The CMOS sensor can respond to lighting conditions in ways that a CCD can't. Every photosite can be accessed individually.

The chip output is in the form of digital bits. Although they are complex, CMOS image sensors are said to be easier and cheaper to manufacture than CCD sensors. Each pixel in the CMOS sensor can be read separately. Processing of image is fast while the sensitivity is low. They are, however, comparatively more vulnerable to noise.

The advancement in CMOS image technology is enabling CMOS sensors to move towards higher levels of performance.

2.2 In terms of their purpose in use

2D Vision

2D is vision is basically a video camera that can perform a lot of different things. From detecting movement to localization of a part on a conveyor. 2D vision has been on the market for a long time and is here to stay. Many smart cameras out there can detect parts and coordinate the part position for the robot so that it can then adapt its actions to the information it receives.

3D Vision

3D vision is much more recent phenomenon as compared to 2D vision. A tri-dimensional vision system has to have 2 cameras at different angles or use laser scanners. This way, the third dimension of the object can be detected. Once again many applications use 3D vision. Bin picking, for example, can use 3D vision to detect objects in a bin and recreate the part in 3D, analyze it and pick it the best way possible.

Force Torque Sensor

While vision gives eyes to the robot, force torque sensors give touch to the robot wrist. Here the robot uses a force torque sensor (FT sensor) to know the force that the robot is applying with its end of arm tooling. Most of the time, the FT sensor is located between the robot and the tool. This way, all the forces that are applied on the tool are monitored. Applications such as assembly, hand-guiding, teaching and force limitation can be done with this device. We have developed a technology called Kinetiq Teaching that allows industrial welding robots to be taught via hand-guiding. All of this using a force torque sensor to monitor the motions of the "teacher". We also have a FT Sensor that is sold separately to accomplish any number of applications that might require force sensing. What if you want to detect the force applied on the robot arm? For example, you want to know if the robot is in collision with something or someone? Well, the next type of sensor answers all these questions.

Collision Detection Sensor

This kind of sensor can have different forms. As the main applications of these sensors is to provide a safe working environment for human workers, the collaborative robots are most likely to use them. Some sensors can be some kind of tactile recognition systems, where if a pressure is sensed on a soft surface, a signal will be sent to the robot to limit or stop its motions. You can also see this kind of sensor directly built into the robot. Some companies use accelerometers, some use current feedback. In either case, when an abnormal force is sensed by the robot the emergency stop is released. This provides a safer environment. Although, before the robot stops you will still be kicked by it, right? The safest environment is an environment with no risk of collision. This is what the next sensor is all about.

Safety Sensors

With the introduction of industrial robots in collaborative mode, industry has to react with a way to protect its workers. These sensors can really appear in a lot of different shapes. From cameras to lasers, a safety sensor is designed to tell the robot that there is a presence around it. Some safety systems are configured to slow down the robot once the worker is in a certain area/space and to stop it once the worker is too close. A simple example of safety sensors would be the laser on your garage door. If the laser detects an obstacle, the door immediately stops and goes backwards to avoid a collision. This can be a good comparision to what safety sensors are like in the robotic industry.

Part Detection Sensors

For applications that require you to pick parts, you probably have no clue if the part is in the gripper or if you just missed it (assuming you don't have a vision system yet!). Well, a part detection application gives you feedback on your gripper position. For example, if a gripper misses a part in its grasping operation, the system will detect an error and will repeat the operation again to make sure the part is well grasped.adaptive gripper object detection Our Adaptive Grippers have part detection systems that don't need any sensors. In fact, our Grippers are designed to grasp parts with a given force. So the Gripper doesn't need to know that the part is there or not, it will only apply enough force to get the best grip on the object. Once the required force is reached, you know that the object is in the Gripper and that it is ready for the next step in the operation. [2]

2.3 In terms of projection-type

Vision sensors come in 2 different types and can be adjusted for different purposes:

Orthographic projection-type: the field of view of orthographic projection-type vision sensors is rectangular. They are well suited for close-range infrared sensors, or laser range finders. Perspective projection-type: the field of view of perspective projection-type vision sensors is trapezoidal. They are well suited for camera-type sensors.

