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Robust traffic lights detection on mobile devices for pedestrians with visual impairment

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ABSTRACT

Independent mobility involves a number of challenges for people with visual impairment or blindness. In particular, in many countries the majority of traffic lights are still not equipped with acoustic signals. Recognizing traffic lights through the analysis of images acquired by a mobile device camera is a viable solution already experimented in scientific literature. However, there is a major issue: the recognition techniques should be robust under different illumination conditions.

This contribution addresses the above problem with an effective solution: besides image processing and recognition, it proposes a robust setup for image capture that makes it possible to acquire clearly visible traffic light images regardless of daylight variability due to time and weather. The proposed recognition technique that adopts this approach is reliable (full precision and high recall), robust (works in different illumination conditions) and efficient (it can run several times a second on commercial smartphones). The experimental evaluation conducted with visual impaired subjects shows that the technique is also practical in supporting road crossing.

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1. Introduction

Most mobile devices are accessible to people with visual impairment or blindness (VIB)[1]. This makes it possible to use these devices as platforms for the development of assistive technologies. Indeed, applications specifically designed for people with VIB are already available in online stores. For example, *iMove* supports independent mobility in urban environment by "reading aloud" the current address and nearby points of interest[2]. Other solutions proposed in the scientific literature adopt computer vision techniques to extract contextual information from the images acquired through the device camera. In particular, this paper focuses on the problem of recognizing traffic lights with the aim of supporting a user with VIB in safely crossing a road.

A number of solutions have been proposed in the scientific literature to recognize traffic lights. Existing solutions have a common problem: they use images acquired through the device camera with automatic exposure. With this approach, in conditions of low ambient light (e.g., at night) traffic lights result overexposed (see Fig. 1) while in conditions of high ambient light (e.g., direct sunlight) traffic lights are underexposed (see Fig. 2).

This paper presents *TL-recognizer*, a traffic light recognition system that solves the above problem with a robust image acquisition method, designed to enhance the subsequent recognition process. Experimental results show that *TL-recognizer* is reliable (full precision and high recall) and robust (works in different illumination conditions). *TL-recognizer* has also been optimized for efficiency, as it can run several times a second on commercial smartphones. The evaluation conducted on subjects with VIB confirms that *TL-recognizer* is a practical solution.

This paper is organized as follows: Section 2 discusses the related work and defines the objectives of this contribution. The basic acquisition and recognition technique is presented in Section 3, while improvements are described in Section 4. Section 5 reports the results of the extensive experimental evaluation and finally Section 6 concludes the paper.

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[1] In case the reader is unfamiliar with accessibility tools for people with VIB, a short introduction video is available at http://goo.gl/mEI6Uz.

[2] At the time of writing, iMove is available for free download from AppStore: https://itunes.apple.com/en/app/imove/id593874954?mt=8.

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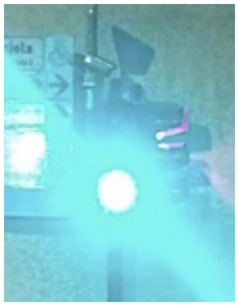

Fig. 1. Pedestrian traffic light is overexposed.

Fig. 2. Pedestrian traffic light is underexposed.

2. Detecting traffic lights for people with VIB

Independent mobility is a challenge for people with sight impairments, in particular for what concerns crossing a road at a traffic light. A solution to this problem consists in the use of acoustic traffic lights. There are many different models of acoustic traffic lights. For example, in Italy, there are acoustic traffic lights that produce sound on demand by pushing a button placed on the pole. The sound signals to the person with VIB when the light is green. In Germany, there are models that always produce a sound when the light is green (no button has to be pushed) and they adapt the intensity of the sound according to the background noise.

Nonetheless, as reported by many associations for blind and visually impaired persons, in most industrial countries (e.g., Italy, Austria, France, Germany, etc.), acoustic traffic lights are not ubiquitous; they are present in some urban areas but may be absent in small towns. Furthermore, acoustic traffic lights are not always working properly because damages often take a long time to be reported and fixed. The situation can be even worse in developing countries.

