Computer Vision-based System for Impaired Human Vision Compensation

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***Abstract*—This paper presents a high-level architecture of a computer vision-based system for partial compensation of lost or impaired human vision. It combines standard smartphone device, external deep learning-based image processing infrastructure and audio/tactile user interface. The proposed architecture is based on input from user-centered design process, involving end-users into system development. The paper discusses user needs and expectations for electronic travelling aids for the blind and highlights limitations of the existing solutions. The suggested architecture may be used as a basis for developing computer vision-based tools for visually impaired individuals.**

***Keywords*–computer vision; deep learning; mobile application; aid for blind and visually impaired; audio feedback; tactile feedback; impaired human vision compensation; user-centered design.**

I. INTRODUCTION

More than 250 million people worldwide have moderate to severe vision impairment, while ($\approx$ 36 million are blind) [1]. During the past decades significant effort was devoted to develop computer vision and other sensor-based aids (e.g., [2]-[5]) for helping the blind and visually impaired users to perceive the surrounding world better. However, computer vision is a rapidly evolving field; systems based on the aforementioned approaches become outdated in a relatively short time and often lack accuracy and reliability in real-world conditions in comparison to the state-of-the-art technologies. In this article, we describe a system, which employs modern computer vision techniques for compensation of lost or impaired vision function in humans. Many of the previously proposed electronic aids for the blind count on highly specialized hardware, for instance smart glasses [5], Microsoft Kinnect sensors [6], helmet-mounted photo sensors and cameras [7]. Such systems often lack convenience and bring additional complexity into daily tasks, which visually impaired people currently manage by the help of a white cane. This project puts major emphasis on developing a tool, which seamlessly integrates with the hardware visually impaired persons already have on-hand and are used to (smartphone). This paper describes a high level architecture of the technology aid for visually impaired people utilizing the latest achievements in the field of computer vision.

We begin our presentation with Section II, describing the methodological foundations of this research. Section III focuses on the architecture of the suggested human vision compensation system. Finally, Section IV summarizes and discusses the results of the conducted analysis.

II. METHOD

Following the principles of the participatory design [8][9] we included end-users into system design process. Two visually impaired persons participated in discussion and focus group meetings together with the project team to identify the key properties of the solution. During the six discussion sessions, major attention was paid to:

1) Functionality and key features of the solution addressing real-life scenarios of visually impaired persons;
2) Technical feasibility, connecting user needs to the latest development in computer vision and assistive technologies;
3) Interface between the visually impaired person and the assistive technology;
4) Appearance, usability and potential costs of the proposed product.

Participatory design process included testing of assistive technologies for the blind and visually impaired people using widely available mobile phone apps like Seeing AI, BlindWays, Be My Eyes, Aipoly Vision, TapTapSee, etc. Semi-structured tests were performed by visually impaired participants and researchers from the project group. Strengths and weaknesses of the existing solutions are reflected in the design of the proposed system.

To have an overview on research progress on assistive technologies for the blind during the last ten years, a systematic literature review in three major research databases (Medline, IEEE xplore and ACM DL) was conducted. It revealed increasing research interest in the field (84 related publications were identified, while 17 were characterized as highly relevant for this project) and provided better understanding of the state-of-the-art in applying computer vision technologies to address the needs of the blind. The review was extended to relevant patents and patent applications worldwide. The search was performed in the following databases: EspaceNet, GooglePatents, USPTO, PatentScope, FreePatentsOnline. It revealed several technological trends in the field of assistive technologies for the blind persons. Based on the aforementioned reviews, our insights are presented in the Results section.

III. Results

User-centered design sessions with visually impaired persons and analysis of the aforementioned data sources provided substantial input for the design of the proposed system (Figure 1). The process made it clear that understanding of the user needs was limited in the project team. Based on the results of the user-centered design process, scientific publications and patent analysis, we present the outline of the system for impaired human vision compensation.

The key part of the proposed system is a smartphone device, connecting User interface (UI) and data processing components into a well-functioning ecosystem. Smartphone was selected due to its high availability and capability to perform required computations or forward visual information for processing to the external server via the Internet.

