ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia CIRP 3 (2012) 442 – 447

www.elsevier.com/locate/procedia

45th CIRP Conference on Manufacturing Systems 2012

High Speed Vision Based Automatic Inspection and Path Planning for Processing Conveyed Objects

M. Weyrich[a], Y. Wang[a,]*, J. Winkel[a], M. Laurowski[b]

[a]*University Siegen, Chair of Automated Manufacturing and Assembly, Paul-Bonatz-Str. 9-11, 57068 Siegen, Germany*
[b]*Automotive Center Suedwestfalen GmbH, Fellmicke 53, 57462 Olpe, Germany*

* Corresponding author. Tel.: +49 271 740 2338; fax: +49 271 740 2542. *E-mail address*: yongheng.wang@uni-siegen.de

Abstract

Under the pressure of cost reduction and productivity improvement, this paper presents a new methodology which provides a fast inspection of defective objects and generates a real time motion trajectory for processing objects being conveyed with high speed in an industrial large-scale production. The image data obtained by a multispectral imaging system is analyzed within image processing algorithms using classification methods based on support vector machine. These data provide a basis for a path planning algorithm which considers location, orientation and arrangement of defects on the conveyed objects. Selective processing tool guided by the planed path is motion controlled.

Keywords: Vision based; Automatic inspection; Path planning; Conveyed objects; Multispectral imaging; Defect detection

1. Introduction

In the industrial quality control, instead of manual inspection, conventional vision based automatic inspection has been applied. The approach aims to sort objects or products according to vision features, which are predefined, into variant categories indicating different quality levels. Quality grading and automatically sorting of oranges is a typical example [1]. However, the increasing interests are not only aimed at simply sorting the defective objects from flawless objects, but also processing the defective objects directly after defect detection. This will help to reduce waste during production under the pressure of cost reduction and productivity improvement. Therefore, vision based path planning which can be applied for guiding the manipulator to process defective objects, is becoming an important issue in vision based automatic inspection system.

2. Objectives, problem formulation and requirements

2.1. Objectives

This paper presents an approach for an automated system consisting of a vision unit, path planning and motion control as well as object processing. The system provides a fast inspection of objects being transported on a conveyor belt with high speed. An object can be a 2D or 3D object. According to the inspection result, the target objects are classified into three categories: (1) flawless, (2) defective and processable and (3) defective and non-processable (see Fig 1). The defective and processable target objects are further classified according to the user-defined defect types. Meanwhile, a real time motion trajectory is generated for processing the defective and processable objects. The schematic representation of work flow concept of our proposed processing system is shown in Fig 1.

doi:10.1016/j.procir.2012.07.076

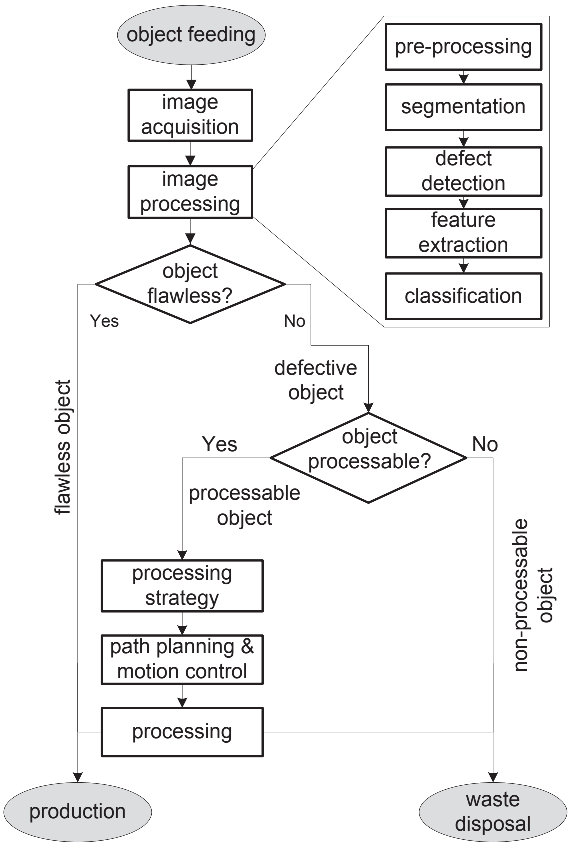

Fig. 1. Schematic representation of work flow concept

Comparing to conventional vision based inspection systems, our approach allows detecting and classifying defects on objects and apply a suitable processing strategy according to detection results; it provides a competitive alternative for handling assembly products and easy-processing product, especially agricultural goods (cucumber, apple, etc).

