Smart Cap for Visually Impaired in Disaster Situations

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ABSTRACT

Natural and manmade disasters pose a myriad of challenges, which are more severe for individuals with disabilities. Ordinarily to perform daily activities, the disabled get support from assistive technological devices and services; these are commonly disrupted during and after disasters. A proposed solution to support those with visual impairment is a cost-effective wearable 'Smart Cap'. The Smart Cap provides narratives about the surrounding environment while establishing communication between the user (the visually impaired) and a rich online reservoir of knowledge base system capable of vocalising narratives. As a proof-of-concept, this study is implemented using Raspberry Pi, the Amazon Web Services and a P-Cap fitted with a camera. The aim of this research work is to provide an assistive technology to help the visually impaired navigate their way out of any potentially disastrous situation like other citizens would. The proposed system and its usage in disaster situations is an innovative, cost-effective solution specifically addressing the needs of visually impaired persons.

Keywords

Visually Impaired, Resilience, Disaster, Smart Cap, Internet of Things.

INTRODUCTION

Our world is witnessing a growing occurrence of different disasters either natural or manmade almost daily (Bar-El et al., 2013) and no society can claim immunity against disasters. Most countries have commenced focusing on their disaster management plan by emphasising disaster risk reduction and enhancing the readiness of different organisations; in New Zealand, according to the Civil Defense Emergency Management Act 2002, the importance and emphasis on preparedness requirements and plans are highlighted (Ministry of Civil Defence and Emergency Management, 2002; New Zealand Legislation, 2017). Nevertheless, it is believed that these plans will be more effective, if the requirements and demands of all citizens from different groups are considered and addressed. In the other words, the plan requires all-of-society engagement and partnerships (Duncan, Parkinson, & Keech, 2018). However, in most cases, there are some neglected communities like physically challenged people who require additional and often special needs. People living with visual impairment are unable to experience the world the way people with normal eyesight do. A fundamental challenge faced by this group of people is the inability to navigate between locations effectively like people with normal eye sight would. In non-disaster situations, these people have access to different assistive technological aids and supporting services; however, during disaster situations, these supporting devices and services may become either unavailable or inaccessible.

Depending on the disaster type and severity, the aftermath can disrupt different infrastructures and the fundamental services provided by government that people rely on. This interruption can seriously impact the lives of citizens and people living with conditions. Furthermore, the situation is made even worse for physically challenged individuals. According to the American Foundation for the Blind, this group of individuals has been identified as a vulnerable group that is highly impacted by the influence of disasters (American Foundation for the Blind, 2016). The study discovered that Christchurch New Zealand's 2011 earthquake and Japan's Honshu Island earthquake of 2016 affected people with visual impairment, and particularly the older adults.

Today, many physically challenged individuals depend on assistive technologies to undertake their day-to-day activities. As a result, they will require additional support during and after disasters especially when the infrastructure and other services are unavailable. Different disaster management plans (Duncan et al., 2018; Ulmasova, Silcock, & Schranz, 2009; World Health Organizations, 2011) have been put forward addressing groups with special requirements. Compared to the diversity of the problems and their population, this is still minimal (World Health Organization, 2017). The term ‘disability’ covers a wide range of disability forms; this study however, focuses on individuals living with visual impairment. A World Health Organization (WHO) report states that there are 285 million people with visual impairment worldwide. According to their statistics, of this group, 39 million are partially blind and more than 1.3 million are completely blind. In most industrial countries, approximately 0.4% of the population is unsighted and in developing countries, it rises to 1% (World Health Organization, 2017).

During disaster situations, those with impaired vision have greater need for assistance and experience more difficulty accessing accurate information than the general public. Disabled people are often excluded from disaster emergency plans while communication, support, mobility, safety, and access to evacuation centres are common concerns (Peek & Stough, 2010). Global positioning system (GPS) has been shown to be unpredictable in the aftermath of earthquakes since the topological terrains become altered hence, roadways and footpaths become blocked and inaccessible (Goods *et al.*, 2016). This becomes particularly traumatic for people with visual impairment as familiar landmarks disappear, road blocks and detours are created, and traffic signals and lighting systems are destroyed.

