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Robotic Manipulator and Artificial Vision System for Picking Cork Pieces in a Conveyor Belt

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Abstract—**This paper describes the use of laser triangulation sensors for the development of a prototype with the ability to sense and measure the position and dimensions of a cork piece in a conveyor belt. Its purpose is to catch the moving piece using a robotic manipulator and put it in a desired place for later handling.**

In this work a procedure to obtain the mathematical equations of the laser triangulation sensor is presented, and an approach to calibrate the laser triangulation sensor (LTS) is described. A developed interface calibrates the LTS and shows the 3D piece reconstruction.

This paper also describes an algorithm of segmentation and image analysis necessary to extract features and measures from the reconstructed cork piece image.

I. Introduction

The cork industry plays an important role and is one of the most powerful branches in the Portuguese industrial environment. Thus, there is a continuous need to improve the cork industry's performance, since the efficiency and time spent in some tasks are nowadays huge factors of success. The implementation of industrial cells with the ability to transport cork pieces in an autonomous way, without human help, is important to improve the process performance.

The objective of this work is to do the 3D image reconstruction of cork pieces. When a 3D image from a cork piece is obtained, an algorithm of segmentation and extraction can be applied with the aim of obtaining the middle point of the cork piece, the orientation and its dimensions. When these measures are known, a robotic manipulator will pick the cork piece and put it in a desired place. This document shows the interaction between the developed application, which obtains the cork piece geometric parameters, and the robotic manipulator ABB and a grip based on the Dynamixel AX-12 actuators.

Figure 1 shows the entire system with the Laser Triangulation Sensor (LTS), the conveyor, the robotic manipulator and the respective grip.

The presented work was developed in the GroundSys Group [1], which is a research laboratory that belongs to the INESC Porto. Some work on robotic manipulators, stereo vision and laser triangulation has already been carried out at the GroundSys Group [2-4].

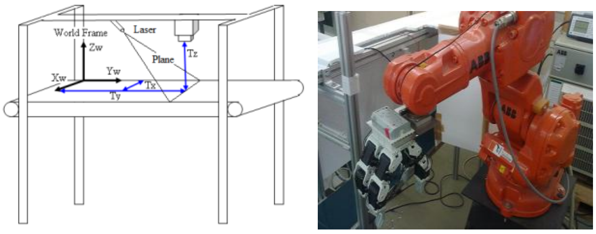

Fig. 1 Conveyor belt and laser triangulation sensor (left). Robotic manipulator ABB and grip (right).

Section II describes an overview of 3D imaging sensors and image analyses. Section III talks about the robotic manipulator (ABB) and the built grip, while Section IV describes the laser triangulation sensor model and the triangulation equations are presented. Section V shows the developed user interface and some results. Finally, in Section VI some conclusions are presented.

A. *Motivation*

The LTS development and growth in research laboratories provide a good background in the field that makes it possible to apply these sensors in systems for material handling in the industrial environment. The developed project focuses on a system with application in the cork industry.

II. 3D Imaging Sensors and Image Analysis Overview

During the 70's and 80's, the development of image reconstruction techniques was only performed in research laboratories [5]. Only after the development of these systems it was possible to apply 3D imaging in industrial environments.

The inclusion of light sources and optical sensors are used nowadays to improve three-dimensional image reconstruction.

Then, the 3D sensors, combined with 2D vision sensors (multi-fusion), can be applied in different areas, such as robotics, collision avoidance and "removing-from-heap" [5]. The three-dimensional image sensors could be classified as non-optical or optical, passive or active and direct or indirect [5].

A. *3D Image Reconstruction Techniques*

Sansoni et al. [5] gives us a reasonable set of three-dimensional image reconstruction techniques:

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-The laser triangulation - this is the approach used in this work.

-Structured light sensors. It is similar to laser triangulation. This technique projects a bi-dimensional pattern of non-coherent lights and then the depth information is obtained by the intersection between the camera and the pattern plane.

-Stereo Vision. Liao *et al*. [6] describe the stereoscopic imaging techniques as a traditional method to solve the problem of loss of depth when a camera is used to perform 3D image reconstruction.

The stereoscopic imaging technique uses two or more fixed cameras to achieve three dimensional imaging. An alternative way it is take more than one image using a moving camera, [6].

-Photometry. In this method, digital images are used and then the camera needs to be calibrated.

