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The Development and Instigation of the 3D Object Identification System

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Introduction

The reconstruction of three-dimensional (3D) object structure and properties or their locating in the environment according to the available two-dimensional (2D) images is one of the most required computer vision tasks to be solved. It has been discussed for few decades and is still one of the main items on the agenda. Some of the industrial processes in which the 3D perception of the surrounding space can be more advantageous against the 2D computer vision systems, is transferring or manipulation of objects. There are many fields in industry and everyday life, such as fast prototyping and reverse engineering, stomatology and medicine, footwear and outfit design, criminology and archaeology, security and person recognition systems, where the use of 3D identification systems are much more efficient and applicable [1].

The reason why the 3D computer vision is not yet widely used in practice is very large quantity of visual information in 3D identification applications. Powerful computer systems are usually used to process that data. With the traditional approach the cameras with analogue interface for picture capturing and the specialized high-speed video processors for picture analysis are used. Such systems can do the 3D processing in real time, but they are very expensive and complicated, so they can only be used in the machinery of extreme significance.

The goal of our work was to create relatively inexpensive 3D object identification system and to investigate the possibility of its use for the specialized tasks in the field of 3D processing. The latest achievements in the computer technology, acquisition and communication technology were used in the development. The use of digital video cameras with wide band digital interface IEEE 1394b and new generation PCs together with standard laser line generators and computer controlled light pattern sources made such system cost effective and exceptionally versatile.

In the system we used two methods of 3D scanning to get the information about the object identified. The first one is the laser scanning method using the mechanical shift or rotation of the object. The second one is object illumination with the programmable light patterns while grabbing pictures (Structured Light Scanning).

We'll also discuss the results of a few practical applications that were tested experimentally.

Main principles of 3D object reconstruction

The reconstruction of the 3D surface of the object is performed using the light line or encoded light source illuminating the object and the video camera capturing pictures of the object at the angle different from the lighting angle (as shown in Fig. 1) [2]. The height or depth of the object is calculated according to the formula:

$$h = b \cdot \frac{\sin\alpha \cdot \sin\beta}{\sin(\alpha+\beta)} \quad (1)$$

Using laser scanner the mechanical transportation of the object or the scanning head must be involved to cover the whole scanning area. Using the structured light scanning the projector covers the entire scanning area and there is no need for the mechanical movement. Two methods of transportation are commonly used in laser scanner systems: linear movement or rotation of the object.

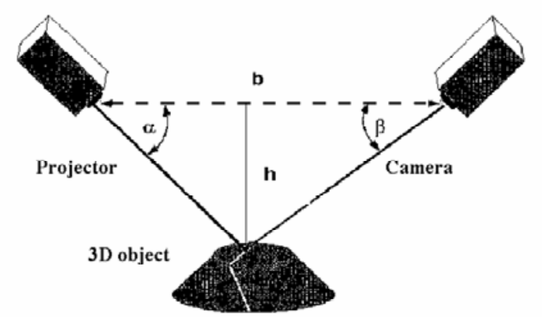

Fig. 1. The calculation of the object height / depth according to the light source falling angle **a** and the camera viewing angle **b**

Laser scanning method and equipment

Special laser scanner equipment was designed and produced for the 3D identification system. It consists of the scanning head with laser line projector and two digital cameras. The scanning head can be fixed in vertical or horizontal position, depending on the movement trajectory of the object - linear or rotary. The drifting / rotating platform was constructed for the object transportation. It is activated by the servomotor with encoder and frequency converter and controlled by the computer. Such design makes it possible to operate it in step or smooth mode at various speeds and makes it irreplaceable when used for the experiments. The block diagram of the identification system using the laser scanner is shown in Fig. 2.

We also used the belt conveyor as the object transportation equipment to test the possibility of using 3D identification system in real production line environment.

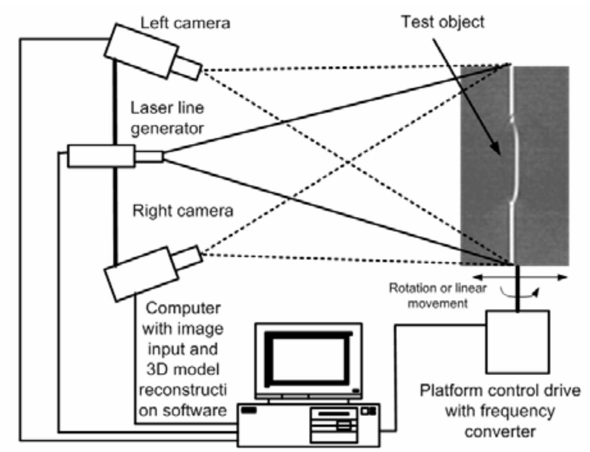

Fig. 2. The block diagram of the 3D identification system when using the laser scanner.

