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Blind Path Obstacle Detector using Smartphone Camera and Line Laser Emitter

Rimon Saffoury*, Peter Blank*, Julian Sessner**, Benjamin H. Groh*, Christine F. Martindale*, Eva Dorschky*, Joerg Franke** and Bjoern M. Eskofier*

*Digital Sports Group, Pattern Recognition Lab, Department of Computer Science
**Institute for Factory Automation and Production Systems
Friedrich-Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany
Corresponding author: Rimon.saffoury@fau.de

***Abstract*—Visually impaired people find navigating within unfamiliar environments challenging. Many smart systems have been proposed to help blind people in these difficult, often dangerous, situations. However, some of them are uncomfortable, difficult to obtain or simply too expensive. In this paper, a low-cost wearable system for visually impaired people was implemented which allows them to detect and locate obstacles in their locality. The proposed system consists of two main hardware components, a laser pointer ($12) and an android smart phone, making our system relatively cheap and accessible. The collision avoidance algorithm uses image processing to measure distances to objects in the environment. This is based on laser light triangulation. This obstacle detection is enhanced by edge detection within the captured image. An additional feature of the system is to recognize and warn the user when stairs are present in the camera's field of view. Obstacles are brought to the user's attention using an acoustic signal. Our system was shown to be robust, with only $5\,\%$ false alarm rate and a sensitivity of $90\,\%$ for $1\,cm$ wide obstacles.**

I. Introduction

According to the World Health Organization (WHO), 285[1] million people are estimated to be visually impaired worldwide: 39 million are blind and 246 million have low vision [1]. Recognizing dynamic and static obstacles is a basic problem for visually impaired people, since most of navigational information are gathered through the visual perception [2]. As a result, blind people usually rely on other sensory information in order to avoid obstacles and to navigate [3]. For example, the motion of dynamic obstacles generates noise allowing visually impaired people to determine the approximate position using their auditory senses. The additional use of tactile senses is required for precise obstacle localization. For this purpose a white cane is commonly used by blind people [4], which has two main disadvantages. It is relatively short and the detection occurs only by making contact with the obstacle which could sometimes might be dangerous. Another popular navigation tool for visually impaired individuals is a guide dog. Compared to white canes, dog guides are able to detect obstacles as well as steering around them, however they are expensive and only have a very limited working life [5].

[1]Updated August 2014.

However, many obstacle detection and avoidance systems have been proposed during the last decade to help blind people navigate in known or unknown, indoor and outdoor environments. This navigation can primarily be categorized as vision replacement, vision enhancement and vision substitution [6]. Vision replacement systems provide the visual cortex of the human brain with the necessary information either directly or via the optic nerve. Vision enhancement and vision substitution systems have similar working principles with regard to environment detection process, however, each provides the environmental information differently. Vision enhancement presents the information in a visual manner, whereas vision substitution typically uses tactual or auditory perception or a combination of the two.

Finding obstacle-free pathways via vision substitution can be further subcategorized into ETAs (Electronic Travel Aids), EOAs (Electronic Orientation Aids) and PLDs (Position Locator Devices). For navigational aid, ETA devices usually use camera and sonar sensors, EOA devices RFID (Radio Frequency Identification) systems and PLD devices GPS (Global Positioning Systems) navigational technology. Balachandran et al. [7] proposed a GPS based device where a DGPS (Differential Global Positioning System) was used which provided more precise user localization and thus better navigation. Tandon et al. [8] applied passive RFID tags for giving location information to users. A passive tag can be embedded in many places, as an internal energy source is not required.

In order to increase the environmental obstacle detection range, the use of image or sonars sensors is essential. Bousbia-Salah et al. [9] used two ultrasonic sensors mounted on the user's shoulders to provide real-time information about the obstacle distance, whereas Berning et al. [10] placed an array of ultrasonic sensors on the head enabling 360 degree distance calculation. The combination of RFID tags and ultrasonic sensors was proposed by Sanchez et al. [11], which allowed them to achieve more confident user navigation. The greatest disadvantage of ultrasonic based systems, compared to camera based systems, is the low angular resolution due to the wide beam angle [12]. Furthermore, a precise estimation of distances to large obstacles cannot be calculated [13]. Owayjan et al. [12] and Rodríguez et al. [14] developed a camera based

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navigation system, which provides the distance to obstacles using a disparity map computed using either Microsoft Kinect or a stereo camera. To support visual impaired individuals during sportive activities like jogging, Ramer et al. [15] used a 3D camera to navigate the athlete on tartan tracks. In order to achieve that, they took advantage of fixed marks on the tartan track. This kind of system is limited to special environments. In general, such systems are computationally demanding making the device too large for good wearability, due to the large processing unit required.

