Contribution of Augmented Reality Solutions to Assist Visually Impaired People in Their Mobility

Benoît Froissard[1,2], Hubert Konik[2], Alain Trémeau[2], and Éric Dinet[2]

[1] Laster Technologies, Courtabœuf, France
benoit.froissard@laster.fr
[2] Laboratoire Hubert Curien, Université Jean Monnet, Saint-Étienne, France
{hubert.konik,alain.tremeau,eric.dinet}@univ-st-etienne.fr

Abstract. The study is dedicated to analyze opportunities of augmented reality eyewear solutions for visually impaired people in a context of mobility. In order to perfectly understand the needs of low vision individuals, their expectation towards visual aids, and to clearly define crucial requirements, an experimental study has been carried out in a re-adaptation clinic. 58 patients with different visual pathologies have been carefully selected by vision-care professionals. During experiments and interviews, professional techniques developed for teaching patients to efficiently use their visual residual capabilities have been analyzed. One of the main objectives was to show the usefulness and the importance to put in the loop all actors to be able to derive relevant knowledge essential to success in the design and in the development of new visual aids dedicated to facilitate mobility of low vision people. The first results are encouraging and they tend to demonstrate the interest to use embedded augmented reality systems in order to propose helpful solutions easily adaptable to the specificities of the different visual troubles affecting mobility.

Keywords: Visual impairment, augmented reality, virtual reality, eyewear, residual capability, handicap compensation, optometry, mobility aids.

1 Introduction

Visual media are becoming more abundant in our daily life and a core constituent of information and communication technologies. This leads the emergence of new needs, changes in behavior, consumption patterns and distribution practices. Today people are less and less refractory for new technologies like smartphones or other embedded systems. Such elements motivate the study presented in this paper. This study is dedicated to analyze opportunities of augmented reality eyewear solutions for visually impaired people in a context of mobility. By adopting credible tools, acknowledging the importance of significantly improving visual impaired condition, mobile visual aid systems answer a critical societal problem.

There are around 285 million of visually impaired people in the world. Aged related Macular Degeneration (AMD) is for example one of the most important visual disease in occidental countries. The forecasts of the World Health Organization

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highlight a major risk it is necessary to face. In this context, developing adapted tools is urgent. Nowadays, the only primary aids offered to visually impaired people for independent mobility consist of different types of canes. Even if electronic travel aids exist and even if they were initially designed to replace canes, they are ultimately used as secondary aids. The main reason of the low success of assistive technologies in the context of navigation is the lack of significant additional information provided by electronic aids to low vision individuals. During the past years many research teams proposed different assistive technologies or solutions to compensate visual troubles. Meanwhile, few researches have been conducted on wearable systems exploiting the residual vision of visually impaired people to assist them in mobility. However, professionals working in the field of low vision agree to say that it is important to stimulate the residual vision early in the sight-loss process.

Many new technological devices such as cell phones, smartphones and augmented reality eyewear are being developed to give to anybody new information and new way to access to information. These devices could be used to help visually impaired people in their daily life by providing salient useful information or enhancement of targeted information.

In the following, a state-of-the-art of works using augmented reality for visually impaired people is presented in Section 2. Section 3 overviews the main visual needs of low vision individuals. Section 4 presents a first work on edge enhancement that we have implemented and tested on an augmented reality device in order to provide additional useful information to visually impaired people. Results obtained during experiments carried out in a re-adaptive clinic are summarized and discussed in section 5. The last part of the paper is dedicated to a brief conclusion and to put into perspective this work in the context of mobility.

2 Related Work

Nowadays some systems take into account the needs of visually impaired people but always in a specific context. For example, the virtual reality solution named "sightmate" is mainly devoted for reading and watching television. This solution exploits low level image processing methods such as edge detection, enhancement, or MPEG modification introduced by Peli *et al.* [1]. Such a tool seems to be useful but only for patients with enough visual residual capabilities from 20/70 to 20/200.

