An intelligent robotic system for depalletizing and emptying polyethylene sacks

M. Kavoussanos[*], A. Pouliezos [†]

[*]Mechanical Engineering Department, Technological Education Institute of Heraklion, Stavromenos, Heraklion, Crete, Greece. e-mail: mkavussa@phestos.stef.teiher.gr

[†] Dept. of Production and Management Engineering, Technical University of Crete, Counoupidiana, 73 100 Chania, Greece. e-mail: pouliezo@dssl.tuc.gr

The development of an intelligent robotic system for depalletizing and emptying of polyethylene sacks is presented. The system is custom designed and controlled by a PC. It utilizes an inexpensive vision system to be able to get information for the pallet's position and the sacks's arrangement.

Keywords : Real-time control, Robotics, Robotic Vision, Edge detection, Hough transform.

---

1. Introduction - Problem statement

The plastics industry uses polyethylene for the production of a series of products, including polyethylene pipes for irrigation, plastic sheet for greenhouse covering and other agricultural uses etc. The usual production procedure is as follows. Polyethylene is kept in 25 Kgr sacks which come in pallets of 40 sacks. Pallets are kept in storage areas and they are transported by fork lifts to depalletization stations when it is needed. Depalletizing is a hard job for the workers. There are some mechanical systems in the market which assist the process in one or another way, but they tend to be expensive and they do not give a complete solution to the problem

2. Proposed and implemented solution

The proposed solution uses an intelligent robotic system to depalletize and empty the sacks of polyethylene. The end effector attached in the system grasps the sack and passes it along a rotating cutting disk. The pellets of polyethylene fall due to gravity in a silo placed below the cutting disk and are transported to big silos by a pneumatic conveyance system. The most important problems in the proposed approach are:

1. The pallet, being very heavy, cannot be placed easily by the fork lift in a specific place, so that the robotic system does not know its position and orientation beforehand but has to calculate it.

2. The arrangement of the sacks in the layers of the pallet is unknown. For the above reasons the robotic system will have vision capabilities to be able to acquire the information needed.

3. Overall system description

A variety of robotic modules (mechanical elements, drives, control devices) can be found in the market which allow the designer to design the appropriate system which best suits the requirements of the application in terms of: degrees of freedom, work envelop, configuration, speed, repeatability etc. [1].

