A Smartphone Application Designed to Detect Obstacles for Pedestrians' Safety

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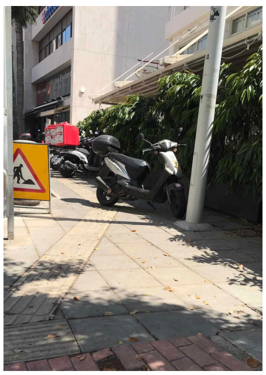
Abstract. Encouraging people to walk rather than using other means of transportation is an important factor towards personal health and environmental sustainability. However, given the large number of pedestrian accidents recorded every year, the need for safe urban environments is increasing. Taking advantage of the potential of citizen-science for crowdsourcing data and creating awareness, we developed a smartphone application for enhancing the safety of pedestrians while walking in cities. Using the application, citizens will monitor the urban sidewalks and update a crowdsourcing platform with the detected barriers and damages that hinder safe walking, along with their location on a city map. To help users assign the correct type of obstacle, and authorities to assess the urgency, a Convolutional Neural Network (CNN) model for barrier and damage recognition is embedded in the application. The results of a user evaluation, based on a group of volunteers who used the application in real conditions, demonstrate the potential of using the application in conjunction with a smart city framework.

Keywords: Pedestrian Safety · Citizen-Science · Crowdsourced Data Collection · Smart City · Obstacle Recognition · Deep Learning

1 Introduction

Walking is directly related to the quality of life, especially in modern urban environments where everyday life is becoming more and more demanding. The benefits it offers to the environment and natural resources, through the reduction of air pollutants and traffic noise, significantly improve the health of citizens. However, the growing number of barriers and damages that block pedestrian paths, often endanger the lives of pedestrians [10]. According to the World Health Organization (WHO), 26% of all road traffic deaths in 2016 involved pedestrians and cyclists [18]. Due to the human, social and economic dimensions of the problem, pedestrian safety has always been a grand challenge for local authorities to address. Keeping routes clear from static barriers (e.g. badly designed pavements, dustbins, furniture, etc.), short-term barriers (e.g. construction work, illegal parking, dense crowds, etc.) and damages (e.g. cracks, holes, broken pavers, etc.) is important for the easy, safe, well-maintained and secure pedestrian access to urban infrastructure environments (obstacle examples are shown in Fig. 1). In addition, it helps to improve the urban environment through the removal of items that cause pollution (i.e. litter and other rubbish on pavements).



(a)

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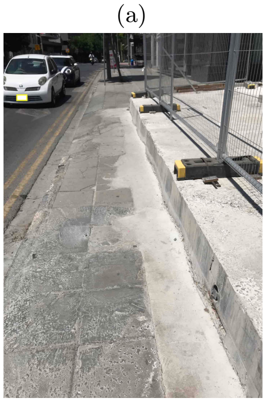

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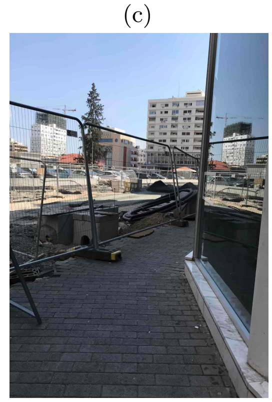

(f)

Fig. 1: Examples of obstacles that impede pedestrian routes (a) Illegal parking; (b) Broken pavement; (c) Pavement blocked by bush; (d) Narrow pavement; (e) Illegal parking/Parking prevention barrier, and (f) Roadworks.

Citizen-science has gained considerable attention in recent years, involving the active participation of citizens in scientific research activities related to real-world problems [3]. By exploiting the widespread and ubiquitous use of smartphones, a large number of citizen-science studies have focused on crowdsourced data collection, overcoming the problems and limitations of conventional collection methods [7]. Several smartphone applications have been developed for the collection and sharing of various categories of information, in both rural and urban areas. Among the most successful ones, *iNaturalist*[1] and *eBird*[2] allow users to share observations about biodiversity and bird sightings, respectively. Other applications have focused on improving the quality of life, for example the *Loss of the Night*[3] application which invites the citizens to measure and submit night sky brightness observations, and *NoiseTube*[4] that aims to monitor noise pollution by allowing citizens to measure and submit the level of noise in cities. Citizen science has played a significant role in the development of meaningful and democratic smart cities since human value allows for creating intelligent smart services [5]. Smart citizens are involved in the governance of their city helping to improve the quality of their daily lives.