Many studies in neuroscience demonstrated that contrast is a very important low level feature for human visual system. The main problem with contrast is the large number of definitions (e.g. physical contrast, perceived contrast, etc.). According to Peli *et al.*, virtual reality systems should measure, enhance, and adjust contrasts of virtual scenes or natural images in order to help visually impaired people [2]. In some visual activities such as reading, image processing is very useful for individuals with low vision, for instance when text is enhanced [3].

In a general way, low level image processing is used to enhance low visual information in 2D images such as edges or colors, whereas 3D computer vision can be used for object recognition and depth perception. Such an approach can significantly contribute to improve the visual perception of low vision people but must be carefully managed to not trouble their residual visual capabilities. Some studies have shown that virtual reality and augmented reality could create inattentional blindness [4]. By multiplexing too much data, there is a risk to mask a more or less important proportion of real information. In such a case, observers can face some troubles to perceive their environment as it is in comparison with direct observation.

In [5], Balakrishnan *et al.* proposed to use a head mounted display coupled to a stereo camera system in order to enhance in real time the visual perception of low vision people. One of the main advantages of this type of device is that it allows an access to information regarding the surrounding environment and the location of scene's elements. According to Chauvire *et al.*, optical see-through eyewear should be used as a visual aid [6]. Peli *et al.* also demonstrated that optical see-through eyewear should help visually impaired people by modifying edges [7-9]. However, they noticed that their edge detector [10-11] is unfortunately not well-adapted to this kind of use because it needs black and white to enhance edges [12].

3 Visual Needs of Low Vision People

Most of visually impaired people are elderly. According to Newell *et al.* [13], these people have more troubles than others to correctly use new technological devices and are not always self-confident in their manipulation. Therefore, it is essential to adapt new technologies by taking into account the habits and the reflexes acquired from interfaces that are now obsolete. To achieve such a goal, Newell *et al.* [14] proposed to put in the loop the users for developing new solutions or new methodologies. The point of view of visually impaired people is very important for researchers to know what should be the main functionalities, how to design an ergonomic visual assistive device, how to imagine a convenient and friendly user interface, how to improve the acceptation of visual aids by users. These questions were studied and analyzed by Shinoara *et al.* in [15].

In order to understand the needs of visually impaired people, their expectation towards visual aids, and to define the essential requirements, an objective experimental study has been conducted in a re-adaptation clinic. 58 patients with low vision have been carefully selected by vision-care professionals. One of the main goals of this study was to put in the loop both patients and vision-care professionals in order to understand what are the visual needs of visually impaired people and how specialists work with them. One of the main objectives of this paper is to show that from the collected data and the derived knowledge, we could design and develop visual aids correlated to the needs and expectations of visually impaired people. Re-adaptation methods used by vision care professionals could inspire the development of solutions adapted to each user and to his/her residual visual capabilities. Vision-care professionals such as orthoptists, opticians, ergo-therapists or locomotion instructors explained the methods and approaches they use with patients. Their practices differ according to their medical specialty:

- Orthoptists analyze the residual visual capabilities and eye-oculomotor fluency of patients. The objective is to train patients to autonomously use their residual capabilities to compensate their visual problem. Generally, after a training period, visually impaired people are able to extract more information from real world by themselves and they can achieve all, or quite all, of their daily tasks with more abilities than before. In this context, augmented reality displays or any type of optical or electronic devices can help low vision individuals into their daily life activities.
- Ergo-therapists analyze movement of patients during near and middle vision tasks such as cooking, eating, as well as for domestic and professional activities. For professional activities, ergo-therapists precisely analyze the working environment to accordingly adapt the residual visual capabilities. The objective is to train patients to better know how using their own capabilities to understand the world, and how to interact with their direct environment.
- Locomotion instructors analyze mobility capabilities of low vision people and how they can find useful information to walk freely and confidently. Patients learn how to: extract information; analyze their surrounding environment; know where they are and how they can go to a targeted destination. These kinds of tasks are very important for patients, especially when they need to navigate by their own inside their home. Patients also learn how to analyze information from canes, sounds, and other signs to have access to complementary information from the world. In outdoor environments, visual information from the surroundings as zebra crossing, traffic ways or number of ways are essential for visually impaired people to navigate freely and safely. Locomotion instructors advise and help low vision patients to use assistance solutions to facilitate their mobility.