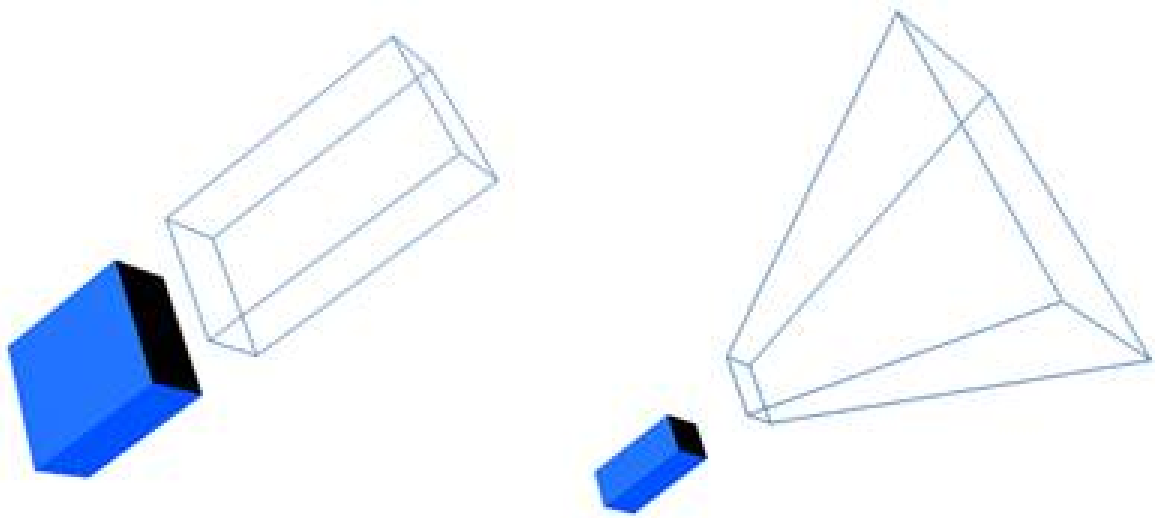

Figure 1: Orthogonal projection-type and perspective projection-type vision sensors

Vision sensors, which are viewable objects, can be looked-through like camera objects. In addition to that, the image a vision sensor generates can be applied as a texture to shapes and custom user interfaces.

Vision sensors are very powerful in the sense that they can be used in various and flexible ways. For instance they can be used to display still or moving images from an external application or a plugin. Plugins can also provide customized image processing algorithms (e.g. filters) as well as evaluation algorithms (e.g. triggering conditions). There are several built-in filters that can be

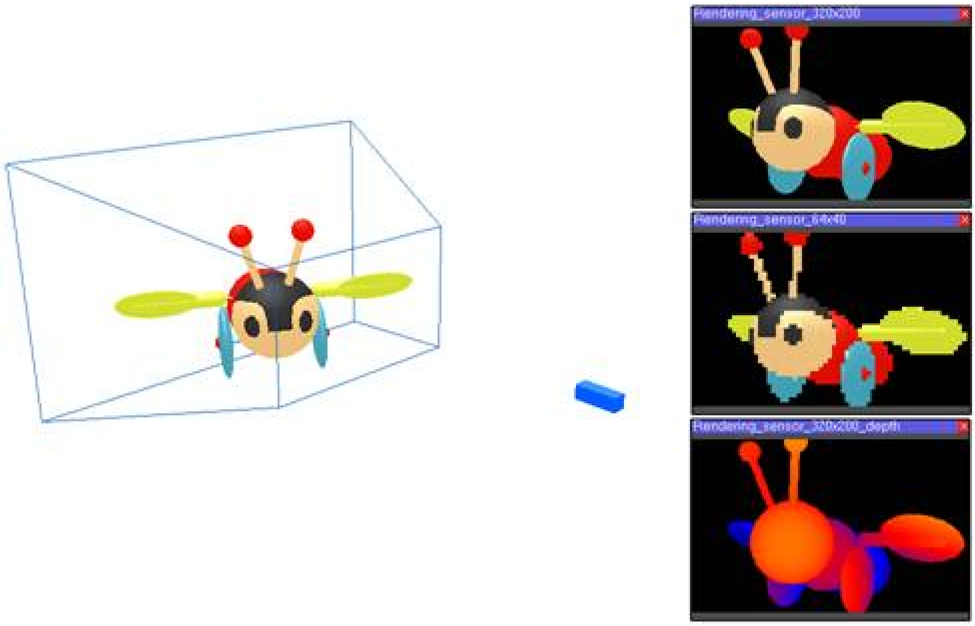

Figure 2: Vision sensor and various filters

applied to images of a vision sensor. Refer to the filter composition section for more details. Vision sensors can only render (and detect) renderable entities. Calculation results of vision sensors can be recorded by graph objects. [3]

3 Commonly Used Sensors

A robot can see interpreting images captured using vision sensors in different ways. These are intelligent sensors used to perform different tasks by robots. In this section of the article, I made an overview of popular vision sensors embedded in robots.

Kinect Sensor
Microsoft creates one of the most advanced vision sensor with features that makes it ideal for robotic applications.

