Escaneo tridimensional y detección de objetos para una subsecuente manipulación por un robot colaborador

3D scanning and detection of objects for a subsequent manipulation by a collaborative robot

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Palabras clave

Robot colaborativo; sistemas de visión; escáner láser tridimensional.

Resumen

En el mundo se utiliza cada vez más la robótica para asistir en los distintos procesos que se llevan a cabo: desde la manufactura, la medicina y muchas otras áreas en las que se requiere alivianar el trabajo del ser humano, ya sea por exceso de esfuerzo, la necesidad de alta precisión o por la peligrosidad de la misma tarea que se desea llevar a cabo, entre otros.

Los robots colaborativos tienen una gran capacidad de llevar a cabo tareas variadas; sin embargo, existe siempre una restricción hacia los mismos, son "ciegos". Los robots pueden llevar a cabo tareas para las que son programados, pero en un principio no cuentan con herramientas que les permitan ver su entorno para reaccionar acorde con él. Se han desarrollado distintas tecnologías para superar estas barreras.

El objetivo del proyecto es desarrollar la integración entre una tecnología láser de escaneo tridimensional con un robot colaborativo, de manera que éste pueda realizar un escaneo sobre una superficie de trabajo. Luego de completarse el escaneo, se debe analizar la información obtenida con un sistema de visión que se implementará, para luego poder darle al robot interpretación de los datos obtenidos y que el robot pueda subsecuentemente tomar decisiones respecto a las acciones a llevar a cabo y la ubicación de los distintos objetos presentes. Se llevará a cabo una investigación progresiva, en la que se puedan ir desarrollando las herramientas necesarias para obtener los resultados deseados, para lograr al final un solo sistema integrado de visión.

Keywords

Collaborative robot; vision system; tridimensional scanning laser.

Abstract

Robotics are used every day more to assist on the different processes that take place around the world: from manufacturing, medicine and many more areas in which human work needs to be eased, rather because there is an overload on the needed effort, a necessity for high precision or for the hazard that the process itself implies, among others.

Collaborative robots have an enormous capacity to carry out a variety of tasks; however, there is always a restriction to them, they are "blind". Robots can perform tasks which they are programmed to do, but in principle they lack of tools that will allow them to view their surrounding and interact accordingly with it. Different technologies have been developed to overcome this barrier.

The objective of the project is to develop the integration between a tridimensional scanning laser technology with a collaborative robot, so that the robot can execute a scan over a working surface. After completing the scanning routine, the obtained information shall be analyzed with a vision system that will be developed, for giving the robot, later on, interpretation of the obtained data and the ability to subsequently take decisions of the actions to be made and the location of the different objects present. A progressive research will be implemented, so that the necessary tools to accomplish the objectives can be developed, to obtain ultimately a whole integrated vision system.

Introduction

The university Duale Hochschule Baden-Wurttemberg (DHBW) in Karlsruhe, Germany, has a Robotics and Automation laboratory that is part of the mechanical engineering faculty, a division of the engineering or "Technics Department". The DHBW owns a light section sensor from Leuze-Electronic.de. The laboratory also has possession of different collaborative robots: one ABB IRB1600, two IRB140 and from Universal Robots a UR5 and a UR10.

The goal of the project is to detect and handle objects with the 3D scanning system and the collaborative robot. It is desired to pick different and challenging objects that can be handled with one gripper. The motivation for developing such a system is based on the availability of the hardware (light section sensor and universal robot) at the DHBW, but also on the necessity to increase knowledge and uses on this type of systems that use 3D scanning technology.

At the moment, the university has a very restricted use for the sensor, but the uses of it can be increased and enhanced by developing further investigation. With the option of scanning multiple objects, the applications also augment. Scanning objects in the given environment for obtaining 3D images can be used for sorting different objects, assembling entire components, augmented reality, service robots and others. The ability to learn about the surroundings and about different objects allows robots to get a better notion of the world, and with this, new applications can be developed [1], for example, synchronized 3D readings with Google 3D Warehouse models. With this, a robot was able to identify real world objects and classify them using as base similar 3D models found on this database. And with the growing use of 3D technologies, understanding the world will be easier every day.