2.2. Problem formulation and requirement for an application

High speed vision based inspection and path planning are the two main issues in this paper. They demand a real time image acquisition (for 2D or 3D objects) and analysis, path planning, motion control and a suitable machine processing within a sequential working system. Especially, in context of the processing of agricultural products several constrains for instance irregular object shape, varying color, high productivity with very fast treatment as well as hygienic standards have to be taken into account. Furthermore, due to the variant defect types of conveyed objects, individual processing on conveyed objects (determined to be defective and processable) are often required, which may enhance the flexibility of large-scale production system.

The application requirements of this approach depend on the desired inspection and processing task. Only reduced special accuracy is economically viable because of the following machining implemented in the industrial process. Therefore, a depth resolution in the range of +/- 1.5 mm is sufficient for the detection of the surface geometry. The size of the testing objects is in the range of a few centimeters in diameter. These dimensions are associated with the size of the inspected objects and constrained by the mechanical integration space.

3. State of the art

Firstly, a survey on the recent development and application of vision based automatic inspection in industry was made. In [1], a vision-based methodology was developed for processing 3D objects on a conveyor belt. In the field of quality inspection of agricultural products, one can refer to [2] [3] [4] [5]. Moreover, in [6], an industrial vision based automatic inspection system was developed for inspecting welded nuts on the support hinge. In [7], a vision system for fast moving objects was introduced.

The acquisition of geometric information of a target conveyed objects has been discussed in [8] [9] [10] [11]. In addition, the technique camera-space manipulation (CSM) is always used in vision based path planning [12] [13]. An approach to methodology for selection of a case-based appropriate imaging system is proposed in [14].

4. Approach

In this section a system concept adapted to the scenario described in section 2.1 is developed. Then the concept solution to each problem described in section 2.2 with respect to our system concept is proposed.

4.1. System concept

In Fig 2, the concept of a vision based automated inspection and path planning for the processing system is illustrated. Continuously fed objects are placed on a conveyor belt and transported with a quasi-constant velocity. The imaging system is set above the conveyor and captures conveyed objects. The obtained image data is analyzed by a computer system. The analysis results provide a basis for a path planning algorithm which considers the location, orientation and arrangement of defects on the conveyed objects. Beside the image acquisition system is a processing unit (e.g. a robot system) which is equipped with selective processing tool. This processing unit is motion controlled according to planned path for removing defects or another desired treatment.

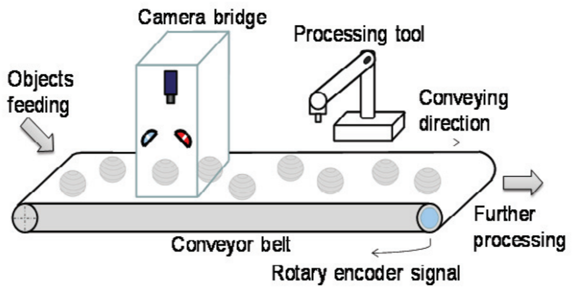

Fig. 2. Concept of the inspection and processing system

4.2. Electromagnetic band for detecting surface defects

In the field of optical surface inspection, improvement of contrast between the defective and flawless area of an object plays a major role for reliable and stable automated detection processes [1]. In order to obtain the optimal contrast, a systematic experiment with variant illumination and corresponding multispectral sensors has to be made. In Fig 3 the experiments with a monochrome camera with different optical band-pass filters in order to examine the spectral response of defects is shown.

Fig. 3. Experiments with a monochrome camera with different optical band-pass filters

4.3. Image acquisition and illumination

Respect to the determined electromagnetic band, an image acquisition and illumination should be developed for surface defects detection and localization. Firstly, the target objects are divided into two categories: 2D objects and 3D objects. 2D objects are considered to be the objects of slice form, whereas 3D objects tuber shape.