In any case the identification process consists of three main steps: scanning of the object, 3D model reconstruction and the final parameter measurements followed by decision making.

The first two steps depend on the scanning process and the third one is performed according to the requirements of the process for which the system is used. It could be measurement of some dimensions of the 3D model, decision making about the correspondence of the 3D object properties to the required ones and deciding about the removal of the defective product or just transferring the model to some other production design or modelling system.

Scanning the object with the use of laser scanner includes the following steps:

1. Pictures capturing. It can be performed at equal time intervals if the transportation system works in smooth mode, or at the moments defined by the control module of the table if it works in the step mode;
2. Pre-processing (initial filtering, correction of geometrical distortions) of the captured images;
3. Storing of the image data on PC RAM or HDD for 3D model reconstruction step.

The 3D model reconstruction algorithm includes following steps:

1. Binarization of the pictures;
2. Determining the angles of the projected lines and the angles of the camera view to the line. The line projection angle in this case is always 90°;
3. Calculating the distance to the back plane of each point on the surface of the object knowing the geometrical layout of the system elements and using formula (1);
4. Interpolating of the data determined by the left and right cameras.

In case of the object rotation the reconstruction algorithm includes an additional process between the processes 3 and 4. In this case we determine the distance to the rotating axis of every point on the surface of the object instead of the distance to the back plane. The process is transforming the 3D model information from polar coordinate system to Cartesian coordinate system.

The 3D object identification system using the laser scanner is precise, quite simple to construct and data process, but slow because of the large quantity (from 200 to 500 and more for high reconstruction quality) of pictures to be processed. Some kind of mechanical transportation system is also required. That makes it especially suitable for production lines to identify objects moving in the production cycle. Because of the long scanning cycle it cannot be used for the objects that don't stay still over the time, such as human body or its parts.

Structured light scanning method and equipment

Multimedia projector LT-170 controlled by the computer or special pattern generator is used for the 3D identification systems structured light scanner. Two digital cameras perform the picture capturing. The block diagram of the identification system working with the structured light scanner is shown in Fig. 3.

The prime problem of coded lighting approach for the 3D surface scanning is to select appropriate light pattern encoding [3]. We use light stripes coded according to the Gray code in our system.

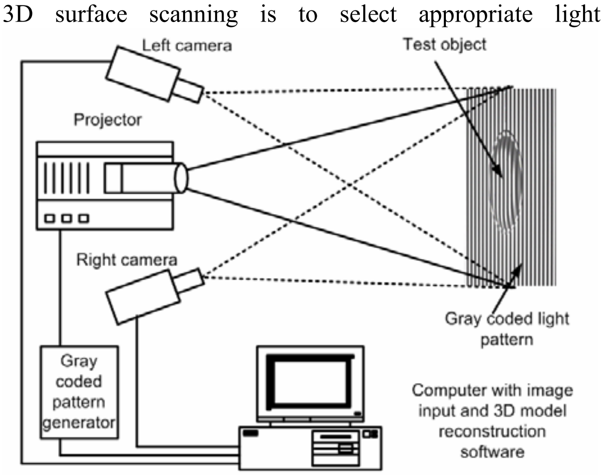

Fig. 3. The block diagram of the 3D identification system when using the structured light scanner.

With this method the projector illuminates the object which is scanned *n* times in stripes coded according to the Gray code. The illustration of this method is given in Fig. 4. With each pattern flash the camera takes a picture.

Using n lighting patterns we get 2^n lines crossing the scanned object. For example using 9 Gray coded light

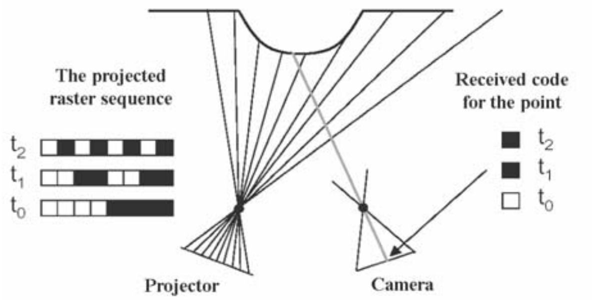

Fig. 4. The illustration of scanning using structured lighting with Gray code.

patterns we can decode 512 object scanning lines. Thus taking only 9 pictures we get the resolution corresponding to 512 pictures in laser scanning [3, 4]. That makes this method much faster and no mechanical transportation system is needed.

