Laser line scanning of a shape of moving objects with various degree of transparency

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Abstract. Laser scanning methods for surface geometry reconstruction have become a common tool in many areas of application due to relative simplicity, high accuracy, and versatility. Nevertheless, scanning of glossy or translucent surfaces still poses a problem for these techniques. The present work aims at assessing the applicability of the laser line scanning method for evaluation of the height profile of a waste stream on a conveyor belt, taking into account that the waste stream may contain a large number of semi-transparent objects. In particular, preliminary results of height profile measurements with regard to the laser emission wavelength for polyethylene terephthalate (PET) bottles with various degrees of transparency, common in the municipal solid wastes, are reported in the paper.

1. Introduction

Over the past two decades, 3D-scanning methods have been increasingly used in research and industrial applications. A wide variety of new experimental methods and commercial solutions have been developed for this field of application. Nevertheless, the reconstruction of the three-dimensional shape of objects with optically transparent or reflective surfaces still poses certain problems [1].

In general, there are several common approaches to optical 3D-scanning for surface shape reconstruction: a laser-line scanning, imaging with spatially structured illumination, and a stereoscopic scanning. For the moving objects, the choice of the available methods is narrowed, as a structured illumination technique usually requires several images with different illumination patterns for the reliable reconstruction. Stereoscopic scanning and laser-line scanning are more suitable for the task. In stereoscopic scanning, the surface shape can be reconstructed from two images, taken simultaneously from two different viewing angles [2]. The main restriction is that the object’s surface should have sufficient contrast. Laser scanning has become one of the dominant methods for 3D surface shape reconstruction (also called shape profile measurement) due to relative simplicity, high accuracy, and versatility [3]. Laser-line scanners are usually based on optical triangulation principle and employ a laser with the special optics that transforms a laser beam into a line (also called “laser sheet”) as a source of lighting and a camera as a sensor. A laser sheet is projected onto the surface of the object and the camera captures the scattered light. A position along the laser line and a distance to the surface is then calculated from the image.

Although the technique of 3D surface profile scanning is well established, glossy and transparent (or semitransparent) objects still pose a problem for laser scanners. For example, for semitransparent objects the intensity of reflected or scattered light is several times lower than the intensity of transmitted
light, which is then scattered over the object’s volume or on less transparent surfaces behind the first semitransparent surface, forming a spurious pattern in the image. Similarly, for glossy surfaces, higher-order reflections tend to occur and superimpose the true (first-order) reflection pattern in the image [4].

The purpose of the present work was testing and optimizing the laser line scanning of semitransparent objects at different wavelengths to assess the feasibility of the technique for height profile measurements of objects transported on a conveyor belt. The motivation for this work was the project at the IT SB RAS aimed at the development of a technology for automated municipal waste sorting using a robotic manipulator [5]. Depending on the strategy adopted for the manipulator control, picking up objects from the conveyor belt may require the height profile of the waste stream on the conveyor. In this case, the correct assessment of the surface profile becomes crucial for sorting efficiency. Since objects made of plastics or resins of various degree of transparency form a large portion of the municipal waste, testing and optimizing height profile measurement technique for such objects becomes necessary. In the present work, attention was mainly focused on height profile assessment for PET bottles, which are common in the municipal solid waste and are valuable recyclable material.

2. Experimental setup and technique

2.1. Experimental setup and data acquisition

The scheme of the setup is shown in figure 1. Both, a camera and a laser diode source with light-sheet forming optics were mounted on a tripod with an extended holder. In the experiments three diode laser light sources were employed: a high-power red laser diode with emission wavelength of 650 nm and a radiated power of 140 mW, low power red laser diode (650 nm, 5 mW) and a blue laser diode (405nm, 20mW). Light sources at these wavelengths are widespread and relatively cheap, which makes them a commonly preferred choice for the laser scanning systems.

A motorized linear stage with a travel range of 150 mm was used as a platform to place on and move objects to be scanned. The motion of the linear stage was controlled by an Arduino Uno controller connected to a personal computer. The laser sheet was aligned normally to the flat surface of the stage. A colored web camera with an image resolution of 1920x1080 pixels was used for registration. The whole setup was placed in a box to shadow the measurement area from the ambient light.

A whole measurement procedure included the following steps. First, before taking height profile measurements an image of a calibration target placed in a measurement area and aligned in a plane of a light-sheet was acquired. A calibration target was a flat plate of 200x200 mm with circular markers at the nodes of a rectangular grid with a distance of 5 mm between nodes. After calibration image acquisition the target got removed from the measurement area and an object, for which a height profile measurements were to be done, was put on the linear stage. To control a data acquisition process, custom software was employed. On the “start” command software initiates a linear stage movement and image acquisition by the camera. As the laser line brightness used to vary because of the different transparency of the test objects, an image brightness tuning using camera exposure time variation was performed for every object before height profile scanning.
2.2. Image processing

To evaluate a height profile from the laser line images, a position of the object’s border in the image should be found and its coordinates in the image should be connected with the 3D world coordinate system. To establish this connection a calibration procedure with a camera model, based on the perspective projection, was used. This model included intrinsic parameters, that is focal length and the coordinates of the principal point in pixels and extrinsic parameters, which are the coefficients of a transformation matrix (rotation and translation) establishing a geometric relationship between the camera coordinate system and the 3D world coordinate system [6]. Calibration procedure and image projection were performed using the OpenCV computer vision software library.

