Visionary Automation of Sack Handling and Emptying

An Inexpensive Yet "Intelligent" Prototype System Using Vision-Guided Robotics for Depalletizing and Emptying Polyethylene Sacks

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In the production line of many industries there exists the procedure of palletizing/depalletizing sacks of raw or finished materials. The plastics industry, for example, uses polyethylene for the production of a series of products, including polyethylene pipes for irrigation, plastic sheets for greenhouse coverings, and other agricultural uses. The usual production procedure is as follows. Pallets are kept in storage areas and are transported by forklifts to depalletization stations when depalletizing is needed. Depalletizing is a labor-intensive job for workers. There are some purely mechanical systems in the market that assist the process in one way or another, but they tend to be expensive and they do not provide a complete solution to the problem.

In the majority of palletizing or depalletizing jobs, the environment is either completely structured or may be structured in such a way that the procedure is automated with dedicated machines. This probably explains the low degree of penetration of robots in this area~~at~~ least until lately. Changes in this area should be expected once the costs of the required robotic systems decrease further [1]. A requirement for a class of palletization-depalletizion problems is that the automated system should have the ability to recognize the shape and the position in space of the pallet or of the pallet elements. The use of a robotic system with vision capabilities seems to be the most appropriate way to tackle this problem.

The Mitsubishi Company presented in 1997 a prototype depalletizing robotic system equipped with stereo vision [2]. The vision system was implemented with the aid of a PC and uses structured lighting techniques to detect the exact three-dimensional (3-D) position of the cargo in the pallet. If the height of the objects in the pallet and the number of the pallet layers are known, then the vision problem is essentially a two-dimensional (2-D) recognition problem. Such a problem~~a~~ carton depalletizing problem~~h~~as also been solved with a robotic system equipped with a single camera [3]. An ultrasound sensor attached in the gripper provides depth information, and the system is reported to be able to handle cartons randomly placed in the pallet layers. A robotic material transport system designed for the automated supply of packaging machines with paper bobbins has also been reported in [4]. A single camera is used to identify the locations of the bobbins, which come in pallets. The manipulator grasps it in turn and moves it to the requesting machine.

In this article a novel structure is presented that is designed and built to minimize costs and increase reliability of the whole system, while at the same time fully automating the depalletizing and emptying of polyethelene sacks. The system is built around a conventional PC that carries out the tasks of control, vision, gripping, and fault monitoring. Simple PID loops are used for the control of all the robot axes, while an inexpensive vision system is used for the determination of the orientation of the pallets. A pneumatic gripper is used for the lifting of the sacks. The most probable faults are monitored for and appropriate actions are taken in the event of fault occurrence. In this way, a form of "intelligence" is built into the system. The system in its present form is ready for use in an appropriate industrial environment.

Solving the Problem with a Prototype Robotic System

The procedure that we are trying to automate is as follows: polyethylene pellets are kept in 25 Kgr sacks that come in pallets of 40 sacks arranged as shown in Fig. 8 (eight layers of five sacks each). A forklift carries the pallet in the depalletizing station where a worker lifts the sacks one by one, cuts them open and empties their contents in a silo for temporary storage (Fig. 1). The problem is to replace the human "depalletizer" with a robotic system.

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For cost-reduction purposes, it was decided that the simplest possible robotic system capable of satisfying the requirements of the application would be designed. In other words, a system designed specifically to suit the requirements of the application in terms of degrees of freedom, work envelop, configuration, speed, payload capacity, accuracy, etc. [5, 6].

The implemented solution uses a 4-degree-of-freedom (DOF) Cartesian manipulator to depalletize and empty the sacks of polyethylene. The end-effector attached in the manipulator 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 system is equipped with a vision subsystem in order to:

- Identify the position of the pallet. In fact, since the pallet is very heavy, it cannot be placed easily by the forklift in a specific place, so that the robotic system does not know its position and orientation beforehand but has to calculate it.
- Identify the arrangement of the sacks in the layers of the pallet.

The mechanical part has a Cartesian configuration with three translations (X, Y, Z) plus a rotation (R) of the end-effector (Fig. 2). 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. 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 maximum speed is 1 m/s.

The end-effector is a construction that utilizes vacuum cups to grasp the sack [7, 8]. 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 (see Fig. 3).