The evolution of robotics brings new opportunities for human development. Every progress made in the research of new technologies brings not only benefits, but also makes noticeable the deficits that had not been detected previously on the various areas of growth among robotics and related areas [2]. Robotics develops in a variety of shapes and functionalities, and it is evident that acquiring abilities inspired in nature are one of the main goals among researchers. Giving a robot the ability to interact with the world in a more real approach is one of the main interests in robotics. One of the abilities desired in robots, that is inspired in nature and also in human abilities is, the sense of sight. To achieve these, there are several attempts that are still on the spot of researchers, and that have grown in the last years.

The 3D scanning has become the attempt to document the real world and understand it better. There have been developed several techniques among time. As Ebrahim states:

3D laser scanning developed during the last half of the 20th century in an attempt to accurately recreate the surfaces of various objects and places. The technology is especially helpful in fields of research and design. [3-4]

One approach for capturing 3D information of the environment is using RGB-D cameras. These specialized cameras capture images as a common RGB camera, but they also capture depth information per pixel. However, using RGB-D cameras has its disadvantages. They have limited distance for information acquisition, the noise level on the measured distances can be problematic depending on the application, and they also have a restricted view angle [4].

There are many other restrictions or problems when using a camera technology for acquiring 3D information, such as the light conditions in which the applications is developed. The lack or excess of light or the uncontrolled conditions of it may cause shadows or faulty information, which may affect the measurements of depth among objects and scenarios. To avoid this problematic, laser technologies have been implemented to get depth information, that is not affected in the same way as cameras by the light on the environment [5].

Despite the application using a laser scan and not a camera, considering the illumination is important. Laser scans are a type of Time-of-Flight sensor. They use a light source, which could be a LED or in this case a laser. They also have an array of pixels that detect and measure the incoming light and its correspondent phase. This will be used to determine the distance from a specific point on space. The measure of received light depends not only on the distance of the object, but also on the reflectivity of the object that is been evaluated. Therefore, the light present on the surroundings does affect the measurements and should be considered. To get a better resolution of the scanned objects, an option would be to utilize a higher power laser, but this would increase the power consumption and overall cost of the system. Another option to avoid this would be to reduce the scanned area or to extend the scanning time of the object [6]. There are then three variables that need to be considered and pondered very cautiously: resolution of the images, cost of operation and cost of the system, and time invested on the scan. As Hornung et al. describe, “memory consumption is often the major bottleneck in 3D mapping systems”[7].

Materials

- Universal Robot UR5
- Light Section sensor LPS 36 from Leuze-Electronic.de
- Test blocks with different shapes
- Software Open CV for image conditioning
- Software Msys for programming multiple interface

Methodology

The project will be divided in several steps that will be explained next:

Step1: Collaborative Robot

Understand the functioning of the collaborative robots available at DHBW, their differences, advantages and disadvantages. Learn on the specification for this robots and how to program them. Select one of the collaborative robots and program it to move the sensor over the scanning area.

Step 2: Light section sensor

Understand how the light section sensor works, its features and limitations and how to get signals from it. Several testing will be carried out to understand better the functioning of the system: how it performs the scanning, and what communication protocol it uses to send this information to the receiver. It is also important to understand what process it uses to build the frame alignment to create the 3D images.

Step 3: Object detection, recognition

After acquiring the data of the objects present over the scanning surface, a series of algorithms to identify and classify different objects with OpenCV will be developed.

Step 4: Combined work

The overall objective is to integrate the robotic system, sensor reading algorithms and computer vision system to perform a complete function. The UR will aid rotate the sensor for the initial lecture, the information will be processed by the system and data will be sent back to the UR, so it can identify the different objects present on the work area, decide how to pick up and pick up the objects, for further manipulation (reposition, stack, relocate or store objects).

Results

The obtained results will be presented in the different stages in which the project was divided, in order to have a clear comprehension of each one of them.

Step1: Collaborative Robot

The ABB robots where at the moment used for different projects from other research students, and both Universal Robots where available for immediate use. The difference between both UR5 and UR10 are in dimensions and capacity, where the UR10 is bigger and can handle more weight. The programming of both robots makes no difference since they run on the same language and environment, and the final decision of which UR would be the best choice depends on the specific application the robot will be developing and its requirements. Since the application developed is for research only (not a real application in the industry), and the parts that will be handled by the robot represent no high demand on power, the UR5 was selected for working on the developing of the project during the semester. However, the solution developed will be possible to use on both URs.