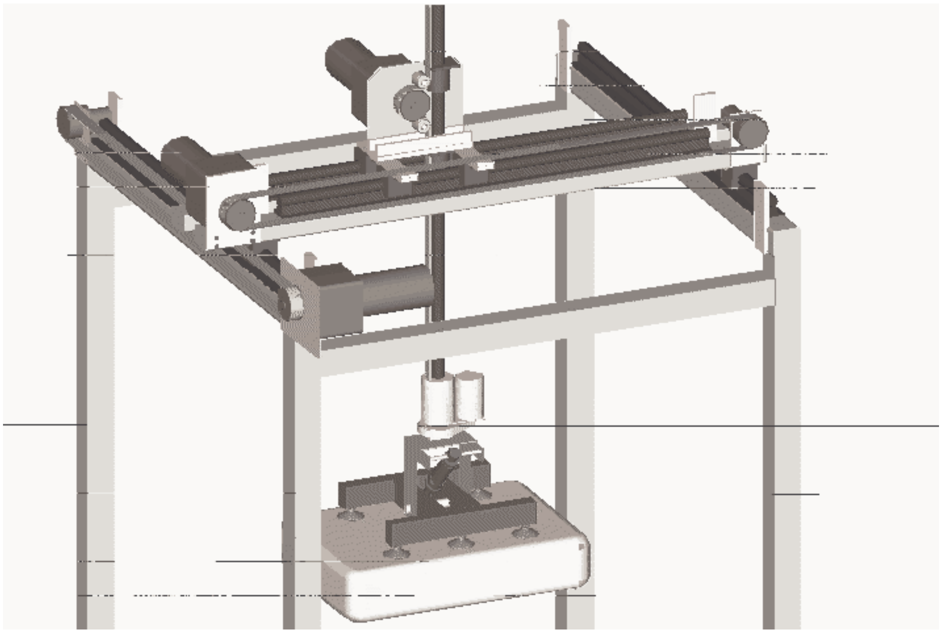


Fig.1. The *X-Y-Z-R* Cartesian robotic system

The mechanical part of the system has a Cartesian configuration with 3 translations (*X*, *Y*, *Z*) plus a rotation (*R*) of the end effector (Fig. 1). Four degrees of freedom are enough for the end effector to be able to move the sack from any place in the pallet and orient it along the cutting disk. The end effector is a construction which utilizes 6 vacuum cups to grasp the sack. It is pivoted in such a way that it can rotate during cutting, with the aid of a pneumatic cylinder, about 45^0, to allow the polyethylene pellets to fall. For the three translations, standard industrial linear bearings are used. Synchronous belts and pulleys convert the rotation of the drive motors to linear motion. The system is designed for 1m/s maximum speed.

Permanent magnet, dc, geared motors are used powered by 4-Q thyristor drives. This is a cheap solution of building servosystems, but it has proved to be adequate for this application.

The vision system incorporates a camera to provide the image of the pallet and a frame grabber for image capturing.

4. Control of the system

4.1 Overall control requirements

There are three main functions of the control system [2]:

1. The control of the four robot axes.
2. The acquisition and analysis of the image of the camera to obtain the information of the position, the orientation of the pallet and the arrangement of the sacks.
3. The monitoring of limit switches or other sensors and the control of ON-OFF air electrovalves.