A relatively low computational effort camera based approach for computing the distance between user and obstacle is the laser rangefinder [16]. This method is based on laser triangulation, thus, the laser light must be detected first. Accurate laser light recognition is crucial for distance measurement. Chmelar et al. [17] proposed a laser line detection algorithm based on RGB color segmentation, where a different threshold value for every color channel. In a later work, Chmelar et al. [18] used GMM (Gaussian Mixture Model) for detecting the laser line. Yang et al. [19] tried to extract the laser line using the minimum entropy models. Nam Ta et al. [20] segmented the laser line using the advantages of YCbCr and HSI color spaces.

All aforementioned methods detected laser scan lines only in environments with low level noises. In this work, we investigate a new approach for obstacle detection and avoidance system for blind people based on laser range finder, which is able to detect obstacles within environments with relatively high level noises. The laser line extraction is achieved by a template matching algorithm. We evaluate the proposed system with respect to reliability and effectiveness. In order to validate our idea, we have built a proof of concept, shown in Figure 1 that can be classified as ETA.

Fig. 1: The optical based laser rangefinder which is composed by two main elements: an Android device and a laser line emitter placed on the bottom of the device and aligned exactly perpendicular to the smart phone camera.

II. Methods

A. Data acquisition

Two main elements were used for implementing the proposed system: a Samsung Galaxy S5 running Android 4.0 Ice Cream Sandwich and a laser module [2].The laser had a line shape, an output power of $5\,mW$, a $650\,nm$ wavelength and a working voltage of $3 - 12\,V$. The chosen laser was a class 1 laser, therefore not harmful. For acquiring the images, the inbuilt smart phone camera was used, which had a frame rate of $10\,fps$ and a frame size of 640×360 pixels. Processing the images was done locally, on the smart phone, and was implemented using the OpenCV library [21]. Feedback to the user was provided using the internal smart phone speakers.

B. Obstacle detection and avoidance system

The implemented algorithm was split in four parts, as shown in Figure 2. In the laser light detection step, the projected laser scan line was extracted from the captured image. Using the pixel position of the extracted laser line on the image plane and a calibrated rangefinder system, the range data to obstacles was calculated. In the next step, the intensity of the extracted laser line was analyzed allowing detection of smaller obstacles, obstacles with $1 - 100\,cm$ width. Finally, instant acoustic feedback warned the user of a pending collision with both small and large obstacles.

Laser light recognition

In this paper, obstacle detection accuracy is highly dependent on the laser light recognition. Detecting the laser scan line also depends on the noise within the acquired image. For detecting the laser scan line, a template matching algorithm was used. The first step in the algorithm was the storage of a laser light template. Due to the high computational cost of the template matching algorithm in the RGB color space, a 1D pixel row was chosen as a template. By using a smaller template, the computation time will considerably increase achieving only a non real-time result. The chosen template is shown in Figure 3a at the top of the image. Afterwards the template image was compared to the captured image by sliding it and calculating its match metric calculated using the normalized sum of squared differences (Equation 1).

$$R'(x,y) = \frac{R(x,y)}{K(x,y)} \tag{1}$$

With:

$$R(x,y) = \sum_{x',y'} (T(x',y') - I(x+x', y+y'))^2$$

$$K(x,y) = \sqrt{\sum_{x',y'} T(x',y')^2 \cdot \sum_{x',y'} I(x+x', y+y')^2}$$

The variables x and y denote the current pixel position in the captured image. x' and y' denote the current pixel position in the template image. The function I stands for the captured