In Fig. 5 we present the pictures of the test object illuminated by a set of Gray coded light patterns.

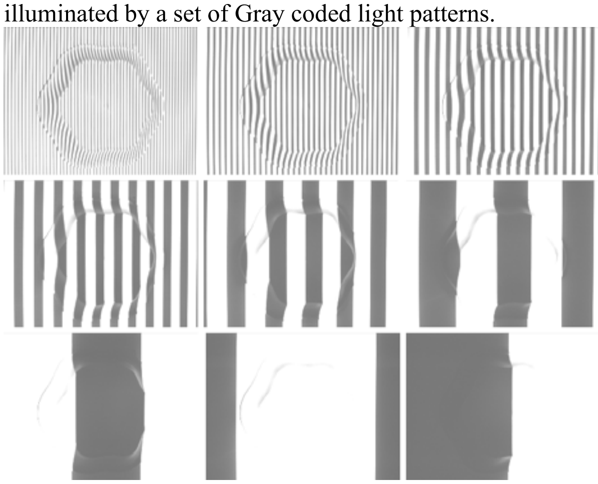

Fig. 5. The set of pictures of the object illuminated by Gray coded light.

In this case we also have three main steps of identification process as described earlier, speaking about the laser scanning.

The scanning of the object using structured light scanner consist of following principal processes:

1. Illuminating the Gray coded pattern on the scanned object;
2. Picture capturing process. It is synchronized with frame synchro signals of the projector;
3. Pre-processing (initial filtering, correction of geometrical distortions) of the captured images;
4. Storing the image data on PC RAM or HDD for 3D model reconstruction step.

The 3D model reconstruction algorithm includes following processes:

1. Adaptive binarization of the pictures. For this reason we capture two additional pictures: one of the fully illuminated object and the second of the totally dark object. These pictures are used to calculate the threshold value for the coded pictures binarization;
2. Determining the code for every pixel of the object picture in the set of the binarized pictures;
3. Filling the codes for every projected vertical line into the special matrix
4. Calculating the projection angles for every projected vertical line and storing them together with the corresponding codes;
5. Calculating the viewing angles seen by the camera (angle **b** in Fig. 1) for each projected vertical line using the geometrical data of the system;
6. Determining and assigning the projecting angle (angle **a** in Fig. 1) to each pixel according to the codes fixed by the camera for each picture pixel;
7. Calculating the distance to the back plane of each point on the surface of the object using formula (1) and the dimensions of the system;
8. Interpolating of the data determined by the left and right cameras.

The 3D object identification system with structured light scanner is much faster than the laser scanner, but it is more sensitive to the illumination noise from the projector and the external light sources. When using the filtering algorithms to reduce sensitivity to noise we loose the overall resolution of the system. Because of the short scanning cycle (only 11 pictures must be captured) it can be used for the objects change, such as human body or its parts [5].

Examples of identification system used in projects

The 3D identification we used is a device that could automatically measure the arch width and altitude length of the teeth by scanning the plaster cast of the mouth. These parameters could be used to evaluate children's facial and dental developmental anomalies and select right treatment options.

In this project the laser scanning process is used. Specialized software for scanning control and 3D model reconstruction was created. In additional to the calculations described this software also includes the calibration module. The usage of the calibration routine makes it possible to determine the position of the camera and laser line generator in relation to the scanned object. This makes the system more precise and there's no need to measure the geometrical layout of the system manually.

In this project the accuracy of ~0.5mm was achieved using the interactive measurement algorithm. The picture of the plaster cast of the mouth scanned is shown in Fig. 6.

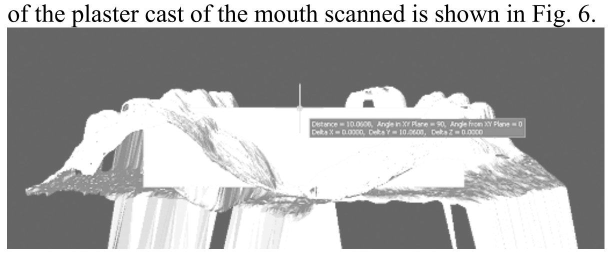

Fig. 6. The measurement of the dental arch width on the 3D model of the plaster cast of the mouth.