-Time of flight. The time of flight principle consists of emitting laser impulses, and the measurement of the return time and intensity makes it possible to reconstruct the intended3D surface.

-Interferometry. Consists of the projection of spatially or temporally varying periodic patterns onto a surface and, mixing the deformed and reflected pattern with the reference projected in the surface, it is possible to compute the variation and the surface geometry.

-Shape from focusing, which exploits the focal proprieties of the camera lens.

-Shape from texture. This technique finds possible geometrical figures in the image.

-Shape from shading. The target surface shadow is helpful to do the object shape reconstruction.

B. Three-Dimensional Image Sensors Application

Three-dimensional image sensors can be used in the industry, in cultural heritage, medical applications and crime scene documentation [5].

In the industrial field, the applications are: surface quality control, dimensional measurement and reverse-engineering of free form shapes, in order to obtain specifications and drawings by object inspection.

In the heritage and cultural fields, these techniques could be used for artistic reconstruction and maintenance and conservation record of real artistic objects. It could also be applied in restoration processes, recognition for mobile robotics, environment modelling and object recognition [7].

Several medical applications are: prosthetics design, plastic surgery, orthopaedics, prosthetic in the orthopaedics and dermatology [5].

C. Laser Triangulation Sensor Approach

The LTS is constituted by the CCD camera, the respective lens and the laser capable of projecting light as a plane (scanner laser). The LTS principle is described by the projection of the laser plane in the surface that we want to reconstruct, followed by the image capture.

Like is said by Acosta *et al*. [7], laser triangulation is constituted by two different steps: the first one consists of identifying the pixels in the image that are under the influence of the laser beam. The second and last steps are related with the triangulation equations. After acquiring the points of the laser plane in the image, it is necessary to solve the triangulation equations and then obtain the points in a world reference frame.

The LTS are nowadays the most common non-contact method used in equipment, such as coordinate measuring machines [8].

The laser triangulation advantages are its effectiveness and economic advantages. It is also a fast computational technique with a large range of applications [7].

D. Laser Triangulation Sensor Calibration

The calibration of the LTS implies the determination of the system parameters [5,8]: intrinsic, which corresponds to the laser plane equation and the CCD geometry; extrinsic, which is equal to finding the relation between the optical sensor, rotation and displacement, and the global and reference frame.

The intrinsic parameters to obtain during the calibration are: the focal length, the distance between the image centre and the origin of the reference frame in the image plane, the distortion parameter according to the chosen distortion model and the relation or size of a pixel in millimetres.

The extrinsic parameters are the orientation and displacement of the camera in the LTS global coordinate frame.

E. Image analysis Overview

There are a set of operators that are responsible for image pre-processing. There are punctual, local and global operators. They are described in chapter "*Image Enhancement*" from [9]. The edge detection is fundamental for the image segmentation. The edge detection separates the homogeneous zones and variable zones, like borders, in the image, and is mentioned in the chapter "*Image Segmentation*" from [9].

The algorithm that makes it possible to determine the equation of lines, in the image, is called Hough transform and is mentioned in the chapter "*Image Segmentation*" from [9].

The skeleton operations are used as methods to smooth or to eliminate the border projections of an object. There are two important operations in the image skeleton process: the open and the closed, and they are described in the chapter "*Representation and Description*" from [9].

III. Robotic Manipulator

After the measurement of some characteristics of the cork piece, they are sent via RS-232 to the ABB controller.

The robotic manipulator used in this work was the model IRB140 that belongs to the ABB. This robotic manipulator has six axes and was designed with the special purpose of operating inside the automation manufacture.

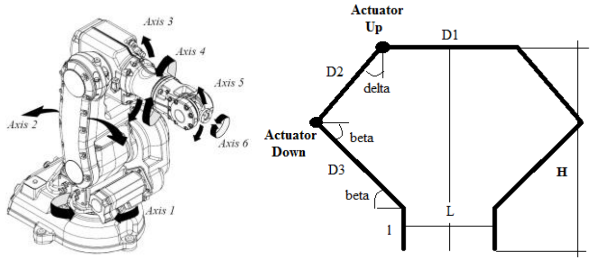


Fig.2 a) ABB robotic manipulator. b) Grip built.

Then, every time any new piece is detected and reconstructed by the LTS and by the developed user interface, a message with the cork piece centre of gravity and orientation is sent to the ABB controller.