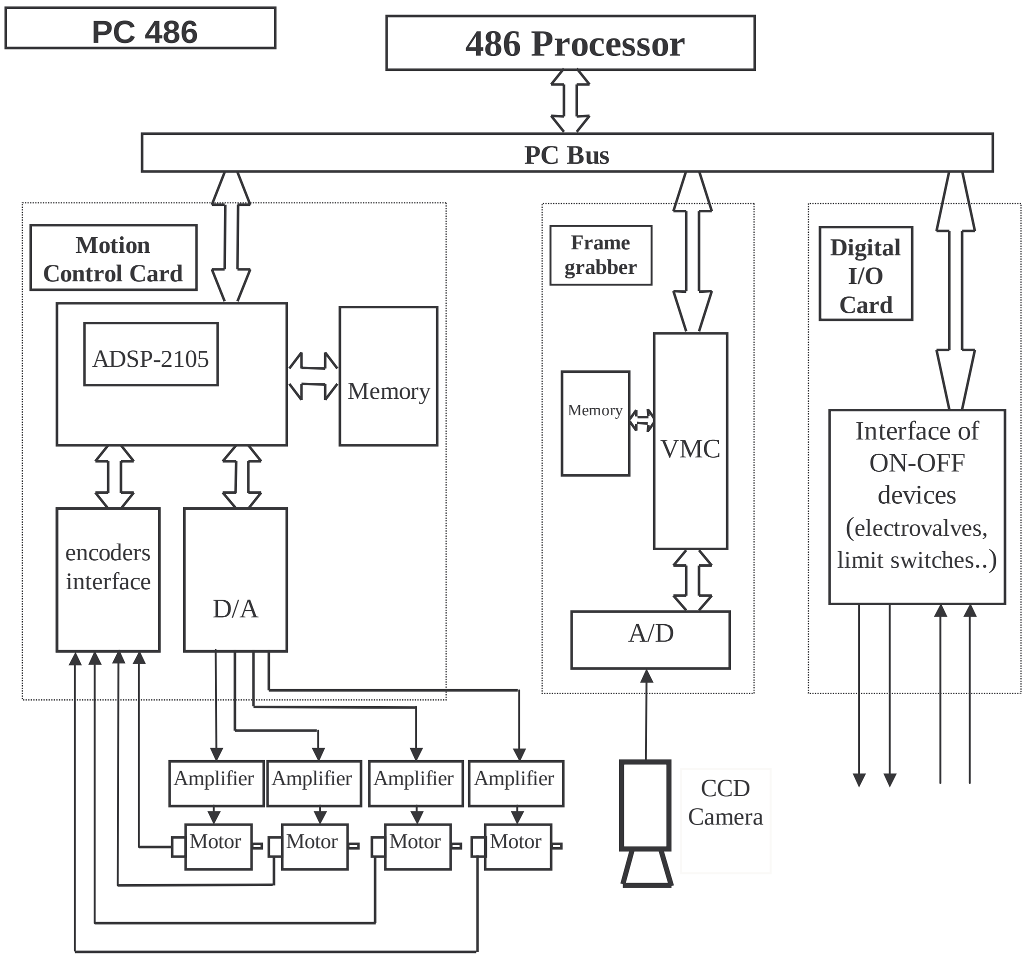


Fig. 2. The overall control scheme

The control system is designed around a PC-486. For the three distinctive functions appropriate plug-in cards are used (Fig. 2). The above approach has been used by several reasons:

1. The environment is user friendly.
2. High-level languages can be used for software development; C is used.

3. Low hardware costs are involved.
4. The high computing power of the PC-486.
5. The ability to integrate all the functions of the control system in the same PC.

4.2 Control of the robot axis

A special purpose motion control card is used for the control of the four axes. As can be seen in Fig. 2, the card utilizes a Digital Signal Processor (DSP), the ADSP - 2105 chip of Analog Devices, to perform the low level servo control of all the axes leaving the main processor (486) free for other tasks. The DSP receives information for the actual position of the axes via rotary shaft encoders attached to the shafts of the driving motors. If the position needs to be changed, correction signals are send to the servo-amplifier via D/A converters. The DSP also receives commands from the main processor, via the PC bus, regarding the desired final position as well as the desired traveling speed and acceleration of each axis.