To sum up, different categories of vision-care professionals can help visually impaired patients by learning how to exploit different types of features, especially visual features. Visual features are very informational for low vision people but they are sometimes not enough perceptible by them. Therefore, one of the main functionalities of a visual aid is to enhance these visual features to make them more informational and more discriminative. After discussion with vision-care professionals, we conclude that visual aids must only enhance the most important visual features to avoid a counterproductive overrepresentation. We also conclude that visually impaired people must exploit their residual visual capabilities when they use such aids and that they should not be totally assisted. Some orthoptists strongly insisted on this last point.

We interviewed patients and asked them to answer to binary questions related to: a particular need (e.g. recognizing faces or reading), the possibility to perform one daily task in autonomy (e.g. walking or cooking), expectations regarding the use of any future assistive solution (e.g. virtual reality or augmented reality), etc. As an example, here is one specific question: “Are you able to walk alone for a short unknown pathway in full self-confidence?” Questions were asked in the mother speaking language of patients to avoid any misunderstanding problem. Table 1 presents an overview of data collected from 24 visually impaired patients. This table summarizes the ratios of the answers of patients to several questions about daily tasks performed in full autonomy.

Table 1. Results related to particular daily tasks

Tasks performed in autonomy	Can do it (%)	Cannot do it (%)
Doing a short known walk	66.7%	33.3%
Doing a short unknown walk	41.7%	58.3%
Doing a long walk	50.0%	50.0%
Shopping in a supermarket	66.7%	33.3%
Recognizing faces	25.0%	75.0%
Reading	33.3%	66.7%

Table 1 shows that mobility activities -long walk and walk onto unknown pathway-cannot be performed in autonomy with self-confidence by many visually impaired people. It is difficult for these people to adapt to new environments. According to our interviews the expectation of low vision individuals is to have access to additional information in order to overcome this issue. For a walk in a well-known area, only 33.3% of patients face some difficulties; on the other hand for a walk in an unknown area, 58.3% of patients face difficulties. Unknown areas are very challenging for patients. Two other main activities which need aids to be performed in autonomy are face and people recognition as well as reading. Face recognition is a very difficult visual task, only 25% of patients can achieve it easily.

4 Edge Enhancement for Low Vision People

Several studies have shown that edges are one of the main visual features useful for low vision people. Consequently, in our experiments we firstly tested the hypothesis that edge enhancement can help visually impaired people to better perceive their environment. The main questions we addressed in this study were what do we mean by edges, by edge enhancement, and by improving visual perception from edge enhancement?

Depending on the observers and on their residual visual capabilities, depending on the visual task to carry out or depending on the task to perform, edges are not perceived in a same way and the expectations of users in term of edge enhancement are not identical. In the everyday life the content of scenes may vary as well as the ambient light conditions. Sometimes under direct illumination there are some spot lights and shadows, sometimes under dim light objects are not well contrasted. Consequently, that does make sense in this context to use an adaptive edge detector. We could for example consider an edge detector invariant to photometric changes but this type of detector will not satisfy all expectations of all users. We could consider another edge detector, for example, more robust to image changes but once again this will not satisfy expectations related to semantic features. All these observations suggest that the visually impaired people should be able to interact with the edge detector in order to easily adjust edge detection and edge enhancement, according to the context and in function of the expectations of the moment.