For the case of 2D objects, a multispectral vision system (see Fig 4) is proposed to facilitate the segmentation of objects and defect detection. Multispectral cameras (denoted by sensor A and sensor B) are perpendicularly installed above the conveyor belt. Two front lighting (spectral lighting A and B) are installed between camera and conveyor belt. A back lighting (spectral lighting C) is installed below the conveyor belt. The benefit of this arrangement is that: the contour of target objects on a structured conveyor belt can be extracted by using the transmitted light. Object segmentation is achieved by the combination of reflected-light illumination (spectral lighting A and B) and transmitted-light illumination (spectral lighting C). This step reduces the redundant image data by focusing the region of interest direct on the target object. In Fig 9 the segmentation of potato slices from conveyor belt is shown.

The condition is more complex for the case of 3D objects. For 3D weak texture object, the defective area is mostly determined by the inhomogeneous geometric shape. Therefore, geometric shape rather than texture needs to be estimated and analyzed. For 3D texture object, defective area is determined by texture analysis of object surface. Therefore in this case, surface inspection and geometry reconstruction are always combined to detect and locate the position of defects. In [1], the prevalent technologies for the shape estimation of 3D objects have been compared. It has concluded that, the stereo vision with auxiliary pattern projection (see Fig 5) is a competitive alternative for both shape estimation and surface inspection. For inspection of a rotationally symmetric part one can refer to [14].

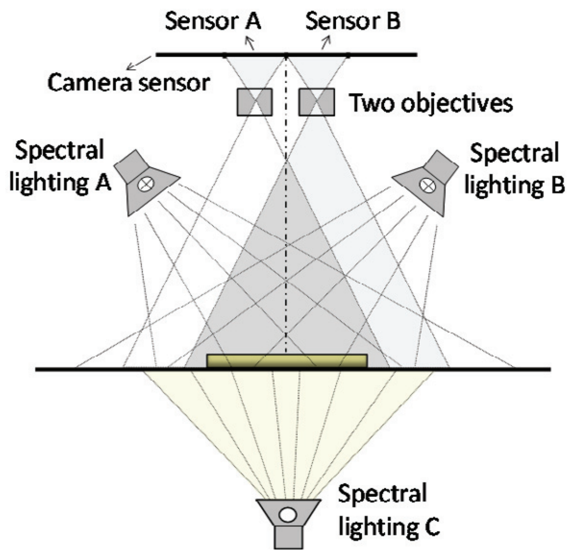

Fig. 4. Imaging setup for segmentation and defects detection of 2D objects

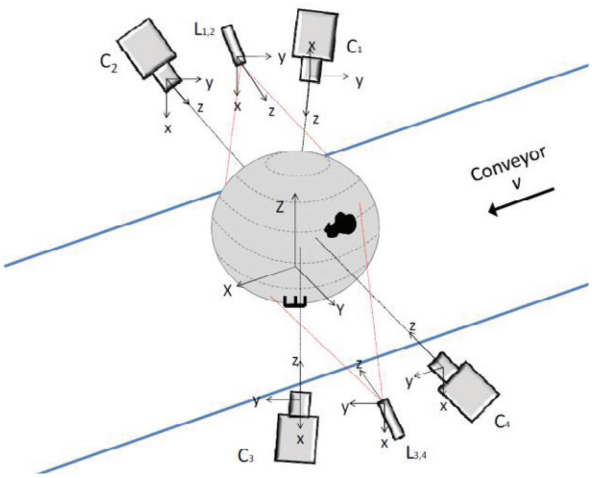

Fig. 5. Imaging setup for shape estimation of 3D objects [1]

4.4. Image processing algorithm

Image processing is the subsequent step to image acquisition. It can be divided into the following steps: pre-processing, object segmentation, defect detection, features extraction and defects classification (review Fig 1).

Texture analysis is the measure to detect surface defects. Statistical features (e.g. variance, third moment, uniformity, entropy) of the texture are utilized to detect defects. Support vector machine developed by Cortes and Vapnik [15] is employed to classify defects. Due to the increasing number of features, an approach cross-validation and Grid-search is introduced in [16] for finding the optimal parameters, if RBF kernel was chosen for SVM.