Building on the idea that citizens can, and should, play the role of knowledge's carriers during their everyday activities for enhancing pedestrians' safety, a crowdsourcing platform can be used for reporting the barriers and damages which put the pedestrians' lives at risk. The proposed citizen-science platform will create awareness and build capacity in regard to pedestrian safety, by informing walkers and public authorities in real time. This paper presents the development and preliminary evaluation of a prototype smartphone application that aims towards this direction. The proposed application allows pedestrians to easily report any obstacle they encounter while walking in a city. A Convolutional Neural Network (CNN), trained specifically for recognising various barriers and damages [15], aids users in quickly choosing the correct type of barrier or damage. The evaluation of the prototype application involves 25 volunteers who tested the application in real conditions and answered an online questionnaire regarding user experience.

The rest of the paper is as follows: Section 2 presents the literature review; Section 3 describes the interactive platform hosting the proposed application; Section 4 presents the proposed smartphone application, while Section 5 describes the evaluation process and its results. Conclusions and future work prospects are explored in Section 6.

2 Literature Review

Several research efforts have focused on the development of smartphone applications to help pedestrians and fulfil their needs. Papageorgiou et al. [9] studied how an application can lead to sustainable walking and analysed the walking patterns of young people, concluding that a dedicated smartphone application on safer walking would encourage more young people to walk. *Walksafe*, presented by Wang et al. [17], is a smartphone application intended to help pedestrians cross the streets safely. The application combines the back camera of smartphones and

[1] https://www.inaturalist.org
[2] https://ebird.org
[3] https://www.globeatnight.org
[4] http://www.noisetube.net

a vehicle detection algorithm to alert users about possible hazards. *mPASS* combines georeferenced data related to urban accessibility with a user's profile and suggests personalised walking routes [8]. Other applications have been developed for enabling people with disabilities [13], collecting real data for walking routes via gamification [6], analysing users ability to see while walking after dark [1], etc. Similar *CIT2ADM* [1] is a smartphone application for pedestrians that allows reporting problems while walking in the neighbourhood, for immediate awareness of the local municipality and other neighbours.

The advances in wearable cameras and the enormous increase in the use of smartphones have aroused the interest of the research community [14] which has created a new field of Computer Vision that includes methods of analyzing data collected through portable cameras. This field is known as Egocentric or First-Person Vision. The analysis of the egocentric data can give useful insights in several domains including health, security, entertainment, etc. Thus, a number of research efforts have been presented for indoor and outdoor applications related to the daily needs of the carriers including nutrition habits [2], automatic recognition of locations in the daily activities [4], digital memory [14], etc.

A method for the recognition of obstacles in egocentric data for pedestrians' safety was presented in [15]. The obstacle recognition was based on a CNN which was specifically trained to classify different obstacle types. For this purpose, a dedicated annotated dataset was used which consists of images collected using a smartphone camera while a pedestrian walked in urban areas. A total number of 1854 bounding boxes related to 15 different barriers and damages was utilized to train a well-known CNN deep algorithm using TensorFlow framework. More specifically, a variant of the VGG-16 architecture was used to classify 15 obstacle types, including *Hole/Pot-hole*, *Narrow Pavement*, *No Pavement*, *Light*, *Bin*, *Parking Meter*, *Plat Pot*, *Tree*, *Shrub*, *Mail Box*, *4-Wheels*, *2-Wheels*, *Safety Sign*, *Fence* and *Traffic Cone*.

Unlike *CIT2ADM*, the application we present in this work incorporates egocentric vision algorithms for the automatic recognition of barriers and damages, intended to aid users in reporting obstacles more quickly. Additionally, we evaluated the user experience, enabling the derivation of results related to the operation of the application that will allow its improvement to deal effectively with users' needs.