In order to evaluate the relevance of different techniques of edge enhancement, we asked to selected patients to compare original images with their enhanced versions. Patients have been divided in two groups because this experiment was performed during two different periods. For this experiment, we considered a set of 48 images of indoor environments, offices or home interiors. All pairs of images (original and enhanced images) were displayed in a random order on a calibrated display. The first objective of this experiment was to validate the hypothesis that edge points superimposed to real world data improve the visual perception of people with low vision when they analyze a scene.

For each pair of displayed images, patients were asked to answer to the following question: “Among the two displayed images which one is easier to analyze?”. During a training phase, the meaning of the question was explained to participants in order that they perfectly understand the relation with recognition and interpretation tasks. Patients could display as many times as they want the two versions of images forming each pair. Observers were allowed to move freely their head and eyes during the experiment. The duration of an evaluation session was about 30 minutes on average.

Few elderly people participated to this experiment (13 out of 58). In general, elderly people face some troubles with new technology devices [15]. However, most of elderly observers involved in the experiment (10 out of 13) were able to perform the evaluation session without any help. When necessary, we assisted patients by switching images when they required.

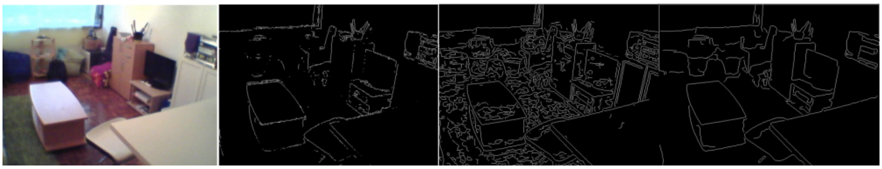

Fig. 1. Examples of edge detection: respectively Sobel, Canny, and the pyramid-based method that we have introduced. Let us note that the quality of images of most of micro cameras used by see-through eyewear systems is very low. Here the resolution of each image is 640×480 pixels.

Many studies conducted in neuroscience demonstrated that contrast is a very important low level feature for non-disabled observers and also for people with low vision. In [16], Haun *et al.* reported that “the perceptual impact of an image, and the way its contrast is interpreted by an observer, is dependent on the structure of the image, thereby suggesting that perceived contrast of complex imagery is not an entirely passive process”. As mentioned above, the main problem with contrast is that there are numerous definitions and numerous computing formulas. In our experiment we compared four standard edge point detection methods (Fig.1): Sobel, Canny (computed either from grey levels only or from color) and a pyramid-based method we developed for our experimental protocol [17-21]. The pyramid-based method uses a real-time multi-scale framework for the selection of the most contrasted edges.

In our experiment, extracted edge points were superimposed to the original image. Four different colors of edges were used during the display (yellow, green, red and blue) and 4 thicknesses were considered. Edge thickness was adjusted according to the visual acuity of patients: the thinner for 10/10, the thicker for 1/20 and two intermediate values for 3/10 and 1/10.

5 Data and Results

5.1 Statistics on Visually Impaired Patients Who Participated to Experiments

Group 1 was composed of 28 visually impaired patients: 2 were less than 40 years old, 5 were between 41 and 60 years old, 14 were between 61 and 80 years old, 7 were over than 81 years old. 82% of these patients were retired. The experiment carried out with this group took place in a re-adaptation clinic for people with low vision. Group 2 was composed of 30 visually impaired patients: 1 was less than 40 years old, 10 were between 41 and 60 years old, 13 were between 61 and 80 years old, 6 were over than 81 years old. 63% of these patients were retired. We classified these patients according to their visual acuity (see Table 2) and according to their pathology (see Table 3). One group performed the experiment in a dark room with images displayed on a CRT device, while the other performed the same experiment under normal light conditions (300cd/m2) with images displayed on a LCD device. Let us note that no statistical disparities were found between the data collected from these two experiments.