After that, the user interface waits for a positive confirmation, which will be sent by the ABB's controller if the data received are correct.

After the robotic manipulator receives the message and sends the positive response, the ABB's tool goes to the desired position and then a new message is sent to the user interface to inform that the robotic manipulator is ready, in the desired position.

After that, the tool of the ABB (grip) is closed and a new message is sent to the ABB controller saying that it could go to another position where the grip opens.

The grip was done based in the Dynamixel AX-12 actuators, [10]. The Dynamixel AX-12 is a small actuator that produces high torque, with a precision DC Motor and network functionally. The Dynamixel AX-12 is a model actuator that belongs to the Robotics series.

Each AX-12 actuator has a table where some data, such as the actuator ID, baud rate, model etc., are stored in Rom memory, while the present actuator position, the goal position, the moving speed or the present torque load are stored in Ram memory. Then, in this table, it is possible to write data that will be helpful in moving the actuator to an intended position, at a reference speed. It is also possible to read the actuator table, which will be helpful to know some actuator parameters, such as the present load.

The actuators exchange data with the CM5 controller using the TTL level half duplex UART. All the commands between the laptop (application that runs on a PC) and controller CM5 are performed via serial communication.

If the objective is to catch a cork piece with length equal to L, angles γ and β need to be determined in order to move the actuators to the desired position.

The angle β is in fact imposed by the grip structure, since the part l of the grip needs to be parallel to the cork piece.

Angle γ is given by the following expression:

$$cos\,\gamma = \frac{D1 - 2.D3.cos\,\beta - L}{D2} \quad (1)$$

The total height of the grip according the cork piece width is equal to:

$$H = D2.sin\,\gamma + D3\,sin\,\beta + l \quad (2)$$

IV. Laser Triangulation Model

This work uses the camera USB CCD Mono DMK 21AU04, [11]. This camera shows images with a 640x480 resolution. The focal length of the lens used in this work is equal to 4mm.

Since the objective is to see pieces of cork with the maximum size of Obj, we need calculate the appropriate working distance (distance between the conveyor belt and the lens plane).

The working distance is given by the following expression:

$$WD = FL.\max\left(\frac{(Obj + CCD)_{width}}{CCD_{width}}, \frac{(Obj + CCD)_{height}}{CCD_{height}}\right), \quad (3)$$

where FL is the focal length.

So, it is possible to know the pixel shape and size. If the pixel shape is considered to be a square with size equal to l, the number of pixels could be transformed into a measurement in millimetres by the following equation:

$$(u_{mm}, v_{mm}) = l.(u_{pixel}, v_{pixel}) \quad (4)$$

A. Distortion

In this work, the distortion from the lens needs to be considered. Two types of distortion could be seen, [12]: the Barrel distortion and the Pincushion distortion.

The distortion correction algorithm is based on Brown's distortion model [13], considering only the distortion correction factors of first and second order:

$$\begin{bmatrix} u_i \\ v_i \end{bmatrix} = \begin{bmatrix} u_{mm} \\ v_{mm} \end{bmatrix} + \begin{bmatrix} u_{mm} \\ v_{mm} \end{bmatrix} \begin{bmatrix} K_1 r^2 \\ K_1 r^2 \end{bmatrix} = (1 - K_1 r^2) \begin{bmatrix} u_{mm} \\ v_{mm} \end{bmatrix}, \quad (5)$$

where K_i is the distortion correction order i, and r is the distance in millimeters between the pixel and the image center.(u_{mm}, v_{mm}) constitutes the coordinates of the distorted pixel and (u_i, v_i) is the equation of the undistorted pixel.

B. Pinhole Model

The pinhole model [14] provides us with a method to relate the 3D coordinates of a point in the 3D space with the coordinates of the same space in the 2D space, the image plane.

In Figure 3, we can see the geometric transformation of the point P_c, the point with coordinates(x_c, y_c, z_c), in the point P_i that belongs to the image plane. P_i coordinates are (u_i, v_i).

