An artificial vision solution for reusing discarded parts resulted after a manufacturing process

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Abstract. The profit of a factory can be improved by reusing the discarded components produced. This paper is based on the case of a manufacturing process where rectangular metallic sheets of different sizes are produced. Using an artificial vision system, the shapes and the sizes of the produced parts can be determined. Those sheets which do not respect the requirements imposed are labeled as discarded. Instead of throwing these parts, a decision algorithm can analyze if another metallic sheet with smaller dimensions can be obtained from these. Two methods of decision are presented in this paper, considering the restriction that the sides of the new sheet has to be parallel with the axis of the coordinate system. The coordinates of each new part obtained from a discarded sheet are computed in order to be delivered to a milling machine. Details about implementing these algorithms (image processing and decision respectively) in the MATLAB environment using Image Processing Toolbox are given.

1. Introduction

Every factory has as main objective to increase continuously the productivity and to lower the production costs. In the last years, these challenges have been realized by using the robotics technologies. Since their introduction in the 70s, they have become a synonym for competitive manufacturing, as stated in [1], by automating a wide area of tasks. Thus, more precise and rapid results are obtained, instead of using human operators. Also, the tasks which have to be done in dangerous conditions are not anymore a threat to worker’s health.

Initially, the environment in which an industrial robot was working was entirely known at each moment of time. Thus, its movements were programmed with respect to a fixed Universal Coordinate System (UCS), without using any real-time information from the environment. Even it is an efficient solution, according to [2], this method has also multiple drawbacks: reduced flexibility, multiple design constraints and frequent maintenance.

Thus, over the last years, the artificial vision systems have become an important part in manufacturing. Using such a system, a robot can perform more difficult tasks and can also adapt to different situations without having a programmed sequence of steps to follow for that type of environment. It can be said that ‘a robot with an embedded vision sensor can have a greater ‘awareness’ of the scene’ [2].
One important aspect which have to be fulfilled by a factory in order to be productive is to be efficient. The number of mistakes done during the manufacturing process has to be decreased as much as possible. A solution for this problem is, as stated before, the usage of industrial robots which can perform repetitive tasks with high precision without becoming bored or tired. However, there are cases due to various reasons (e.g. decalibration, decreased quality of the processing tool due to prolonged usage, unexpected variations in the material’s composition of the processed component) when even an industrial robot makes wrong movements and fails the performed process. Thus, a discarded component is produced. Even that a component resulted after a manufacturing process is not meeting the required demands, there are cases when it can be used to produce another component. This paper is focused on such an action.

It is considered the case of an industrial process where sheets of different sizes made from the same metallic material are produced. These parts are placed on a conveyor. In different locations, the resulted sheets can be analysed using different sensors to check if the production requirements (e.g. dimensions, weight) were met. Using an artificial vision system, the shape and the size can be determined. For each component it is decided whether the requirements for one of the desired types are fulfilled or a discarded part was obtained. In the last case, it is determined whether one of the considered types of sheet can be obtained from the analysed part. Then, the required commands (the start point and the trajectory) for milling the existing sheet are computed. After that, these information can be sent to a milling machine.

In this paper it is described a possible solution (architecture and implementation) for this problem. The testing of the algorithms was performed using MATLAB software and its Image Processing Toolbox. The next section describes in more details the work space considered. After that, the visual detection of the parts with different sizes and shapes is described, followed by the explanation of the decision algorithm in the next section. In the last two parts of this paper, the experimental results are shown and the conclusions are drawn respectively.

2. The work space
It is considered that \( N \) types of rectangular metallic sheets are produced by various machine tools. Each type has a specific width \((w_i, i = 1, 2, ..., N)\) and length \((l_i, i = 1, 2, ..., N)\) which do not have any restrictions. However, it is recommended that these dimensions to be comparable between them (such that a video camera calibrated to detect one of the parts to be able to also detect the others) but not very close (otherwise, depending on the resolution, the video camera could not distinguish the differences). The height of all the sheets it is considered to be the same \((h)\) for all types. Moreover, this dimension is consider to be on the order of millimeters. Thus, any manufacturing mistake in dimensions can be detected always from the plane determined by the width and the height.

