DETECTION OF GLASS EDGE CORRUGATION FOR CUTTING DISTANCE OPTIMISATION

ONDREJ MATUSEK, ZDENEK VIT, VLASTIMIL HOTAR

Technical University of Liberec Department of Glass Producing Machines and Robotics

Liberec, Czech Republic

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e-mail: ondrej.matusek@tul.cz

This paper proposes a new method of surface shape determination for transparent objects. Concretely it deals with a detection of glass-sheet corrugation nearby the sheet edge. This variable is important for cutting distance optimization. Time-dependant laser reflection was used to generate a surface profile. Projection dependence was set. That allows calculating a distance of deformed part. Results were compared with another innovative method, confocal sensor distance measurement and with zebra test, optical test widely used in glass industry.

KEYWORDS

3D acquisition, 3D data, transparent materials, glass deformation, glass corrugation

1 INTRODUCTION

Machine vision and industrial camera sets present new branch in production line automation field. It is surely becoming more popular, especially because they bring a considerable saving in production costs. The most common is to use machine vision for a quality inspection, where it brings faultlessness for dispatched products. Another no less common application is using of eye-hand coordination system, when a robot is directly guided by an industrial camera [Matusek 2011].

Highly up-to-date problem is obtaining 3D coordinates by a machine vision. Many practical tasks in industry, such as mentioned automatic inspection, robotic automated manipulation, bin-picking, robot space orientation etc. often require scanning of three-dimensional shapes with non-contact techniques [Perez 2016]. These procedures are also slowly becoming applied out of engineering field, such as agricultural industry [Ma 2014, Barnard 2016, Sture 2016], food industry [Bar 2016], healthcare [Lun 2015], education, or even leisure activities [Microsoft 2016].

2 TRANSPARENT OBJECT ACQUIRING

As it was described in the introduction, machine vision is widely used for common product identification. However, transparent objects, such as those made of glass, still pose difficulties for classical scanning techniques. The reconstruction of surface geometry for transparent objects is complicated by the fact that light is transmitted through, refracted and in some cases reflected by the surface. Simply besides being transparent are these materials loaded by parasitic reflection. Current approaches can only deal relatively well with sub-classes of objects. The algorithms are still very specific and not generally applicable. Furthermore, many techniques require considerable acquisition effort and careful calibration. Therefore acquisition of these materials still remains a challenging task. It is very often necessary to find out an appropriate positioning and choose proper combination of illumination [Hotar 2016]. It has also been suggested to use a different electromagnetic spectrum, than visible.

One possibility is to use ultra-violet (UV) cameras. These specific devices are determined to a visualization of processes in ultraviolet part of an electromagnetic spectrum, which presents a wavelength of 240 - 380 nm. Due to shorter waves, it is possible to acquire higher details than during acquiring under common visible light. Use of ultraviolet light may also bring other advantages. Glass is transparent in visible spectrum (380 - 750 nm). However, it is not transparent in whole electromagnetic spectrum. The transparency range depends on glass composition. For common window glass there are completely absorbed waves under approximately 280 nm. For added glass the transparency finishes around 400 nm. Thus, UV cameras detect it as a non-transparent material [Ihrke 2010, Osorio 2012].

Another approach is to use infrared (IR) cameras (also known as thermo cameras). These are specific devices determined to a detection and visualization of processes in IR part of electromagnetic spectrum that means approximately 700 - 900 nm. Usually, there is an IR filter used, which allows the IR light to pass through, but it blocks most of visible spectrum. For longer waves then a visible spectrum, common glass is by normal temperature transparent up to middle infrared waves (MWIR, 3 000 - 8 000 nm). Theoretically it is possible to use cameras able to acquire electromagnetic radiation higher than 4500 nm (exact value is influenced by glass composition). Another approach is to measure the glass under heat load, where it is possible to acquire a radiation in NIR spectrum material [Ihrke 2010, Osorio 2012].