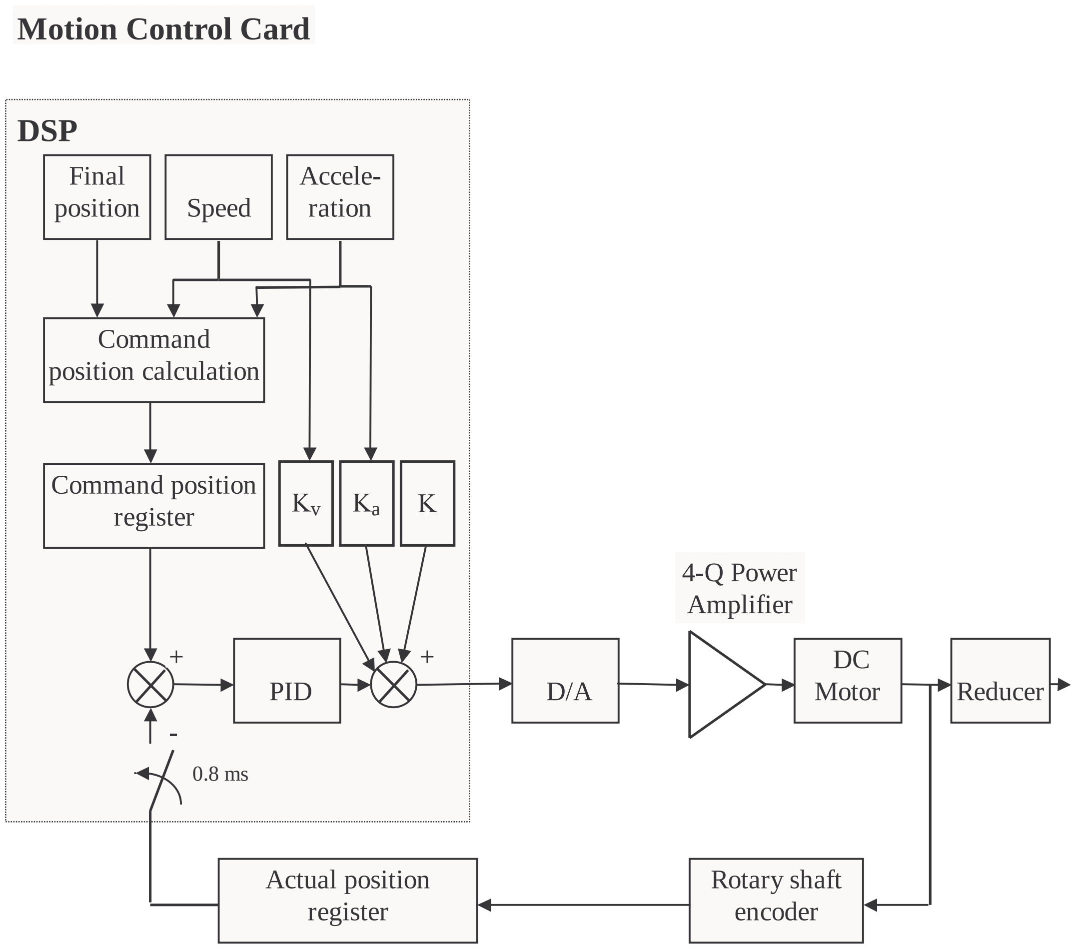


Fig. 3. The servo control of each robot axis

In Fig. 3, the servo control loop of one axis can be seen. The DSP calculates continuously, utilizing the desired final position, velocity and acceleration data, the profile of the desired axis position in time, and loads it to the command position register.

Every 0.8 ms the content of the register is compared with the content of the actual position register and the error goes to the PID filter. The output of the filter is added to the velocity and acceleration feedforward terms as well as with the offset, and the result goes to the D/A converter. The analog signal of the converter drives the servo amplifier which powers the DC motor to move the axis to the desired position. It is therefore a PID control with velocity and acceleration. The parameters of the PID filter, as well as of the constants of the feedforward terms, can be altered by the PC processor. The DSP, running at 40 MHz, closes the control loops of all four axes.

If point-to-point motion is desired, the main processor only needs to send data for the four final positions accompanied with desired speeds and accelerations. Then the DSP undertakes the rest of the task and the main processor simply waits for the motion to be executed. When continuous path motion is desired, the main processor interpolates the path and sends intermediate points to the DSP for execution. In this application the desired path is a series of straight line segments. For smooth transition from one segment to the other, an appropriate arc tangential to both segments is calculated by the main processor.

5. The vision system

5.1 Requirements and hardware used

As mentioned earlier, the vision system provides the necessary 'intelligence' so that the robot is able to find the correct position of the pallet as well as to recognize the pattern of the arrangement of the sacks in the pallet's layers. The pallet is obviously a 3-D structure, but the exact information of the elevation of each pallet layer from the base is not necessarily needed. For the robot to be able to 'find' the sack, it only needs to bring the gripper in the correct (X, Y)-position and move the Z-axis towards the pallet until a proximity detector is activated. So the vision problem is actually a 2D problem if the camera is placed above the expected centre of the pallet looking towards the (X, Y)-plane.

The vision system incorporates a CCD camera and an inexpensive frame grabber, the Screen Machine II of the FAST Electronics, as a plug-in card for the PC bus. The A/D converter samples the video signal (RGB) of the camera and converts it to digital. The signal is then filtered and routed either to the PC screen as 'live image' or captured to a 1 MB memory, which the card has on-board. The captured image is then transferred to PC memory for analysis. The whole process is controlled by the Video Memory Controller according to instructions sent by the PC processor via the bus.

Colour information is not needed, therefore gray scale images are manipulated. Image resolution has been set as recommended by the frame grabber manufacturer, at 368x280 pixels. With the above resolution a system resolution of about 4 mm is achieved, since the 'inspection' area is about 1.4 x 1.2 m^2 (the pallet size is 1.2 x 1.0 m^2), which is satisfactory for the application.

5.2 Image analysis - Detection of the pallet's layer boundary

In Fig. 5(a) an image of a rather distorted pallet layer is shown. As can be seen, the boundary of the pallet layer is easily discriminated from the black background but the same cannot be said for the inner sides of the sacks. So the problem of finding directly the boundary of each sack, and hence its position, is not an easy task.

Since the detection of the boundary of the whole pallet layer seems to be easier, this boundary is found first and then the arrangement of the sacks is identified.