2.1. Related work

One of the first contributions on traffic light recognition was presented by Kim et al. [1]. This solution is aimed at assisting drivers with color deficiency. Images are acquired through a digital video camera and processed by a notebook. The main limitation of this solution is that it works correctly only when there is a uniform background (e.g., the sky). Consequently this solution cannot be applied to the purpose of detecting pedestrian traffic lights, because they are located in urban environments where the background contains, for example, shop lights and trees.

Several other solutions proposed in the literature are specifically designed for smart vehicles [2–6]. These techniques cannot be directly used to guide people with VIB because they are specifically optimized for circular or elliptical lights, while pedestrian traffic lights have different shapes.

Differently, other solutions, while designed for smart vehicles, are not specialized for circular or elliptical traffic lights and hence can be adapted to recognize pedestrian traffic lights. The solution by Wang et al. [7] aims at recognizing traffic lights in a complex urban environment. The proposed technique first computes color segmentation in the HSI color space, then identifies candidate regions and finally uses a template-matching function to validate a traffic light. The solution by Cai et al. [8] is aimed at recognizing 'arrow-shaped' traffic lights. In this solution, the dark regions of the images are singled out. Then, the regions that are either to small or too big are discarded. Subsequently, a color filter for green, red and yellow is applied to the candidate regions. Eventually, the arrow is recognized through Gabor transform and 2D independent component analysis. The solution by Almagambetov et al. [9] discusses a technique aimed at guaranteeing recognition of traffic lights from large distances (this is clearly an important feature for smart vehicles) and tackles the problem of recognizing 'arrow-shaped' traffic lights through a template-matching technique. The solution proposed by Charette and Nashashibi [10] detects, with a template-matching technique, the optical unit, the signal head as well as the traffic light pole.

Other solutions have been specifically proposed to support detection of pedestrian traffic lights with the aim of supporting users with VIB. Ivanchenko et al. [11] present a recognition algorithm for smartphones designed for traffic lights in U.S.. The status of the traffic light is represented by the white shape of a pedestrian together with a circular light that can become red, yellow or green. In the first step, the algorithm uses smartphone sensors to determine the position of the smartphone with respect to the horizon and it analyzes only the upper part of the image. Secondly, it detects the circular light and the shape of the pedestrian. This algorithm also searches for a pedestrian walk to validate the result.

Roters et al. in [12] investigate an algorithm consisting in three stages: *identification*, *video analysis* and *time-based verification*. In the identification stage, the algorithm recognizes the traffic light in front of the pedestrian. The video analysis stage tracks the candidate traffic light in different frames of the video. Finally, during the time-based verification stage, the results of the identification stage are double-checked with those of the video analysis. Our contribution focuses on the first stage only; the other two forms of reasoning are important in the final application, and in fact the proposed architecture implements them in the *TL-logic* module (see Section 2.3). This contribution improves the identification stage by proposing a technique that is rotation invariant and that also takes into account the shape of the pedestrian traffic light.

Most of the techniques mentioned above have a common problem: the images are processed *after* their acquisition with the aim of guaranteeing robust recognition under different lighting conditions. The problem has been explicitly highlighted by Diaz-Cabrera et al. [5] that proposes a method for smart vehicles for detecting and determining the distance of Italian suspended vehicle traffic lights. The approach uses normalized RGB color space to obtain a consistent accuracy in different illumination conditions. However, experimental results are still unsatisfactory in bright days or at night.

A follow-up publication by Diaz-Cabrera et al. [6] argues that it is impossible to reconstruct information with high precision from overexposed or underexposed images like the ones in Figs. 1 and 2. Thus, the authors propose dynamic exposure adjustment based on sky pixels segmentation and luminosity evaluation. The paper also proposes an enhanced fuzzy-based color clustering and improves the previous solution with a faster, parallelized detection and a higher accuracy detection and distance computation. In our approach we also propose a dynamic method for exposure adjustment based on external luminosity that makes it possible to acquire suitable images in all illumination conditions at the desired distances. Differently from Diaz-Cabrera et al. [6], our approach also uses shape matching to identify pedestrian traffic lights. Also, due to the fact that the device is held by the user, we leverage accelerometers and gyroscopes to compute the device's position in space and correctly detect and measure the distances between the user and the pedestrian traffic light.

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