

# A FEASIBILITY STUDY ON A NOVEL METHOD OF VISUAL OBSTACLE DETECTION

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## ABSTRACT

*We discuss potential applications of a novel visual sensing method that is particularly suitable for obstacle detection and/or path planning. In this method, scenes are illuminated by short laser pulses and images are captured by a gated camera. By controlling the pulse width and the gating time, it is possible to get images that contain only objects within a predefined distance from the camera. The rest of the scene remains invisible. The presented experimental results confirm that the method can be prospectively used to create very fast, robust and reliable systems for vision-based navigation. Many significant constraints of the existing algorithms are overcome.*

## 1. INTRODUCTION

Vision is prospectively the most powerful sense of intelligent robotics, but the real-world applications of machine vision are often constrained by a 2D nature of camera-captured data. One of the typical robotic tasks of computer vision is vision-based navigation (e.g. obstacle detection and/or recognition, finding safe passages, etc.). In general, such tasks cannot be completed using only 2D images. Instead, complex systems equipped with multiple sensors and sophisticated algorithms (multi-camera stereovision, structure from motion, vision and ranging fusion, etc.) are developed. Systems designed according to these principles have been presented in numerous papers (examples of recent results can be found in [1], [2], etc.). However, such systems have some disadvantages, e.g.:

- performance may strongly depend on the content of observed scenes as feature detection and/or matching is a crucial part of the algorithms;
- results are often produced after computationally complex data fusion (e.g. range-scanning data, stereo-matching, ultrasonic sensors, etc.) so that the systems cannot be used in high-speed applications;
- mechanical reconfiguration (e.g. a camera orientation and/or position shift) may be needed to adopt the system to changing conditions or requirements.

In this paper, we discuss a novel method of visual sensing that offers many advantages over the existing techniques. The method is particularly suitable for obstacle detection and/or path planning.

The basic ideas are very similar to the principles of radar and sonar technologies that have been used for many decades. A short laser pulse illuminates the observed scene and, subsequently, an image is captured by a gated camera. By controlling the pulse width and the gate opening/closing time we are able to obtain the image that contains only objects within a predefined distance from the camera, i.e. only the potential obstacles or objects of interest. The rest of the scene would remain invisible.

Although range-gating and lidar-based methods have been intensively investigated for many years (e.g. [3], [4]) the envisaged applications are rather different from our method. The researchers have been primarily trying to improve visibility in highly-scattering media (e.g. [5]). The recent survey [6] lists other novel applications of lidars (e.g. detection of objects hidden in grass). Our research has also emerged from projects on short-range visibility improvement in highly turbid waters ([7], [8]).

The paper presents the initial phase of the conducted research. We concentrate on the experimental verification of the expected visual quality of gated images. Although the scale of experiments was limited (because of technical constraints and safety considerations) the obtained results have strongly confirmed our expectations. Obstacles can be visually detected very straightforwardly, satisfactorily accurately and extremely quickly. The performance parameters (e.g. the range of obstacle detection) can be rapidly adjusted by tuning electronic parameters of the system. We believe that the proposed method opens new options in the area of visually-guide navigation. The following sections present justifications for this claim.

Section 2 overviews the basics of the method and briefly describes the laboratory equipment. In Section 3, we present exemplary results illustrating various aspects of the tested method. We concentrate on shorter ranges primarily because for these ranges the existing systems seem to be particularly ineffective. The actual ranges are below 3m (this is the size of our laboratory setup).

## 2. IMAGING SYSTEM

Systems based on range-gated lidars are one of the advanced methods that can be used to enhance visibility in highly noised environments (e.g. turbid water, heavy fog, etc.). Fig.1 shows the principle of operation for such systems under idealized conditions.