[2] Laser type: LFL650-5-12(9x20)60

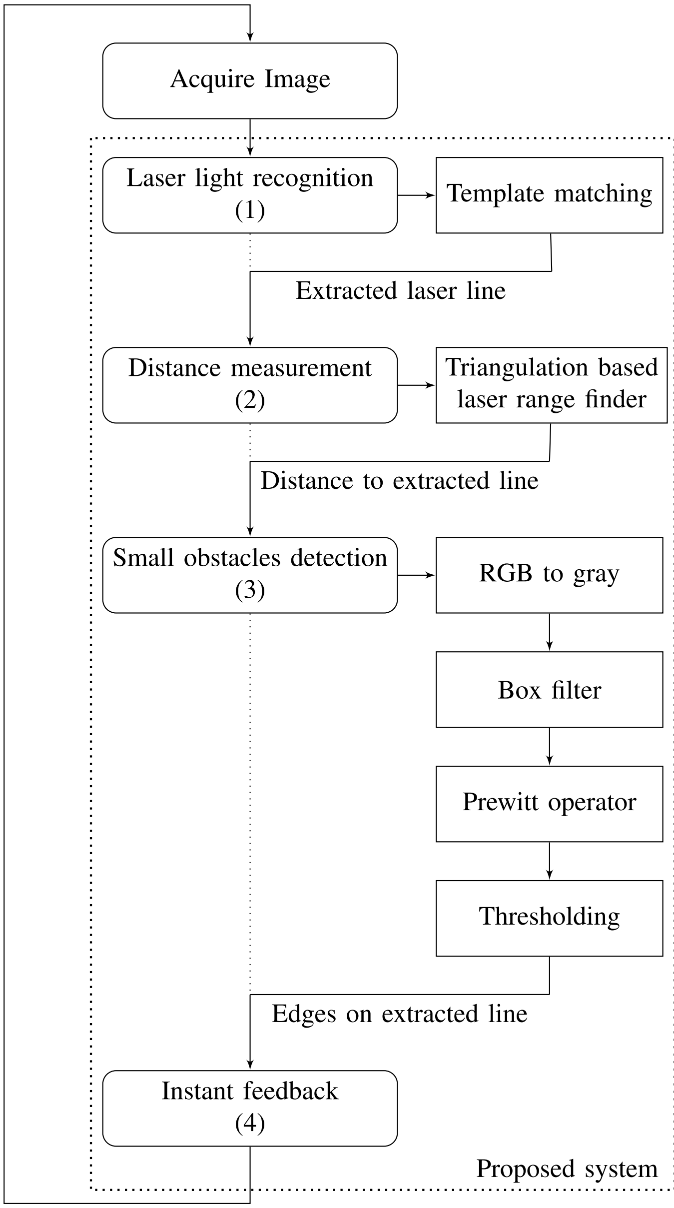
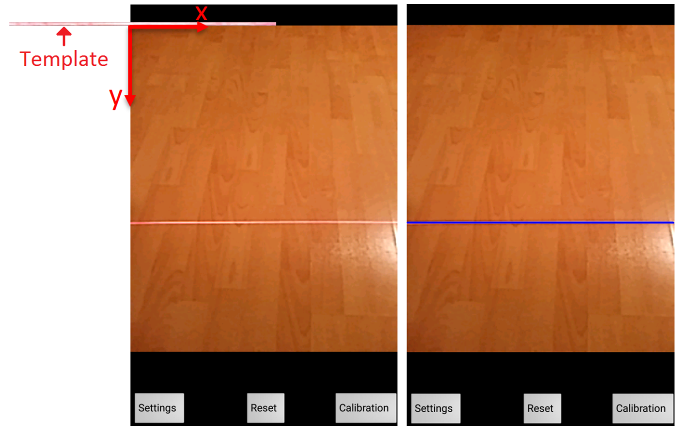


Fig. 2: Algorithm pipeline for the proposed obstacle detection and avoidance system. Firstly, the laser light was extracted using a template matching algorithm. The distance to obstacles was calculated using a triangulation based laser range finder system. Furthermore, a box filter followed by the prewitt operator was applied on the extracted laser line. Magnitude of the prewitt operator was set in order to allow small obstacle detection. Finally, when a user is heading towards an obstacle, the user was notified acoustically.

image (Figure 3a), T for the template image (top of Figure 3a). $R'(x,y)$ represents result image at position x and y, where the function $R(x,y)$ the sum of squared differences and $K(x,y)$ the normalization factor.

The greater the pixel match between template image and captured image with respect to their intensity values, the lower the intensity value $R'(x,y)$ meaning pixel is darker on the result image. Thus, the lowest intensity value on the image plane was extracted, which indicated the highest probability of a match (blue line on Figure 3b).