For the detection of the layer's boundary, local edges are first detected by applying an edge detection operator to the image. A local edge is a small area in the image where the luminance changes significantly. Obviously, the boundary of the layer is composed of local edges.

For the detection of edges, several well known gradient operators can be used (4-7). A gradient operator for a gray scale image is essentially a mask which scans the whole image. For each pixel a new value is computed which measures the gradient of the luminance in the pixel area. The size of the mask affects the quality of the detection and also the computation time. For industrial applications, the Sobel edge detector operator is considered to be efficient [7]. A 5x5 mask is considered, as a good compromise between the quality of edge detection and the required computation time. In Fig. 4(a), one of the masks used is shown. For each image pixel a value S_x is computed which equals the sum of the products of each of the 24 neighboring pixel values times the corresponding mask coefficient. S_x measures the gradient of the luminance in the X direction of the image. Accordingly, in Fig. 4(b) the mask used for the Y direction is shown for the computation of S_y. The magnitude of the gradient is then computed as,

$$GradMag = \sqrt{S_x^2 + S_y^2}$$

and the direction of the gradient as,

$$GradAng = \tan^{-1}(S_y / S_x)$$

*F*inally $\pi/2$ is added to the above value to compute the direction of the detected edge.

Y ↑

-10	-10	0	10	10
-17	-17	0	17	17
-20	-20	0	20	20
-17	-17	0	17	17
-10	-10	0	10	10

→ X

(a)

10	17	20	17	10
10	17	20	17	10
0	0	0	0	0
-10	-17	-20	-17	-10
-10	-17	-20	-17	-10

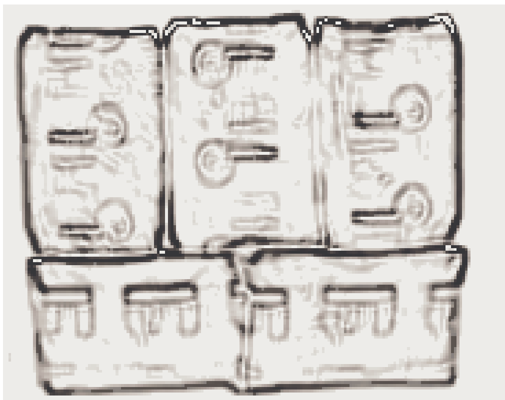
(b)

Fig. 4. 5x5 Sobel edge detection masks
(a) *X* direction, (b) *Y* direction

From the above process, two new images are created (the values are normalized to be between 0 ... 255): one with the magnitude of the gradient which measures the magnitude of the edge and one with the angle of the edge.

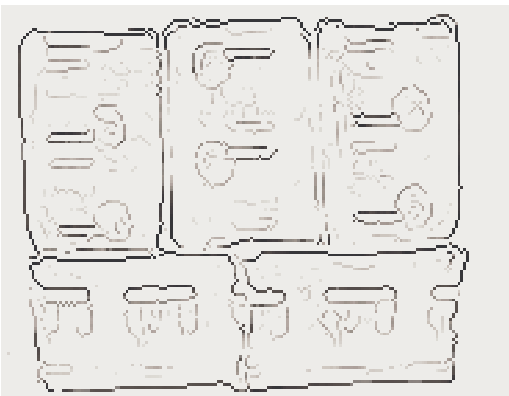
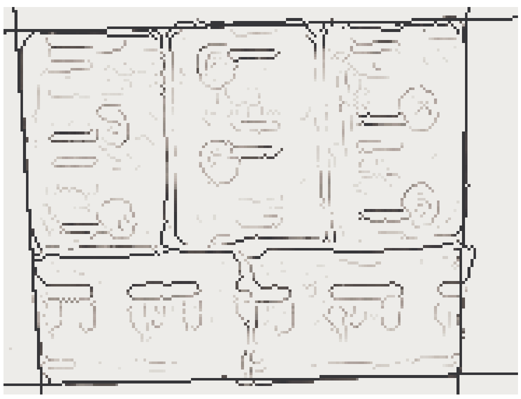
In Fig. 5(b) the image of the detected edges for the arrangement of the pallet layer shown in Fig. 5(a) is shown. As a result of the fact that a 5x5 mask is used, the specified edges are rather ‘thick’. A process of line thinning follows which aims to generate a new image which will have edges one pixel thick. Thinning is a standard process well analyzed in literature [4-7]. It uses the information of the edge direction and this is the reason it is calculated at the previous stage.