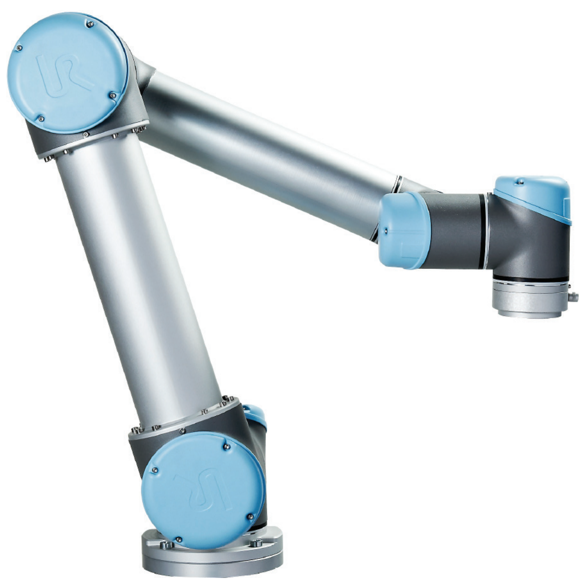

Figure 1. UR5 Universal Robot selected for the application.

For the development of this project, there are two different Ethernet communications needed. The first one is between the Leuze sensor and the central computer, where the laser sensor functions as the server and the PC as the client. The second communication is between the PC and the UR Robot, where the UR behaves as a client and the PC will be working as a server. A diagram is presented in figure 2.

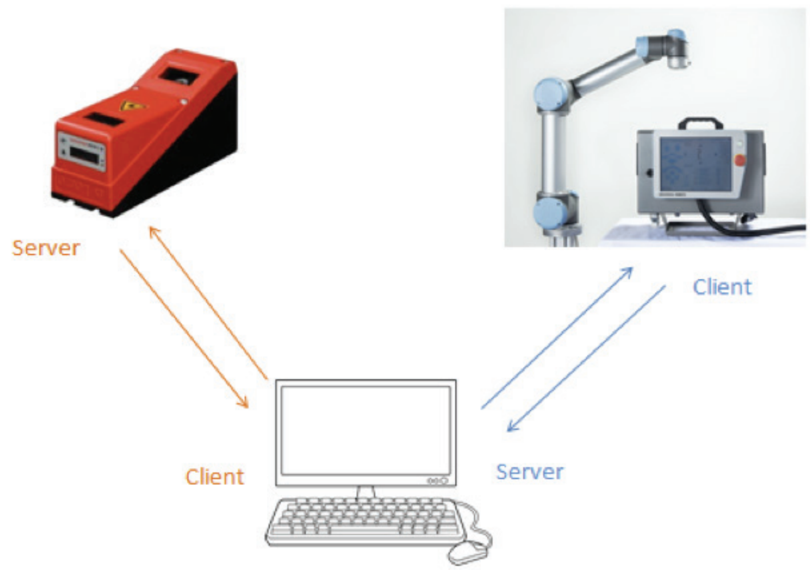

Figure 2. Communication diagram.

The UR5 was programmed using the teach pendant that comes with the robot, which offers the user a friendly interface to create the routine that wants to be carried out. However, a good comprehension of the kinematics of the robot is important in order to comprehend the movements of the robotic arm, to understand the space of the robot, and to relate this coordinates to the working space and the objects on it. The UR kinematics are performed by the UR's controller, and can be obtained with different functions that the UR's software provide.

Rotations can be calculated with the functions: [8]

$$Rx(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & -sin\theta \\ 0 & sin\theta & cos\theta \end{bmatrix}$$

$$Ry(\theta) = \begin{bmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{bmatrix}$$

$$Rz(\theta) = \begin{bmatrix} cos\theta & -sin\theta & 0 \\ sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The UR's software allows defining features to make the programming easy. The user can define Points in space, Lines, and Planes. For this project, a plane is needed, which will be the table or measuring surface.

Figure 3 explains the disposition of points on the plane created:

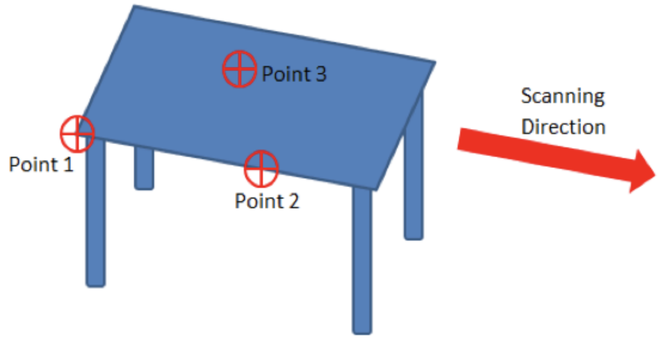

Figure 3. Measuring plane for the UR.

