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Multi-dimensional Data Visualisation using Mobile Augmented Reality

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In the era of "The Internet of Things" (Rodriguez, Kaczmarek, & Depew) devices are becoming smart and each smart device generates data every second. This data is in multi-format, multi-perspective and multi-sectoral. Therefore, the handling of such multi-dimensional data is a significant challenge, as the normal display screen is two dimensional (2D) and data is multi-dimensional. This research proposes and develops a multi-display data visualisation algorithm using mobile augmented reality, as augmented reality (AR) is beyond the two-dimensional screen. Therefore, this algorithm uses AR to provide a multi-display solution for improved data visualisation after processing, summarising and classifying data. The results show that the AR-based multi-display is better than traditional 2D display. This algorithm is mobile based. Therefore, this system can provide rapid and easily accessible information to policy and decision makers.

Key words: *Augmented reality, Big Data, Data visualisation, Internet of Things, Multi-Dimensional data, Multi-Display.*

Introduction

Electronic devices are becoming smarter and intelligent by the day. All smart devices generate data every second. Therefore, a huge amount of data is produced by these devices. According to Jeff Desjardins (2019), this large amount of data can only be shown using the 60 second time scale. Anything bigger and our brains couldn't process these massive quantities in any useful capacity. The following Figure 1 shows an illustration of an internet minute during 2019.

Figure 1. Internet Minute

Source: https://www.visualcapitalist.com/what-happens-in-an-internet-minute-in-2019/

Here are a few key numbers scaled to a monthly basis:
1 million Facebook logins
3.8 million Google searches
41.6 million WhatsApp messages sent
188 million emails sent

On an annualised basis, the data becomes even more ridiculous, with something close to 100 trillion emails sent.

Augmented reality (AR) during the past years has been achieving great progress in mobile computing hardware, tracking algorithms and expanding the accessibility of data through APIs (Application Programming Interface). Nowadays, the complexity of data analysis keeps increasing and has become a significant obstacle in analysing a process for acquiring an accurate outcome or result. Therefore, visualisation techniques and methods need to be improved by implementing an augmented reality feature.

As data is being generated through a range of different sources, it is a challenge to visualise such a huge amount of data in a 2D screen. Existing techniques in data visualisation have some limitations especially in space where the visualisation takes place. As augmented reality goes beyond the 2D screen, it can overcome those obstacles. In brief, augmented reality is where a computer-generated image or object is being displayed in the real-world environment which can help in triggering users' immersive feeling, apart from being able to use a wide space.

This research is being conducted to design and apply a better visualisation process for multi-dimensional data. The flow of this system will start by designing and implementing algorithm for multi-dimensional data visualisation through an android mobile AR system. Data pre-processing is the process of manipulating data prior to the actual mining steps which are separated into different stages: data cleaning, integration, transformation, reduction and compression. Finally, an algorithm is designed that is suitable for visualisation in multi-dimensional data with the compatibility of android based mobile AR.

The continuous parts of this paper will be organised as follows: Section 2 - discussion about background and related works. Section 3 - system development and section 4 - results and discussion. Lastly, Section 5 presents the conclusion.

Background and Related Works

Various types of existing AR technology have been applied for creating effective visualisation. This part contains a brief explanation about data visualisation, and a discussion about different types of AR technology and toolkits.

Data Visualisation

Computer-supported, interactive, visual representations of data are used to amplify cognition (Card, 1999). Effective data visualisation does more than just replace the number or words, instead they reveal structure, pattern, trends, anomalies and relationships in data (Rodriguez et. al., 2016; Khan, Cheng, Oon, & Technology, 2018). Wünsche (2004), point out that data visualisation consists of two different parts: encoding and decoding. The part for encoding is called visualisation and explains how data is merging into a clear and informative representation. The decoding part is referred to as visual interpretation and explains how the representation is unloaded to access all internal data. Subsequently, decoding is divided into two steps which consist of perception and cognition. Perception is about how visual data is being viewed, while cognition refers to how users derive and interpret meaning from the perceived information.