The other application of the 3D identification system is candy quality control and packing line. We used specially designed laser scanning systems to determine the 3D dimensions of the candy and to spot the defects on the chocolate covering. This quality control system incorporates 9 cameras, 4 laser line generators and diffuse illumination source. The candies are checked while moving by on the conveyer belt and are rejected if they don't meet the requirements. The view of the quality control unit is shown in Fig. 7.

This system can control up to 1800 pc/min with the accuracy of candy dimension measuring ± 1 mm.

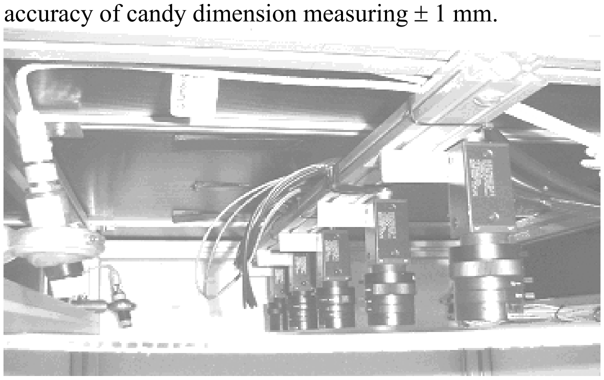

Fig. 7. The quality control unit on the candy packing line.

At present a few other quality control systems with 3D identification are in the process of being developed and the specialized foot scanning device for footwear design systems is designed and constructed.

Conclusions

1. The developed 3D identification system can be used as a perfect tool for evaluating and testing in the design and construction phase of industrial 3D vision applications.
2. The laser scanner is suitable for applications with objects moving in the production cycle. Because of the long scanning cycle it cannot be used for unstable objects such as human body.
3. The structured light scanner is much faster than the laser scanner, but it is more sensitive to the illumination noise. It can be used to scan human body or its parts.
4. Correctly designed algorithms and optimized software make the real–time 3D identification possible.

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Meskauskas R., Jokuzis V. The Development and Investigation of the 3D Object Identification System // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 5(69). – P. 41–44.

The experimental system for three-dimensional object identification was developed and investigated. A laser scanner and structured light scanner was designed and produced specially for this system. Advantages and weaknesses of every scanning method was explored and experimentally tested. The 3D object model reconstruction algorithm was developed for every scanning method and specialized programs were optimized for every application case. The principles of the 3D identification system are given and the algorithms used are listed in this work. Real projects developed on the basis of the 3D identification system and technical data of the equipment produced are also presented. Ill. 7, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

Мяшкаускас Р., Иокужис В. Создание и исследование системы идентификации трехмерных объектов // Электроника и электротехника. – Каунас: Технология, 2006. – № 5(69). – С. 41–44.

Создана и исследована экспериментальная система для идентификации трехмерных предметов. Специально для этой системы были сконструированы и произведены лазерный и растровый сканеры. Преимущества и слабости каждого метода сканирования были исследованы и экспериментально испытаны. Алгоритм реконструкции модели трехмерных предметов был сотворен для каждого метода сканирования и созданы специализированные программы, оптимизированы для каждого случая применения. В этой работе даются принципы системы идентификации и изложены используемые алгоритмы. Также опубликованы реальные проекты, начатые на основе системы идентификации трехмерных предметов, и технические данные произведенного оборудования. Ил. 7, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

Meškauskas R., Jokužis V. Trimačių objektų identifikavimo sistemos kūrimas ir tyrimai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 5(69). – P. 41–44.

Sukurta ir ištyrinėta eksperimentinė trimačių objektų identifikavimo sistema. Šiai sistemai buvo sukonstruoti ir pagaminti lazerinis skaitytuvas ir skaitytuvas su rastriniu šviesos šaltiniu. Tyrimų metu išnagrinėti ir eksperimentiškai patikrinti abiejų nuskaitymo metodų teigiamybės ir trūkumai, sukurti kiekvienam metodui pritaikyti trimačio objekto modelio atkūrimo algoritmai ir specializuotos, kiekvienam taikymo atvejui optimizuotos programos. Straipsnyje pateikiami trimačių objektų identifikavimo sistemos veikimo principai, veikimo algoritmai, realių sistemos taikymų pavyzdžiai ir jos pagrindu sukurtų įrenginių charakteristikos. Il. 7, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).