3 Smart City Digital Twin Platform

The smartphone application has been developed to connect to the interactive platform which is implemented within the *iNicosia* [2]. This project aims to create a Digital Twin of Nicosia city by integrating available data into a 3D model and visualising the real-time and future conditions of the city, simulating solutions to optimise planning activities and providing the best solutions in case

[1] https://cit2adm.com

[2] https://inicosia.rise.org.cy (under development), backup url: https://7e3fa2d3.ngrok.io

of emergency scenarios. The project builds on top of the Nicosia Municipality Smart City infrastructure. Its ultimate goal is to setup the proper technical infrastructure that will enable the city digital transformation, as well as host data and modules for real-life applications, advancing both the research capabilities in the city as well as citizen quality-of-life. Such infrastructure will include the data storage and standardisation modules that will transform the data originating from different services into standardised formats, enabling the integration of the data. Furthermore, it includes modules for analysing and visualising the data, as well as providing the data and/or results of the analysis to interested stakeholders, either through well-formed Application Programming Interfaces (APIs) or applications. The architecture of the platform is depicted in Fig. 2.

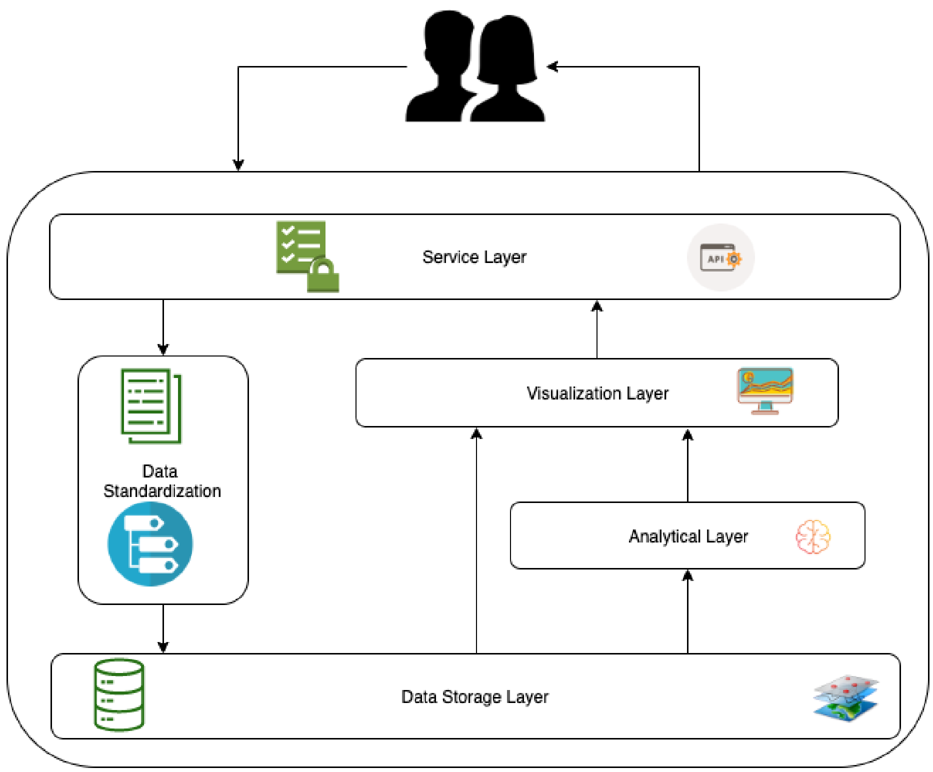

Fig. 2: High-level architecture of the interactive platform.

In addition to the crowdsourcing application for pedestrians safety, the platform so far hosts other applications and services including visualisation and prediction of road traffic, as well as the visualisation of open data concerning the city, such as the Quality of Life evaluation of various areas based on the priorities of citizens, and identification of micro-scale events happening around the city from online Social Networks. Currently, the development team is working towards the preparation of a 3D model of Nicosia city by utilising data from the Department of Land and Survey of the Cyprus Government, and on a Mixed Reality collaboration app, where Virtual Reality and Augmented Reality users can communicate in real time and exchange information in the city to create valuable stories.

4 The Prototype Smartphone Application

The proposed mobile application has a single objective; to enable citizens that want to report obstacles they encounter during their journey in the city. To succeed on this objective it tries to make the reporting as easy as possible by incorporating advanced AI methods that aid the user during this process. Towards this end, the proposed application utilises the users' smartphone feature, i.e. camera, GPS and other sensors, to capture an image of the obstacle, enables the user to tag further details of the surroundings in the image and upload the information in a crowdsourcing platform for the further analysis.