Types of Augmented Reality

Marker-Based AR is also called recognition of image or pattern-based AR. This innovation utilises the camera in AR devices to deliver a computer-generated outcome. The QR-code is an example of a visual marker. Users will obtain the outcome when cameras scan over the AR marker. Marker based or recognition is a type of augmented reality that uses the recognition of shapes, faces or other real-world items to provide supplementary virtual information to the user in real-time (Oui, Ng, & Khan, 2011; Ng, Khan, Adruce, & Oon, 2012; Ng, et. al., 2013; Katiyar, Kalra, & Garg, 2015; Khan, Vivian, et. al., 2018; (Khan et al., 2019). AR devices such as mobile phones with AR integrated software will recognise the product bar code or the marker to display relevant information like reviews or prices. In developing a marker-based AR application, the most important step is to identify a marker through extracted features and superimpose virtual objects in the real environment (Cheng, Chen, & Chen, 2017). To recognise the AR marker, a specific algorithm is needed to extract the feature within the marker and then identify it. There are several types of AR SDK (software development kit) available in the market. For instance, Vuforia software is automatically used in this project. It provides an algorithm that can automatically track and extract features from the target marker.

Markerless augmented reality identifies or recognises objects that were not directly provided to the application beforehand unlike the marker that requires displaying the augmented object. An active tracking and recognition algorithm within the AR application identify patterns, colours or other feature that are caught inside the camera frames for displaying augmented images or objects in the real world. For instance, application features such as information about pop-up events or business provide navigation hints and are markerless types of augmented reality. “Markerless AR” is a term used to define an Augmented Reality application that does not require any pre-knowledge of a user's domain to overlay the 3D content into a scene and hold it to a settled point in real world space (Fetters, 2017). Markerless AR allows placing the AR experience anywhere, as long as it’s a fairly flat surface (Darvis, 2017). The biggest impact for changing the concept of augmented reality is Simultaneous Localisation and Mapping (SLAM). This technology can effectively perceive wall, floors and other physical barriers in the real-world environment without the need to place any trackers as the base to be detected. SLAM is a technology used in computer vision technologies which obtains visual data from the physical world in a shape of points to create an understanding for the machine (Tabatabaie, 2017).

The marker-based type of augmented reality will be chosen based on several aspects. Marker-based type seem to be commonly used in existing AR applications which only require users to scan over the image target as the marker based to bring out the augmented object. Apart from that, this type of AR technology does not require any internet connection and users can access the application in any situation without constraint. Although the augmented surface or object can be displayed anywhere, users will need to have a stable internet connection on their mobile phone to enable the process of localisation and mapping.

Augmented Reality Toolkits

A toolkit used for building augmented reality application is an open source computer tracking library with the ability to create an application that places a virtual object in the real-world space. Vuforia has been chosen in this research paper, for creating the AR application. This SDK is offered by Qualcomm which has boosted its market share in the augmented reality industry (Vuforia, 2018). The Vuforia SDK supports almost all existing platforms such as Android, IOS (mobile operating system), UWP Universal Windows Platform and Unity editor. This software platform consists of impressive feature including the capability to recognise both two and three dimensional objects that such as the shape of cylinders, planes, boxes and any commercial products using the Vuforia object scanner function. In addition, Vuforia SDK is also equipped with text recognition ability over 100000 words from the English language. Vuforia can play a video based on the target images or surfaces as marker based and also own barcodes (VuMarks) that work as encoding data or functioning as a marker.

Related Works

The IBM Immersive insight created an Augmented Reality technology to visualise information and help experts like Data Scientists, Business Analysts and Business Executives investigate and analyse specific data. Features included geospatial mapping, real-time loading of data, time-series and collaboration. Immersive Insights aims to be a tool that provides data scientists with insights about large-scale data through a spatial visualisation experience (Ruiz, 2017). Streaming data in real-time view through the headset can enable users to fully manipulate and scale the data at the same time. As a result, it helps in providing an opportunity for users to explore and importantly help in refining the next generation of enterprise applications for data analysis purposes. Immersive Insights enable users to view and analyse their information and communicate findings. Visualising data in 3D and reviewing information from various perspectives can help reduce the duration of finding key patterns and connection within the data. Furthermore, Immersive Insights has the potential to be used as a presentation tool, which for non-data experts simply presents their data through multi-dimensional visualisation. The value of Immersive Insights and AR is primarily based on context and environment (Clemente, 2018). This system needs very high specification computers. AR allows the computation of the entire world as the environment. In summary, IBM Immersive Insights enable users to explore information and convey their discoveries. By bringing the power of Augmented Reality (AR) visualisation to data science tools, users' experience can be enhanced using multi-dimensional data visualisation.

Microsoft HoloLens is built up particular components that empower holographic computing. It's equipped with advanced sensor lock-step in the optical systems. The HPU easily takes care of handling a lot of information per second. As a result, all these components enable users to move freely and interact with multi-dimensional images.