A relatively simple approach to the laser line detection in the image was used. First, the background brightness was assessed in the image, and then a position of the first (starting from the top of the image) pixel in each of the columns with a brightness higher than the threshold, set to the background brightness, was considered as corresponding to the position of the laser line in the image. In such a way it was possible to extract a cloud of points for the reconstruction of the object’s height profile along the laser-sheet plane cross-section.

To reconstruct the shape of the laser line in the 3D world, the recorded images of the line were projected onto the plane of the calibration target using a homography transformation with the coefficients evaluated from the camera calibration.

3. Application to the PET bottle height profile measurement

3.1. PET spectral characteristics

To analyze a degree of transparency of colored PET samples at different wavelengths transmission spectra of several typical samples were measured. The measurements were carried out in the range of wavelengths from 300 to 890 nm and were performed using a monochromator-spectrophotometer using a halogen lamp as a light source. Transmission spectra were measured for blue, green, matte, and brown PET samples (see figure 2).
Figure 2. Transmission spectra of the PET samples

For PET of different colors, the transmission curves are also quite different, so there is no single wavelength that is preferable for all samples. In general, samples have a lower transmission at shorter wavelengths, but brown and green samples have dedicated transmission minimum in the range of 400-450 nm and, much smaller one – in the rage of 620 – 680 nm, while for matte and blue samples transmission curves were almost monotonic. Besides, the blue sample transmission coefficient varies within the range of 65 – 85 % over the whole visible spectrum, which makes the very possibility of height profile scanning for this plastic rather questionable.

3.2. Height profile measurements
According to the described procedures, measurements of the height profiles for PET bottles were carried out. Besides, measurements for the same blue PET bottle with non-transparent white matte paint sprayed over its surface were carried out in a separate experiment to compare results for highly transparent (worst case) and non-transparent surface.

The results of the measurements are shown in figures 3 and 4. As it was expected, for green and brown bottles measured profiles obtained with blue lighting source were less noisy and of better quality in general than profiles, obtained with red lighting source,

Figure 3. Examples of a height profile of brown PET bottle measured with red (a) and blue (b) lighting sources.
Measuring the height profile for the blue highly-transparent bottle appeared the most problematic. At both wavelengths, an image of the line on the translator’s stage was much brighter than the image on the surface of the bottle. Increasing the camera exposure time to the level at which the bottle surface is clearly visible led to the strong oversaturation of the image on the stage (figure 4a). Besides, images clearly featured secondary (and higher-level) reflections of the surface that led to the spurious height data at some parts of the bottle. Nevertheless, even in these conditions, a rough estimate of the height profile was still possible.

![Figure 4](image_url)

**Figure 4.** Instant images of the highly transparent blue PET bottle lightened by blue laser light sheet (a), the same bottle with sprayed matte screen layer (b) and x-z projections of the height profiles for transparent (c) and matted (d) bottle

To estimate an uncertainty of the achieved results a maximum height of the bottle was measured independently (by a ruler) and compared to the maximum height acquired from the height profile. In most cases, the measurement uncertainty was within the range of ±2.5 mm. For example, for the brown PET bottle a real (measured) maximum height was 55±1 mm, while laser line measurements demonstrated 53.4 mm height.

A main source of error in the height profile measurements was thickness of the laser line in the image. Depending on the used light source and measurement conditions it varied from 0.4 mm (2 px) to 4.4 mm (22 px). Assuming that the real position of the objects’ border within the bright line is unknown, an error introduced should be amounted to half of its thickness (up to ±2.2 mm). This error, however, can be reduced either by the improvement of the image processing procedures or by dynamic tuning of the light source output power or exposure time.

This reveals another problem associated with the laser line scanning for semitransparent objects. Depending on the transmission coefficient and orientation of the surface, the laser line image on the border of the surface may become thick and strongly oversaturated or barely detectable. To resolve this
issue, again, dynamic tuning of the light source output or camera exposure time for every new object is required. This is not easy to do in case of the objects moving on a conveyer belt, as a high frame rate is required to provide consistent height profile measurements. One of the possible solutions is to use several scanning modules in a row to tune the working parameters gaining additional information while objects are moving from the first module to the last in a row.

**Conclusion**

Preliminary results of height profile measurements of PET containers employing laser line scanning were reported in the paper. Measurements were taken using laser diodes with emission wavelengths of 405 and 650 nm. It was shown that shorter wavelength is more preferable in general for PET objects scanning and it is possible (although with a high amount of noise in the data) to assess height profile for the PET having about 70% transparency at 405 nm wavelength.

In the conducted experiments the measurement uncertainty was about ±2.5 mm. A main source of error in the measurements was thickness of the laser line in the image. Improvements in the measurement scheme and the data processing procedures are required to provide reliable height profile measurements. In particular, dynamic tuning of the light source output or camera exposure time could improve the quality of the raw data.

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