There is also a possibility to use a light reflection generated on a surface (optical interface) to build a 3D model. That actually means to acquire data, which allow us virtual object reconstruction and object contactless measurement. Theoretical aspects with use of Fresnel equations show the usage possibility by relatively large angle of reflection, approximately over $\Phi i = 50°$ and with a use of polarized light [Hotar 2013]. This method is based on sample projection onto shaped spatial object. The deformation of reflected samples is used for the surface evaluation, or to generate the 3D model. This method is commonly used in glass industry, known as a zebra test.

The last approach listed is a use of confocal sensors. Principle of this technology is in focusing of polychromatic white light to desired spot by a set of lenses. Lenses are in this sensor arranged as to disperse the white light into monochromatic with use of chromatic deviation. Certain deviation is assigned to certain wavelength by initial calibration by a producer. For measuring itself, there is only appropriate wavelength focused on desired surface or material used for evaluation. The light, which is reflected from desired surface pass through confocal diaphragm to a receiver. Its task is to receive, detects and process spectral changes. This method allows very precise distance measurement. Confocal technology offers nano-metric resolution and is able to be used for any surface material. Moreover, this method is possible to be used for distance measurement of diffuse or mirror surfaces. For transparent materials, such as glass, it allows one-sided thickness measurement together with a measurement of distance.

Shading influence during a measurement is eliminated as transmitter and sender are arranged in one common axis [Automatizace 2015, Omron 2015]. This technology is suitable for any transparent material usage. Narrow range of measured distances, high price and limited distance between a sensor and measured surface is a limitation for an industrial praxis. Furthermore, for exact measurement there is a need of environmental cleanness and sensor's perpendicular position to a measured surface.

3 PROPOSED METHOD OF TRANSPARENT OBJECT'S SURFACE EVALUATION

There is an innovative method of determining the surface shape of transparent objects presented in this paper. Applicably for industrial praxis it in detail deals with a detection of glass-sheet corrugation nearby the sheet edge. The flat glass sheet is deformed by the edge due to a production process, when glass-melt is mechanically spread out by the top rollers. This deformed part of glass is hardly visible, or acquirable by a camera. Therefore there is a glass sheet under a projection of zebra pattern shown on Fig. 1. The deformed part appears as a distortion of a pattern. This deformed part needs to be cut out during the production process and is subsequently recycled. For economical reason it is necessary to optimise this cutting distance. Therefore, there is a need of a surface evaluation.

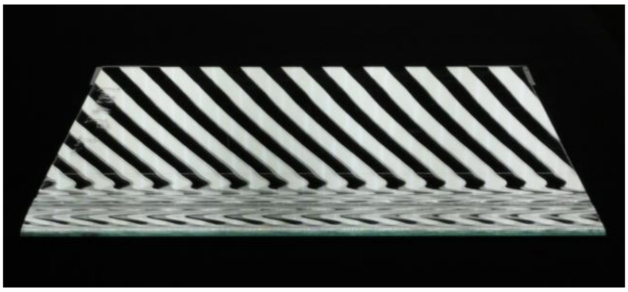

Figure 1. Deformed glass sheet

Currently this evaluation process is being executed offline, several samples a day are analysed by the operator on an optical zebra test system [Hotar 2011, Hotar 2013]. Cutting distance is subsequently adjusted manually.

This paper proposes a new method of cutting distance optimisation of deformed glass edge, which is applicable for an on-line production. This innovative method of surface determination for transparent objects is based on laser beam projection and subsequent reflection onto a reflective board. The principle is shown on Fig. 2.