(a) (b)

Fig. 3: (a) captured image, where in the middle of the image the emitted laser scan line and at the top of the image the chosen template are shown (b) result image after applying template matching weighted with the normalized sum of squared differences, where the blue line denotes the location of the highest probability of a match

Distance measurement

After detecting the laser light, the distance between the laser emitter and the laser scan line was determined using a triangulation technique through a calibrated rangefinder system (Figure 4).

Using the static offset h between the smart phone camera, the laser emitter and the dynamic angle α between the center of focal plane and the projection line, the distance to the target D was calculated as follows [22]:

$$D = \frac{h}{\tan \alpha}. \tag{2}$$

The angle α is a dynamic variable and is given by

$$\alpha = \rho \cdot R + rad \tag{3}$$

where:

ρ : number of pixel from the center of focal plane

R : radians per pixel pitch

rad : radian compensation for alignment error

The pixel number from the center of focal plane ρ was calculated in the previous subsection through the position of the line which was extracted using the template matching algorithm. For determining R and rad a system calibration was performed. In order to calibrate the system, Equation (2) was rewritten as

$$\alpha_{reference} = \arctan(\frac{h}{D_{reference}}), \tag{4}$$

where $D_{reference}$ is a real measured distance and $\alpha_{reference}$ its corresponding angle. After measuring 15 real distances and

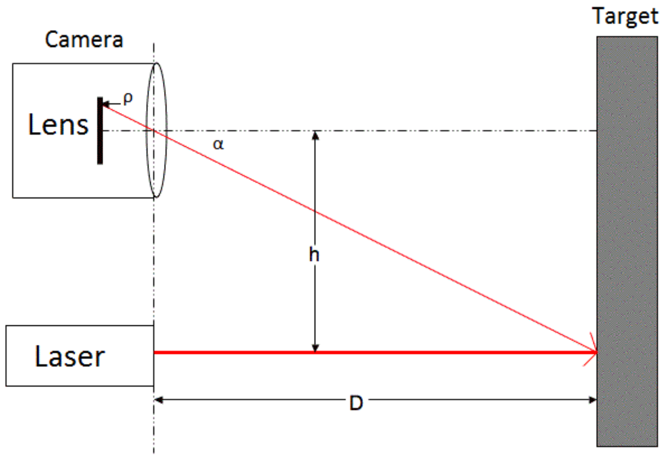


Fig. 4: Principle of laser rangefinder system based on triangulation technique. The variable D denotes the distance between laser emitter and target, h the offset between smart phone camera and laser emitter, ρ pixel position of the image plane, α the angle between center of focal plane and projection line

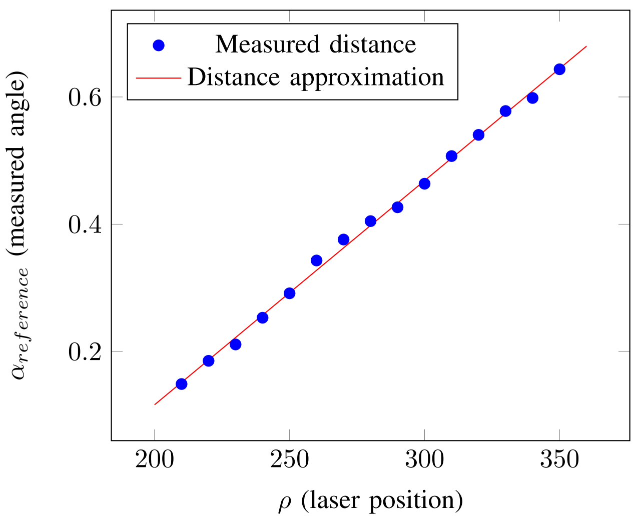


Fig. 5: Example of measured data with its regression line, which approximates the equation for the angle α (Equation (3)) with $R \approx 352.248 \cdot 10^{-3}$ and $rad \approx -588.205 \cdot 10^{-1}$. ρ denotes the current pixel position on the image plane, while $\alpha_{reference}$ represents the real angle measured using Equation (4).

their corresponding angles, the angle α (Equation (3)) was approximated by the regression line of the real measured data, where the slope-intercept corresponds to the radians per pixel pitch R and the y-intercept to the radian compensation for alignment error rad (Figure 5).

In this way, the calibrated range finder system was able to calculate the distance between the laser emitter and its projected laser light.