Recently, the need for navigation and positioning aids has increased. Almost all persons with impaired vision use some sort of systems, services, devices, or equipment to help them make their activities easier and provide safe mobility (Duncan et al., 2018). Most of these aid devices and services are designed for normal situations; only a few have taken emergency or disaster conditions into account. The visually impaired and blind population have been neglected in most disaster management plans (Duncan et al., 2018). Many government disaster relief agencies are yet to address key issues pertinent to the physically challenged during disaster situations, such as what is the government’s plan to provide proper support and safety maintenance for the disabled? Has the government considered the disabled in their resilience and preparedness plans? Is there any specific evacuation plan for the physically challenged by considering their special needs? Special requirements need to be taken into consideration and enshrined within the disaster management framework. This research attempts to understand these requirements and challenges while providing a proof-of-concept within the context of the visually impaired during and after a disaster occurrence.

The Blind Foundation of New Zealand (2018) have outlined specific needs for this category of people during a disaster, which include: the availability of support persons that could lead them to safety, or the use of a guide dog (harness) that could lead them to safety while taking along a home emergency survival kit. In the absence of these, the Blind Foundation of New Zealand advises on the use of a white cane for safe navigation to safety. However, the submission by Royal New Zealand Foundation requires the presence of a second party, which during a disaster situation may prove difficult because the second party could be helpless or scampering for safety as well. Therefore, the proposed smart cap offers a reliable and safe navigation system to safety without requiring a second party. The Smart Cap is both an all-purpose solution that can be used on any occasion and during disaster situations, as it offers some unique features like, not requiring the deployment of specialised equipment. Other unique differences in comparison to other disaster aid support for the visually impaired are outlined in table 1.

Table 1. Unique Features of Smart Cap in Comparison to some Disaster Response Systems

Aid Type	Limitations of Aid Type	Smart Cap’s Uniqueness
Support person	Support person may be unavailable, trapped or scampering for safety too.	User only needs to wear the smart-cap to navigate to safety and does not require help from a support person.
Guide dog (harness)	Could be trapped, killed or even traumatized due to disaster.	User only needs to wear the smart-cap to navigate to safety; can augment or replace the need for a guide dog.
White cane	Ineffective as it cannot be used to map a pathway to safety during disaster.	A smart cap be used to map a pathway during disaster.

The objective of this research study is to design an assistive wearable cap for the blind or visually impaired persons. The proposed solution presented is an assistive wearable 'Smart Cap' that helps people with visual impairment interact and navigate their way to safety by wearing a cap fitted with a camera, which interacts with an online voice navigation system (Smart Cap). This solution could support visually impaired people to navigate their way to safety as well as identify dangerous objects, ditches, fire and flood water scenarios after disasters. The organisation of this paper is as follows: firstly, a discussion on related assistive technologies for the visually impaired are highlighted. Next, a description of the design of the proposed solution along with the physical implementation of the Smart Cap is presented. The paper concludes with some proposed future work.

Table 2. Assistive Technologies for Visual Impairment Problems

Technology	Description	Functionalities	Limitations
BrainPort V100 (Wicab Inc, 2017)	This device provides mild electrical stimulation patterns over a person's tongue based on the information translation of the wearable video camera.	▪ An electro-tactile stimulation to assist the blind for mobility and object recognition	▪ Not useful for text and sign recognition ▪ Mostly suitable for totally blind individuals ▪ Users need to learn how to interpret the signals on their tongue
Eye cane (Watrin, 2014)	Augments or translates point-distance information (5 meters) into auditory and tactile cues for people with impaired vision.	▪ Enhanced navigational abilities ▪ Covers greater distances (5 meters) and more angles compared to traditional White-Cane ▪ Allows visually impaired person to have better distance estimation ▪ Helps navigate from obstacles	▪ Not useful for text and signs ▪ Limited to obstacles identification
Vision smart glasses (University of Oxford, 2014)	A navigational pair of glasses, which helps the visually impaired to navigate paths and avoid obstacles.	▪ Enhanced awareness of surroundings through spatial awareness ▪ Helps navigate past obstacles ▪ Enhances people's social interaction	▪ Limited to only people with partial blindness and not suitable for the totally blind
Screen readers (American Foundation for the Blind, 2007)	A software program that reads the displayed text on a computer screen for the blind or visually impaired person	▪ Acts as a navigation interface between user, OS and the computer programs ▪ Enhances a person's interaction with computer/electronic devices ▪ Reads or spells words, sentences or complete text. Content searching, and audio notification searched content.	▪ Use is limited to the computer or other portable electronic devices ▪ learning to listen to speech output is challenging and takes time for users to use to it
Screen magnifiers (American Foundation for the Blind, 2007)	A software program that magnifies text for people with low vision	▪ Text or graphics enlargement on electronic devices/screens ▪ Can follow mouse or keyboard command prompt	▪ Not suitable for blind or near blind people ▪ Limited to computer devices and not for the environmental signs in disaster.
Smart braille watches (Pulvirent, 2017)	A smart watch for the blind, fitted with sensors to help with time notification and alerts	▪ Displays time using up to four braille characters at a time ▪ Vibration and touch sensor for tactile recognition of time notification and alerts	▪ Usage is limited to alerts and notifications. Other functionalities become unusable to the blind