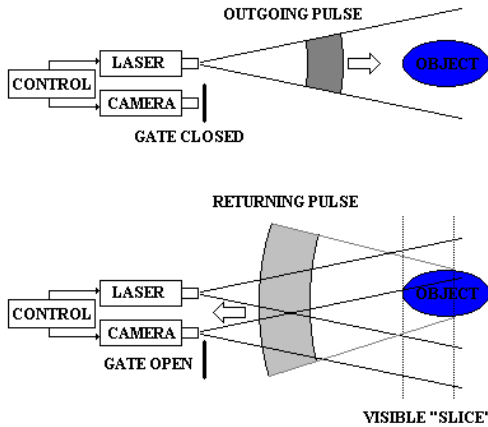


Fig. 1. Idealized principle of operation of range-gated lidars.

The actual performance of such devices is more complex. As an example, Fig.2 shows the light intensity profile at the receiver (camera) when a flat distant target is illuminated by an approx. 10ns laser pulse.

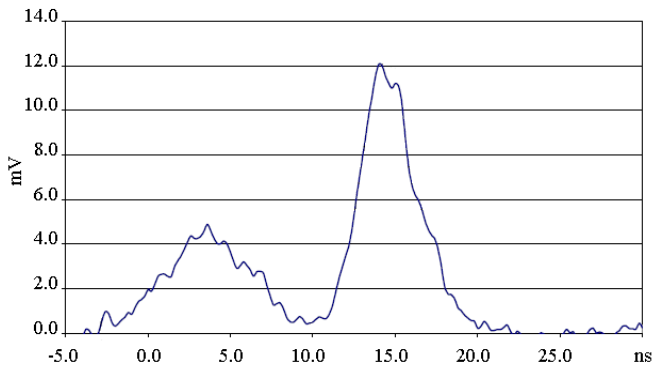


Fig.2. An exemplary intensity profile of the received signal for a 10ns illumination pulse.

The measurements have been done in water so that a strong backscattering effect (the lower peak in Fig.2) is seen. Nevertheless, it can still be concluded that if the camera gate closes at the time corresponding to the selected distance - e.g. at approx 20ns for the example shown in Fig.2 - only the objects (and possibly other visually observable phenomena) within this distance will be seen at the image.

We conducted the experiments using a laboratory setup shown in Fig.3.



Fig.3. General layout of the equipment.

Although the lidar system is attached to a 3.0m long water tank (the original scope of researches was underwater visibility enhancement) during our experiments the tank was emptied. Thus, the open space conditions have been approximately obtained. Because of safety reasons the system cannot be transferred to elsewhere. The major components of the system are:

- A Nd:YAG pulsed laser producing approx. 10ns pulses at 10Hz or 20Hz frequency. The laser beam diverges into a conical shape.
- An ICCD camera system with Xybion ISG-250 camera, a high-speed photo-detector and a camera control unit. The effective minimum gating time is 20ns. The photo-detector rise-time is below 350ps.
- Meteor II card containing a Matrox frame grabber with NTSC video output.
- Signal delay generator with 5ps resolution.

## 3. EXPERIMENTAL RESULTS

In the conducted experiments, we have created scenes (both static and dynamic ones) of diversified complexity placed at various distances from the lidar system. Because of the tank size, the farthest objects could be 3m away (they represent the background part of the scenes) while the "obstacles" are either fixed at shorter distances or moving within similar ranges. In order to monitor the dynamic changes and to quickly get a large number of sample images, we video-recorded the results. The presented images are frames extracted from the digitized video. Thus, both the quality and the resolution are inferior to the original images captured by the system (samples of the original quality can be found in [7] and [8]). The dark patch in the centre of all images is a damaged part of the CCD matrix.

The experiments are focused on the following two issues:

1. Comparison between gated and non-gated images.

2. Obstacle detection and identification using gated images.

**3.1. Gated versus non-gated images**

Examples of non-gated images (equivalent gates images can be obtained by using a continuous illumination) and their gated counterparts are shown in Fig.4.