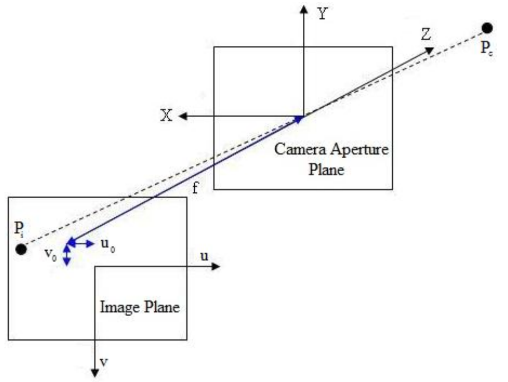


Fig. 3 Pinhole Model

As Figure 3 shows, each point with coordinates in the 3D camera frame is projected in the image plane symmetrically relatively to the origin.

The mapping from 3D to 2D coordinates described by a pinhole camera is a projection followed by a 180º rotation in the image plane. This corresponds to how a real pinhole camera operates. The resulting image is rotated 180° and the relative size of projected objects depends on their distance to the focal point and the overall size of the image depends on the distance between the image plane and the focal point.

The expressions to turn the 3D coordinates of a point into the coordinates in the image plane are given by:

$$\tan\theta = \frac{-x_c}{z_c} = \frac{-u_i - u_0}{f} \leftrightarrow u_i = \frac{x_c}{z_c} f - u_0 \quad (6)$$

$$\tan\theta = \frac{-y}{z_c} = \frac{-v_i - v_0}{f} \leftrightarrow v_i = \frac{y_c}{z} f - v_0 \quad (7)$$

When the distance x_c is equal to the focal distance, the expression becomes equal to:

$$u_i = x_c - u_0,\ v_i = y_c - v_0 \quad (8)$$

Note that, the 3D point can be transformed into the image plane, in the 2D space. However, the contrary is not possible. In the limit, only the equation line that contains the 3D point could be known. The true point could be anyone that belongs to this line. So, the line equation that was found is given by the following equation:

$$y_c = \frac{(v_i - v_0)}{(u_i - u_0)} x_c \quad (9)$$

C. Transforming the camera into the world frame

To know the 3D coordinates of a point in the camera frame, it is necessary to turn the 3D coordinates of the point in the world frame into the coordinates of the same point in the camera frame. This transformation is equal to the translation followed by the rotation of the absolute/world referential.

So, the point in the camera frame, in homogenous coordinates $P_c = (x_c, y_c, z_c, 1)$, related to the same point, but in the world frame $P_w = (x_w, y_w, z_w, 1)$, is given by the equation:

$$P_w = \begin{bmatrix} R_c^w & T_c^w \\ 0 & 1 \end{bmatrix} P_c, \quad (10)$$

The translation matrix is given by the following matrix:

$$T_c^w = [T_x \quad T_y \quad T_z]^T \quad (11)$$

Any rotation could be modulated by three simple rotations:

$$R_c^w = R_{y_w,\theta} R_{x_w,\varphi} R_{z_w,\beta} \quad (12)$$

Figure 4 shows the rotations in each axis. The first rotation is done in turn of the x_w axis with an angle of $(\theta - 180°)$. The second rotation is done in the new y_w axis with an angle of φ (phi). Finally, the last rotation is done in the new z_w and the rotation angle is equal to β (beta).

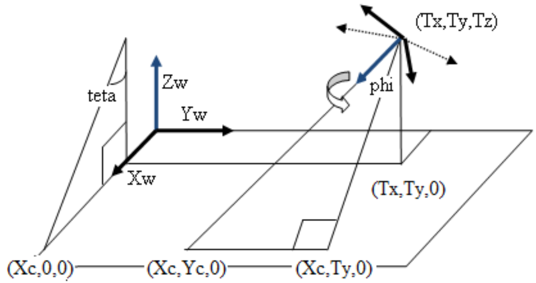


Fig. 4 Rotation in turn of the new z axis of an angle of β.

D. Camera calibration

At this moment, the coordinates in the world referential are known, from the points P_{oc} and P_{cc}. These two points allow us to determine the values of the angles of the first and the second rotations. P_{oc} is equal to:

$$P_{oc} = T_c^w \quad (13)$$

The point P_{cc} could be measured. Considering the coordinates of P_{cc} equals to:

$$P_{cc} = [x_c \quad y_c \quad z_c]^T = [x_c \quad y_c \quad 0]^T \quad (14)$$

The first and second rotation angles (θ and φ) could be computed:

$$\theta = \tan^{-1}\frac{(x_c - T_x)}{(z_c - T_z)} = \tan^{-1} - \frac{(x_c - T_x)}{T_z} \quad (15)$$

$$\varphi = \tan^{-1}\frac{y_c - T_y}{\sqrt{(x_c - T_x)^2 + {T_z}^2}} \quad (16)$$

The third rotation and the respective angle cannot be geometrically obtained. This happens because the last transformation only changes the image plane orientation.

