Computer vision based navigation systems — requirements and proposed system idea

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This article highlights the main challenges and constrains concerning computer vision based navigation systems. A few special conditions in which the systems have to work are pointed out. Different approaches to sense the surrounding environment are reviewed. Finally, the navigation system which incorporates two computer vision techniques: time of flight and stereovision is proposed.

Keywords and phrases: computer vision, navigation, depth estimation, distance measurements, obstacle detection, collision avoidance.

Introduction

Nowadays ubiquitous high speed computing poses the opportunity to develop and enhance camera based vision algorithms and systems. These systems have vast applications in machine vision, robotics, medicine, obstacle detection in car traffic, pedestrian navigation and home device control systems. Researchers in this field have investigated many different approaches to sense the environment using camera and dedicated algorithms in order to extract interesting features from the image or from a sequence of images. As a result of these research and these experiments, systems able to find a previously defined object or its feature were built. However, this task becomes more complicated when the distance from an obstacle is the feature to be measured. Distance from the obstacle is the key feature in navigation systems and obstacle detection. In order to compute this parameter, a couple of algorithmically complex methods were developed. Those methods rely mainly on 2D images taken from different views (example of the method is stereovision) or by utilizing a picture of the same object taken by the same camera with different optical parameters (i.e. by adjusting the focal length). The methods do not fulfill all requirements of mobile applications, especially when we consider pedestrian or vehicle navigation. In such cases, the following conditions should be met: high output frame rate (very important when a guided object is moving fast), a measuring device with its own source of light (working as well during the day as during the night), able to sense all kind of surfaces and materials that obstacles are made from, and the range of depth recovery not less than 8–10 meters. Besides this, the device should be calibrated automatically to face conditions that appear. At first impression, the active method using time of flight seems to consist of the above counted properties. The measurement idea of TOF method is as follow: sinusoidally modulated, light wave is emitted and the phase delay between the original and received light signal is exploited for the extraction of the time [1]. Modulation frequency (fmod) may be chosen from a range of 19–30 MHz and the choice depends on what distance is interesting for us (greater fmod means shorter distance but better accuracy). In this paper, time of flight and a stereovision methods are examined in order to build a system able to meet all requirements for mobile applications for navigation.

Existing vision based navigation systems

Reviewing the current literature in the field of vision based navigation systems, a few attracting attention prototypes can be found. Authors of [2] tested the time of flight camera for detecting obstacles in car navigation.

Prototypes based on ToF are also tested for the purpose of people tracking [3] and for robot navigation [4]. In spite of much afford by scientist there are still many problems to solve and experiments to run in order to make them accessible for normal users.

Experiments

In this section, a couple of difficult depth recovery scenes were chosen and then tested. The SR3100 time of flight and Bumblebee2 stereovision camera were used for experiments, that were divided into four stages to examine all requirements mentioned in the introduction: frame rate, lighting conditions, accuracy and the range of measurements.

1) frame rate: Both available devices (the stereovision camera and ToF camera) give appropriate value which is within the range of 10–25 fps.

2) lighting conditions: the tests were divided into two categories: under day light (natural and artificial) and during the night. The ToF camera can be used in all conditions, as the device emits modulated infrared. It works as well during the day as during the night. The depth can also be precisely recovered in varying bright conditions (sunny weather) by decreasing integration time of the CMOS sensor. In the case of the stereovision camera, external illumination of the scene is required as the camera is not equipped with its own light source.

3) accuracy: In order to test an accuracy and usefulness of both cameras in real life situations, four scenes were designed. Scenes with following obstacles were used:

I. white smooth screen
II. shiny wrinkled tinfoil.
III. net made of fabric
IV. a large square glass pane

The objects were considered difficult to detect and the experiments were focus on demonstrating how the methods could handle them.

First scene (I.) is an example of an obstacle which is sensed only by the SR3100 (Fig. 1). The stereovision is unable to detect it as it is smooth and without texture.

In case II., the scene is a shiny object from which the reflected light saturate the ToF camera. As the object consists of edges and texture, it is easily detected by stereovision.

In the case of the fabric net (III.) the Bumblebee2 only sees edges, whereas the SR3100 detects everything

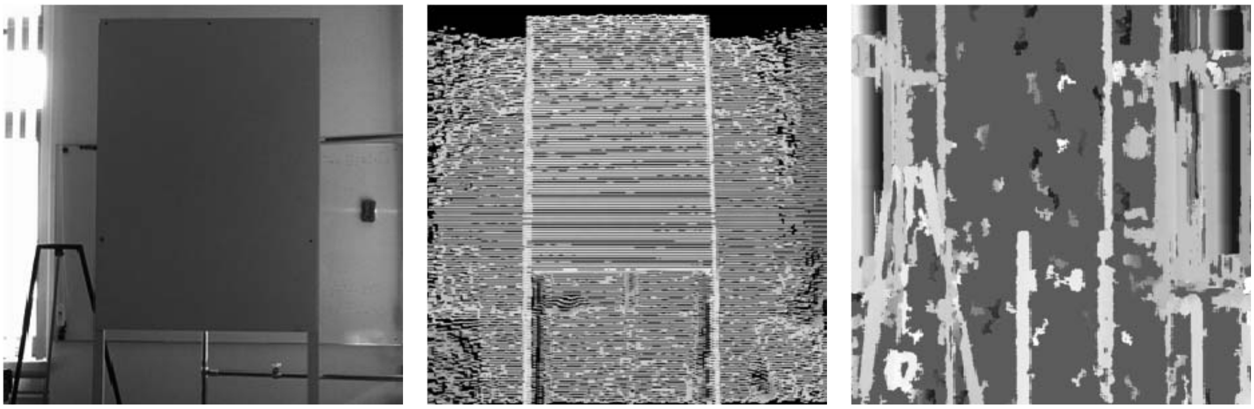

Fig. 1. White smooth screen and its remonstrations: ToF method (in the middle) and stereovision (on the right).