In this section, we describe the main components and methodology of the mobile application prototype development. We provide an overview of the mobile architecture, details on the automatic obstacle classification embedded in the application, the information collected in the database and a demonstration of the application workflow.

4.1 Application Architecture

The application is based on the Model-View-ViewModel (MVVM) architecture paradigm [16]. MVVM, the recommended Android application development architecture, is structured around three main components:

- Model: Data access layer for retrieving and storing data
- View: Interacts with the rest of the application through the ViewModel
- ViewModel: Exposes streams of data

MVVM follows the principle of the "Separation of concerns", whereby the View contains strictly User Interface (UI) related logic, and is driven by the data contained in the DataModel, as exposed by the ViewModel. For our prototype, the View is structured around the Single Activity-Multiple Fragments pattern (Subsection 4.2). Relevant information and user actions are gathered and stored in an on-device database. When there is an appropriate network connection (i.e. WiFi or LTE connection based on the user preferences) the application synchronises the reported obstacles with the Smart City Digital Twin platform presented in Section 3. The users have the option to use their mobile data for the synchronisation process. As per the latest guidelines and requirements of mobile application development, upon first launch of the application, the users are informed and give their consent for access to their devices' camera and GPS

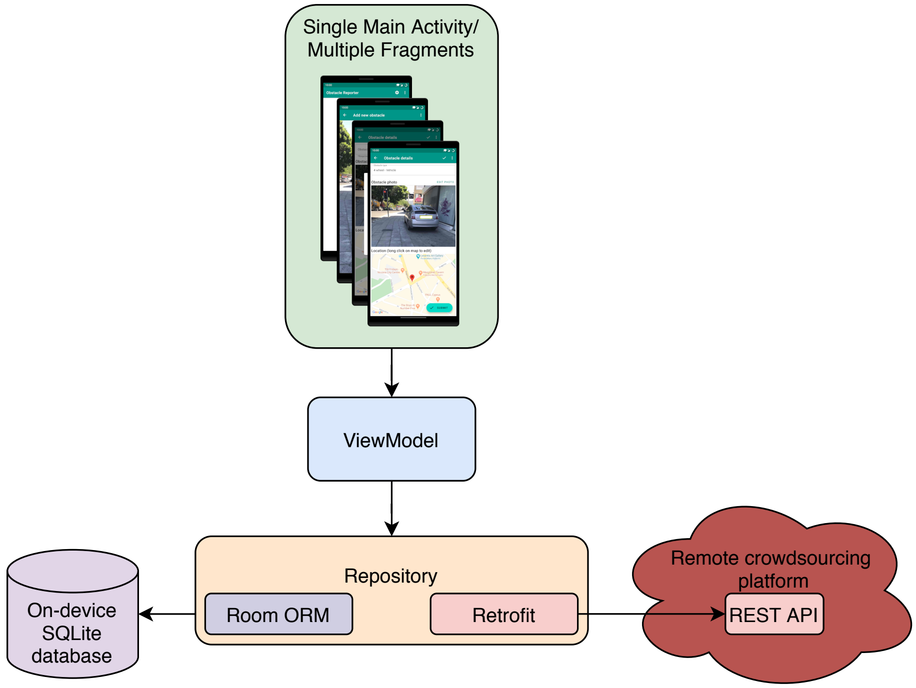

Fig. 3: Application architecture.

sensors by the application. A graphical representation of the architecture is shown in Figure 3.

The application prototype was developed for the Android operating system, with the Kotlin programming language, and can run on devices with Android version 5.0 and up (SDK 21). Among others, the following libraries were used in the development process: the Navigation Component library [1], an on-device SQLite database accessed via the Object-Relational Mapping library Room [2], and the Retrofit HTTP client library [3] for communicating with the remote crowdsourcing platform.

Additionally, a Machine Learning (ML) algorithm that provides an automated list of obstacle type recommendations was embedded in the application. For this functionality, we utilised a related publicly available CNN model [15] that was tuned using transfer learning, based on a dedicated dataset of typical obstacles found in urban environments [15]. To incorporate the ML model in the application, we used the TensorFlow Lite converter Python library[4] to convert the CNN to the mobile compatible TensorFlow Lite format.