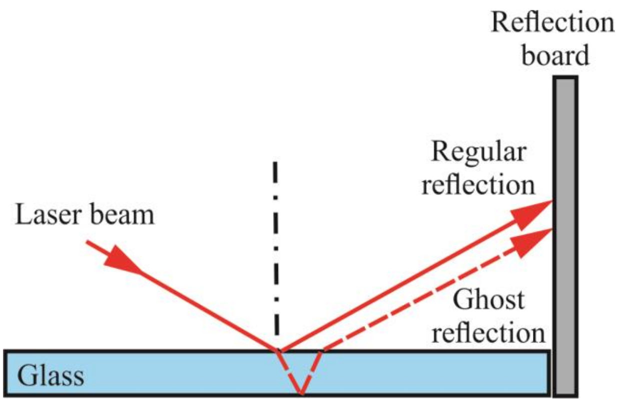

Figure 2. Proposed method principle

For the purpose of this article there has only been considered with the regular reflection. However, ghost reflection might be used for glass thickness determination as well.

4 WORKPLACE

There was a laboratory workplace prepared Fig. 3 simulating the situation for real industry application. Laser line is projected onto a glass sheet which is analyzed. Commonly used method of laser beam deformation on a surface is not possible to acquire, due to glass transparency. Thus, a laser beam reflection projected on a reflection board is acquired and analyzed.

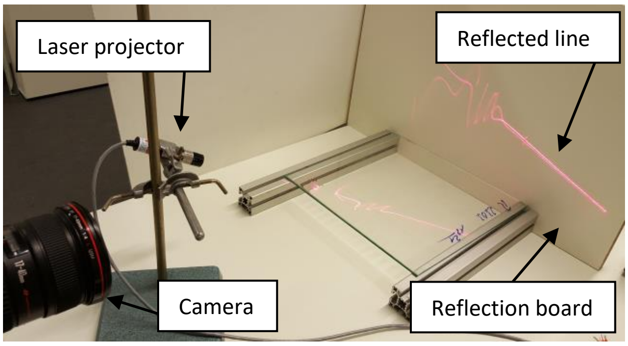

Figure 3. Laboratory workplace

For a proper calibration there was a standard prepared. An exact grid was burnt into a flat glass sheet Fig. 4a). This allows us to investigate the reflected light dependence.

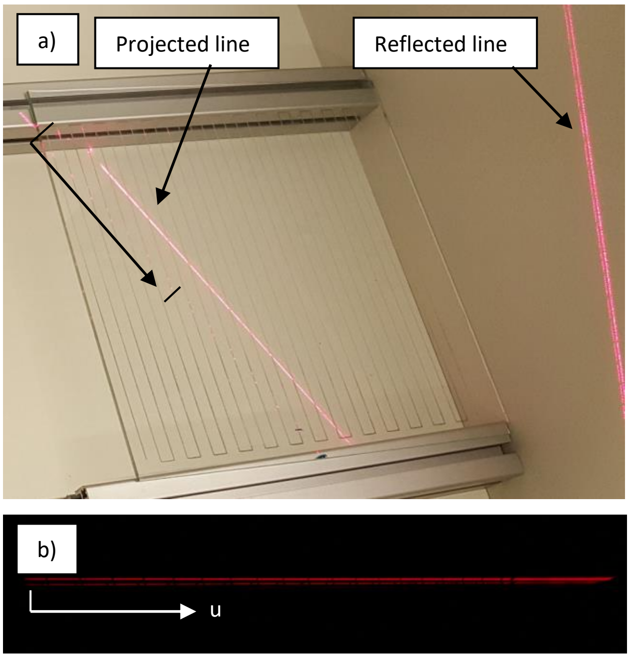

Figure 4. a) Calibration standard, b) Reflected line

The length's dependence equation was calculated by means of least squared method from 22 defined points. Points were 22 known crossings of laser beam and line burnt on a grid and 22 sections on a reflected line (Fig. 4b). The established equation is:

$$l = -0{,}008u^2 + 3{,}320u + 3{,}240 \qquad (1)$$

Where u is measured length of the reflected line and l is recalculated real line length.

Once there is a known dependence equation we can comfortably set the length of the deformation. However, by the laser projection method it is very difficult to identify the edge on a deformed part of a glass. Therefore, laser line length was measured from its beginning - the non deformed side of a glass sheet. For all tested samples this position was unique and same as for the calibration standard. This line beginning was set to *120 mm* from a glass edge, see Fig. 5. This was secured by constant laboratory setup and unchangeable position of glass sheet.