Imagine that we know point P_2 , different from the center of the image, in the world frame, assuming that this point is also known in the image frame, i.e. we know point P_{i2} is equal to:

$$P_{i2} = [u_{i2} \quad v_{i2}]^T \quad (17)$$

If $\beta = 0$ and the origin of the axis in the image plane is the central pixel, then $(u_0 v_0) = 0$. P_{i2} is given by:

$$P_{i2} = \begin{bmatrix} \frac{x_c}{z_c} & \frac{y_c}{z_c} \end{bmatrix}^T f \tag{18}$$

Until now, we do not know the value of the focal distance, but the angle of the estimated vector does not depend on it since it is only a scale factor parameter. The angle of the estimated vector is given by:

$$\beta_1 = \tan^{-1} \frac{x_c}{y_c} \tag{19}$$

The angle of the true vector is equal to:

$$\beta_2 = \tan^{-1} \frac{u_{i2}}{v_{i2}} \tag{20}$$

The difference between these angles is equal to beta (β).

Now it is necessary to determine the focal distance. The Euclidian norm of P_{i2} is equal to:

$$\|P_{i2}\| = f \sqrt{\left(\frac{y_c}{z_c}\right)^2 + \left(\frac{x_c}{z_c}\right)^2} \tag{21}$$

The norm of the true point P_{i2}:

$$\|P_{i2}\| = \sqrt{{u_{i2}}^2 + {v_{i2}}^2} \tag{22}$$

Finally, the focal distance is given by:

$$f = \frac{\sqrt{{u_{i2}}^2 + {v_{i2}}^2}}{\sqrt{\left(\frac{y_c}{z_c}\right)^2 + \left(\frac{x_c}{z_c}\right)^2}} \tag{23}$$

E. Laser Triangulation

The intersection between the laser plane and the line containing the camera point makes it possible to determine the coordinates of the point in the 3D world frame.

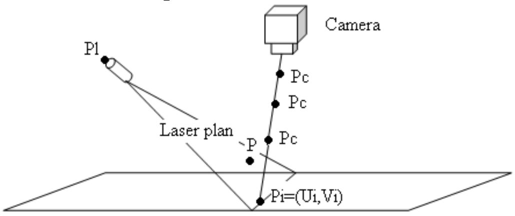


Fig. 5 Laser triangulation concept. The intersection of the line that contains the camera image point and the laser plane.

To define the laser plane, the vector perpendicular to the laser plane and a point that belongs to the plane are necessary. If we consider the origin point of the laser P_l and the vector that P_l do with any point P of the laser plane:

$$w_n.(P_l - P) = 0, \tag{24}$$

where w_n is the normal vector to the plane.

Any point inside the line defined by w_l is equal to:

$$P = w_l \alpha + P_c, \tag{25}$$

where P_c is the point of the camera.

The point P belongs to the laser plane and to the line:

$$w_n{}^T.(P_l - w_l \alpha - P_c) = 0 \tag{26}$$

$$\leftrightarrow$$

$$\alpha = \frac{x_n(T_{lx} - T_x) + y_n(T_{ly} - T_y) + z_n(T_{lz} - T_z)}{x_n x_l + y_n y_l + z_n z_l} \tag{27}$$

V. User Interface And Results

A user interface was implemented aiming to reconstruct the cork piece 3D, and to determine several characteristics and measurements of the cork piece, as well as to manage the communication between the ABB, Grip and itself.

As it has already been mentioned, the measurements to be obtained from the cork piece are: the gravity centre, the orientation and the cork piece dimensions. The algorithm to obtain these measures from the cork piece and applied to the reconstructed cork piece image can be described by the following steps:

-The image values are rescaled to values in the gap [0,255].

- A dilate is applied, followed by an erode, to delete holes inside the cork piece image.

-Threshold application. Then, in the image, all the elements different from zero (grey) will be equal to 255 (white), and all elements equal to zero (black) hold their value.

-The gravity center was determined.

-Application of the edge detection filter.