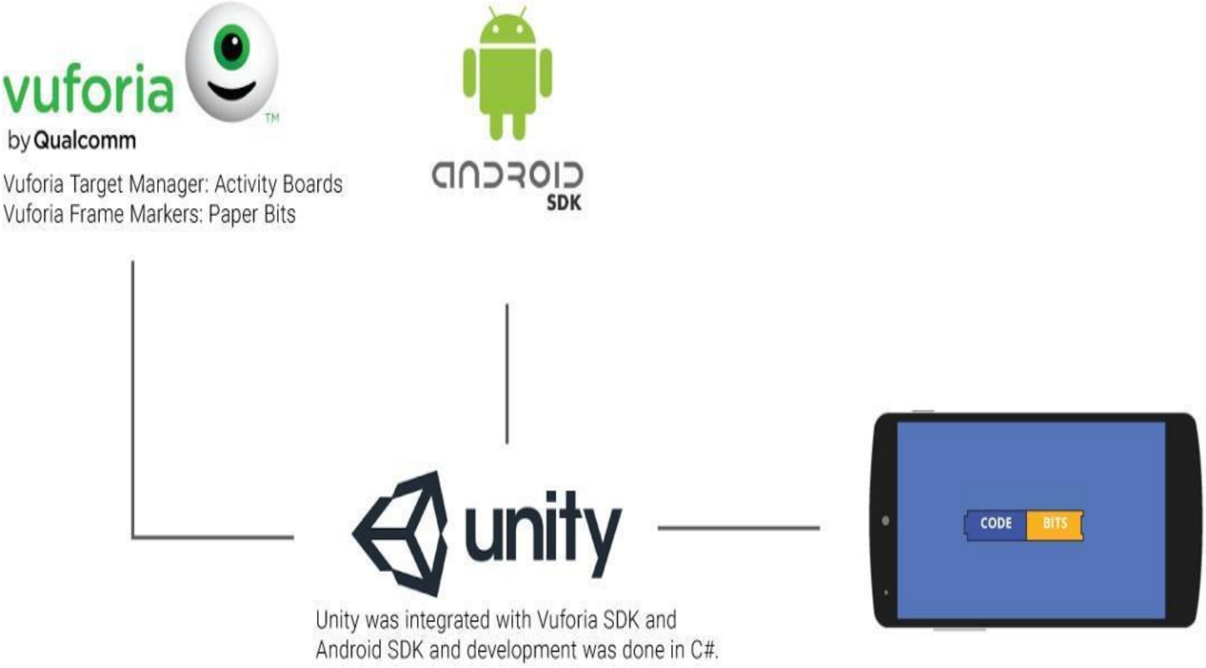
Similarly, LOOOK developed a cutting-edge solution for visualising data in 3D. With our data-driven application, KPMG can visualise more dimensions of data than it is possible using traditional 2D visualisation and presents data insights that are more natural and intuitive(Motte, 2017). In brief, applying augmented reality in data visualisation can help in improving users experience throughout the visualisation process and feel more immersive within their surroundings.

Methodology

Rapid Application Development Model (RAD) is used for designing this AR application. This model that requires minimal planning and time to develop a high-quality application (Naz & Khan, 2015). RAD consists of requirement, design, and technical analysis as well as implementation and testing in order to achieve the fully functioning application. Finally, the testing stage is completed with a specific test case to evaluate the effectiveness of data visualisation using AR mobile.

Unity software is used for designing the multi-dimensional graph, Vuforia as the AR toolkits in tracking the marker or image target and Android Studio for generating the APK file. Figure 2 below depicts the use of development software in developing the application.

