Comparative Analysis of Stairs Construction's Non-Contact Identification Methods

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ABSTRACT

This study analyzes possibilities of laser and ultrasound scanning as well as computer vision to recognize a first stair of the stairs construction. Three methods were proposed for the purpose. A mathematical model for stair recognition by ragefinder scanning was proposed. The methods were examined experimentally. It was obtained that method of ultrasound scanning indicate the biggest errors and methods of computer vision and laser scanning have lower and similar errors. Obtained results are important for autonomous mobile robot navigation in multistory buildings.

Keywords: Autonomous mobile robot, ragefinder, laser scanning, ultrasound scanning, computer vision

1. INTRODUCTION

Activity of autonomous mobile robot (AMR) in a multistory building is not limited by the only floor. While performing a task, AMR has to reach one or another floor. Floors of the building are connected by stairs. Therefore it is very important for AMR to be able to recognize stairs construction through which it could move into the following floor of the building. If AMR will be unable to recognize stairs, it will be unable to move between the floors of the building and to perform the task given to it. Also, AMR in the multistory building can detect objects having similar features as fragment of stairs construction. When stairs recognition is wrong, AMR can start moving, slip and turn over or even fell down from the wrong recognized object which has features of stairs construction by having mechanical breakdowns of movement platform of control system. Possible results of this may be partial or full unfunctionality. Stairs construction consists of stairs that are connected into integral system. To avoid unnecessary vast of energy of AMR for analysis of entire frame of the stairs, it is enough to detect and classify the first stair of the stairs construction, that is, to measure its geometrical parameters and compare them to statistical data of construction’s stairs.

Technology of information processing and digital analysis of data [1, 2]; automatic optical quality control and processing of images [3]; are making easier identification of objects in an environment. While mobile robot performing a search of the stairs, stereo vision is used, that means two cameras are used to acquire the same scene from different views. Stairs recognition is performed in accordance to the length of vertical lines, that is, according to the possible length (run) of stairway [4]. Also, in the stairs identification there was used one linear laser forming vertical lines in accordance to the form of the stairs for processing of visual information according to the key points by using algorithm of Douglas-Peucker, visible lines both from stairway and riser are being processed [5]. In the search and recognition of the stairs, big influence is made by height of mounting of video camera and laser, because the number of recognized stairs and distinguishing from possibly detected doorstep depend on it [6]. The aim of research is to compare non-contact method to identify stairs construction according to measurement of a stair inside a building. There were proposed methods of the first stair recognition by combining a ragefinder with scanning. Experimental data were obtained by three different methods: vertical laser ragefinder scanning, vertical ultrasound scanning, and computer vision.

2. METHOD

Ragefinder is a device used to measure the distance from the observer to object. Ultrasonic ragefinder measures ultrasound signal propagation time from observer to object and back to observer. Simplest laser ragefinger uses image sensor and triangulation method for calculations. Scanning for object recognition must be used minimally in one plane.

The research was performed by using scanning in vertical plane by tilt mechanism which consists of servo-gear with minimal step angle $\Delta \alpha = 1.50$. A sensor of ragefinder was mounted on the tilt mechanism. In the first case, there were placed a red light laser and a camera on the tilt mechanism. In the second case we used ultrasound transducer US-02. In both cases there also was used accelerometer to measure sensor declination angle to respect of a vertical.

![Fig 1: The parameters of stair: h – riser height, e – stairway runs](image)

It was decided to create method to detect and classify the first stair of the stairs construction. The next plan was proposed: to perform scanning, to detect critical points, to calculate parameters of possible stair and compare them to statistical data of construction’s stairs. The two main parameters of stair are shown in Fig. 1.
Obtained height $h$ of stair’s riser needs to meet the condition: $0.14 \, m \leq h \leq 0.20 \, m$ and stairway run - $0.26 \, m \leq e \leq 0.32 \, m$ [7].

Process of stairs scanning could be explained by diagram shown in Fig. 2. Here an interval between points A and C is ground level, interval between C and D - a riser of the first stair, interval between D and E - a stairway of the first stair. A centre of scanner is located in a point O. Height of the scanner over ground is $h_{AMR}$. The scanner could be rotated about axis, which goes throw point O perpendicularly to plane of drawing. Firstly we assume that that height of scanner centre is bigger then height of stair riser ($h_{AMR} > h$, see Fig. 2a). Let at start of scanning scanner looks at point B. Then angle between vertical line $OA$ and line $OB$ is $\alpha_0$ and scanner can measure distance from O to B, which is equal $d_0$. That to look at point C, which is beginning of stairs, scanner must rotates by angle $\alpha_1$. In the interval BC (for example for point X) we can calculate distance to ground $k$ (length of line OX) as function of scanner rotation angle using equation:

$$k(\alpha) = \frac{h_{AMR}}{\cos \alpha};$$  \hfill (1)