UI consists of a wearable forehead belt, integrating RGB and depth cameras, Inertial measurement unit (IMU), tactile feedback device and bone conduction headphones. Although more expensive than standard ones, bone conduction headphones do not block the ears and allow the user to perceive audio information from the surrounding environment and the system at the same time, which is essential for the visually impaired people.

However, some types of guidance information may be more efficiently perceived through tactile feedback device than audio channel. For instance, indicating the direction of a detected object with a vibromotor on the corresponding area on the forehead belt, instead of providing audio description. More research is needed to clarify how various types of guidance information should be represented to the user in the most convenient and efficient way. For instance, the detected objects could be presented to the user in a configurable order, based on the subjective importance of particular object classes or other personalized criteria. USB and Wifi data links can be used for bidirectional data transmission between UI and smartphone component.

Although modern high-end smartphones are powerful computational devices, many computer vision algorithms require hardware of significantly higher processing capabilities (e.g., a server equipped with a high-end Graphics Processing Unit (GPU)). Therefore, an external server is used for live video data processing. In our design we envision a computational server hosting a set of computer vision algorithms implemented and exposed via web services: faster Regions with Convolutional Neural Network features (faster R-CNN) object detector [10], trained to detect important objects, Convolutional Neural Network (CNN) and Recurrent Neural Network-based (RNN) scene descriptor [11], which provides textual annotation of a given RGB image, place recognition [12], face detection and recognition [13], obstacle detection [14], action recognition [15], among others. After video analysis is completed on the server side, results are transmitted back to the smartphone component and represented to the user through the aforementioned UI.

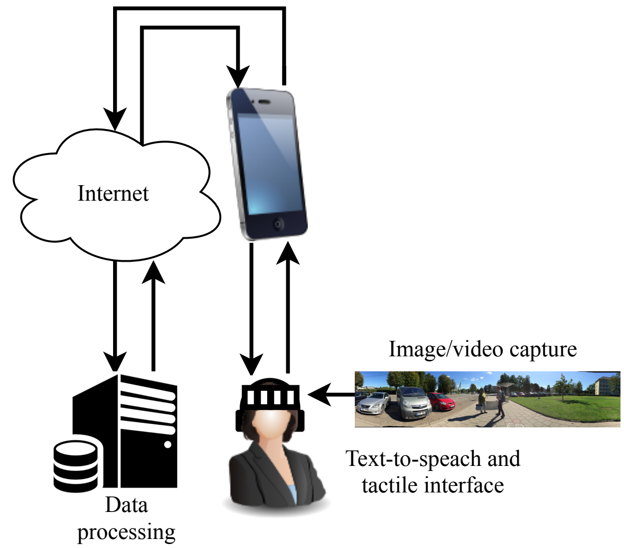

Figure 1. Schematics of vision compensation device.

The user interacts with the system through gestures, voice commands or specifically designed user interface on the smartphone. User input is required for selecting operation mode of the system, i.e., switching between Optical Character Recognition (OCR), currency recognition, object detection, navigation aid and other available functions.

Social networking functionality was highlighted as a potentially important feature allowing other users/volunteers contribute to up-to-date and high quality guidance (for instance, temporary road works) with exact location and description. Navigating around such obstacles can be challenging for computer vision-based tools and may decrease user's trust in the tool. Integration of additional information from other users, governmental organizations and volunteers could be of high value for the visually impaired people.

Discussions on the key features of the proposed solution revealed a gap between the functionality of the existing tools, which are often focused on advanced navigation and scene description features, and actual user needs. For example, the end-users highlighted that a simplistic solution for navigating is lacking. Major focus was put on an easy-to-use and minimalistic tool, which can be trusted. Reliable object detection, direction and approximate distance to an obstacle were highlighted as the main requirements. To our surprise, only 5-8 distinctive object classes (for instance, buss stop, pedestrian crossing, doors, stairs, etc.) were of major importance while navigating. Additional information, such as type of a passing car, blossoming flowers in the park or a person riding a bicycle was considered as overwhelming and distractive.