4.5. Path planning and motion control

Path planning is the next issue of our vision system after location of defective objects and their defects. Aljarboua [17] introduced an interesting geometrical path planning for general robot manipulator. However in our work, more than obstacle avoidance and seeking shortest moving path, path planning in our work is associated with path achievability and maximization of regain value from defective objects.

For the analysis of path achievability, current state of manipulator should be fed back and taken into account. And then within the achievable area, an optimal path is calculated to obtain a maximal regain value from the defective object.

4.6. Conveyor belt

Conveyor belt for material feeding should be carefully designed according to the following factors: shape of conveyed objects, further treatment with respect to the inspection result, desired productivity, hygienic standards (for food industry), etc. The following general conveyor means and their variation have been compared in our work:

- Conveyor belts with nests
- Rotary indexing table
- V-Band

Moreover, the material of conveyor belt as a crucial influence factor to the treatment step on target objects should be considered.

4.7. Manipulators for treatment

The selection of a manipulator for processing tool is a major challenge according to the given problem formulation. For the materiel processing, an efficient, fast and food compatible system have to be found. Within an extensive application analysis, the systems shown in Fig 6 have been compared with the consideration of desired processing task.

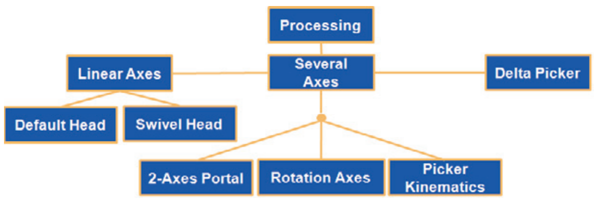

Fig. 6. Comparison of manipulators

5. Implementation and experimental result

The feasibility and advantages of our approach will be proved by the implementation with an example of agricultural product quality control. The production of quality and safety food is quite demanding in modern food industry. In the production of e.g. potato chips, there is a variety of requirements. For instance, some defective fraction, which is harmless to health (e.g. peel), may be remained or removed (according to the customer requirement); some defective fraction, which is harmful to health (e.g. green, seed), have to be definitively removed; even the whole chip must be sorted out.

According to the system concept described in section 4.1, an experimental system of chips inspection and processing was developed and built up (see Fig 7). A line scan camera, which is positioned above the conveyor belt and triggered by an encoder signal, acquires the image of conveyed objects. The image information is sent from the camera to the industrial computer PC-VU (vision unit), which is equipped with a frame grabber that captures the image. In PC-VU, the location of a target object and defects, as well as information of defect types will be obtained by a developed image processing algorithm. Meanwhile a motion trajectory, which is comprised of a list of coordinates, is generated and sent to the second industrial computer PC-PU (processing unit). Data transmission between PC-VU and PC-PU is synchronized (by using rotary encoder signal of conveyor belt) via a field bus system. Fig 8(a) displays the experimental setup of water jet as the processing tool, which is motion controlled by a linear axis manipulator with a maximal acceleration of 15 G; Fig 8(b) displays the water beam with a diameter of 0.2 mm.