All the metallic sheets manufactured are placed on a single conveyor. Thus, a single artificial vision system is needed in order to detect the discarded parts. The cost required for this automation system is impressively reduced because only one hardware equipment (conveyor plus artificial vision system) is needed and not a different one for each type of metallic sheet. However, the drawback of this reduction is the increased level of the required software’s complexity. The dimensions of the conveyor have to be set according to the types of metallic sheets. It has to be also taken into account that the parts produced can be placed after the manufacturing process on the conveyor on any angle in the width-length plane.

The main component of the artificial vision system used to detect the shape and the size of the produced metallic sheets is a video camera. This camera has to be placed with its main axis perpendicular on the conveyor. Thus, a conclusion regarding the shape and the dimension of each sheet can be completely drawn. The camera has to be placed at a height such that an entire segment of the conveyor to be in its field of view. The quality of the camera used dictates the quality of the results obtained. In the tests presented in this paper, a video camera for Raspberry Pi developing board was used. This camera acquires RGB images with a resolution of 2592 by 1944 pixels.
A milling machine can be placed near the conveyor in order to modify the shape of the discarded parts according to the decision taken by the analysis algorithm considered. Optionally, an industrial robot which picks the metallic sheets and places them in a storage area can be used.

A possible configuration of the work space considered with all its components can be seen in figure 1.

**Figure 1.** A possible configuration of the work space considered (1 – machine tool, 2 – conveyor, 3 – metallic sheet, 4 – video camera, 5 – camera’s field of view, 6 – milling machine, 7 – a standard sheet cut with sides parallel with axis of the coordinate system inside a discarded metallic sheet, 8 – industrial robot used for picking and placing the metallic sheets in a storage area).

3. **Shape recognition and dimensions measurement**

The video camera of the artificial vision system considered acquires RGB images of the metallic sheets present on the conveyor. For simplicity, it can be considered that each image which will be delivered to the image analysis algorithm presented further on, contains only one complete projection of a part (figure 1.). No other part of any other projection is included in an acquired image. This can be done by a preprocessing algorithm which detects when an entire sheet appears in an image and sends the corresponding region to the image analysis algorithm. Also, this can be done using sensors (e.g. distance sensors, Hall sensors) which can send a signal to the camera when a metallic sheet is present in its field of view.

The improvement stage follows the acquisition stage. Now, each image is enhanced, restored and some geometrical modifications can be applied eventually. Further on, the image has to be segmented in order to select only the region corresponding to the metallic sheet projection. The algorithms for these steps have to be chosen and tuned according to the environment in which the system operates. Explanations of the operation and the effects of these steps can be found in the works specialized in image processing [3, 4]. After these preliminary stages, a binary image containing only one region corresponding to the projection of the metallic sheet is delivered to the image analysis algorithm.

Firstly, the shape of the region obtained has to be analyzed. According to the restriction imposed, the region should have a rectangular shape if not any manufacturing mistake appeared. Various method can be applied in order to verify if a region has a rectangular shape. One of them, presented in [5], implies the verification of the following three conditions (these conditions are based on the measurements of a region’s properties done by `regionprops` function from Matlab’s `Image Processing Toolbox`):

1) The absolute difference between the lengths of the ellipse’s axes which includes the analyzed region (such that it has the same second-moments as the region) has to be smaller than a threshold value (inequality (1)):

\[ | \text{MajorAxisLength} - \text{MinorAxisLength} | \leq \varepsilon_1 \] (1)

2) The absolute difference between the area of the region and the area of the ellipse which includes the analyzed region (such that it has the same second-moments as the region) has to be smaller than a threshold value (inequality (2)):

\[ | \text{Area} - \frac{\pi}{4} \text{MajorAxisLength} \times \text{MinorAxisLength} | \leq \varepsilon_2 \] (2)
3) The absolute value between the extent of the rotated region (such that the major axis becomes parallel with the horizontal axis) and value 1 (which represents the extent of a rectangle) has to be smaller than a threshold value (inequality (3))

\[ |\text{Extent} - 1| \leq \varepsilon_3 \]  

(3)

For these conditions, inequalities were used instead of equalities due to the fact that some approximations may occur because of the spatial discretization implied by the acquisition stage of the images. The threshold values used (\( \varepsilon_1, \varepsilon_2, \varepsilon_3 \)) have to be set experimentally because they depend on the environment and on the setup of the work space. If all these conditions are fulfilled then the region analyzed has the shape of a rectangle.