When $\alpha_0 \leq \alpha \leq \alpha_1$. In that interval function $k(\alpha)$ monotonically increases because cosine decreases. When the point of scanner view slides on riser (interval CD in Fig. 2) the distance $k$ starts to decrease slowly. Now we can calculate distance $k$ to riser (length of line OY) as function of scanner rotation angle using equation:

$$k(\alpha) = d_1 \cdot \sqrt{1 + \csc^2 \alpha};$$

where $\alpha_1 \leq \alpha \leq \alpha_2$, here $d_1$ is length of line AC. When scanner slides through stairway (line DE), it is valid equation:

$$k(\alpha) = \frac{h_{MR} - h}{\cos \alpha};$$

where $\alpha_2 \leq \alpha \leq \alpha_3$.

Eq. (1) and (2) are valid for the case, when $h_{AMR} < h$ (see Fig. 2b). Here is abrupt jump of distance from $k_2$ to $k_3$.

There was done simulation of ragefinder data changes versus sensor orientation angle. For simulation there were used such stair parameters: riser height $h=0.15 \, m$, stairway run $e=0.3 \, m$, distance from stairs $d_1=1.75 \, m$, and scanner sensor centre height $h_{AMR}=0.15 \, m$. The results of simulation are plotted in Fig. 3.

Stair riser height $h$ could be calculated in accordance to theorem of cosines:

$$h = \sqrt{k_2^2 - 2 \cdot \cos(\alpha_2 - \alpha_i) \cdot k_2 \cdot k_i + k_i^2};$$

where $k_i$ and $k_2$ are distances to bottom and top part of riser as indicated in Fig. 2.

Stair run $e$ could be calculated using trigonometry:

$$e = k_3 \cdot \sin(\alpha_3) - k_2 \cdot \sin(\alpha_2);$$

3. RESULTS

Experimental data were collected using three methods: laser scanning, ultrasound scanning, and computer vision. Firstly control measurement of stair of stairs constructions in contact method was performed by...
using electro-mechanical sliding caliper and data were obtained \( h = 0.149 \text{ m} \), and \( e = 0.305 \text{ m} \).

### 3.1 Results Using Laser Scanning

A scanning of stairs by laser was performed 3 times from 3 different distances (totally 9 times). The results of scanning are shown in Fig. 4. For the first scanning sensor of AMR was displaced at distance 1.75 m from stairs. The initial accelerometer indications (sensor deviation angle \( \alpha \)) were very close to 60°. At the beginning of scanning measured distance monotonically increased as was predicted by mathematical model. When angle of sensor deviation reached 83°, change of distance practically stops. It could be stated, that scanner detected a vertical plane (a riser of stair). When angle of sensor deviation reached 90.5°, \( k \) took jumping increase and this shows the end of vertical plane.

![Fig 4](image)

**Fig 4**: Measured distance \( k \) dependence versus laser scanner orientation angle \( \alpha \) when AMR distance to stairs \( d \) is fixed at three levels

Data of arithmetical averaging of the distances to critical points of stairs from 3 identical trials are presented in Table 1.

Here we also can see evaluated stair parameters as riser height \( h \) and stairway run \( e \) calculated by Eq. (4) and (5). The results show that the errors of evaluated parameter increase with distance of stairs from scanning sensor.

![Table 1](image)

**Table 1**: Distances To Critical Points And Evaluated Stair Parameters Obtained By Laser Scanning

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( d=1.75 )</th>
<th>( d=2.25 )</th>
<th>( d=2.75 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_{1} ), m</td>
<td>1.757</td>
<td>2.253</td>
<td>2.754</td>
</tr>
<tr>
<td>( k_{2} ), m</td>
<td>1.750</td>
<td>2.250</td>
<td>2.750</td>
</tr>
<tr>
<td>( k_{3} ), m</td>
<td>2.051</td>
<td>2.551</td>
<td>3.052</td>
</tr>
<tr>
<td>( h ), m</td>
<td>0.153</td>
<td>0.155</td>
<td>0.165</td>
</tr>
<tr>
<td>( e ), m</td>
<td>0.303</td>
<td>0.304</td>
<td>0.306</td>
</tr>
</tbody>
</table>

### 3.2 Results Using Ultrasound Scanning

9 trial were performed using ultrasound scanning. Scanning results are presented in Fig. 5 and parameters in Table 2. It could be noticed that obtained stair parameters have large values as they are in reality.