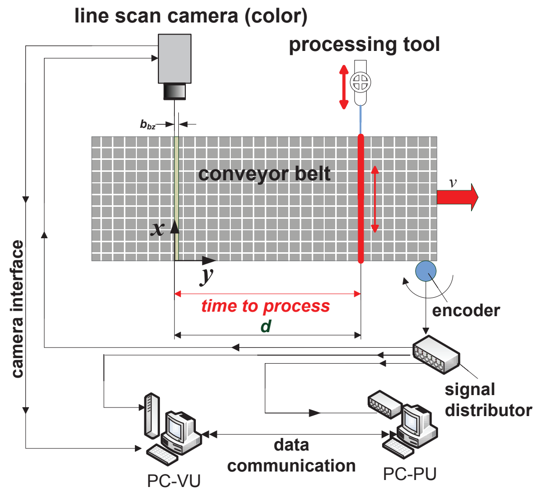

Fig. 7. Configuration of inspection and processing system

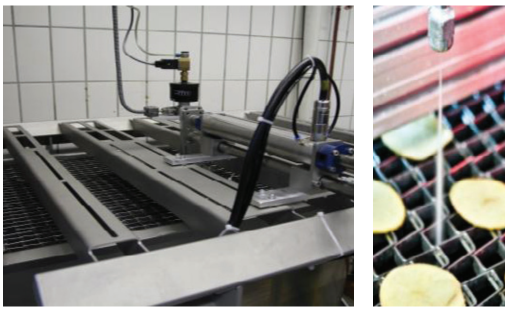

Fig. 8. (a) Water jet motion controlled by a linear axis manipulator; (b) water beam with a diameter of 0.2 mm

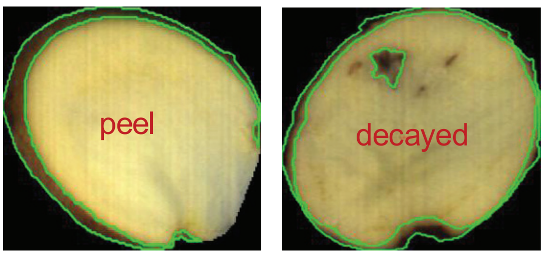

Fig. 9. Segmentation and defect classification (a) peel; (b) decayed

The proposed multispectral vision system in section 4.2 is used for inspection of potato slice. The image processing algorithm is implemented with the development platform LabVIEW. The image processing is performed in the color space HSL. Fig 9 displays some experimental results; wherein, (a) displays the defects of peel, (b) decayed spot.

5.1. Path planning and processing strategy

In Fig 10, an example of a direct processing strategy using a LabVIEW-based path planning is shown. The equivalent ellipse according to the geometry shape of a defect will be firstly analyzed. Cutting path is planned to be parallel (with an offset of s) to the major axis of the equivalent ellipse. If a potato slice has a big defective fraction, after cutting only a small non-defective fraction will be left. In this case, this potato slice will be considered as a non-processable object. Cutting path will be planned to go around the potato slice with the avoidance of wrong treatment (e.g. cutting a non-processable potato is also a wrong treatment). Due to limited behavior of linear axis manipulator, the minimal accessible cutting angle α is a key factor for the processing strategy.

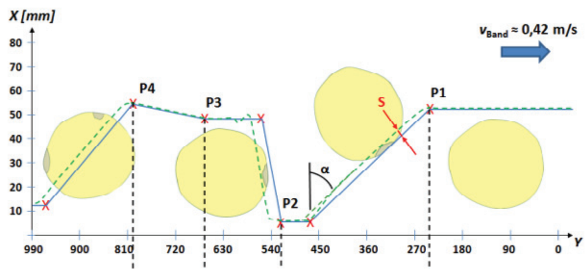

Fig. 10. Path planning based on the result of image data analysis.

5.2. Remove of defects by using water jet

The system behavior of the water jet cutting application was tested in different experiments. With the maximum speed of the conveyer belt of 0.4 m/s the system is able to process approximately 2-3 defective objects per second.

The removed defective fractions of potato slices may be eliminated by pick and place robots. To approach this, the center point of the removed defective fraction should be given in LabVIEW-based image processing algorithm. Due to the constraint of working speed of pick and place robots, 3 cycles per second is overstrained.

6. Conclusion and outlook

This paper presents a systematic development approach, which is applied for the development of a vision-based automatic inspection and path planning system for processing conveyed objects. This approach is based on existing technologies and application-oriented combination of required components. The novelty of the proposed approach lies on the application-oriented combination of technologies and system control. By using the described system, significant savings of inspected products, such as products in food industry, can be achieved. The approach has been implemented and tested on an example with the field of agricultural production. The prototype system is able to automatically inspect the surface of objects and remove the defects from objects in the subsequent processing step. The setup consists essentially of a conveyor belt, vision unit, and control unit. For powerful data processing and system control, industrial PCs are used. They work in a synchronized way based on the encoder signal, and communicate through an industrial bus system. In the vision unit, the image acquisition and analysis, classification and location of defects are performed. The following processing system allows the removal of the detected defects. The experiment demonstrates practicability of the development concept and functionality of the application, which can be transferred to the other similar applications.