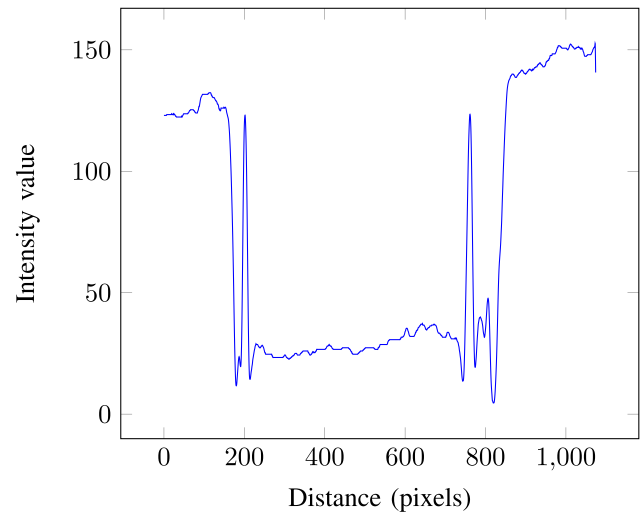


Fig. 6: Intensity profile along the dashed green line on Figure 7c that was extracted by the template matching algorithm after transforming it to gray scale color space followed by box filtering. Discontinuity in intensity values was displayed in case where the pathway contained small obstacle

Small obstacles detection

Due to the method used to detect the laser scan line, only the distance to larger objects such as walls or stair steps can be determined with the algorithm so far (Figure 7). Therefore, an additional analysis of the intensity values on the extracted line was required.

We found that the intensity profile was smooth in the case of an obstacle-free path, while in cases where the way contained obstacles, it displayed discontinuity in intensity values (Figure 6). Hence, this problem was reduced to an edge detection problem, which was solved by finding edges on the extracted profile using the Prewitt operator [23].

Firstly, the extracted RGB line was transformed into a gray scale color space. To improve the performance of the edge detector with regard to noise, the gray scale line was filtered with a box filter. Since the filtered line was a 1D line, edges on this line showed high gradients in the x-direction. The determination of gradients on the filtered line was achieved using the forward differences

$$f(x)' = f(x+1) - f(x), \tag{5}$$

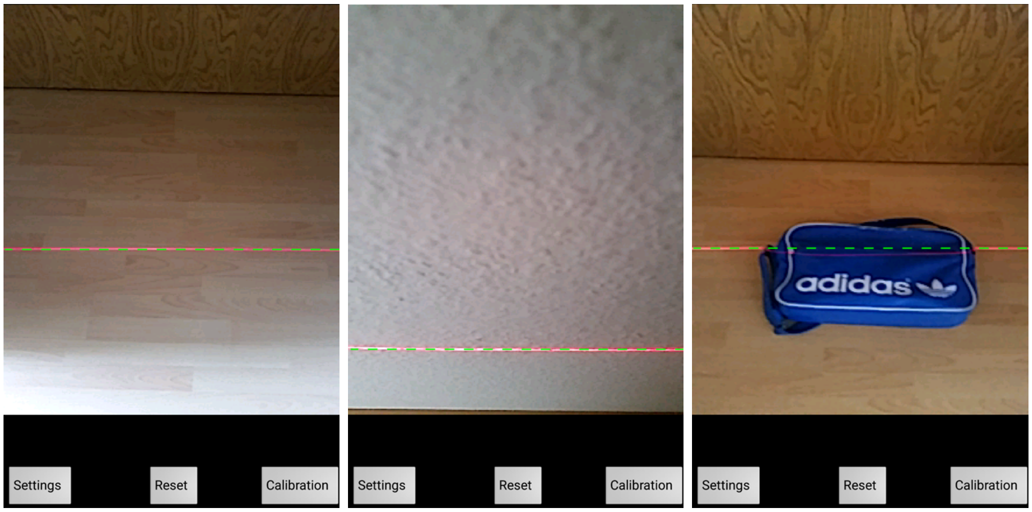
which approximate the first derivative in a discrete space. For making the edge detection less susceptible to noise, the 1D Prewitt operator was applied which is inexpensive in terms of computational cost as its impulse response is shift invariant (Equation (6)).

$$f(x)' = f(x+1) - f(x-1) \tag{6}$$

Thus, by thresholding the edge magnitude $g(x)$

$$g(x) = \sqrt{f(x)'^2} \tag{7}$$

with a suitable value the system was able to identify smaller obstacles. The threshold value was determined empirically.