Computer vision technology is under rapid development and during the last years made a major breakthrough in performance and efficiency. Deep learning neural networks, which are de facto standard in modern image/video processing in many real-world problems allow to achieve accuracies, similar to that of human decision (e.g., face recognition [13], object detection [10], among others). These models are now well supported by software libraries (e.g., [16]) and dedicated processing hardware is built-in even in relatively low-power computational devices, such as smartphones. These devices are also equipped with 4G Internet connectivity and sufficient computational power to perform partial or in certain cases even full visual data processing locally. The maturity of the aforementioned technologies suggest that our proposed computational aid for visually impaired persons may be highly feasible.

The cornerstone of this project is the interface between the visually impaired person and the assistive technology. We are proposing a combination of audio and tactile feedback, which may improve the interaction between the assistive technology and the user. Similar interfaces were suggested by research communities earlier [4][5], however, existing knowledge on user preferences and evaluation of various options of tactile feedback (types of actuators, placement on the body, frequencies, strength, etc.) is limited.

Appearance, usability and cost of the end product are of major importance to the users. The proposed assistive technology should supplement the tool that visually impaired persons used for decades - the white cane. Using a white cane requires little to no training, has very low costs and is relatively reliable. It provides information on the surrounding objects 1-2 meters in front of the user. While the cane can be used to detect nearby obstacles, electronic travel aid could be beneficial for longer range (2-10m) route planning and object detection. However, it should integrate seamlessly into the existing navigation practices of visually impaired people.

IV. Discussion

This paper outlined a high-level architecture of a computer vision-based system, which may help to partially compensate impaired or lost human vision. The main advantages of therein suggested system are: ability to use efficient (but still computationally intensive) modern computer vision algorithms via the Internet connection and present the output of the video processing to the user through a combined audio/tactile interface.

Similar functionality has been previously addressed by research communities [2]-[5] and industry [17][18]. The main difference between the aforementioned commercial solutions and the proposed system is the ability to utilize external resources for computationally intensive image and video processing tasks. While the availability of the computational power could be seen as the main advantage, it comes with high cost - dependency on a well-functioning mobile broadband. The development of the high-speed mobile networks (4G and 5G in the nearest future) is likely to make the major limitation of the proposed architecture obsolete, especially in densely populated areas containing many hazards for the blind. On the other side, increasing computational power of smartphones may also allow to perform more advanced image and video processing locally. Although not always technically feasible, local processing is especially important in low connectivity areas to ensure at least partial functionality of the system. Combined audio/tactile interface may also be more convenient for the users, allowing to provide feedback in a more efficient way than using tactile or audio interfaces separately.

Both open source (e.g., [16]) and state of the art commercial computer vision software libraries (e.g., [19]) may be applied implementing the suggested architecture. Moreover, a detailed specification of the suggested hardware components, following open hardware approach (providing an open repository containing a detailed list of electronic components, schematics, and 3D models of mechanical parts) could provide a solid basis for semi-standard reference platform for the researchers in the field.

It is important to emphasize that the suggested system does not aim to replace the main travelling aid of visually impaired people - the white cane. Instead, this computer vision tool aims to enhance and push the perception of the surrounding environment boundary from 1-2 meters (achieved by using the white cane) to 2-10 meters. It may improve route planning and identification of objects of interest (for instance, doors, stairs, elevators, bus stops, etc.). This functionality corresponds with the main requirement for electronic travelling aids highlighted by the end-users - direction and distance estimation to a selected object. The proposed hardware architecture can be used as basis for various computer vision-based software modules, aiming to assist visually impaired users in daily activities (e.g., outdoor/indoor navigation, object/face recognition, obstacle detection, etc.).

The proposed architecture is based on several assumptions, which may be characterized as limitations of the system. For instance, technical feasibility of the solution is dependent on the availability of high bandwidth Internet connection ensuring access to high-power data processing components. Insufficient bandwidth may result in latency, which may not be tolerated by the users.

Economical feasibility of the proposed solution may also be questioned. Advanced technology (high-end smartphone, depth camera, tactile feedback device, bone conduction headphones) is needed to ensure reliable functioning of the system. A combination of such components may be perceived as costly by the end users. More research is needed to demonstrate the cost-benefit analysis of the system in real-world scenarios.

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