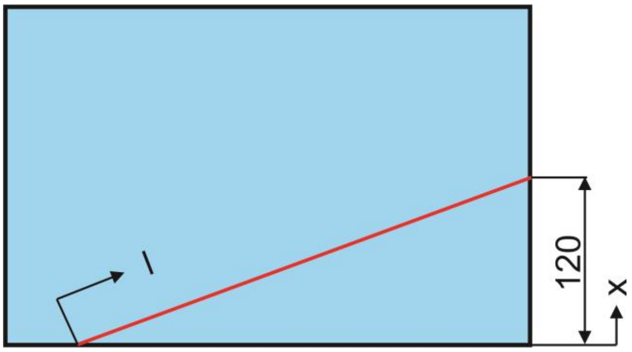

Figure 5. Laser beam projected on a glass sheet

There was a simple software prepared to provide a deformed glass distance. The script analyzes the reflected line and it determines the length of a straight line upon to deformed part. Obtained line length *u* is subsequently recalculated into a perpendicular distance from a glass edge as follows:

$$x = 120\text{-}(-0{,}003u^2 + 1{,}441u + 1{,}323) \quad (2)$$

Where 120 presents a fix distance from the sheet edge, *u* is measured length of the reflected line and *x* is a perpendicular distance from a glass edge. These variables are as well shown on Fig. 5. Values *l* and *u* are dependant according to equation 1. Results of three tested samples, labeled as L1, L2 and R1 are shown on Fig 6.

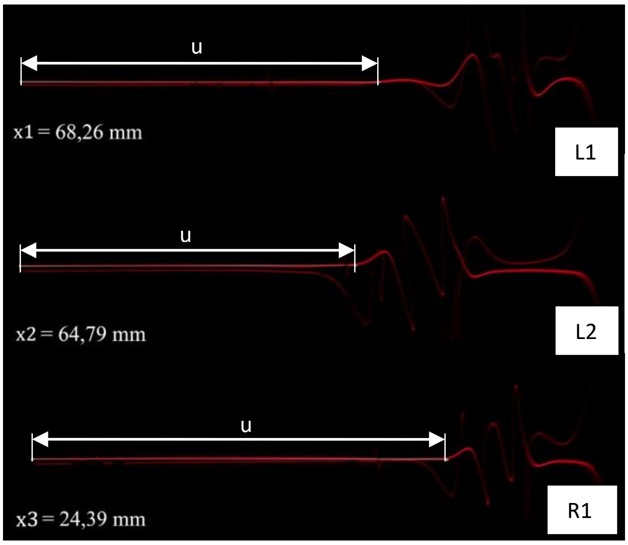

Figure 6. Laser projection - evaluated glass sheets

5 RESULT DISCUSSION

Three provided samples were analyzed by proposed laser projection method to prove the results obtained by this method a comparison with in glass industry commonly used zebra test was realized. Since this optical test is only subjective, samples were also measured on a laboratory workplace with confocal sensors.

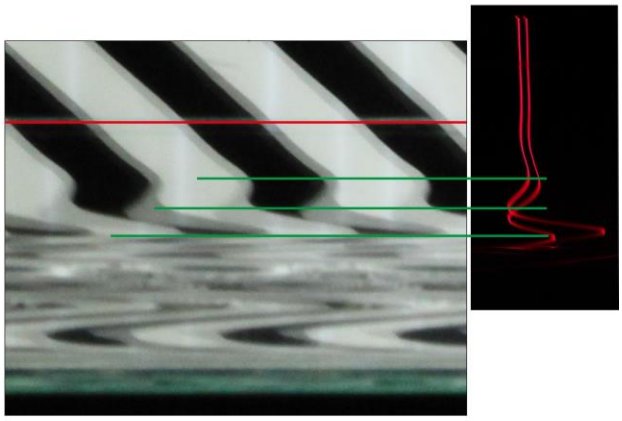

Figure 7. Laser projection and zebra test comparison for L1 glass

There is a laser projection and zebra test behavior comparison for L1 glass sample shown on Fig. 7. Since the zebra test is only subjective manual method (as mentioned in chapter 2) and it is very difficult to set the exact interface between the deformed and flat part, the accuracy was set to +-1 millimeter. Measured distances are compared with other methods in Tab. 1.