Table 3: Unique Features of Smart Cap Matched Against the Special Needs of the Visually Impaired During Disaster/Emergency Situation

Special needs of the visually impaired	Unique qualities of Smart Cap for disaster/emergency situations
▪ Need or expect special rescue efforts	▪ Smart Cap is used independently to navigate a damaged path
▪ Desire confirmation of blurry images	▪ Smart Cap is ideally suited to those with severe impairment in a disaster situation
▪ Need a confirming 'calm voice' in a disaster/emergency situation	▪ Smart Cap is excellent for those living alone (often overlooked in emergencies)
▪ Extra support in unfamiliar circumstances or environments	▪ Smart Cap can be used immediately in disasters if relief efforts are stretched
▪ Disabled need to do things for themselves	▪ Smart Cap confirms and relays information clearly (when normal communication channels are disrupted)
▪ Need familiar, unchanging environments	▪ Smart Cap is connected to the Cloud thus, navigates if terrain is changed during disaster
▪ Require independence and non-vulnerability	▪ Smart Cap can build confidence in user in emergency situations
▪ Visually impaired need support for atypical activities	▪ Smart Cap is supplements most guide related efforts like the use of a guide dog
▪ Require support in new surrounding	▪ Smart Cap can offer additional support in evacuation centres
▪ Require sensory inputs to concur for greater self-assurance	▪ Smart Cap cleverly combines sensory substitution and position display signals
▪ Need items to be left or stored in the same place, in the same way	▪ Smart Cap can be kept by the door or in an evacuation kit easily when needed

RELATED TECHNOLOGIES FOR THE VISUALLY IMPAIRED DURING DISASTER

The recent advances in today's technological innovations has helped mitigate the adverse effects of the several challenges and problems faced by many people that are physically challenged. For the physically or mentally challenged, advanced technologies have the potential to make their lives easier and more comfortable. In this context, Information Technology (IT) makes the scope of mobile assistive technologies broader (Hakobyan, Lumsden, O'Sullivan, & Bartlett, 2013). IT can assist people with visual impairment continue their studies, work, interact with their communities and maintain an independent lifestyle. Some of the common technologies for this group are screen readers or magnifiers, braille printers and watches, reading and writing assistive devices. More recently, people with impaired vision problems can use some of the most recent technologies such as BrainPort V100, Eye Cane, assisted vision smart glasses, and Amazon Echo. A description of some related technologies, their features and limitations are provided in table 2.

It should be noted most of the IT technologies developed for the visually impaired are mostly designed for normal (non-disaster) situations. To the best knowledge of the researchers, no specific technology or device has been proposed to support and assist visually impaired persons during disaster situations. There are no assistive technological devices that provide basic navigation to safety, reading sign posts to lead evacuees to safety etc. Moreover, most of the available assistive devices are not portable or cannot work as a stand-alone system (such as screen readers). In addition, other assistive technologies are not immediately available, accessible or workable during disaster circumstances. Additionally, immediately after disasters all the routine tasks and procedures are normally changed based on the disaster response plans, to cope with disaster situations and consequently there could be a high possibility that some of the assistive technologies become unavailable or inaccessible due to the occurrence and magnitude of the disaster.

A one-size fits all approach to planning for the different phases of disaster management cannot work. Support agencies and civil defence organisations are overwhelmed and in reality, they have a very limited idea of how many disabled persons live or work in their jurisdiction (Fox *et al*., 2007). Often local authorities unintentionally create more difficulty in their attempt to solve problems, increasing the vulnerability of the visually impaired. Guide dogs often have to be comforted or retrained and also suffer trauma (Goods *et al.*, 2016). Even if support does reach them, people with disabilities can be left behind in evacuated buildings as rescue agencies often do not understand how someone could be unaware of evacuation efforts (Fox *et al*., 2007). In all, it is very necessary to consider the special conditions of people with visual challenges during and after disasters. These people may be challenged with diverse issues during and after disasters (Ulmasova et al., 2009). During disasters, they may have difficulty sensing approaching dangers, reacting in timely manner to avert such dangers, movement to safe locations and sensing the presence of disaster responders nearby for help. Also, after disasters, they may be incapacitated to follow their evacuation camp due to their inability to see.