Vision Sensor: iVu Series
Brings the simplicity of a photoelectric sensor and the intelligence of a vision sensor together to provide inspection solutions that can be applied and supported right on the factory floor.

No PC required to configure, change or monitor
Easy configuration: install/connect iVu, select sensor type, acquire image, set inspection parameters
Advanced capabilities: menu-driven tools guide you as you set up your inspection
Three advanced sensors in one rugged package: a Match, an Area, and a Blemish sensor type
Software emulator lets you perfect your application offline
Integraded models offer a touch-screen for programming on the factory floor
Remote models offer separate touch screen display that mounts remotely from the sensor to allow easy access for setup and monitoring
Compact, rugged housing available with or without a variety of integrated ring lights- red, blue, green, and infrared
Ability to change parameters on the fly

Ethernet option available for simplified communications and enhanced control of the sensor

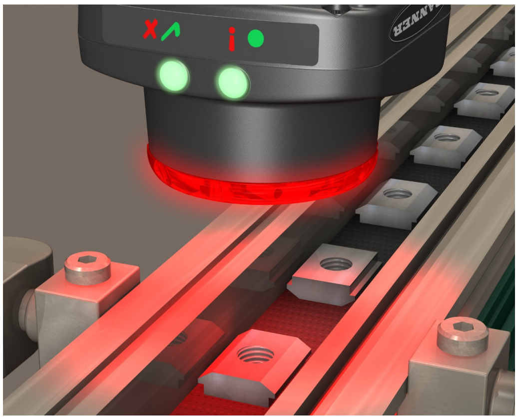

Figure 3: iVu Series vision sensor

Smart Cameras:PresencePLUS P4 - It uses Bar Code tool to read and grade bar codes
-Finds and decodes advanced 2D and 1D linear bar codes
-Standard BCR model (640 x 480 pixels) or high-resolution BCR
-1.3 model (1280 x 1024 pixels) features 1.3 megapixel imaging
-Reads 2D Data Matrix ECC200 and PDF 417 and 1D linear codes
such as Code 39, Code 128, Codabar, Interleaved 2 of 5, EAN-8 and EAN-13 (supports UPC-A).
-Features compact, self-contained P4 housing
-Includes remote TEACH, configurable I/Os, live video and communications standard to all PresencePLUS sensors
-Available with a color match tool to inspect for specific colors
[1]

Figure 4: PresencePLUS P4 Smart Camera

Creates shadows to detect changes in depth Illuminates specific surface angles Avoids glare of reflective surfaces when directed at an angle away from lens Lights distances greater than 12 inches Available in 62 x 62 mm, 70 x 70 mm, or 80 x 80 mm light sizes with 24V dc supply voltage Offers choice of models with infrared or visible red, white, blue or green lights, UV 365 (nm), UV 395 (nm) Continuois or strobed operation models available Offers useful life of 10,000 to 60,000 hours, depending on model Sealed and high-intensity models available

4 Working Principles

4.1 Inside of CMOS Image Sensors

Advent of CMOS technology in eighties led to the phenomenal growth in semiconductor industry. Transistors have become smaller, faster, consume less power, and are cheaper to manufacture. It is CMOS technology which has enabled very high integration on the chips leading to modern high performance, miniaturized integrated circuits.

Apart from the valuable contribution in miniaturization of integrated circuits, CMOS technology found applications in sensing applications.

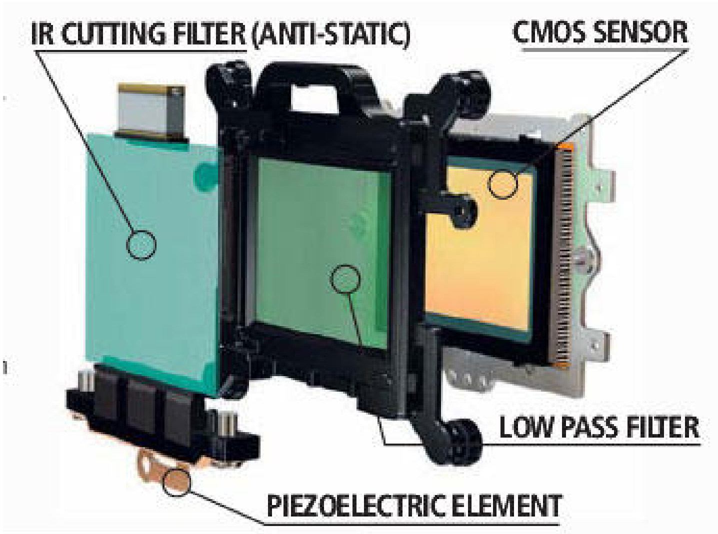

Figure 5: CMOS sensor inside

CMOS technology has been adopted to design sensors, especially in the field of imaging. Due to the wide usage of CMOS based image sensors, CMOS sensors are often considered to be a synonym of CMOS based image sensors and have emerged as a competitor to CCD based image sensors.