More precise measurement was also realized for all three samples on a confocal sensor laboratory workplace. The samples were scanned among the whole length and the deformed part was subsequently calculated. The whole image is shown on Fig. 8 and detail of the deformed part is presented on Fig. 9.

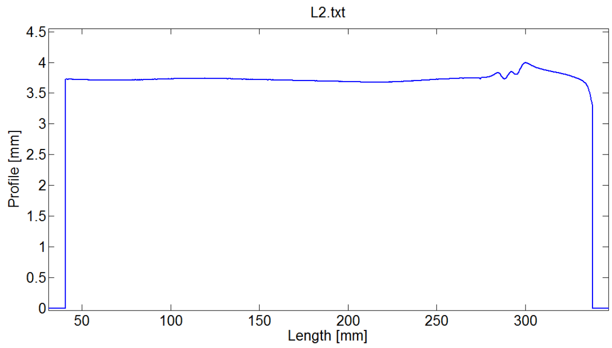

Figure 8. Confocal sensor - evaluated glass sheet L2

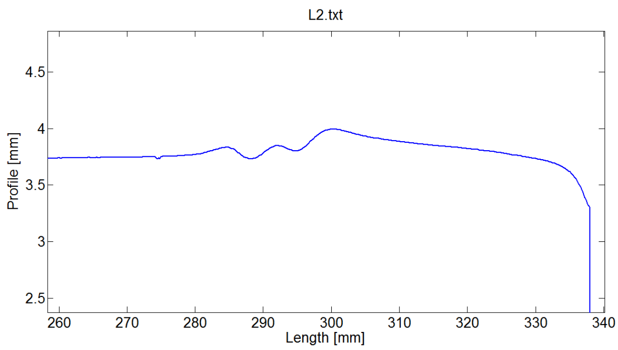

Figure 9. Deformed part of a glass sheet L2 by confocal sensor

Results from three used method, laser projection, zebra test and use of confocal sensor are compared in Tab.1. It is obvious that the most precise method is a confocal sensor use. Thus this had been taken as a correct etalon. Results from zebra test were used as approximate.

	Laser projection	Zebra test	Confocal sensor
L1	68,3	70	66,9
L2	64,8	65	62,9
R1	24,4	27	25,8

Table 1. L1, L2, R1 length comparison by three measuring methods

Realized comparison shows that tested laser projection method corresponds to commonly used zebra test optical method. It has also been verified by a use of confocal sensor workplace. In this comparison there was a difference of almost 2 mm measured. This might be improved by better hardware and software calibration. However, for the purpose of cutting distance adjustment this accuracy is sufficient.

6 CONCLUSION

In this paper, there were four innovative approaches for transparent object identification introduced. Concretely it appraised the use of UV cameras, IR cameras, reflection on an optical interface and use of confocal sensors. The method of reflection use was adopted and adjusted to an actual problem from glass industry, which is a detection of glass edge corrugation.

There was a laser line reflection on a reflection board acquired and analysed. Results were than compared with standardized zebra test and also with confocal sensor laboratory measurement. As it is presented in result discussion, obtained results are more accurate than a commonly used zebra test. Results obtained by confocal sensors are the most accurate, however, it is not possible to use this method on a production line and process a glass edge on-line. Prepared laser projection solution allows this on-line implementation.

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CONTACTS

Ing. Ondrej Matusek
Technical University of Liberec
Department of Glass Producing Machines and Robotics
Studentska 2, 461 17 Liberec 1, Czech Republic
Tel.: +420 485 352905,
e-mail: ondrej.matusek@tul.cz
http://www.ksr.tul.cz