In Fig. 6 (a) the image of the ‘thinned edges’ of the pallet can be seen. The edges have become much more clear. Also the boundary of the pallet can be seen to be well discriminated from the background. For the identification of the boundary an edge ‘chaining’ procedure can be followed (7). With such a procedure, one starts with a point in the boundary and ‘travels’ along the detected edge keeping the detected points in memory. If there are no discontinuities in the path then one will return to the starting point having identified the points in the boundary. In our case the chaining procedure does not work satisfactorily: the boundary is almost never a continuous path and there are a lot of points in which it breaks to two or three paths.

(a) (b)

Fig. 5. (a) A pallet layer, (b) the detected edges

(a) (b)

Fig. 6. (a) thinned edges, (b) the detected boundary

To identify the boundary of the pallet’s layer, use is made of the information that it is a rectangle, thus we are actually looking for 4 straight line segments. To identify those segments, points on them are needed. Points in the pallet boundary are found by scanning the image of the thinned edges horizontally and vertically. In fact with two horizontal scans, from left to right and vice-versa, and two vertical, it is easy to identify points in the boundary. They are the first points to be found with the previous scans.

Robust regression is then used to find the lines which best suits the identified set of points. Least squares were tried, but it proved inadequate. Indeed, in many cases it would give erroneous results when one or more points are found ‘far’ from the others. Robust regression on the contrary is, up to a certain degree, insensitive to outliers [4].

The least-median-squares robust regression method was used. The method works as follows:

- Two points are chosen in random, from the set of points in which a line should fit.
- The line which passes from the two points is computed.
- The median of the squares of the distances of the points from the computed line is then determined.

The procedure is repeated until the median is sufficiently small.

In Fig. 6(b) the four lines which best fit the pallets boundary using the least median square method is shown.

5.3 Image analysis - Recognition of the sack arrangement

Once the outline of the pallet’s layer is found, there are only two possible arrangements of sacks as Fig. 7 shows. Indeed there are always 5 sacks in the layer and the length of the rectangle is not equal to its width. The problem is therefore how to determine which of the two arrangements is the actual one in the detected outline.

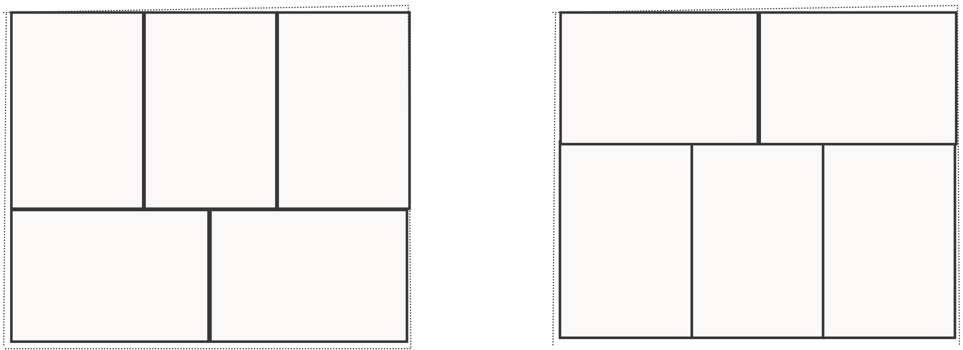
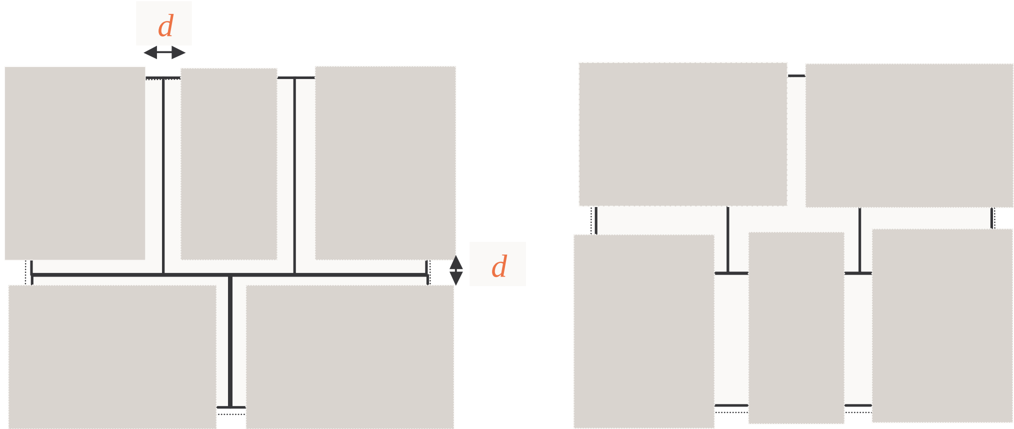