The coordinate system (origin) of the table will be located at Point 1.

The following algorithm (figure 4) was used to program the UR to perform a first scan of a surface:

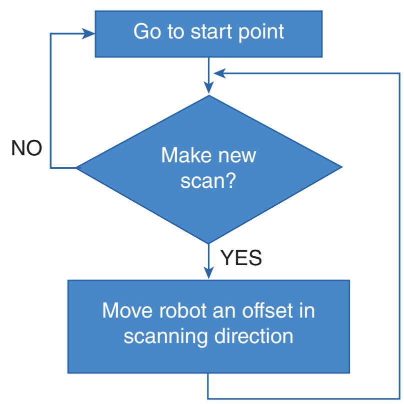

Figure 4. UR basic algorithm.

Step 2: Light section sensor

On this section, it will be developed the steps taken for programming the communication between the Leuze Light Section Sensor and the host computer. To achieve this communication, the sensor must first be studied, its technical characteristics, the protocol used by Leuze for the communication and the different possibilities that the sensor offers to the user, to define the scope and flexibility that the sensor will offer for the desired objectives.

On the figure 5, it is possible to observe a scheme of the functioning of the sensor.

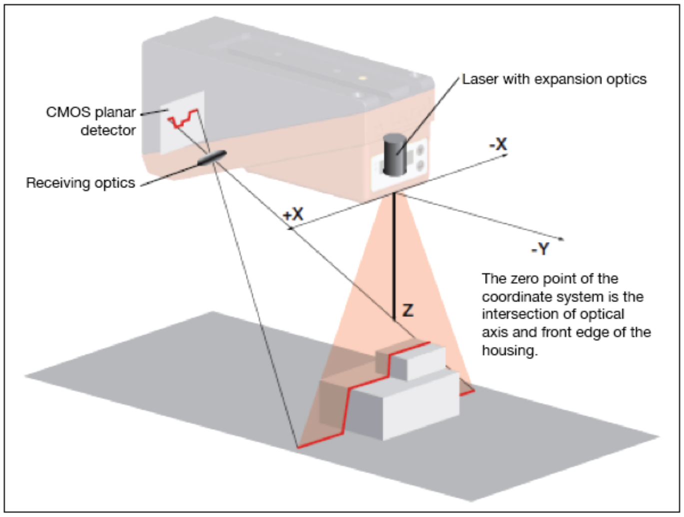

Figure 5. Leuze LPS functioning scheme.

As it is shown, the laser beam is projected over a surface from the laser. The laser line will be projected to the CMOS planar detector accordingly to a position relative to the point of reflection of the beam on the surface. This allows mapping the gradient of the laser beam proportional to the real 2D cut. The sensor then converts these values to a certain position, both in X and Z coordinates, that correspond to the real life surface. With one isolated lecture, a 2D profile will be obtained. When making continuous lectures, and if there is a relative movement between the sensor and an object, it is possible to create a 3D map of the readings.

There is one common problem that may present when making lectures, and it is called "Occlusion".

As the scanning of a surface is based on the reflection phenomenon from the laser beam to the CMOS detector, if the beam is obstructed partially or completely, it will not reach the destination as it is expected. This can be better explained when observing in figure 6.