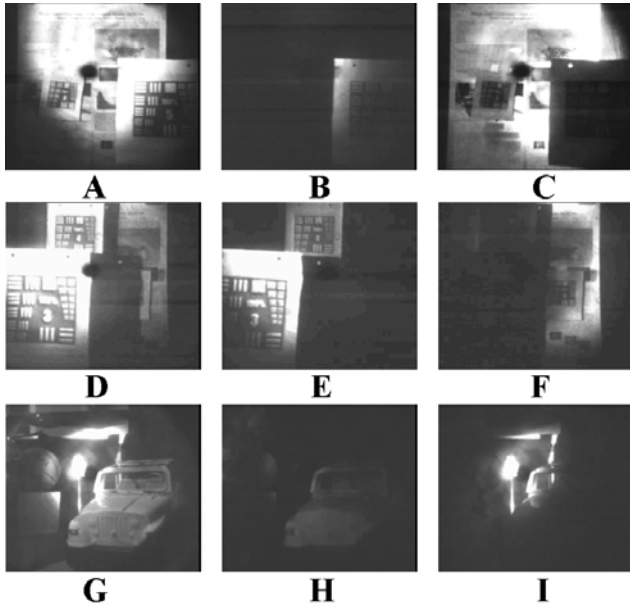


Fig. 4. Examples of non-gated (A, D, G) and the corresponding gated images.

The scenes contain foreground objects (at ranges between 0.4m and 2.4m) but in non-gated images the automatic extraction of those objects from the background would not be straightforward.

The effective duration of the laser pulse is approx. 10ns, and the effective camera gating time exceeds 20ns. Thus, for the short-range gated images (e.g. Fig.4B) the gate opens earlier than the laser pulse is produced. For the image shown in Fig.4E the pulse and the gate opening are approx. simultaneous (the timing characteristics of laser pulses cannot be accurately measured in the available system). Images from Figs 4C, 4F and Fig.4I have been captured by a delayed gate opening (approx. 10ns after the laser pulse).

Such experiments have confirmed that by changing gate opening characteristics it is possible to capture images that contain only those fragments of the scene that are within the corresponding distance from the camera.

**3.2. Detection and recognition of moving obstacles**

From the robotic perspective, the most importance application of gated images would be detection and/or recognition of objects approaching the camera system (i.e.

potential obstacles). In a series of experiments, we captured sequences of images representing such situations. In Fig.5, an obstacle is fixed at 1.0m distance, while another obstacle is approaching the camera. It can be clearly seen how the moving object is gradually becoming visible.

In the experiment shown in Fig.6, the original scene does not contain any obstacle within the visible range. Subsequently, a perpendicularly moving object enters the visible area at a very short distance (approx. 0.4m). In both experiments, the background part of the scenes was very complex, but the visual detection of the incoming obstacles seems straightforward.

The examples show that detection of obstacles intruding the visible volume can be prospectively done using very simple algorithms (e.g. image thresholding).

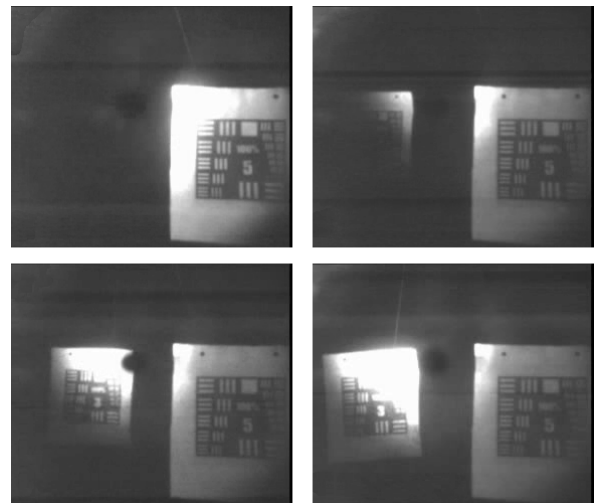


Fig. 5. A sequence of images for an obstacle approaching the camera.