Fig. 7. Possible sack arrangements

To get a robust solution for the problem, we have designed two masks which are superimposed to the detected outline as Fig. 8 shows. The idea is to hide as much irrelevant information as possible - letters, illustrations - but keep the areas where the sack sides probably are; indeed this will happen only in one of the two cases.

Fig. 8 shows how the image of the thinned edges appears after the imposition of the masks. In Fig. 9(a) the mask has revealed the sack sides while in Fig. 9(b) it has almost hidden them. In the first case one can observe that there are longer straight lines than in the second case. Therefore the two images are next searched for straight lines. This is done using a Hough transform [4-7].

Hough transform associates each pixel in an image of edges with the straight line which passes from the pixel and has the direction of the edge in that pixel. The line is described with its Hesse form, that is with the pair (r, θ), where r is the distance of the line from the origin and θ = (angle of edge - $\pi/2$) . It is obvious that all pixels lying in the same line will correspond to the same pair (r, θ).



(a) (b)

Fig. 8. Masks to hide irrelevant information
(a) Inner boundaries revealed, (b) Inner boundaries almost hidden

The transform produces a new ‘image’, with (r, θ) coordinates. Each ‘pixel’ of this image, which describes a straight line, has a value which is the number of the pixels of the original image found to belong to the specific line. Thus, searching for straight lines in an image of thinned edges means searching the transformed image for ‘pixels’ with high values.

(a) (b)

Fig. 9 Image after the imposition of the masks
(a) Mask reveals the arrangement, (b) Mask reveals nothing.

The lines found to have length less than the distance d (Fig. 8) are then discarded. With the remaining lines, for each image the index,

$$T_L = \sum \ell_i \text{ , } l_i = \text{length of } i\text{th line}$$

is evaluated. It is obvious that the index is much greater when the correct arrangement is detected.

6. Conclusions - Results

The design and development of an intelligent robotic system for depalletizing and emptying of polyethylene sacks has been presented. It seems that as robotic technology is getting mature, various modules can be found in he market which challenge the designer to try more intelligent systems for the solution of a variety of industrial problems. The fact is especially interesting since the 'robotic' approach to system design can lead to better as well as less expensive solutions.

References

1. Canny and K.Y. Goldberg, "A RISC Approach to Sensing and Manipulation", *Journal of Robotic Systems*, **12**(6), 1995.
2. Fu, R.C.Gonzalez and C.S.G. Lee, *ROBOTICS: Control, Sensing, Vision and Intelligence*, McGraw-Hill, Inc., 1995.
3. Fielding and E.D. Illos,'PC Based Robotic Control System', *IFAC 12th World Congress*, Sydney, 1993.
4. Jain and R. Kasturi and B.G. Schunk, *Machine Vision*, McGraw-Hill, Inc. 1995.
5. Klaus and P. Horn, *Robot Vision*, The MIT Press, 1993.
6. Ballard and C. Brown, *Computer Vision*, Prentice Hall, Inc., Englewood Cliffs, New Jersey.
7. Baessmann and P.W. Besslich, *Bild Verarbeitung ad oculos*, Springer Verlag, 1991.