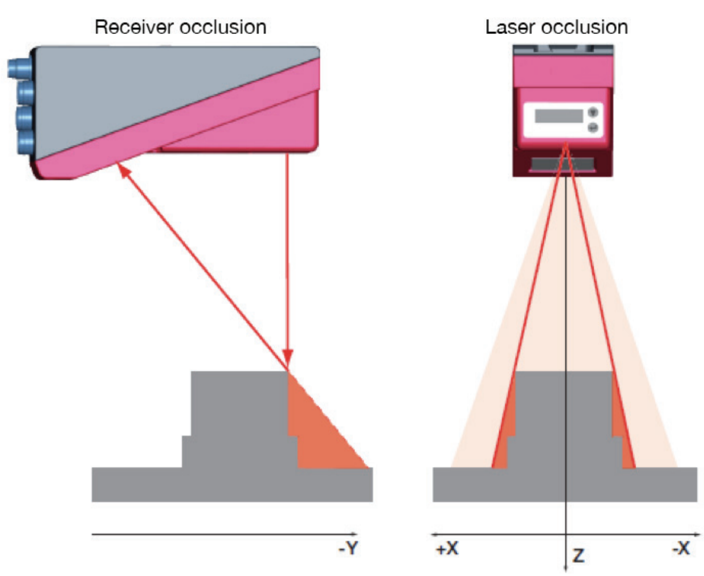

Figure 6. Occlusion phenomena on Leuze LPS.

The occlusion appears on a scanned object when not every part of the object can be reached by the laser beam that will get the depth information of the scanning surface, or when a point that was reached by the laser beam cannot reach back the CMOS sensor inside the Leuze LPS. This problem was detected on the scans performed, as in the figure 7 obtained:

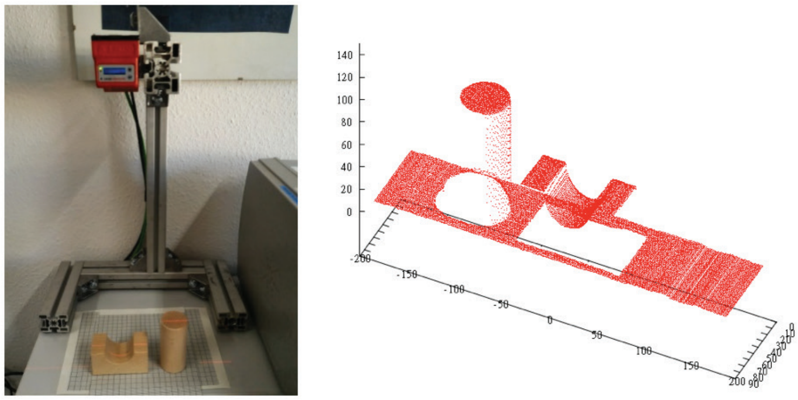

Figure 7. Static working station and cloud points from manually performed scan.

Step 3: Object detection, recognition

Point Clouds is a graphic interpretation in a 3D space in which every point has its own coordinate and can be located creating the space that the object would be occupying. The advantage when working with Point Clouds is that the data is managed in space as it is obtained. Every point (xi, yi, zi) will have a specific coordinate with no possibility of occupying the same space than another point. Libraries like PCL have developed algorithms that handle these data, and allow to extract information and to transform the data (transforming the coordinate system or stitching with another point cloud for example). However, OpenCV cannot handle point clouds, which requires a different approach for a solution.

At this point of the project, there are files created with a list of points with x, y and z coordinates. A proposition for working with these data is to make a transformation from a 3D point cloud to a 2D grayscale image. The intensity of the gray represents in a 2D image the Z value of the 3D image, while the X and Y coordinates remain the same.

If the Z channel is output as a grayscale image, the above result is printed (see figure 8).

Figure 8. First grayscale image

As expected, the image is a grayscale representation of the 3D image that represents the height with a different intensity of gray. The darkest zones represent what is farther from the sensor, and the brightest zones represent what is closer to the LPS.

Different conditioning algorithms were implemented to analyze the images obtained from the 3D scans, starting from edge detection. A Canny function was selected because it gives equal priority for both X and Y directions. Other functions for finding borders are for example: Gaussian filter, Sobel filter, Scharr filter. The canny edge detector uses the Gaussian filter to filter out noise from the image, and then applies a similar to Sobel filter to find the gradients on the image. It is also known as Optimal Detector. The following result was obtained after experimenting with different values to obtain an optimal result (see figure 9).

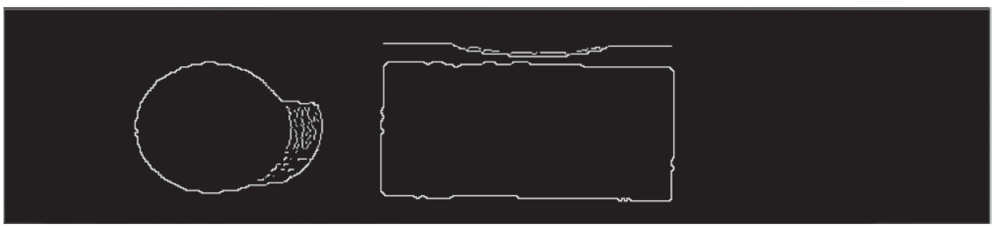

Figure 9. Edges of filtered grayscale image

The idea of the filters is to isolate from noise and to obtain geometric figures that can be further analyzed to classify each object. More image analysis needs to be done, but new images are necessary. Because of this, the integration of the UR and the Leuze sensor is now mandatory.

