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Detection of Laser Beam's Center-line in 2D Images

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Introduction

During the last decade, modeling, reconstruction and visualization of 3D models became widely used in such fields as industrial engineering and manufacture, medicine, game development, etc. Among different methods for acquisition of 3D objects, one is based on scanning them with a laser in 3D.

The 3D laser scanner is a simple device used to transform real-world objects into their 3D representations in the virtual space. In the simplest configuration, the laser scanner includes four basic components: a rotating table, a laser light source, a video camera, and a data processor such as a PC (Fig. 1). More advanced setups involve more cameras and laser light sources (see, e. g., [1]).

During scanning, the video camera captures the laser beam seen on the surface of the scanned object. This beam is then detected in the video frames. Further processing

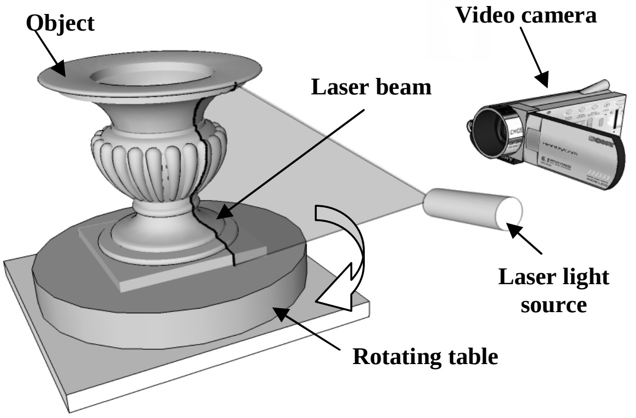


Fig. 1. A simple 3D laser scanner

requires extracting the laser beam's center-line and forming a point cloud. That latter allows reconstruction of the 3D object using special methods [2].

Different algorithms have been proposed to ensure extraction of the center-line in 2D images with high precision, which determines the quality of the point cloud. Some of these algorithms are based on skeletonization by erosion – an iterative procedure with the number of iterations proportional to the largest dimension of a certain feature in the image [3].

Another technique for skeletonization, known as the medial axis transform (MAT), yields good results for continuous images. However, its performance degrades with images composed of a finite number of pixels [4]. Generally, the results obtained with the MAT agree well with those provided by the sequential erosion.

A technique using the unbiased detector of curvilinear structures allows detecting the center-line with sub-pixel accuracy [5]. The technique uses eigenvalues and eigenvectors of the Hessian matrix obtained from the image.

More recently, an algorithm was proposed combining certain aspects of the distance-transform technique as well as iterative thinning and Voronoi diagram [6]. There are also other methods based on the object geometry or wave-front propagation (see, e. g., [7] for a review).

In this paper, we present a technique suitable for detecting the center-line of a laser beam with subpixel precision in 2D images. The detected center-line is to satisfy the following criteria:

1. smoothness – no scatter of the points allowed;
2. continuity – the center-line must be continuous along its region;
3. centeredness – no intersection with the line's edges allowed.

Detection of Lines in 1D

Our technique is based on the nonlinear multiscale line filtering method that uses two shifted kernels of the first order Gaussian derivatives combined in a nonlinear way [8]. First, the left and right edge detectors, $E_l(x)$ and $E_r(x)$, respectedly, are applied:

$$E_l(x) = -G'_\sigma(x+s), \quad (1)$$

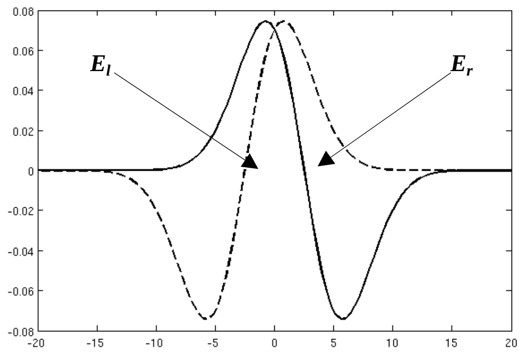
$$E_r(x) = G'_\sigma(x-s), \quad (2)$$

where $G'_\sigma(x \pm s)$ denote the shifted kernels of the first order Gaussian derivatives; σ – is the standard deviation of the Gaussian distribution and $\sigma = s$, parameter s depends on the width of the line profile w.