-The Hough transform is applied. The maximum values of the obtained Hough matrix are determined and then the equations of the lines that contour the cork piece are also determined, which makes it possible to compute the cork piece dimensions.

Figure 6 shows the results of the application of this algorithm to a cork piece reconstructed by the LTS.

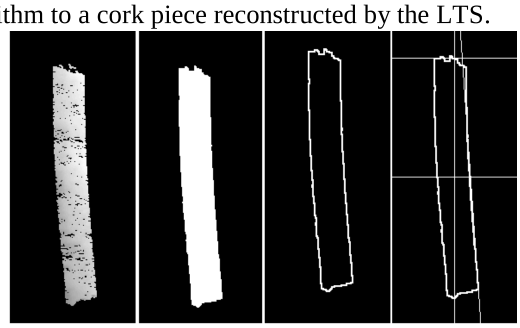
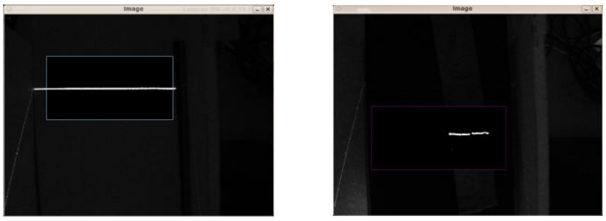


Fig. 6 Image segmentation and algorithm for the extraction of features applied to a real cork piece. a) Reconstructed image (grey scale). b) dilate/erode application result c) Edge filter application result. d) Gravity centre found and the orientation lines.

An OpenSource tool of OpenGL for Lazarus [15], GLScene, was used to draw the 3D image of the cork pieces, aiming to verify laser scanner errors and to validate the calibration.

Figure 7 shows the user interface and the laser line projection, during the calibration and during the cork piece reconstruction.



a) b)

Fig. 7 Camera vision. a) Laser line during the calibration. b) Projection of a laser line onto a surface that we want reconstruct.

Figure 8 shows a real cork piece and the respective reconstructed 3D image.

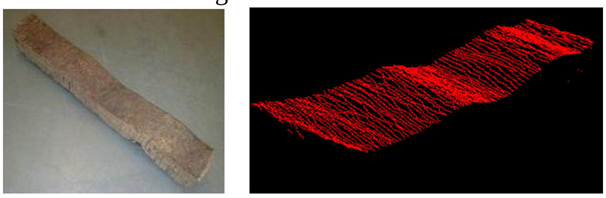


Fig. 8 Real cork piece (left). 3D reconstruction (right).

In summary, the entire developed system can be described as a state machine approach for a high level of understanding by the reader. The state machine states are described below:

-Any cork piece in any position is put in a conveyer.

-The LTS (laser triangulation sensors) do the 3D reconstruction of the cork piece using the triangulation equations. However, before that, the calibration method is applied aiming to obtain the intrinsic and extrinsic parameters of the LTS.

-The algorithm of segmentation and features extraction is applied to the 3D image with the aim of knowing where is the middle point of the cork piece in the world frame, the orientation and its dimensions.

-The cork piece dimensions, orientation and dimensions are sent via RS-232 to the robotic manipulator ABB.

-The robotic manipulator tool goes to the world position and orientation aiming to catch the piece. When the robotic manipulator tool reaches the goal position, then a message is sent via RS-232 to the laptop where the Lazarus application runs.

-When the Lazarus application knows that the robotic manipulator is in the desired position, according the piece dimension, it sends an order, again via serial communication, to the robotic manipulator tool controller (grip controller), to get close to and catch the cork piece.

-Then, a command is sent again to the robotic manipulator, now aiming to make the robotic manipulator move to the position where it should leave the cork piece.

-When the manipulator is in the new desired position, an order is sent to the grip so that the grip opens.

The entire process is repeated if any new cork piece is detected.

VI. CONCLUSION

This paper addresses the problem of developing a prototype that can be applied to the cork industry. This prototype's main aim is to handle cork pieces using a robotic manipulator.

In this work, a laser triangulation system was developed and the respective mathematical model and calibration procedure are presented.

The 3D reconstruction of a cork piece is obtained. The cork piece dimensions, its world reference frame position and orientation are obtained, which ensures a later interaction with the robotic manipulator. A user interface was developed, which ensures the communication with the robotic manipulator and the assembled grip.

As future work, the ability to determine several simultaneous cork pieces (possibly in a pile) should be considered.

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