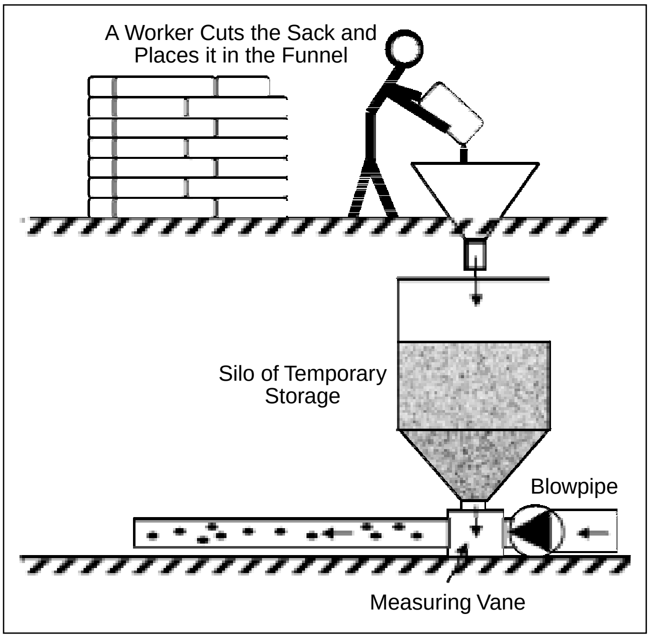

Figure 1. *The depalletizing procedure.*

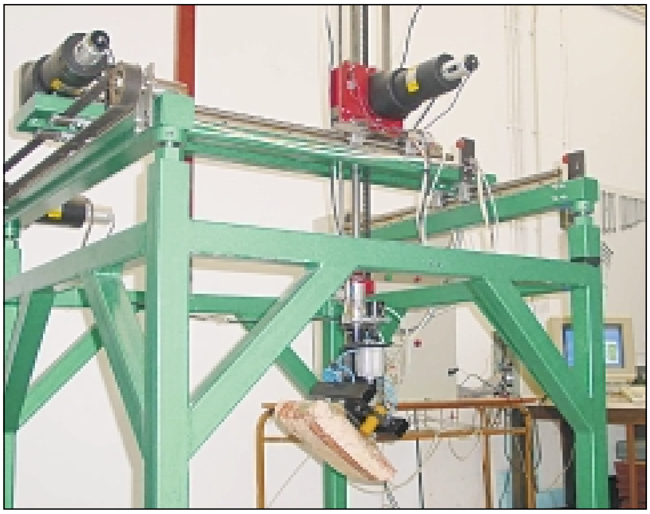

Figure 2. *The prototype robotic system.*

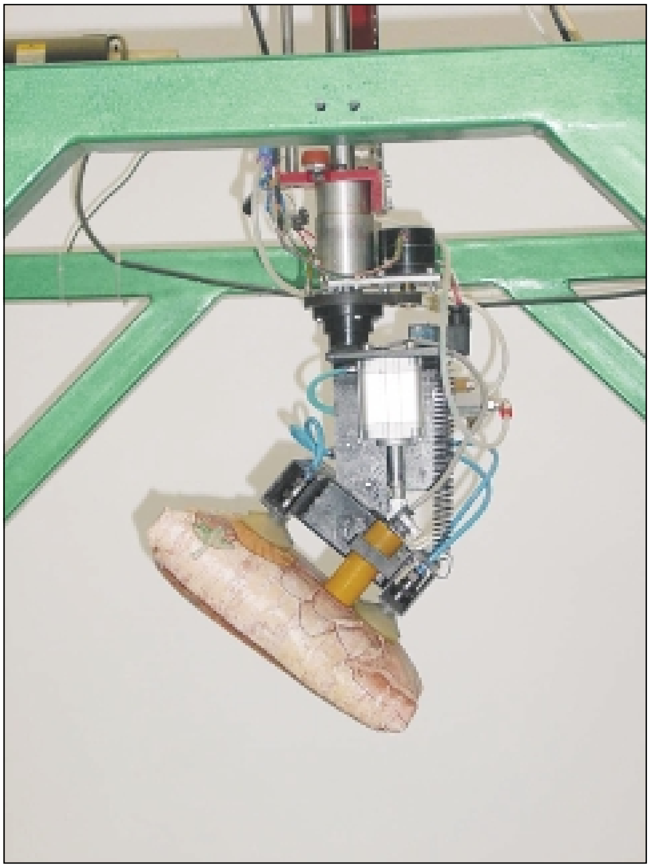

Figure 3. *The gripper subsystem.*

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

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

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.