[1] https://developer.android.com/guide/navigation
[2] https://developer.android.com/topic/libraries/architecture/room
[3] https://square.github.io/retrofit/
[4] https://www.tensorflow.org/lite/convert

4.2 Obstacle Reporting Workflow

The View component of our MVVM architecture is structured around a single activity, that displays one of multiple fragments, depending on the task at hand. The general process consists of capturing a photo of an obstacle and storing relevant information about it in a database; this process is divided in four fragments.

1. Main: Start a new obstacle capture process and observe previous ones.
2. Obstacle capture: Take photos of the obstacles.
3. Obstacle type: An automated recommendation list of possible obstacle types.
4. Overview: An overview of the information gathered about the obstacle.

In the *main* fragment the user can start a new obstacle capture process or observe the ones they have already captured (see Fig. 4a). If the user chooses to start a new capture, the application directs them to the second fragment, *obstacle capture*, where the user's camera is initialised within the application. Here, the user can take a picture of the obstacle encountered in their urban walk (Fig. 4b). Following the capture, an *obstacle type* selection fragment is shown, where the user is presented with the five most probable obstacle types to choose from, with an additional option to show more types if the actual obstacle type is not included in the recommended types (Fig. 4c). For a full list of urban obstacle types used, see the list in [15]. In the scenario where the obstacle does not fall under any of the predefined types, the user has the option of entering the obstacle type manually.

Between the *obstacle capture* and the *obstacle type* fragments, the photos taken by the application are pre-processed and passed as inputs to the mobile adapted CNN model. The pre-processing includes a down-sampling to the resolution of $128 \times 128 \times 3$ pixels, and normalisation of the pixel values to the range of $[0, 1]$. The input is passed through the CNN in a feedforward manner, which outputs the probabilities of each obstacle class. We exploit these probabilities as a ranking mechanism for our automated obstacle recommendation list. The employed image classification function is implemented as a coroutine, that runs in a background thread, and passes the results to the main thread once the analysis is finished, to be displayed by the UI. Our employed image classification model takes a reasonable amount of time and does not impede the obstacle capturing process.

Once the user specifies the obstacle's type, they are presented with the *overview* fragment, which shows all information gathered about the obstacle by the application (Fig. 4d). To make obstacle reporting fast, efficient and effortless, we automatically gather as much information about the obstacle as possible with minimal user input, using all available sensors in the user's device, namely GPS, accelerometer, magnetometer and gyroscope. Hence, we are able to collect latitude, longitude, altitude and the orientation of the device. The current location is displayed in the *overview* screen using a Google Maps view. Users can edit the location using the map view, in case the location retrieved is erroneous, or can even input manually the location if their device does not have a working GPS sensor. To hinder malicious intent we store both the original and edited GPS