A further development of the system may be accomplished by increasing the performance of the automatic evaluation system as well as by optimizing the processing unit. These both steps could achieve an improvement in the system productivity.

Acknowledgements

This work was funded by the European Fond for Regional Development and the government of North Rhine Westphalia under the reference number NA035D.

References

[1] Weyrich, M., Laurowski, M., Klein, P., Wang, Y.-H., 2011, A Real-time and Vision-based Methodology for Processing 3D Objects on a Conveyor Belt, Int. J. of Sys. Appl. Eng. & Dev., Issue 4, Vol. 5, pp. 561-569.

[2] Gracia, L., Perez-Vidal, C., Gracia, C., 2011, Computer Vision Applied to Flower, Fruit and Vegetable Processing, proceedings of ICPRCV, year 7, issue 78, Amsterdam, Netherlands.

[3] Wilson, A., 2011, Machine-vision-based inspector sorts oranges and mandarins in: Vision Systems Design, Volume 16, Issue 10.

[4] Narendra V G, Hareesh K S, 2010, Quality Inspection and Grading of Agricultural and Food Products by Computer Vision – A Review, International Journal of Computer Application (0975 - 8887), Volume 2, No. 1.

[5] Cubero S., Aleixos, N., Molto, E., Gomez-Sanchis, J., Blasco, J., 2011, Advances in Machine Vision Applications for Automatic Inspection and Quality Evaluation of Fruits and Vegetables, Journal of Food and Bioprocess technology, vol. 4, no. 4, pp. 487-504.

[6] Kim, S.-M., Lee, Y.-C., Lee, S.-C., 2006, Vision Based Automatic Inspection System for Nuts Welded on the Support Hinge, SICE-ICASE, pp. 1508-1512.

[7] Kopacek, P., Han, M.-W., Putz, B., Schierer, E., Wurzl, M., 2005, An industrial image processing system for fast moving objects, IEEE, pp. 278-282.

[8] Laurowski, M., Kerstein, T., Klein, P., Weyrich, M., Roth, H., Wahrbug, J., 2011, One Shot Optical 3D Surface Reconstruction of Weak Textured Objects for an Agricultural Application, proceedings of 56th International Scientific Colloquium IWK, Ilmenau.

[9] Kerstein, T., Laurowski, M., Klein, P., Weyrich, M., Roth, H., Wahrburg, J., 2011, Optical 3D-Surface Reconstruction of Weak Textured Objects Based on an Approach of Disparity Stereo Inspection, proceedings of ICPRCV, year 7, issue 78, p. 581-586.

[10] Gao, G., Chen, X., Zhang, H.-M., 2010, A Fast Structured Light Matching Method in Robot Stereo Vision, in Journal Applied Mechanics and Materials, vol. 29-32, pp. 1981-1984.

[11] Ambrosch, K., Kubinger, W., 2010, Accurate hardware-based stereo vision, in Journal of comput. Vis. Image Understanding, vol. 114, pp. 1303-1316.

[12] Bonilla, I., Galvan, E.-J., Olivares, C.-C., Mendoza, M., Loredo-Flores, A., Reyes, F., Zhang, B., 2010, A Vision-based Impedance Control Strategy for Industrial Robot Manipulators, 6th annual IEEE on CASE, pp. 216-221.

[13] Zhang, B., Wang, J.-J., Rossano, G., Martinez, C., 2011, Vision-guided Robotic Assembly Using Uncalibrated Vision, ICMA, Issue 7-10 Aug., pp. 1384-1389.

[14] Laurowski, M., Klein, P., Weyrich, M., Scharf, P., 2011, Use-Appropriate Design of Automated Optical Inspection Systems for Rotationally Symmetric Parts, 56th IWK.

[15] Cortes, C., Vapnik, V., 1995, Support-vector network, Machine Learning, 20, 1-25.

[16] Hsu, C.-W., Chang, C.-C., Lin, C.-J., 2010, A Practical Guide to Support Vector Classification, Department of Computer Science, National Taiwan University, Taipei 106, Taiwan.

[17] Aljarboua Z., 2009, Geometric Path Path Planning for General Robot Manipulators, proceeding of WCECS 2009, Vol. II.