(a) (b) (c)

Fig. 7: Demonstration of small obstacle detection problem. The dashed green line denotes the detected laser line using the template matching algorithm. (a) case of an obstacle free pathway (b) case of a large obstacle on the pathway causing laser line shifting on the image plane and thus another distance (c) case of a small obstacle on the pathway causing no laser light displacement on the image plane.

In addition, the position in which the obstacle blocking the pathway was determined using the position of the detected edges.

Instant feedback

Finally, the task was to bring obstacles to user's attention in real-time. Since there is only one vibration module in the Samsung Galaxy S5, acoustic signals were the only way to transmit helpful hints about location or type of obstacles to the user. The user received very brief and relevant acoustic signals in the fashion of "attention obstacle left" or "attention stairs".

C. Evaluation

In order to test the method described above, a real time android application was developed using the JAVA programming language.

For application evaluation purposes the number of correctly detected obstacles were assessed. To make this evaluation more realistic, five blindfolded persons were separately sent through a room with several objects, simulating the situation of a visually impaired person (Figure 8), albeit, newly visually impaired. The test subject used the obstacle detector application while trying to avoid collisions with obstacles in their path. Besides obstacle recognition, the smart phone camera was also used to record the correctness of detection. Overall, the system was tested on four different flooring materials with 20 obstacles of different sizes, shapes and colors. The detection rates as well as the false alarm rates were measured.

III. EXPERIMENTAL RESULTS

The subjects did not feel comfortable in the all tested environments while using the system. Four out of five subjects did not have any collision, whereas the fifth subject collided with one obstacle. The false alarm rates associated with the tested flooring materials are shown in Table I. Carpet and polished tiles flooring materials produced a high false alarm rate of ($30\,\%$) and ($15\,\%$). False alarm means that the user receives acoustic information about an obstacle ahead even though there was no obstacle. On laminate flooring there were low false alarm rates, which was similar to the results from environments with concrete flooring.

The measurement error of the distance between laser emitter and laser scan line was $0.88\,cm\,\pm0.96\,cm$ at 1 meter. The laser range finder system was, therefore, well calibrated with $R^2 = 0.9976$. The variable R^2 denotes the coefficient of determination and is a statistical measure of the strength of the relationship between the fitted regression line and all measured data. In this case, a high coefficient of determination means more precise distance computation.

This system was able to detect objects that are $1\,cm$ wide or larger. The detection rate strikingly decreased for smaller objects smaller than $1\,cm$ (Table II). An additional test, concerning the effect of object color, was performed and is shown in Table III. Black, white, gray and transparent obstacles produced detection rates of $100\,\%$, $90\,\%$, $100\,\%$ and $80\,\%$ on laminate flooring.

Flooring	Correct reject	False alarm	False alarm rate [%]
Polished tiles	17	3	15
Laminate	19	1	5
Concrete	19	1	5
Carpet	14	6	30

TABLE I: The effect of flooring material on the false alarm rate. The color of polished tiles was light with dark joints, laminate was light and carpet was dark. The high false alarm rate made the proposed system impractical for some real world scenarios.

Object size [cm]	Miss	Hit	Sensitivity [%]
10	0	10	100
5	0	10	100
1	1	9	90
0.5	3	7	70

TABLE II: The effect of object size on the sensitivity. The proposed system showed very high sensitivity even for small obstacles, e.g. obstacles with $1\,cm$ width.

Object color	Miss	Hit	Sensitivity [%]
Black	0	10	100
White	1	9	90
Gray	0	10	100
Transparent	2	8	80

TABLE III: The effect of object color on the sensitivity. The obstacle color considerably influenced the sensitivity making the system not robust enough for some obstacle.

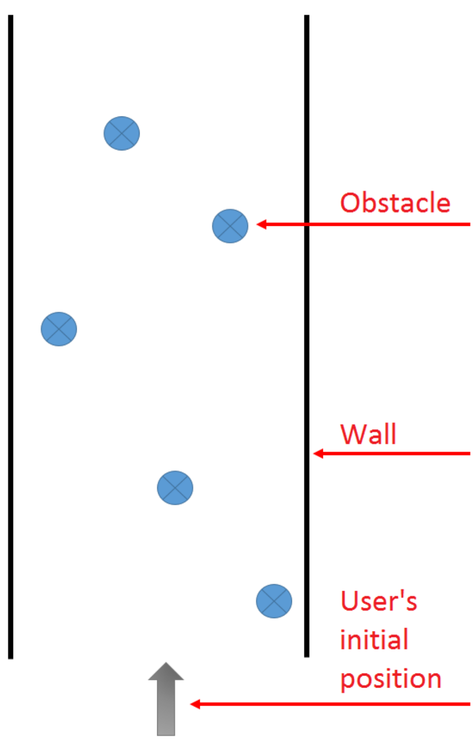


Fig. 8: Demonstration of the test case.