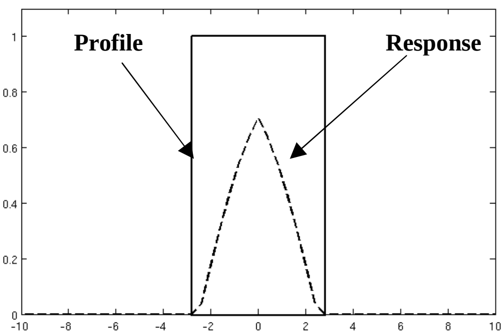
The filter's response at location x for the line profile $f(x)$ is given as

$$\min\left[\mathrm{Pos}\{E_l(x)\otimes f(x)\},\mathrm{Pos}\{E_r(x)\otimes f(x)\}\right], \qquad (3)$$

where $\mathrm{Pos}(x)$ is the positive part of x.



a



b

Fig. 2. (a) – kernels of left (E_l) and right (E_r) edge detectors, (b) – the filter's response to a bar-shaped profile with a sharp peak at its center

Kernels of the left and right edge detectors are shown in Fig. 2, a, whereas Fig. 2, b displays the filter response to a bar-shaped line profile with a sharp peak at its center.

Initialization of Parameter *s*

As mentioned before, $\sigma = s$. Kernels of the left and right edge detectors depend on *s* that, in turn, is a function of *w*. Thus, both kernels are determined solely by the width of the line profile *w*.

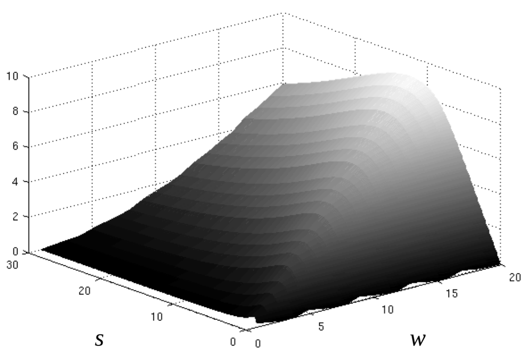


Fig. 3. Maximal filter response to a bar-shaped profile estimated by varying *w* and *s*

To reveal the relationship between *s* and *w*, the values of these parameters were varied experimentally, and the maximal filter response to the profile was calculated as shown in Fig. 3. Since the filter response is relatively low for narrow profiles, detection of the center-line in this case is expected to deteriorate.

The relationship between *s* and *w* is seen more clearly when the data is plotted in 2D (Fig. 4). The relationship is rather linear and it is approximated by the equation:

$$s(w) = 0{,}4482 \cdot w - 0{,}002. \qquad (4)$$

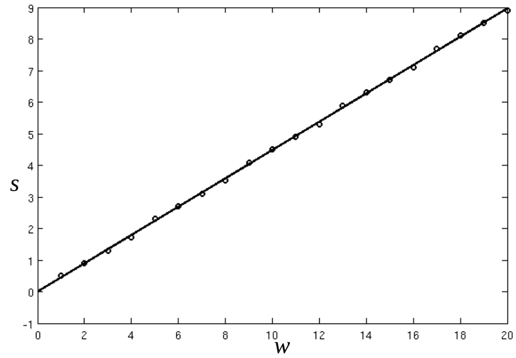


Fig. 4. Parameter *s* as a function of *w* and the approximating line

Using the suggested implementation for *s* (see Equations (1) and (2)), both edge detectors $E_l(x)$ and $E_r(x)$ as well as the filter in general depend only on the width of the line profile.

Detection of Lines in 2D

This filter implementation uses 2D kernels; otherwise it is analogous to the 1D case. A scaled Gaussian function and its derivatives in *x* and *y* directions are used to implement the left and right edge detectors:

$$E_{lx}(x,y) = -G'_{sx}(x+s,y), \qquad (5)$$

$$E_{ly}(x,y) = -G'_{sy}(x,y+s), \qquad (6)$$

$$E_{rx}(x,y) = G'_{sx}(x-s,y), \qquad (7)$$

$$E_{ry}(x,y) = G'_{sy}(x,y-s), \qquad (8)$$

where G'_{sx} and G'_{sy} are the first derivatives of the 2D Gaussian function in *x* and *y* directions, respectively.

Filtering procedure is applied iteratively for a discrete number of directions (the steerable filter [9]) followed by selection of the direction with the maximal value.

Center-line of the laser beam is detected by finding the local maxima in the filtered image. This is achieved by calculating the first and second derivatives of the filtered image. The condition $F'(x,y) = 0$ yields the points of local maxima and minima, whereas $F''(x,y) < 0$ ensures that the point under consideration is a local maximum.