If the shape of the region is considered to be a rectangle then the length of the sides have to be computed in order to verify if one of the \( N \) dimensional types was respected. Thus, it is necessary to determine the position of the rectangle’s vertexes. According to [5], this can be done by selecting four out of the eight extreme points computed by the \texttt{regionprops} function from the Matlab’s \textit{Image Processing Toolbox}. The selection condition is that the distance between a candidate vertex and all the previously selected vertexes have to be greater than a threshold value. After the determination of the vertexes, the length of the sides can be easily computed and compared with the \( N \) known set of sizes. These comparisons have to be performed also as inequalities related to a threshold value due to the spatial discretization which may introduces small differences. If the analyzed rectangular region respects one of given set of dimensions then an industrial robot can be commanded to pick the metallic sheet and place it in a storage area. Otherwise, the decision algorithm is started in order to determine the best option to reuse the discarded part in order to minimize the factory’s losses.

If the shape of the region is considered to not be a rectangular one (if at least one of the three conditions previously presented is not fulfilled) then the decision algorithm is also started.

4. Decision algorithm

The task of the decision algorithm can be formulated as follows: Given a convex polygon without holes in the Cartesian coordinate system, the largest area rectangle between the \( N \) given types, having the sides parallel with the axis of the coordinate system and which can be fitted inside the polygon has to be determined.

In order to solve this task, two approaches are presented further on: one is based on dynamic programming technique and one is based on searching in a histogram. These solutions are based on the matrix which contains the binary representation of the analyzed image (the elements equal with 0 define the region having the contour a convex polygon, and the elements equal with 1 represent the environment). The searched rectangle has to contain inside it and on its borders only elements equal with 0. If only one value equal with 1 is inside it or on the border, then the choice is not valid because the rectangular shape would not be respected.

4.1. Decision algorithm based on Dynamic Programming

For this solution, a preliminary stage is required. For each element of the matrix, defined by the row number \( i \) and column number \( j \), the number of elements equal with 1 inside and on the border of the rectangle having the upper-left corner on the first row and the first column and the lower-right corner on row \( i \) and column \( j \) has to be computed. This can be done using a recurrence formula (4) and the values obtained are stored in a matrix (named \( No1 \)).

\[ No1_{i,j} = No1_{i,j-1} + No1_{i-1,j} - No1_{i-1,j-1} \]  

(4)

Further on, the valid positions for any given rectangle are searched. By covering element by element the matrix, the upper-left corner of the rectangle is set. For any upper-left corner set (row \( i1 \), column \( j1 \), the lower-right corner (row \( i2 \), column \( j2 \)) is determined based on one of the \( N \) set of given dimensions. Firstly, the coordinates of the lower-right corner have to be verified if not overcome the boundaries of the matrix. Secondly, it has to be verified if inside the set rectangles are any elements equal with 1. This can be done using the previously computed matrix (\( No1 \)). If the number of elements equal with 1 computed with the formula (5) is equal with 0 then the set rectangle is a valid
one and it becomes a candidate for the final solution. Between all the determined candidates, the one
having the maximum area is selected in the end. If there are multiple choices having the same
maximum area, any of them can be chosen.

\[ No1_{\text{Inside}} = No1_{i_2,j_2} - No1_{i_2,j_1-1} - No1_{i_1-1,j_2} + No1_{i_1-1,j_1-1} \]  \hspace{1cm} (4)

For the final rectangle selected (if exists), the coordinates of the vertexes are known and have to be
converted from pixels to millimeters in order to send the commands to the industrial robot. This can be
done using the equation (6), where \( \text{length}_{\text{mm}} \) and \( \text{length}_{\text{px}} \) are analogue lengths using millimeters
and pixels respectively as measurement units, determined experimental after the setup of the work
space.

\[ \text{Size}_{\text{mm}} = \text{Size}_{\text{px}} \times \frac{\text{length}_{\text{mm}}}{\text{length}_{\text{px}}} \]  \hspace{1cm} (6)

Additionally, for each rectangle there are two possibilities of positioning such that its sides are
parallel with the axis of the coordinate system: one with the length parallel with the horizontal axis
and one with the length parallel with the vertical axis.