IV. DISCUSSION

An obstacle detector application was developed with the goal of supporting visually impaired people in their daily lives. For maximizing the replicability of this system, only hardware primitives were used.

The system presented a good performance on laminate and concrete flooring for indoor applications. Almost all subjects were able to walk through the simulated environments without collisions. In addition to this good detection rate, the subjects were able to distinguish the direction in which the obstacle was located, i.e. to left, right or ahead of the user. Stair recognition was also successful. Since a template matching algorithm was used to find the laser light, problems like saturation phenomenon or white ambient of laser light did not effect the detection rate.

However, the false alarm rate considerably increased when walking on carpet or polished tiles flooring, which lead the user to feel confused and unsafe more often than not. The high false alarm rate on the carpet flooring was caused by the weak laser reflection, which made the laser scan line hard to find for the template matching algorithm. This problem could be solved using more powerful lasers. On the polished tiles flooring the reflection was almost flawless, however the high-contrast joints caused a high false alarm rate. The system recognized the joints as small obstacles and falsely warned the user. A similar scenario occurred when moving between two different flooring materials of different colors.

Calculating the distance to large obstacles using the triangulation based laser range finder system was precise, with a measurement inaccuracy of $0.88\,cm \pm 0.96\,cm$ at $1\,m$. However, due to the low detection range, the subjects felt safe only while walking slowly across the room. Furthermore, since the subjects were holding the smart phone while walking, the measured distance occasionally fluctuated causing a false alarm. Study subjects rated the usability of our system as poor. For this purpose, a phone holder which can be attached to the body would solve many of these issues. This would have the added advantage that users are able to use the system hands free.

In contrast to ultrasound based systems, the small obstacle detection rate of this system was very high; even for very small objects, e.g., obstacles with a $1\,cm$ width. Obstacles with a width under $1\,cm$ were rarely detected however have a lower risk of causing harm. Detecting smaller obstacles can be achieved by using a higher resolution per frame, e.g. a resolution of 848×480 pixels. However, a trade-off between frame resolution and real time computation should be considered.

The obstacles color also effected the detection rate. Since we used an edge detection algorithm to detect and locate small obstacles, the extracted line should have at least two different colors in case of a small obstacle on the pathway. This was not always the case. In our case, due to the laser saturation phenomenon, the laser light caused a relatively light color on the extracted profile and therefore white obstacles were occasionally not recognized. This predominantly happened while trying to detect white obstacles on light colored flooring materials. Furthermore, the recognition of transparent obstacles was slightly worse than white obstacles. The fact, that transparent medium normally diffracts the incident light producing a displacement of the laser scan line resulting in an edge on the extracted line, and thus an obstacle recognition.

The method of information transfer to the user about obstacles was efficient and useful as almost all subjects did not collide with an obstacle. However, some of them knew immediately how to handle the appearing obstacle, whereas other firstly needed to rethink. Nonetheless, an acoustic signal as feedback may reduce the natural use of the visually impaired person's sense of hearing. Transmitting the environmental information, about obstacles, by other means should also be explored.

V. SUMMARY AND OUTLOOK

In this paper, a system which allows visually impaired individuals to detect and avoid obstacles was implemented as an android application. The obstacle detector application provides a high detection rate of up to 100 % on selected environments. The main limitations of this system were flooring materials which have extremely weak light reflection and obstacles with a color similar to the laser light.

In order to improve the robustness of this system a powerful line laser module could be used, allowing an improved laser line detection. A cross laser module, as opposed to a line laser module, should be investigated. The proposed system could be also applied to smart phones that have two back cameras, thus enabling us to additionally measure a depth map of the environment. This application could be enhanced with GPS information, a common feature to most smart phones.

Additionally, if the processing performance is improved it will allow the processing of a higher frame resolution, and thus allow more precise acquisition of the local environment. This can be achieved by limiting the search of the template matching algorithm, since the laser light is moving in a predefined range. Furthermore, the template matching algorithm search can be terminated after obtaining a certain threshold with respect to similarity.

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