Control of the System

Main Control Functions

There are four main functions of the control system:

- The control of the four robot axes.
- 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.
- The control of ON-OFF air electrovalves.
- The monitoring of limit switches and critical control signals for fault detection.

The control system is designed around a PC-486. Appropriate plug-in cards are used for the control and the vision subsystems [Fig. 4]. The above approach has been motivated by several reasons:

- The environment is user friendly.

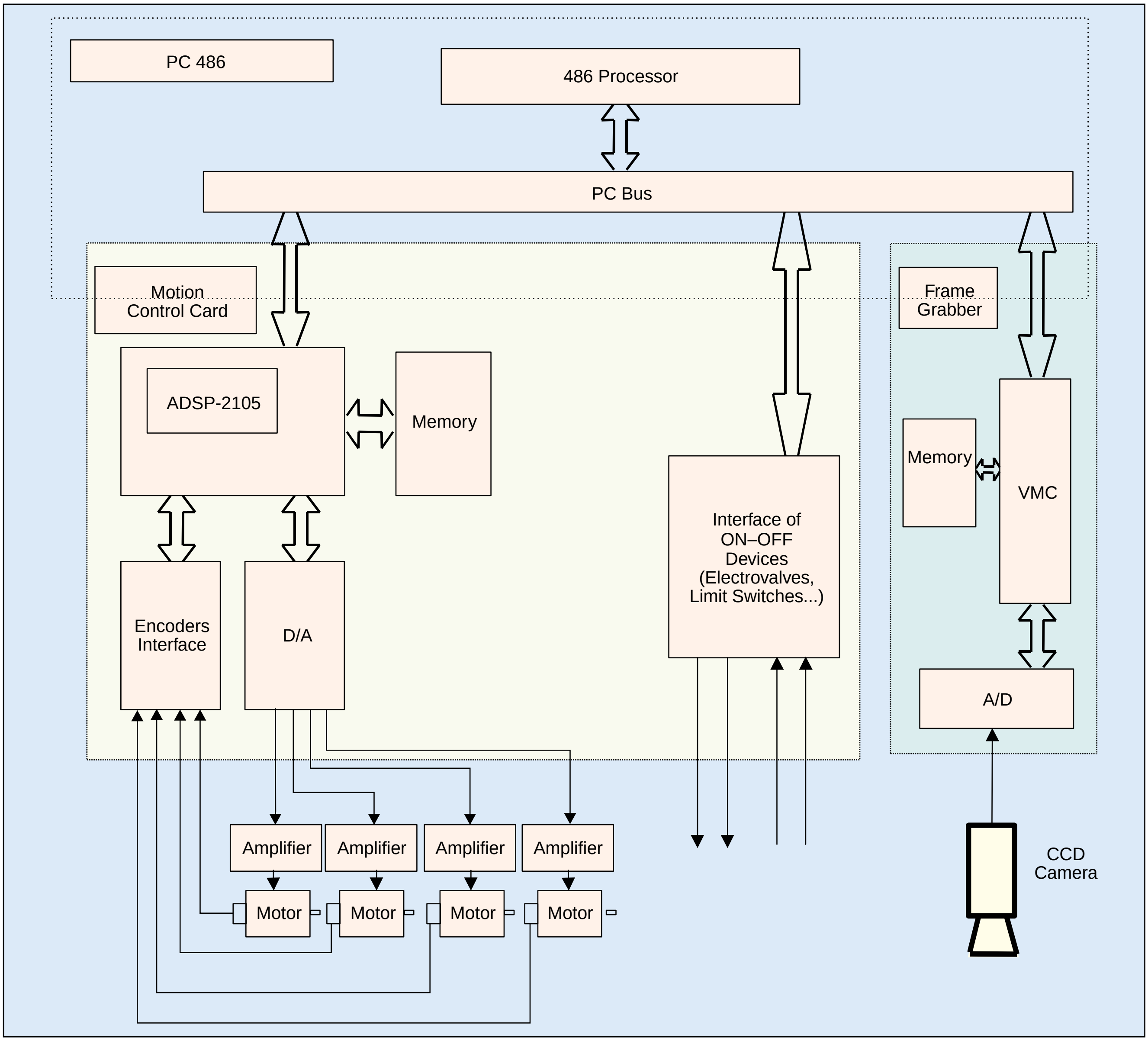

Figure 4. The overall control scheme.