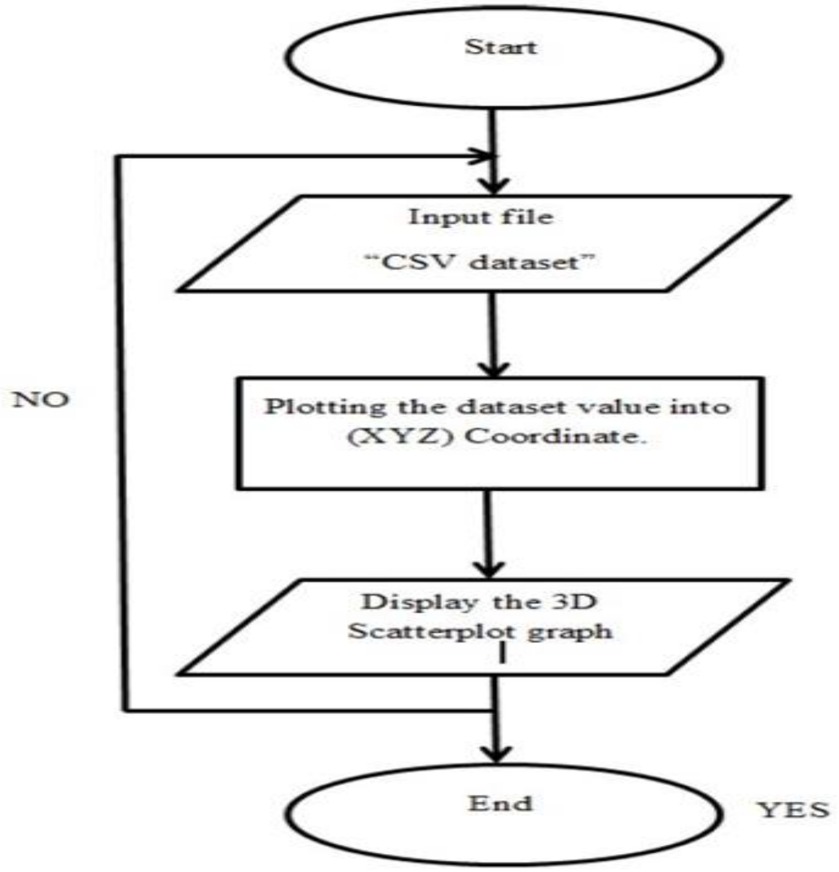
Figure 2. Development software



System Flow Diagram

According to the system flow diagram shown in figure 3, the start phase will begin by running the visualisation application. This is followed by input data stages where multi-dimensional data is inserted and prepared for pre-processing which involves data cleaning, integration, transformation, as well as the reduction and compression process. I The visualisation (process) phase is set up for the attribute or component that is suitable for the x and y axes of a graph. Subsequently, the display stage will display the graph that has been set up at the previous phase. If the outcome at the display phase doesn't fulfil the design requirements, then the system will loop back to the start phase and go through the input data again.

Figure 3. System flow diagram of Multi-dimensional Data Visualisation using mobile application



Results, Discussion and Conclusion

This system consists of a three-part test case for importing the CSV file to Unity, plotting points in Unity and adjusting the label orientation for camera movement. All test conditions are passed successfully.

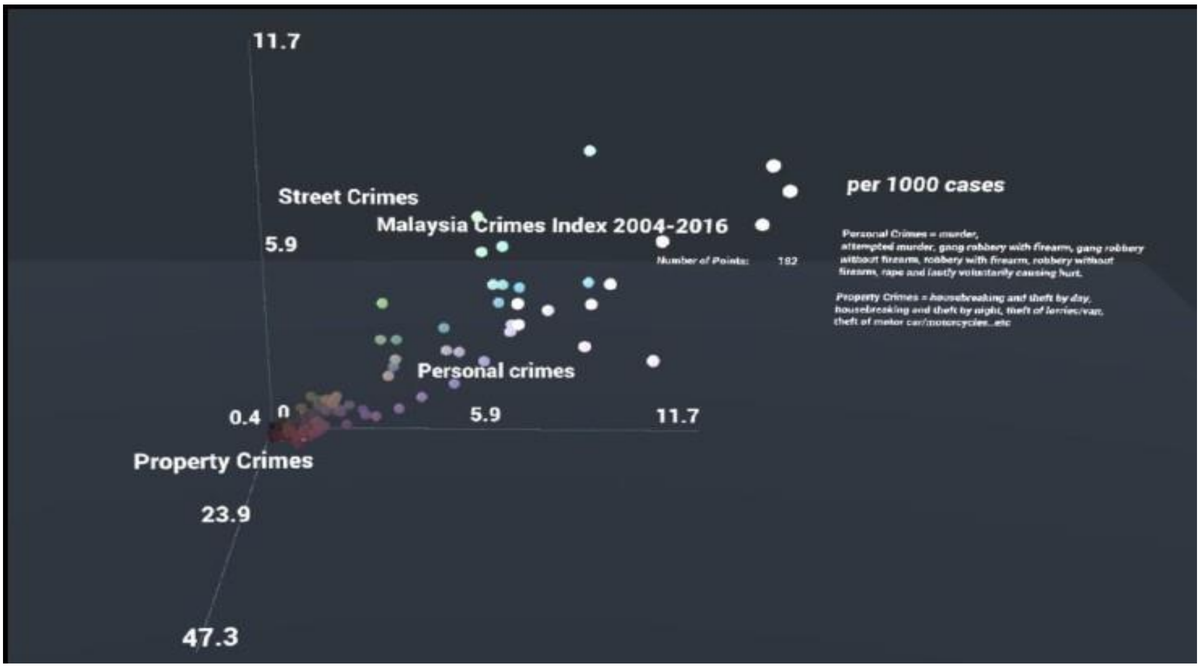
The limitation of this system consists of lack of interaction such as clicking data balls to show their values. Furthermore, a bright environment is needed in order to use an AR marker-based technology, as the image recognition process needs to be completed for tracking over the image target to display the augmented scatter plot. Finally, AR-based scatter plot project needs a high specification mobile phone camera for a good quality display of the scatter plot.