Until recently, Charge Coupled Devices (CCDs) dominated most of the image sensing systems, i.e., cameras, camcorders, etc. CCDs have been in use in astronomical cameras, video camcorders and scanners. However of late, CMOS Imaging have emerged as an alternative to CCD imagers and it also offers better features.

Subsequent sections will discuss both CCD and CMOS sensor based imagers, their pros and cons, and also their applications. Further, other applications of CMOS technology in the field of sensing will be discussed.

CMOS Vs CCD

Invention of CCD marked the end of vacuum tube imagers used in television cameras as it overcame the disadvantages of vacuum tubes like chronic picture artifacts as lag and burn-in, fragility of large glass tubes or the sensitivity to shock, vibration and electromagnetic radiation, painstaking periodic alignment of tubes, etc. It also marked the beginning of a new era in imaging systems and for decades, it enjoyed quality advantages over the rival CMOS sensors. Wherever image quality was paramount, CCDs were preferred, CMOS were used mainly in applications where small size and low power were prime requirements.

With the technological development in CMOS technology, gap between CCD and CMOS sensors has narrowed; CMOS sensors can also achieve competitive quality. Choice amongst CCD and CMOS sensors has become increasingly difficult.

Both CCD and CMOS image sensors use large arrays of thousands (sometimes millions) of photo-sites, commonly called pixels. Both carry out same steps.

i. Light-to-charge conversion

Incident light is directed by the microlens (a tiny lens placed over the pixel to increase its effective size and thereby fill factor) onto the photo-sensitive area of each pixel where it is converted into electrons that collect in a semiconductor "bucket." The bigger the pixel, the more light it can collect.

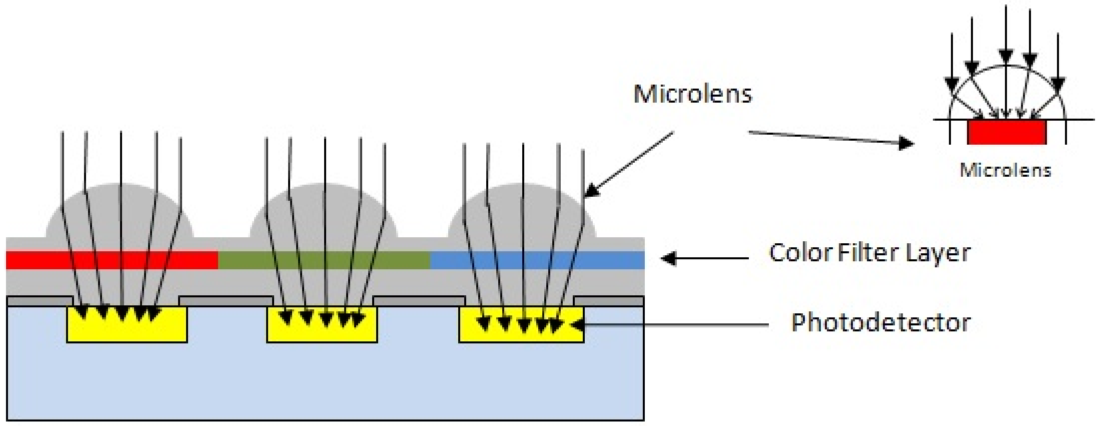

Figure 6: Light-to-charge conversion

Thus, big pixel sensors work best under low-light conditions. For the same number of pixels, bigger pixels results in bigger chip, this means higher cost. Conversely, smaller pixels enable smaller chip sizes and lower chip prices, as well as lower lens costs. But there are limitations on pixel size reduction. Smaller pixels are less sensitive to light, the optics required to resolve the pixels becomes expensive and requires expensive fabrication possesses.

ii. Charge accumulation

As more light enters, more electrons accumulate into the bucket.

iii. Transfer

Accumulated charge must be transferred to the signal conditioning and processing circuitry.

iv. Charge-to-voltage conversion

The accumulated charge must be output as the voltage signal.

v. Amplification

Voltage signal is then amplified before it is fed to the camera circuitry. Both CMOS and CCD perform all these tasks; however the aspect in which they differ is the order of execution of these tasks.