To reiterate, people with disabilities need to be prepared to do as much for themselves as possible during crises (Gretchen & Phibbs, 2017) and a simple, portable and multi-faceted system such as a Smart Cap that supports, guides and assures the visually impaired in emergency situations would be invaluable.

In this regard, we believe that the proposed Smart Cap solution has a high potential to be of great utility to the visually impaired during and after disasters. This device is portable, with little time required for setup, few hardware/software setup requirements, and besides, it can be deployed and used anytime and anywhere to assist and support the visually impaired. A summary is provided in table 3 of the special needs of visually impaired people and the uniqueness of Smart Cap in addressing these needs.

SMART CAP: DESIGN AND IMPLEMENTION

Mobility assistance for the visually impaired can be categorised into two types. First, the sensory substitution system, such as a cane, which extends the sensing range for the individual. The second is the position display systems, which provides directions or ambient information and is exemplified using acoustic signals or footpath indicators (Amemiya, 2009). According to Ulmasova *et. al*, a combination of visual and audio messages and signals are some of the strategies used for caring for the visually impaired (Ulmasova et al., 2009). The Smart Cap aims to provide support for visually impaired persons in a way that a user can interact with their environment via a device that provides navigational narratives of direction and objects surrounding the user. The narrative is generated by converting the scenes in front of the person to text, which describes important objects captured by the Smart Cap. The design of the Smart Cap is shown in figure 1. In the design, the user (who is visually impaired) can make a voice interaction that interfaces with a cloud-based machine learning database, which helps provide navigational directions and interpret objects around the user. The user can query for directions in order to get to a safe location. A series of program codes have been written in Python, which gets the keywords of captured scenes from the Microsoft Cognitive Services (converts scenes in front of the user to text) and describes the important objects in the scene. The generated text describes important objects in the scene and is saved to the database. This generated text helps users identify objects around them even though they are unable to see the objects. As a result, users are able to identify evacuation signs and thus, glide their way to safety.

Implementation

To provide a proof-of-concept for the implementation of our design, we have used the Microsoft Cognitive Services which interacts with a fitted visual camera to a P-Cap via a Raspberry Pi for interpretation of objects captured by the camera. Figure 1 shows the schematic implementation design of the Smart Cap using a combination of Raspberry Pi, camera and cloud technologies (Microsoft Cognitive Services and Amazon Web Services). In the figure, the input could be voice query by the user or picture taken by the camera that is transmitted via the Raspberry Pi to the Microsoft Cognitive services, which performs task identification. The task is identified, interpreted and stored in the AWS DynamoDB database. For interpretation of tasks, the AWS Alexa Skills kit triggers an event via AWS Lambda, which triggers the function that extracts the text from the DynamoDB and forwards it to Amazon Echo in an audio format understandable to the user. A data/process flow diagram is further shown in figure 2, which shows the interactivity between the cloud-based systems and the input from the user.

A description of the functionalities provided by the cloud technologies used are highlighted below:

- Amazon Web Services (AWS): AWS is a cloud platform that acts as an interface with Internet of Things (IoT) gadgets. This platform is used as a device gateway, rule engine, things registry, security services and thing shadow that ultimately makes the interaction of IoT sensors/devices possible for exchanging, storing and recovering information. In addition, from the created connections through IoT-enabled devices, a rich and comprehensive dataset and functionalities become available and accessible for use.

- AWS Software Development Kit (SDK): AWS SDK helps clients associate the equipment with the IoT gadget.
- Raspberry Pi: The Raspberry Pi publishes the message to AWS-IoT Shadow.
- Microsoft Cognitive Services: Used for tasks and objects identification.