Approximating the points of local maxima by a smoothing spline extracts the center-line of the laser beam with subpixel accuracy.

Fig. 5. Image of the elephant statue acquired by a digital video camera during laser scanning

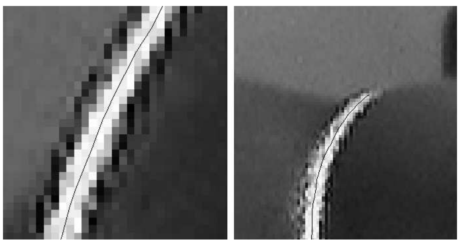
In general the method can be applied by following these steps:

1. Calculate image scale space by convolving image with Gaussian smoothing kernel;
2. Apply left and right edge detectors (Eq. 5 - 8) for a discrete number of directions (0, $\pi/4$, $\pi/2$, $3\pi/4$):
   a. Select maximal value
   b. Apply minimum operator on positive parts of image scale space (3)
   c. Repeat (2) for all image points
3. Search for local maxima by calculating firs and second order derivatives;
4. Approximate points of local maxima by smoothing spline.

Results

The suggested technique was tested on images acquired by a digital video camera. Scanning with the laser was performed in half-light.

Fig. 5 shows an image of the elephant's statue acquired by a digital video camera during laser scanning. To reduce distortions, the image was convolved with the 2D Gaussian kernel. The trace of the laser beam is much lighter than the rest of the image. Center-line of the laser beam closely follows its trace on the statue's surface.



a b

Fig. 6. Sample zoomed regions of the image: (a) demonstrates the ability of the technique to detect the center-line of the laser beam with subpixel accuracy, and (b) shows that the technique also handles well end of the line

Using the technique described here, the center-line of the laser beam is detected with subpixel accuracy (Fig. 6, a). This is important for laser scanning in 3D. Furthermore, the technique handles well ends of lines in images (Fig. 6, b), which gives an advantage over some other methods of skeletonization.

Fig. 7 shows the effect of applying a filter to an image with two separate laser beam traces. This demonstrates the possibility of detecting more than one center-line of the laser beam using the proposed technique.

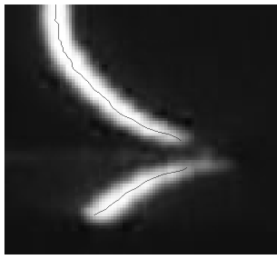


Fig. 7. Filter applied to an image with two separate lines

The method was implemented using MATLAB©. Filtering procedure applied on 640×480 test image takes 30,1 *s*. Filtering speed can be reduced to 3,4 *s* by applying the method only on region of interest (360×380) in image.

Conclusions

This paper presents a technique for detecting the center-line of a laser beam in 2D images. Detection of the center-line is an integral part of the laser scanning in 3D process.

The technique uses the so-called left and right edge detectors – a filter made of a nonlinear combination of the shifted first-order Gaussian derivatives. The filter depend only one parameter – the width of the line profile.

Filtering is performed in an iterative fashion for a number of directions to select the one with the maximal value.

The center-line of the laser light trace is detected by finding the local maxima in the filtered image. These occur at the points where the first-order derivative of the filtered image is equal to zero and the second-order derivative is negative.

The center-line of the laser beam closely follows its trace on the surface of the scanned 3D object. Approximating the detected points of the local maxima by a smoothing spline allows achieving subpixel accuracy. The technique also performs well at the line ends in images, which offers a clear benefit compared to other skeletonization methods. Furthermore, the technique enables detection of the center-lines of multiple laser beams in a single 2D image.

References

1. **Adaškevičius R., Vasiliauskas A.** 3D Multicamera Dental Cast Scanning System // Electronics and Electrical Engineering. Technologija, 2008. – Vol. 82. – No. 2. – P. 49 – 52.
2. **Matiukas V., Paulinas M., Ušinskas A., Adaškavičius R., Meškauskas R., Valinčius D.** A Survey of Point Cloud