5 Applications

5.1 Industrial Usage

A vision sensors finds its place in many fields from industry and robotic services. Even is used for identification or navigation, these systems are under continuing improvements with new features like

3D support, filtering, or detection of light intensity applied to an object.

Applications and benefits for vision systems used in industry or for service robots:

automating process;
object detection;
estimation by counting any type of moving;
applications for security and surveillance;
used in inspection to remove the parts with defects;
defense applications;
used by autonomous vehicle or mobile robots for navigation;
for interaction in computer-human interaction;

5.2 Applications in Research and Development Projects

Development of a Depth-Augmented Dynamic Vision Sensor for 3D SLAM

The PrimeSense technology enables depth sensing devices which are capable of perceiving a scene in three dimensions, and has become increasingly popular in research because of the favorable trade-off between accuracy, speed, and affordability. Instead of the common Lidar and time-of-flight sensing technology, it employs a structuredlight approach – officially named light coding. A speckle pattern, called structured light, is continuously projected onto the scene in near IR light, invisible to the human eye. The pattern is hereby pseudo-randomly generated, unique in all positions, and hard-coded into the device. A dedicated off-the-shelf monochrome CMOS sensor is employed to recognize the pattern in the scene. Effectively there are two pictures available now, a hard coded image of the pattern which is projected onto the scene and the image produced by the CMOS sensor. Through stereo triangulation and measuring the distances between the pattern's dots, depth is derived. The Xtion Pro Live is a proprietary product produced by Asus and uses the Prime- Sense Carmine 1.08 RGB-D sensor; this product was used in the implementation presented in this thesis. Some official specifications are denoted in table below.

Specifications	
Power Consumption	$\leq 2.5\,\mathrm{W}$
Distance of Use d	$0.8\,\mathrm{m} \leq d \leq 3.5\,\mathrm{m}$
Field of View	58° H, 45° V, 70° D (Horizontal, Vertical, Diagonal)
Depth Image Size	VGA (640×480) : 30 fps QVGA (320×240): 60 fps
Dimensions	$18 \times 3.5 \times 5\,\mathrm{cm}$

Figure 7: -

The Figure-7 shows a sequence of RGB and depth frames as produced by the Xtion. For easier interpretation of the depth information, a color map has been applied to the depth frames with varying colors depicting different levels of distance from the sensor.

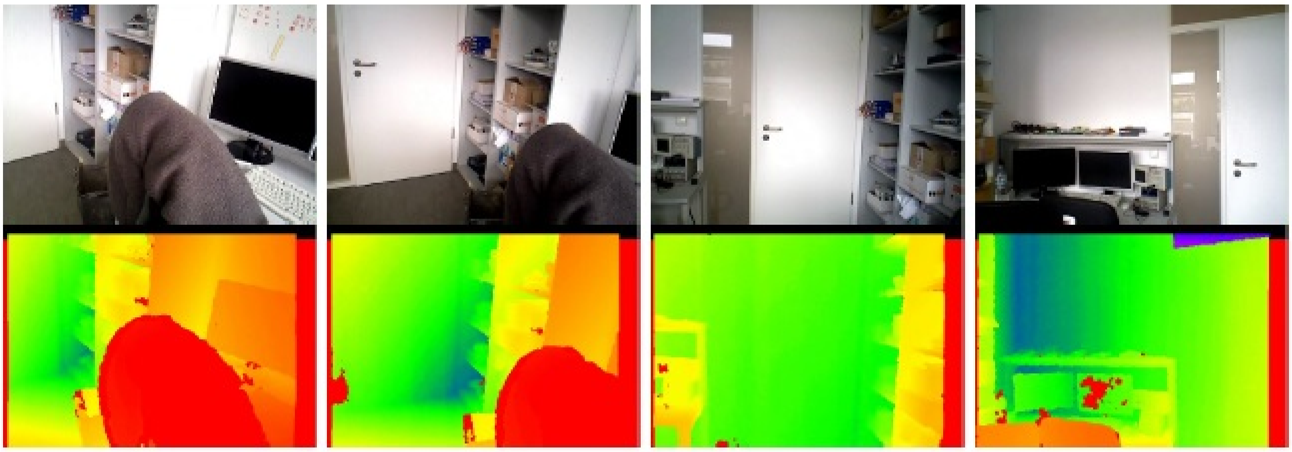

Figure 8: Series of non-consecutive color and depth frames. Red indicates near, or in case of the chair missing information. Blue depicts larger distances. The images have been registered and share the same view.

References

[1] www.bannerengineering.com.

[2] www.blog.robotiq.com/bid/72633/7-types-of-industrial-robot-sensors.

[3] www.coppeliarobotics.com/helpfiles/en/visionsensordescription.htm.