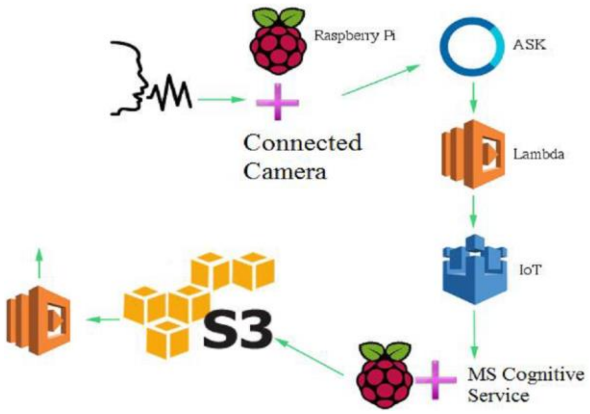

Figure. 1 System Design of Smart Cap

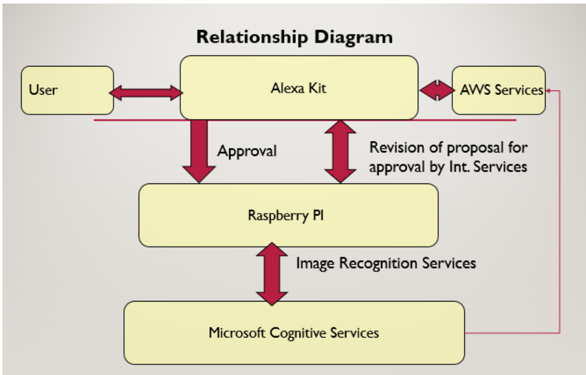

Figure 2. Data and Process Relationship Diagram

Hardware Setup

A list of both hardware and software requirements for the Smart Cap are presented in table 4, while figure 3 shows the full setup of the Smart Cap fitted with a camera and connected to a Raspberry Pi B+ model. The Raspberry Pi is wirelessly connected to the Amazon Alexa that hosts all the AWS services being used in this implementation.

Table 4. Hardware and Software Setup Requirement for Smart Cap

S/No.	Device	Description
1	P-Cap	Used by the user and hosts the camera.
2	Camera	This is fitted to the P-Cap. The Creative live HD webcam was used.
3	Raspberry Pi B+ model	The Raspbian framework was installed and used.
4	Microsoft Cognitive Services	Deployed for image recognition.
5	Amazon Alexa	Deployed in order to use the AWS services

Figure 3. Full Setup of the Smart Cap

TESTING AND EVALUATION

To test the performance of the Smart Cap, an individual stood in front of the camera fitted P-Cap (Smart Cap) with the following result. The image shown in figure 4 was captured, recognised and interpreted using appropriate keywords, which was transferred and stored in the AWS-S3 bucket (storage). The output was further translated and stored in the form of a table in Dynamo DB (see figure 5). In addition, the Python command-line output classification is shown in figure 6. The output provides an easy query-style that can be used by Alexa. Finally, Alexa delivers the audio interpretation of image captured. For clarity, the Dynamo DB generated output of figure 5 is re-presented in table 5.

Figure 4. Captured Image Source by the Smart Cap Camera

Figure 5. A Dynamo DB Table Script Translation of Captured Image

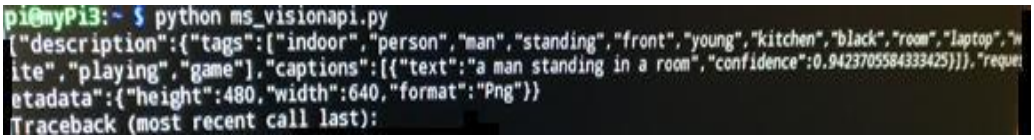

Figure 6. A Python Script Classification of Captured Image

Table 5. Sample Output of an Image Recognition

Image Source	Image metadata	Keywords	Description	Request Id
Smartcap1	Height:480 Width:640	Person, indoor, man, standing, front, posing, black, holding, shirt, camera, room, wearing, large, table, woman, young, white, blue, kitchen	A man standing in a room.	4fe73a03-6197-4daa-8ad9-fb6e9bb468a4

CONCLUSION AND FUTURE WORK

Various research studies have investigated the challenges that disabled people, especially those with visual impairment face during and after disasters. Unfortunately, this group of individuals are constantly being excluded from disaster management plans in different countries, and no specific supporting devices or services are provided for them during and after disaster situations. These people have been identified as a vulnerable group who may be affected dramatically by disasters. Besides their loss of vision, their challenges also extend to mobility and communication difficulty in disaster scenarios.

To address this challenge, this research study has proposed the Smart Cap solution that can be utilised by the visually impaired for normal activities, and especially during disaster situations. This Smart Cap device provides a real-time navigation and narrative system. The device is cost effective (about NZD 200), which makes it affordable and accessible for the wider community who suffer from this problem. We hope that this proposed Smart Cap can be a step to providing the visually-impaired people with the missing support and services they so desperately need during and after disaster situations.

This research work is only a proof-of-work; in our future work, we hope to make a complete standalone version with additional assistive functionalities for the blind.

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