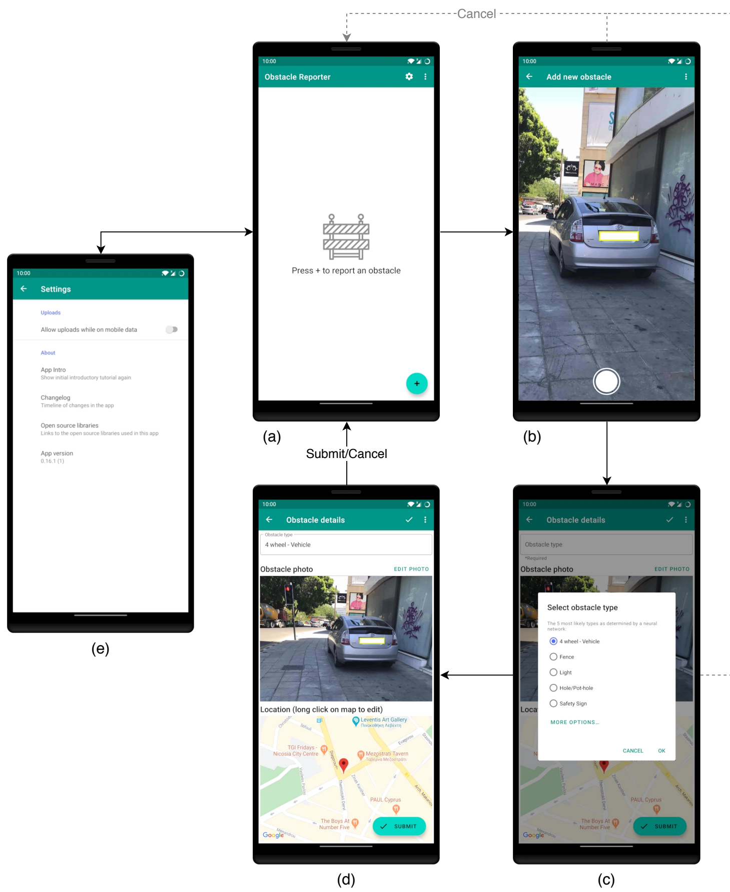

Fig. 4: Application workflow (a) Main screen; (b) Obstacle capture; (c) Obstacle type selection; (d) Overview; and (e) Settings.

coordinates. Additionally, the users are able to crop the captured photo for a better obstacle representation.

In parallel, information regarding the obstacle prediction model is collected. These include the user's obstacle type choice and the complete list of obstacle types along with their predicted probabilities. Once the users are satisfied with the collected information they can submit their report. The information is then automatically uploaded to the crowdsourcing platform when there is an available network connection. A graphical representation of the complete workflow is shown in Fig. 4.

5 Evaluation & Discussion

The preliminary evaluation of the application prototype regarding user experience (UX) was achieved with the aid of a group of volunteer users. The users were asked to use the application for at least 10 minutes while walking around the city, and to report at least 3 obstacles they encountered during their walk. Then, they were asked to complete an online questionnaire, which consisted of three parts: (A) Demographics, (B) Evaluation, and (C) Feedback.

Part A included demographic questions in regard to the gender, age, average walking time per day, and familiarity with smartphones and technology in general. In total 25 volunteers participated in the evaluation, 9 female and 16 male, aged between 16 and 60 years old (Fig. 5a and 5b, respectively). 10 participants stated that they walk 10 to 30 minutes every day on average, 10 participants that they walk from 30 to 60 minutes on average, while the remaining 5 stated that they walk less than 10 minutes per day (Fig. 5c). The majority of the participants answered that they are quite familiar with technology, with 15 stating that they are very familiar (Fig. 5d).

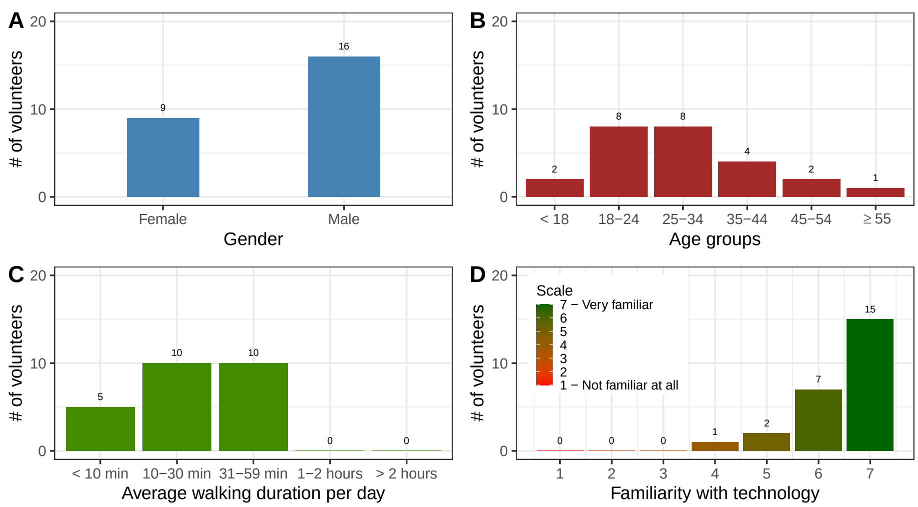

Fig. 5: Demographic information concerning the volunteers that participated in the app evaluation.

Part B was concerned with the UX evaluation and was based on a shortened version of the User Experience Questionnaire (UEQ) [11,12]. The questionnaire included 12 of the 26 UEQ questions, 2 for each one of the following 6 scales: Attractiveness, Dependability, Efficiency, Novelty, Perspicuity and Stimulation, as shown in Table 1.