![Table 2](image)

**Table 2**: Distances to critical points and evaluated stair parameters obtained by ultrasound scanning

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( d=1.50 )</th>
<th>( d=2.00 )</th>
<th>( d=2.50 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_{1} ), m</td>
<td>1.630</td>
<td>2.130</td>
<td>2.613</td>
</tr>
<tr>
<td>( k_{2} ), m</td>
<td>1.541</td>
<td>2.062</td>
<td>2.609</td>
</tr>
<tr>
<td>( k_{3} ), m</td>
<td>1.960</td>
<td>2.415</td>
<td>3.010</td>
</tr>
<tr>
<td>( h ), m</td>
<td>0.161</td>
<td>0.165</td>
<td>0.171</td>
</tr>
<tr>
<td>( e ), m</td>
<td>0.315</td>
<td>0.321</td>
<td>0.329</td>
</tr>
</tbody>
</table>

![Fig 5](image)

**Fig 5**: Measured distance \( k \) dependence versus laser scanner orientation angle \( \alpha \) when AMR distance to stairs \( d \) is fixed at three levels

### 3.3 Results Using Computer Vision

In the third case for recognition of stairs construction we used computer vision. There were used video camera of 2 MP and laser with lens of cross lines dispersion angle 60° with help of which we will light stairs construction and will identify the first stair according to the data obtained. Calibration of video camera is performed with help of Calibration Toolbox for Matlab. Video camera is angled \( \beta = 42° \) in regard to the laser. We used [5]; approach for the performance of the research. The difference is that during the research we evaluated light illuminance of the environment under research because illuminance [8]; determines quality of the view recorded and in accordance to it laser power was regulated. It was done because when laser power is too high, the reflection of its rays creates corona around itself, which makes problems in ray’s segmentation. When laser ray power is too weak, its reflection’s segmentation is non-qualitative, and cracking of sections appears. Therefore we selected laser power for the case of our research. A view recorded by video camera presented in Fig. 6.
In Fig.6 it is visually seen a stair formed reflection of laser ray. Constituents of this form are sections, lengths of which show dimension of stair planes that depend on the number of section points. Recorded view is additionally improved and binarized, which simplifies segmentation. Processing of black-and-white pictures allows detection of small objects [9]. Sections have been detected by using Matlab functions, Hough transformation, and other details are removed. Significance of the obtained sections is analyzed from the bottom. First section is assumed as a path to the object and is removed from the picture [10]. Second section can be evaluated as a riser and its height value \( h \) will depend on the number of section’s pixels. A following section could be evaluated as a stairway and its value \( e \) will depend on the number of points as well. All other sections are removed. Residual view of sections presented in Fig.7.

**Table 3:** Evaluated stair parameters by computer vision

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Distance, m</th>
<th>( d=1.50 )</th>
<th>( d=2.00 )</th>
<th>( d=2.50 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h ), pixels</td>
<td>428.6</td>
<td>364.8</td>
<td>287.9</td>
<td></td>
</tr>
<tr>
<td>( h ), m</td>
<td>0.152</td>
<td>0.154</td>
<td>0.157</td>
<td></td>
</tr>
<tr>
<td>( e ), pixels</td>
<td>857.2</td>
<td>729.6</td>
<td>3112</td>
<td></td>
</tr>
<tr>
<td>( e ), m</td>
<td>0.304</td>
<td>0.308</td>
<td>0.314</td>
<td></td>
</tr>
</tbody>
</table>

**3.4 Comparing of Method Errors**

Relative errors of investigated methods are presented in Fig. 8. Results show that the biggest errors are for ultrasound scanning. Rest two methods give very similar errors.

![Graph showing relative errors of stair parameters](image)

**Fig 8:** Errors of stair parameters: solid line - stairway run \( e \), dotted line - riser height \( h \), triangle- laser scanning, diamond - ultrasound scanning, circle - computer vision

Bigger errors of ultrasound scanning could be explained by divergent propagation of ultrasound waves. Also it could be noticed that riser height has higher relative errors. Errors increase with the sensor distance from stairs.

**4. CONCLUSIONS**

During the research, a stair of the stairs construction was identified by using three methods of recognition. Different sensors of environment scanning gave different results. By ultrasonic data there were identified stair’s data relative errors of which in comparison to contact measurement are less 14 %, relative errors of laser scanner are less 10 %, and relative errors of computer vision is less 5 %. Errors increase with increase of scanning distance.

Drawback of vision based systems for objects recognition is such that they are using additional light sources and needs acquire light. They are dependent on conditions that determine light absorption, like smoke, dusty environment, causing light dispersion. It seems that it is purposeful to combine ultrasonic and vision systems of environment scanning, and priority would depend on clearness of the space under detection.

**REFERENCES**


AUTHOR PROFILES

Gintautas Daunys head of Department of Electronics (since 2000); Associate Professor (since 1999); Professor (since 2011). 1999: Doctor in Electrical Engineering and Electronics (Kaunas University of Technology, Lithuania) by thesis "Two-Dimensional Pursuit Eye Movement".

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