- High-level languages can be used for software development; C is used here.
- Low hardware costs are involved.
- High computing power of the PC-486.
- The ability to integrate all the functions of the control system in the same platform of the PC.

Control of the Robot Axis

A special-purpose motion control card is used for the control of the four axes (Motion Engineering Inc.'s LC/DSP). As can be seen in Fig. 4, the card utilizes a digital signal processor (DSP) (the Analog Devices ADSP-2105 chip) 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 sent 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.

Figure 5 shows the response of the robot's X-axis to a command of 0.6 m displacement with a velocity of 0.5 m/s. It is clearly seen that velocity feedforward has eliminated satisfactorily the steady-state position error.

For details on the control method used, the reader is referred to [9].

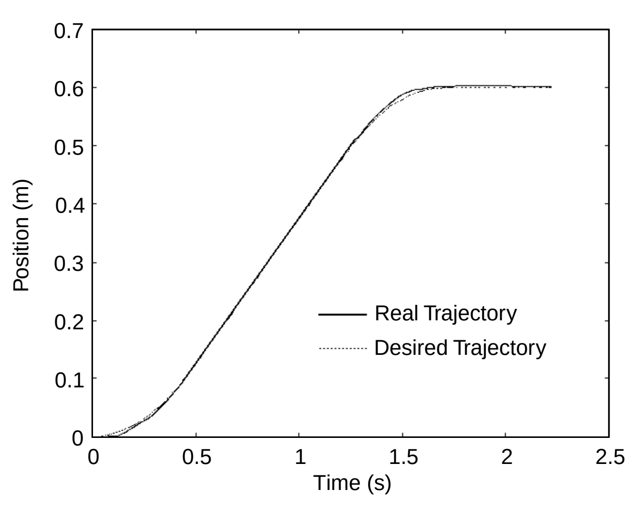

Figure 5. *X-axis trajectory (displacement 0.6 m, velocity 0.5 m/s).*

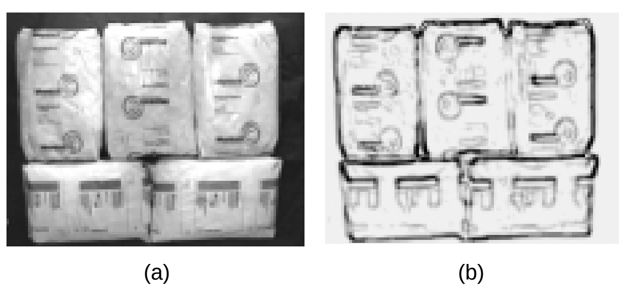

Figure 6. *(a) A pallet layer; (b) the detected edges.*

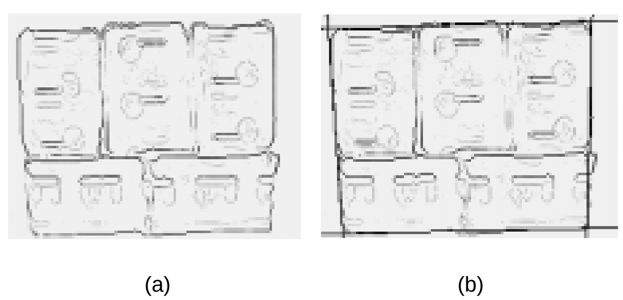

Figure 7. *(a) Thinned edges; (b) the detected boundary.*

The Vision System

Functions and Hardware Used

As mentioned earlier, the vision system provides the necessary information 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 2-D problem if the camera is placed above the expected center of the pallet, looking toward the X-Y plane.

The vision system incorporates a CCD camera and an inexpensive frame grabber (Screen Machine II, 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 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.

Color information is not needed, therefore gray-scale images are manipulated. Image resolution has been set at 368 × 280 pixels, as recommended by the frame-grabber manufacturer. With the above resolution, a system resolution of about 4 mm is achieved, since the "inspection" area is about 1.4 × 1.2 m (the pallet size is 1.2 × 1.0 m), which is satisfactory for the application.

Image Analysis: Detection of the Pallet's Layer Boundary [10, 11]

In Fig. 6(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.

In Fig. 6(b) the image of the detected edges for the arrangement of the pallet layer shown in Fig. 6(a) is shown. As a result of using 5×5 mask, the specified edges are rather "thick." A process of line thinning follows that aims to generate a new image that will have edges one pixel thick. In Fig. 7(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.