Table 2. Classification of patients according to their visual acuity measured for both eyes

Far visual acuity	Group 1	Group 2
Higher than 5/10	4	12
Between 1/10 and 5/10	23	24
Between 1/50 and 1/10	15	15
Lower than 1/50	14	9

Table 3. Classification of patients according to their pathology

Visual pathology	Percentage of patients
Scotoma	67.2 %
Tunnel vision	29.3 %
Eccentricity	6.9%

5.2 Statistics on the Gain Resulting from Edge Enhancement

82 % of people with low vision preferred the enhanced images whereas 17% preferred the original ones. Only 1% had no preference. Whatever the image shown and whatever the pathology and the residual visual capabilities of observers, most of them preferred enhanced images (see Table 4). However, when we consider one by one

Table 4. Improvement rate due to edge enhancement with edge thickness adapted to the visual acuity of patients

Visual pathology	Does edge enhancement help people with low vision to better analyze images?
Patients with a scotoma	Yes for 77%
Patients with tunnel vision	Yes for 68%

Table 5. Preference rates for each edge detection method

Edge detection method	Patients with a scotoma	Patients with tunnel vision
Edges	79 %	87 %
Sobel	59 %	67 %
Canny	47 %	47 %
Color-Canny	32 %	53 %
Pyramid-based approach	65 %	67 %
Pyramid-based vs Sobel	86 %	88 %
Pyramid-based vs Canny	94 %	100 %
Pyramid-based vs Color-Canny	89 %	88 %

each pair of images, there are some subtle differences between results. It appears that the answers depend on various parameters, such as the content of the scene, the lighting conditions under which the image of the scene has been captured, the recognition task, the interpretation task, etc. Most of observers explained that they prefer to see local edges enhanced only on certain areas rather than on the whole image.

According to Apfelbaum *et al.* [12], for visually impaired people, the edge detection is the crucial step before the edge enhancement step. To confirm this assumption, for each edge detector tested we analyzed the percentage of enhanced images for which all patients expressed a preference in comparison with the images without enhancement and in cross-comparison with the other edge detection methods. The first row of Table 5 illustrates the proportion of observers who expressed a preference for enhanced images (whatever the method used) rather than for non-enhanced images. The following rows illustrate the relevance of each specific method by cross-comparison with the other methods. The improvement due to edge enhancement is clearly demonstrated. Moreover, these results demonstrate that the pyramid-based approach outperforms the others. Whatever the pathology, there is a clear difference between the percentages of enhanced images for which all patients expressed a preference for the pyramid-based method.

6 Discussion

According to the conclusion of reference [12], a development of a dedicated edge detector for visually impaired people is necessary. In our study, we have proved that the quality of edge detection plays a pivotal role in edge enhancement and in image improvement for low vision people. We have also shown that the quality of edges depend on various factors which vary in function of many parameters.

From the surveys we conducted and from the discussions we had with visually impaired patients and vision-care professionals, we can argue that augmented reality optical see-through eyewear could be a relevant solution to improve the visual perception of low vision people and that this type of system could be efficiently used as a visual aid. The experiment performed in this study contributes to prove that additional information multiplexed with real scene is beneficial for visually impaired people and could help them in their daily life, for object recognition (e.g. in kitchen, office), for environment understanding (e.g. localize doors in a corridor, stairs in a building), as well as for basic visual tasks (e.g. reading, watching TV). Our experiment relied on multiplexing real visual data with low level features based on edges.

We also developed a real-time edge detector for videos. Corresponding experiments with low vision patients will be carried out to test it in real mobility conditions. The main constraint in this domain is to obtain the required authorizations from accredited authorities to develop the experimental protocol. At short term, in the context of mobility, we aim to validate: (a) the edge detector and the multiplexing technique that we have defined, (b) the usability of the augmented reality eyewear system that Laster Technologies has designed, (c) the relevance of the interactive software solution that we have developed specifically for visually impaired people.

Other parameters, out of the scope of this paper, such as technological characteristics (e.g. the consumption and the autonomy of the system) or ergonomic parameters (e.g. the weight of the system) have to be taken into account to ensure the success of assistive technologies in the context of navigation. These additional parameters will be studied during new interviews of both low vision patients and vision-care professionals.

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