Step 4: Combined work

The following algorithms for the integration stage were developed (figure 10):

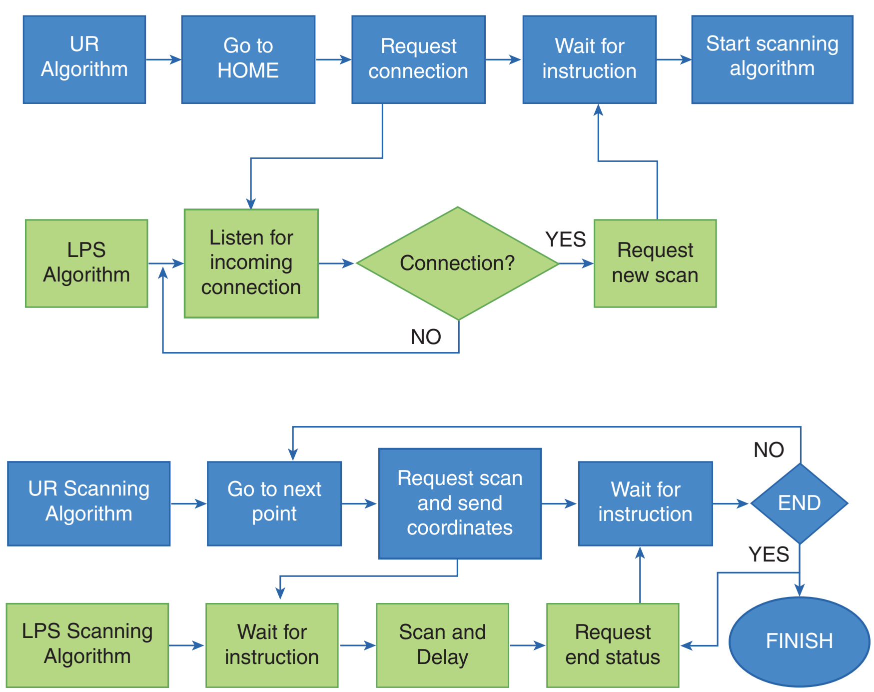

Figure 10. Final scanning algorithm with UR5 integrated.

After obtaining new images with the use of the UR5, and applying canny filter, followed by a sequence of dilate and erode stages, very good images were obtained (see figure 11).

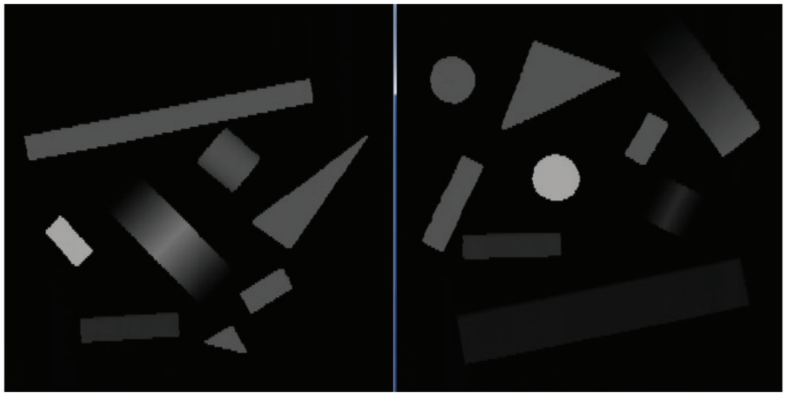

Figure 11. Filtered images obtained with different objects present on workspace

To identify and classify the present objects, edge detector algorithms and best fit algorithms were applied. The best fit algorithm compares an object with the best probable fit, and can be done using rectangles, circles and triangles as reference, as showed in figure 12.