The results of the UEQ evaluation are shown in Figure 6. The prototype application received a positive evaluation, having all scores greater than 0.8

Table 1: UEQ scales used in the app evaluation, and their individual components.

Scale	Component 1	Component 2
Attractiveness	Attractive - Unattractive	Friendly - Unfriendly
Dependability	Meets expectations - Does not meet expectations	Obstructive - Supportive
Efficiency	Fast - Slow	Impractical - Practical
Novelty	Conservative - Innovative	Inventive - Conventional
Perspicuity	Clear - Confusing	Complicated - Easy
Stimulation	Not interesting - Interesting	Valuable - Inferior

according to the study of Schrepp et al. [12]. Based on the benchmark intervals provided by the same authors, the prototype application achieved *Excellent* evaluation for the scales of Attractiveness, Dependability, Efficiency, Novelty and Stimulation, while it scored *Above Average* for Perspicuity. The Perspicuity scale represents how easy it is for users to get familiar with the application and learn how to use it, indicating that the prototype application will greatly benefit if this is improved in its future versions.

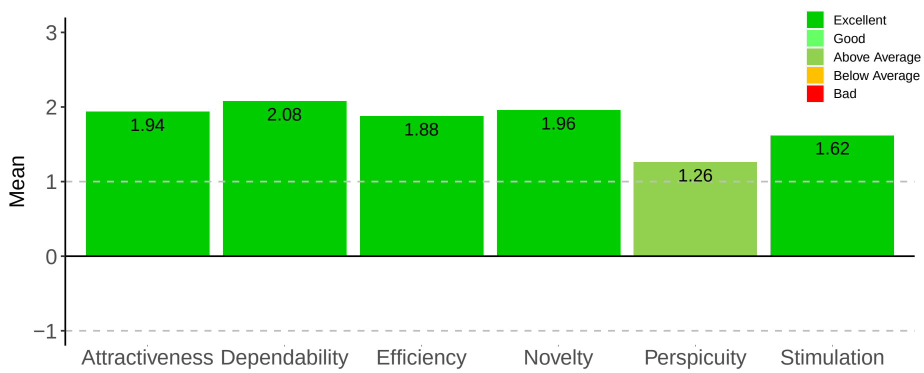

Fig. 6: Results from the UEQ evaluation.

The last part of the questionnaire (Part C) focused on collecting users' feedback on problems they may have faced during the evaluation procedure and possible improvements that they believe will help the prototype application to offer a better user experience. No major problems were reported, while a few minor issues reported were: (i) the quality of photos used in application's introductory tutorial, (ii) the slight delay during the photo analysis by the CNN, and (iii) the difficulty in translating the obstacle types in the users' native language. In regard to possible improvements, the users suggested the use of rewards in order to attract more pedestrians to use it during their everyday activities, and the availability of the application in their native language.

6 Conclusions & Future Work

This work presents the prototype Android application we have developed, aiming to enhance the pedestrians' safety. The application provides users with the opportunity to report obstacles which put pedestrians at risk for the creation of safe access in urban environments. An automatic recognition algorithm based on a CNN assists the users in choosing the appropriate type of the detected obstacles. The prototype was positively evaluated in regard to the user experience using the UEQ with 5 of the 6 sections having an *Excellent* score. The application has great potential to be used in a citizen-science crowdsourcing project, for reporting damages and barriers which endanger pedestrians. In addition, the application can be used for the creation of annotated first-person datasets, as an attempt to address the challenge of training deep learning algorithms for egocentric vision content analysis.

The feedback collected from users in the preliminary evaluation will help us to improve the application, and will be taken into account for its finalisation. Thus, future plans include, firstly, the enhancement of the application with a more accurate version of the obstacle recognition model, in order to improve the recognition accuracy during the reporting phase. Data collected through the application could be used to retrain the CNN periodically, and the improved CNN could be redistributed to the application via updates. Second, a new application introductory tutorial will be created based on better-quality images, and improved with more information, so as to help the users to become more familiar with the application. Third, the application will offer multi-language support, so that it is accessible to users from different countries. In addition, the application will be evaluated in a larger scale, including more volunteers and different scenario tests, before it is finalised and made available to the general public through app stores.

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