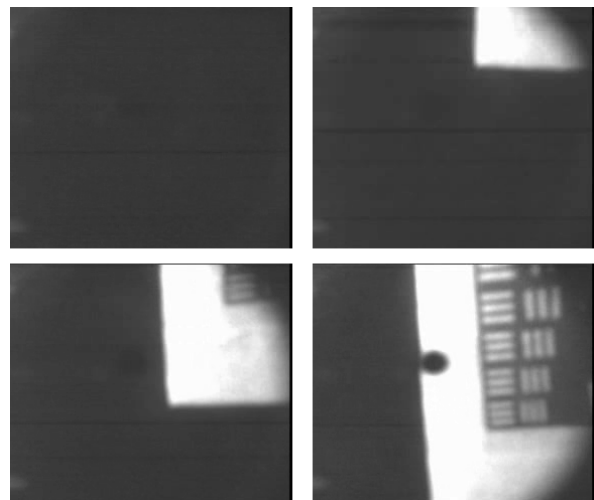


Fig. 6. An obstacle moving perpendicularly.

In automatic detection, however, the problem of (usually unavoidable) ambient light should be properly handled. In our experiments, for example, there is a mixture of day- and artificial light. Under such conditions, the “invisible” parts of gated images may have the same (or even higher) intensity than darker details of obstacles. We have found that in case of isolated obstacles within the visible range, the problem can be solved by double image capturing – using high and low gain of the CCD sensor. High-gain images are practically always saturated within the obstacles (regardless their texture or colour). Because of various optical effects (a combination of refraction and backscattering on the air particles is suspected) a certain area surrounding the obstacles is also saturated. Low-gain images, however, contain fine details of the obstacles. Thus, the saturated area can be used as a very fast estimator of obstacle shapes. The same area within the corresponding low-gain image can be used to perform the detail analysis/recognition of the obstacles. Exemplary results are shown in Fig.7.

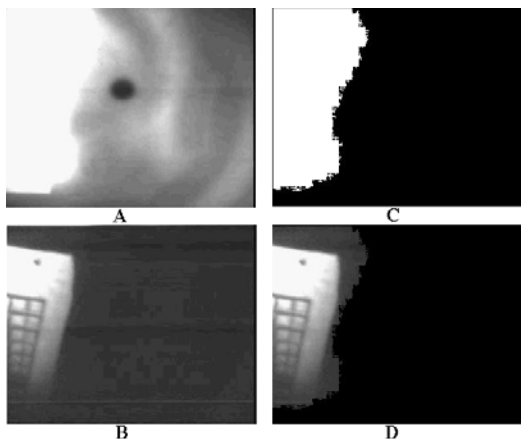


Fig. 7. High-gain image (A), low-gain image (B), the saturated area of the high-gain image (C), and the low-gain image masked by the saturated area (D).

For more complex object configurations, the method is less reliable (i.e. it could produce an impression of a fully blocked way, while actually passages between the obstacles may exist) and alternative solutions have to be proposed (to be reported in the incoming papers). It should be emphasized, however, that the “over-saturation” effect gradually diminishes when the observed objects approach the camera, i.e. gated images “naturally” become more reliable when such a reliability is needed.

#### 4. SUMMARY

The content of gated images depends on the characteristics of an imaging system. In particular, the visibility range may fluctuate depending on the pulse duration stability. In our system, the duration of laser

pulses can fluctuate by approx. 1ns, i.e. the actual visibility range deviates by 15cm (in air). Moreover, the image intensities may fluctuate due to the pulse energy instabilities. In general, however, the visual distortion of gated images caused by the parameter fluctuations are within a tolerable limit.

Although the scale of experiments was limited, the results have confirmed the advantages of gated images in vision-based navigation. Obstacles can be detected with satisfactory accuracy using very simple methods even at very short distances (below 1.0m). Even though gating time control and stability of the laser pulses are the key issues, the method is sufficiently robust with some fluctuations of these parameters. Moreover, image capturing is fast enough for any imaginable applications. However, the data capturing and transmission rates should be increased to exploit the data-capturing speed.

Generally, gated imaging is still far from technical maturity required in fully autonomous navigation, but nevertheless it should be considered one of the promising options in this research area.

In our future researches, we will focus on further development of obstacle detection methods for diversified types of scenes, and on theoretical models of short range gated imaging.

#### 5. REFERENCES

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