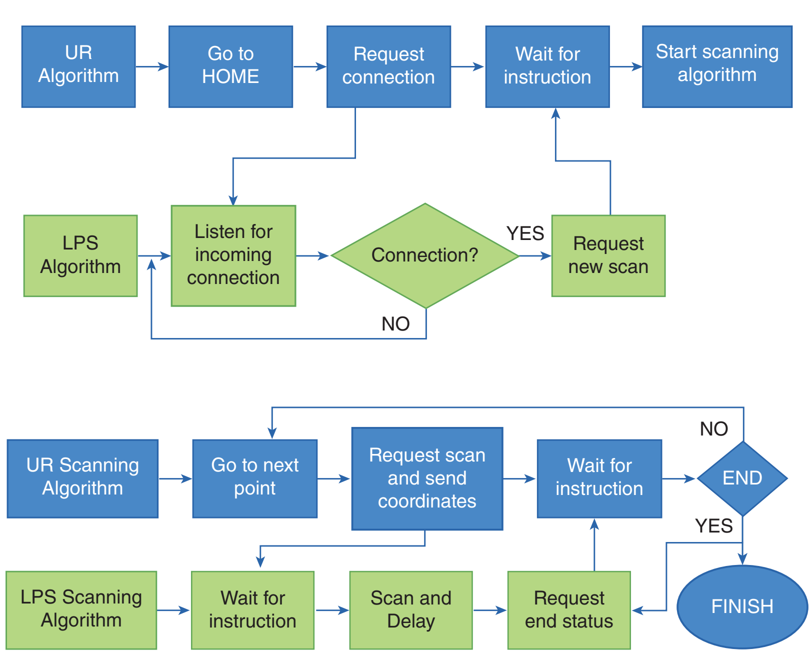

Figure 12. Detected objects and best fit analysis.

The areas of the objects were compared to make a final decision on what kind of object was been analyzed at the moment, the area units are pixels. The following results from comparing areas were obtained from analyzing two different objects (see table 1).

Table 1. Area comparison Figure A and Figure B.

Area	Figure A	% Error	Figure B	% Error
Original Figure	2048.5	-	1563	-
Best fit Rectangle	2115	3.25	1893.13	21.12
Best fit Triangle	4050.09	97.7	2524.71	61.53
Best fit circle	3325.39	62.3	1777.12	13.7

This area comparison made possible to determine that Figure A is a rectangle and figure B a circle, because the lower error on areas indicates which figure has the best fit.

In the end, for every object detected, the following information was displayed to the user:

- Object shape (rectangular, circular, triangular)
- Origin coordinates of the object (X,Y)
- Width and Height of the object
- Angle (orientation) of the object
- Area of the object

With the information obtained, it is possible to identify, classify and reach the different objects present on the scanned surface.

Conclusions

The use of light section sensors is optimal for acquiring 3D images on scanning surfaces, as it is very flexible to program, and offers the user a wide range of possibilities of configuration for obtaining the desired results.

The use of an assisting robot, in this case the UR5, to assist a depth sensor on realizing a scan over a measuring surface is very useful. It allows the user to make complicated scans with a high precision when a transporting band is not an option to move objects.

Vision systems are very powerful for analyzing data, and the extent of their scope is tied to the user's imagination and programming skills. An open-source tool such as OpenCV gives the user more than enough options for developing object identification, characterization and image treatment, but a background on image processing is required.

The integration of different areas such as Sensor programming, Robotics programming and kinematics, Image processing and others are a very useful quality for mechatronics, as they allow the user to build a wide variety of solutions that can be applied on the industry with success and for a large amount of applications.

Recommendations

The time for scanning was not very good, as it takes approximately 1 minute to scan a surface of 50cm. This is because of the logic that was used all along the programming of the algorithms.

A proposed solution is to make the Leuze sensor scan continuously and the UR also move continuously from the start point to the end point. An algorithm for managing the data sent from the sensor to the PC needs to be programmed, probably using a buffer that stores all the data and then stores it properly. With no delays on the scanning process, the scanning time should be reduced drastically, probably to less than a final 10% of the actual scanning time.

Point Cloud Library (PCL) is a powerful tool that will allow treating the data as it is taken by the Leuze sensor. It only requires point coordinates on a 3D space to analyze data. PCL has algorithms for stitching more than one point cloud, which would allow making scans to an object from different directions, and putting them together in only one image. With this, it is even possible to create complete 3D images of objects that can later be used to reproduce the objects with 3D printers or CNC machines.

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