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 four straight line segments. To identify those segments, their points need to be located. 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. The least-median-squares robust regression is then used to find the lines that best suit the identified set of points. In Fig. 7(b), the four lines that best fit the pallets boundary using the least-median-square method are shown.

Image Analysis: Recognition of the Sacks Arrangement

Once the outline of the pallet's layer is found, there are only two possible arrangements of sacks, as shown in Fig. 8. Indeed there are always five 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.

To get a robust solution for the problem, we have designed two masks that are superimposed on the detected outline, as shown in Fig. 9. The idea is to hide as much irrelevant information as possible letters, illustrations but to keep the areas where the sack sides probably are; indeed, this will happen only in one of the two cases.

Figure 10 shows how the image of the thinned edges appears after the imposition of the masks. In Fig. 10(a), the mask has revealed the sack sides while in Fig. 10(b) it has almost hidden them. In the first case one can observe that there are longer straight lines "almost" parallel to the sides of the mask's rectangles than in the second case. Therefore, the two images are next searched for straight lines. This is done using a Hough transform.

For each image the index

$$T_L = \sum l_i ,$$

During motion execution, the main processor has enough time to monitor several critical functions for the operation signals.

where l_i = length of ith "almost" parallel line to the corresponding rectangle of the mask, is evaluated. It is obvious that the index is much greater when the correct arrangement is detected; thus, it is considered as the recognition feature.

Reliability-Fault Detection

The use of the PC as a platform offers computing power that permits the incorporation of fault detection functions, which increases the reliability to the system. In fact, during motion execution, the main processor has enough time to monitor several critical functions for the operation signals.

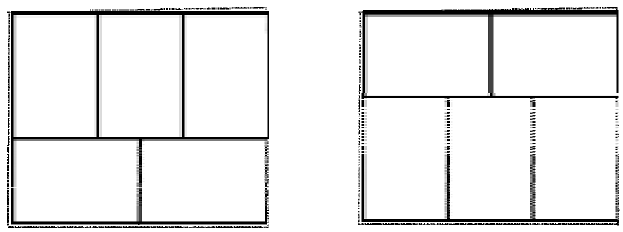

Figure 8. *Possible sack arrangements.*

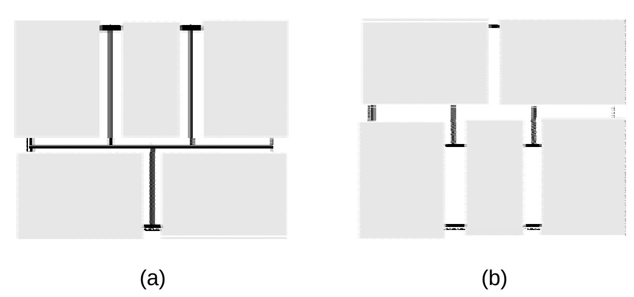

Figure 9. *Masks to hide irrelevant information. (a) Inner boundaries revealed. (b) Inner boundaries almost hidden.*

Figure 10. *Image after the imposition of the masks. (a) Mask reveals the arrangement. (b) Mask reveals nothing.*

Monitoring of travel limits for each axes of motion—a common practice for such systems—is performed by the motion control processor itself. Both hardware (limit switches) and software limits are monitored and immediate halt of motion is commanded if they are overpassed.

Except for travel limits, the main processor monitors the error signal of all position control loops. This signal is found to be sensitive to a number of malfunctions and progressively developing faults. The signal is used to detect:

- "Loss" of actual position information in the axis servoloops. This could be due to either encoder failure or lead cutting.
- "Loss" of power to servoloops. This could be either due to power amplifier failure or lead cutting.
- Certain failures to the motion control card itself, which do not influence the actual position registration.
- Wear or malfunction of mechanical parts.

The error signal of the vertical axes is also used as redundant information to verify that the sack is grasped—very critical information for the operation of the system. For the same task, an appropriate proximity detector is used in the gripper assembly.

Conclusions/Results

A vision-guided robotic system for depalletizing and emptying of polyethylene sacks has been presented. At the moment, a prototype system is working in the laboratory and has passed several tests. Its industrial version is designed with minor changes, necessary for the adaptation to the hard industrial environment: the PC will be an industrial one, the slides will be protected from dust, and standard industrial cable rails will be used. In the authors' opinion, this project demonstrates how a "robotic" approach to system design can lead to better as well as less-expensive solutions for a class of industrial problems.

Keywords

Real-time control, robotics, robotic vision, edge detection, Hough transform.

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