Reconstruction Methods // Electrical and Control Technologies – Proceedings of 3RD International Conference on Electrical and Control Technologies (ECT – 2008). Technologija, 2008. – Vol. 3. – P. 150–153.
3. **Russ J. C.** The Image Processing Handbook // CRC Press, 2007. – 3RD Ed. – P. 498–504.
4. **Mott**-Smith J. C. Medial Axis Transformations // In Picture Processing and Psychopictorics. Academic Press, 1970. – P. 267–283.
5. **Steger C.** An Unbiased Detector of Curvilinear Structures // IEEE Transactions on Pattern Analysis and Machine Intelligence. 1998. – Vol. 20. – P. 113-125.
6. **Rokicki J., Miniotas D., Meilūnas M., Ušinskas A.** An Algorithm for Step-wise Skeletonization of Blood Vessel Network // Electronics and Electrical Engineering. Technologija, 2007. – Vol. 80. – No. 8. – P. 87–90.
7. **Žitkevičius E., Grigaitis D., Navakauskas D.** On Skeletonization of Blood Vessels in Angiographic MRI Images of Human Brain // Information Technology and Control. Technologija, 2007. – Vol. 36. – No. 4. – P. 372-376.
8. **Koller Th. M., Szekely G., Dettwiler D.** Multiscale Detection of Curvilinear Structures in 2-D and 3-D Image Data // IEEE Computer Society Press, 1995. – P. 864–869.
9. **Freeman W. T., Adelson E. H.** The Design and use of steerable filters // Pattern Analysis and Machine Intelligence. 1991. – Vol 13. – No 9. – P. 891–906.

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V. Matiukas, D. Miniotas. Detection of Laser Beam's Center-line in 2D Images // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 7(95). – P. 67–70.

Modeling, reconstruction and visualization of 3D images is crucial in such fields as industrial engineering and manufacture, medicine, game development, etc. A physical object can be transferred to 3D virtual space by using a 3D laser scanner. Quality of the 3D model of the object scanned strongly depends on that of the laser beam's center-line detected in the 2D image. A technique for detection of the laser beam's center-line in a set of 2D images is presented. It uses two shifted kernels of the first-order Gaussian derivatives combined in a nonlinear way. Filtering is performed in a number of directions to select the one with the maximal response. The laser beam's center-line is identified by the local maxima in the filtered image through evaluation of its first- and second-order derivatives. The technique was tested on images with a laser trace left on the object scanned. Ill. 7, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

В. Матиукас, Д. Миниотас. Выделение центральной линии лазерного луча в двухмерных изображениях // Электроника и электротехника. – Каунас: Технология, 2009. – № 7(95). – С. 67–70.

Моделирование, реконструирование и визуализация трёхмерных изображении являются важными в таких областях, как промышленная техника, производство, медицина, индустрия компьютерных игр и т. д. Одним из способов перемещения реального объекта в трёхмерное виртуальное пространство является применение трёхмерного лазерного сканнера. При этом качество полученной трёхмерной модели объекта сильно зависит от качества выделения центральной линии лазерного луча в двухмерном изображении. Представленный метод предназначен для выделения центральной линии лазерного луча в наборе двухмерных изображений. В методе используется фильтр в виде нелинейной комбинации двух смещённых ядер производных первого порядка нормального распределения, Фильтрация осуществляется по нескольким направлениям с целью выбора той, у которой отклик наибольший. Центральная линия лазерного луча обнаруживается по локальным максимумам в профильтрованном изображении при определении его производных первого и второго порядков. Метод проверен на практике для изображений с отпечатком лазерного луча на сканируемом объекте. Ил. 7, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Matiukas, D. Miniotas. Lazerio spindulio centrinės linijos išskyrimas dvimačiuose vaizduose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 7(95). – P. 67–70.

Trimačių vaizdų modeliavimas, rekonstravimas ir atvaizdavimas yra svarbus tokioms sritims, kaip pramoninė inžinerija ir gamyba, medicina, kompiuterinių žaidimų pramonė ir t. t. Fizinį objektą perkelti į trimatę virtualiąją erdvę galima naudojant erdvinį lazerinį skaitytuvą. Taip gauto trimačio objekto modelio kokybė labai priklauso nuo lazerio spindulio centrinės linijos išskyrimo dvimačiame vaizde kokybės. Aprašomas metodas, skirtas lazerio spindulio centrinei linijai išskirti dvimačių vaizdų rinkinyje. Taikomas filtras – dviejų perstumtų branduolių, aprašomų pirmosios eilės Gauso skirstinio išvestinėmis, netiesinė kombinacija. Filtruojama keliomis kryptimis ieškant tos, kuriai gaunamas maksimalus atsakas. Centrinė lazerio spindulio linija filtruotame vaizde randama pagal lokaliuosius maksimumus, skaičiuojant jo pirmosios ir antrosios eilės išvestines. Metodas patikrintas praktiškai vaizduose su lazerio spindulio pėdsaku ant skaitomo objekto. Il. 7, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).