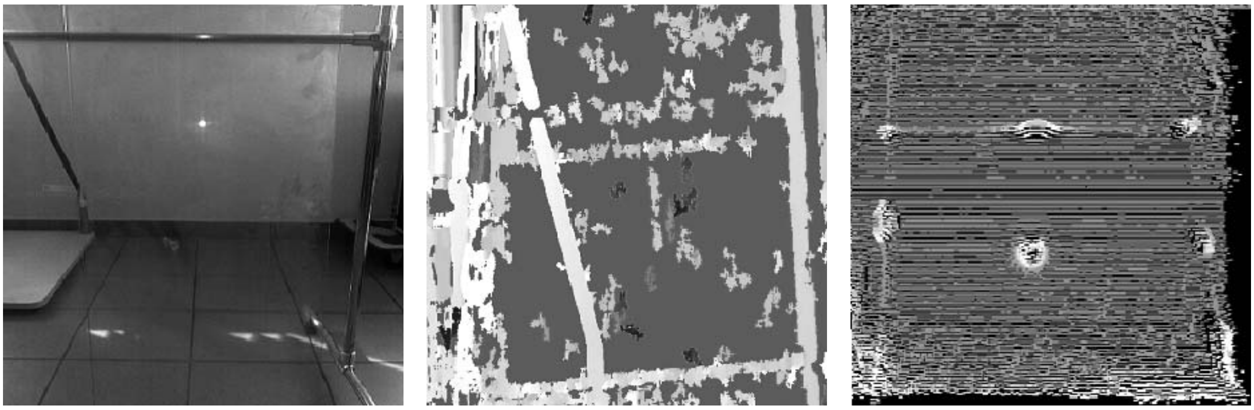

Fig. 2. A large square glass pane and its remonstrations: ToF method (in the middle) and stereovision (on the right).

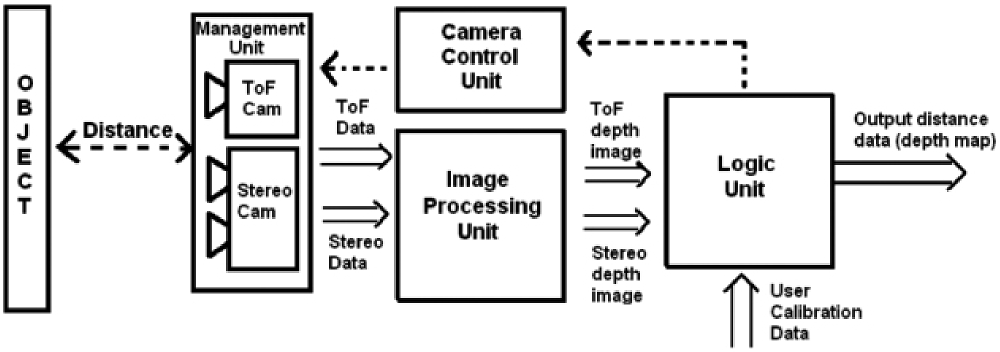

Fig. 3. Idea of the hybrid system.

however, the measurements have to be precisely filtered as obstacles behind the fabric are also visible.

In the last example (IV), the scene consists of a transparent glass pane (Fig. 2). In this case, the SR3100 method was not able to locate the obstacle, because infrared penetrates glass. Likewise the Bumblebee2 camera did not detect the object as the surface was smooth and without edges.

4) range of measurements: The maximum distance range in ToF depends on modulation frequency and amount of energy emitted by the lighting diodes. Camera parameter settings allow increased standard range (8 m) up to a dozen or so meters. In the case of the stereovision camera, the maximum distance depends on the optics of the applied cameras and can be extended to a few dozen meters.

Proposed system

In order for the depth sensing system to work in real time conditions, a hybrid of ToF and stereovision is proposed (Fig. 3). The system is composed of a Measurement Unit (MU): ToF camera and stereovision camera, an Image Processing Unit (IPU), a Logic Unit (LU) and a Camera Control Unit (CCU). It works as follows: the MU consists of a ToF camera as the main depth sensing device. A user can also activate the stereovision camera if the required ranges are longer than ten meters (standard range for ToF camera is up to 10m) or if sunlight is bright enough to saturate the CMOS sensors of ToF camera. Data acquired by the MU are processed in the IPU. It produces a full depth map. It has two outputs (one for the ToF depth map and one for the stereo depth map) controlled by the LU of the system. The LU also manages the CCU. The CCU module activates and deactivates the stereovision camera and controls the system parameters such as integration time, intensity of the emitted infrared light, measurement range and the modulation frequency of the ToF camera. The presented system can also learn how to adjust the filtering algorithms and the camera frame rate to the required accuracy and reduce power consumption.

Conclusions and future work

The described experiments have shown that the ToF method is able to face the challenges which may occur in mobile applications. However, there are also situations in which ToF fails or cannot be used: i.e. long distance measurement ranges or saturation of the CMOS sensors for the ToF sensing matrix during bright light conditions. For resolving these kind of constraints, a stereovision camera is proposed. A supplementary method can ensure high accuracy and reliability for the depth sensing system. In the next chapter, the idea of the hybrid ToF and stereovision was presented. It was initially tested and seems to have the potential to work properly in scenarios in which the ToF camera working alone fails. In the next stage, the tests will be extended. The author will improve accuracy of the distance measurements by applying additional depth recovery algorithms and selecting optimal settings for the ToF and stereovision cameras. In order to handle transparent surfaces such as glass or transparent thermoplastic (poly), ultrasound transducers are being considered.

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