The time complexity for this approach is \( O(\text{rows} \times \text{columns}) \) and depends on the number of rows
and number of columns of the analyzed image. This is the time complexity when one of the given \( N \)
types of rectangles is searched. For covering all the given types of rectangles, the time complexity
becomes \( O(N \times \text{rows} \times \text{columns}) \). Even that this complexity is considered in general cases a big one,
for this case is enough because the number of rows and the number of columns are in the worst case
equal with the video camera’s resolution, obtaining a relatively small product value comparing with the
number of operations which can be performed by a regular processor. The auxiliary space
complexity is \( O(\text{rows} \times \text{columns}) \) due to the fact that a secondary matrix is required for this
approach.

4.2. Decision algorithm based on histogram analysis

This method is based on constructing a structure having a similar meaning with a histogram. The
algorithm starts with the first row (the one from the top) and continues step by step with the rows
below until the last row.

Each row is considered one by one to be the base of a histogram. Each column of the histogram has
the same size with the number of consecutive elements equal with 0 from the corresponding column of
the matrix starting from the base. This histogram can be computed in a \( O(\text{columns}) \) time complexity
for each row based on the recurrence formula (7) (where \( \text{Hist} \) is a row vector representing the
histogram, \( \text{Hist}^{\text{OLD}} \) represents the values of the histogram from the previous step, \( i \) represents
the current row, \( j \) represents the current column and \( M \) is the matrix containing the binary image
analyzed).

\[ \text{Hist}_{ij} = \begin{cases} \text{Hist}^{\text{OLD}}_{ij} + 1, & \text{if } M_{ij} = 0 \\ 0, & \text{if } M_{ij} = 1 \end{cases} \]  \hspace{1cm} (7)

For each row, after the histogram is computed, a selected rectangle from the given \( N \) can be verified if can be fitted in the polygon having one of the sides on the base of the histogram. This can be
done by checking if in the vector which represents the histogram exists a number greater or equal
with one dimension of the selected rectangle of consecutive values greater or equal with the other
dimension of the rectangle. The time complexity of this operation is \( O(\text{columns}) \).

As for the previous method, both orientation possibilities have to be verified for each rectangle.
From all the possible rectangles which can be fitted in the given polygon, the one with the largest area
is selected. Its coordinates of the vertexes are determined as explained in the previous subsection,
using the formula (6).

The time complexity for this approach results the same as for the previous one, \( O(\text{rows} \times \text{columns}) \). The difference is that the complexity of the auxiliary memory is only \( O(\text{columns}) \) in this
case (the memory required for storing the histogram).
5. Experimental results

Further on are presented the results obtained for two examples in order to illustrate the functioning of the described solution.

Figure 2 shows the image acquired by a video camera for Raspberry Pi developing board with a resolution of 2592 by 1944 pixels. The contour’s shape of the metallic sheet from the image had to be a 120 by 80 millimeters rectangle. Figure 3 shows the binarized corresponding image. The red rectangle placed on top of the metallic sheet’s region represents the result of the decision algorithm (the rectangle with the biggest area which can be placed entirely inside the region determined by the metallic sheet). The dimension of the resulted rectangle is 100 by 50 millimeters. The other two possible dimensions for a rectangle were 100 by 70 millimeters and 50 by 40 millimeters respectively.

Figure 4 shows the matrix representation of the binarized image acquired. The metallic sheet from the image has a similar shape with the one from figure 2 but with smaller dimensions (the matrix corresponding to the binarized image from figure 3 couldn’t be shown due to the higher dimensions). The red rectangle represents the result of the decision algorithm (the same result was obtained using both methods).

6. Conclusion

In this paper, a solution for profit improvement of a manufacturing factory by reusing the discarded parts was presented. The detection of the parts produced which does not respect the shape and dimensions requirements can be made using an artificial vision system. The algorithm for this task was presented, according to the work space considered. Further on, two decision algorithms which determine the best part which can be produced from a discarded component were described. The results obtained for two examples were shown in the last section of this paper.

The accuracy of the results obtained depends very much on the quality of the video camera used (especially its resolution), the image processing algorithms used and on the choice of the threshold values. The presented solution can be improved by eliminating the restriction of finding the largest area metallic sheet with the sides parallel with the axis of the coordinate system. Solutions based on mathematical results for the case of any orientation can be studied in [6, 7, 8].

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