Table 1 shows the comparison between 2D screen and 3D Augmented Reality scatter plot.

Table 1: Comparison between various types of scatterplots

Characteristic	**2D Screen Scatter plot**	**3D AR scatter plot**
Reliability	Scatter plot data visualisation in 2D form shows low reliability due to limited axis or dimension that can display multi type of variables.	Display 3D view for three different variables and can provide a close look of plotted point by manipulating the camera position
Error prevention	The process of finding the max and min value for multiple variables will take more time as the graph needs to be carefully examined and tends to have higher chances for mistakes.	Rotating the AR maker base can show a better view in finding the max and min value for multiple variables because users can manipulate the view of scatter plots, which can help avoid errors.
Time Consumption	User will need to switch on the computer/laptop then launch the application in order to display the scatter plots which tend to require more time for setting up.	Users only need to have a mobile phone camera to scan over the marker-base to view the scatter plots which tend to save time and make it more efficient.

Figure 4. Overall view of 3D AR scatter plot



Each axis displays the min, mid, max value of variables. Regarding data balls, a darker colour means a lower value while a lighter colour refers to a higher value.

Figure 5. View from Property crime (x- axis)

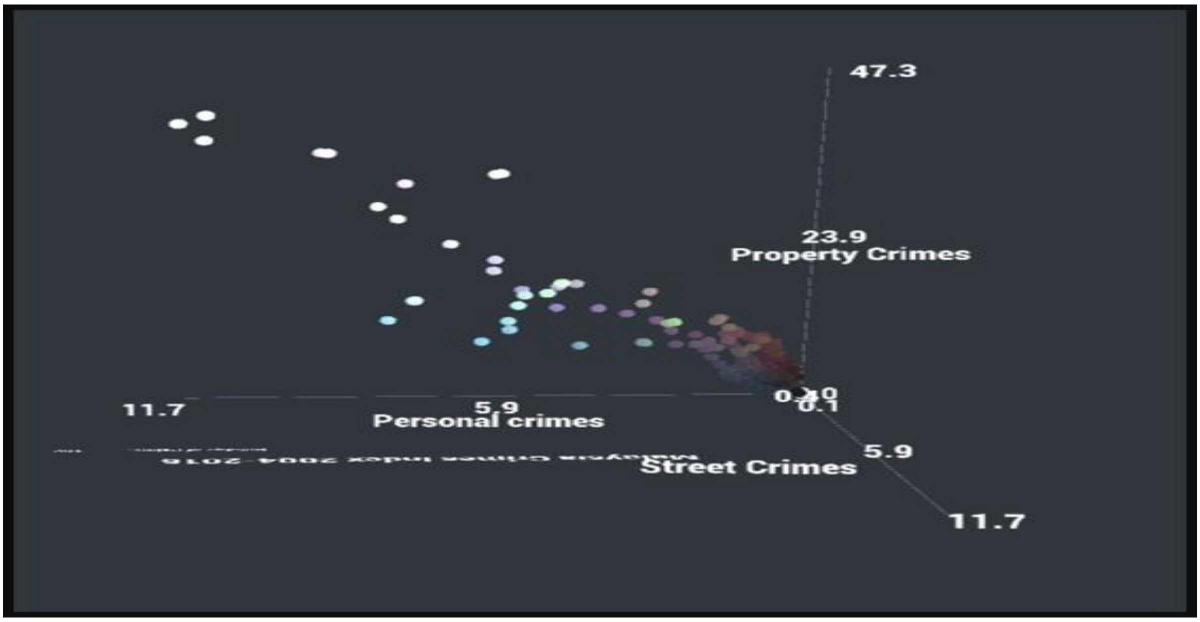


Figure 6. View from Personal crime (z-axis)

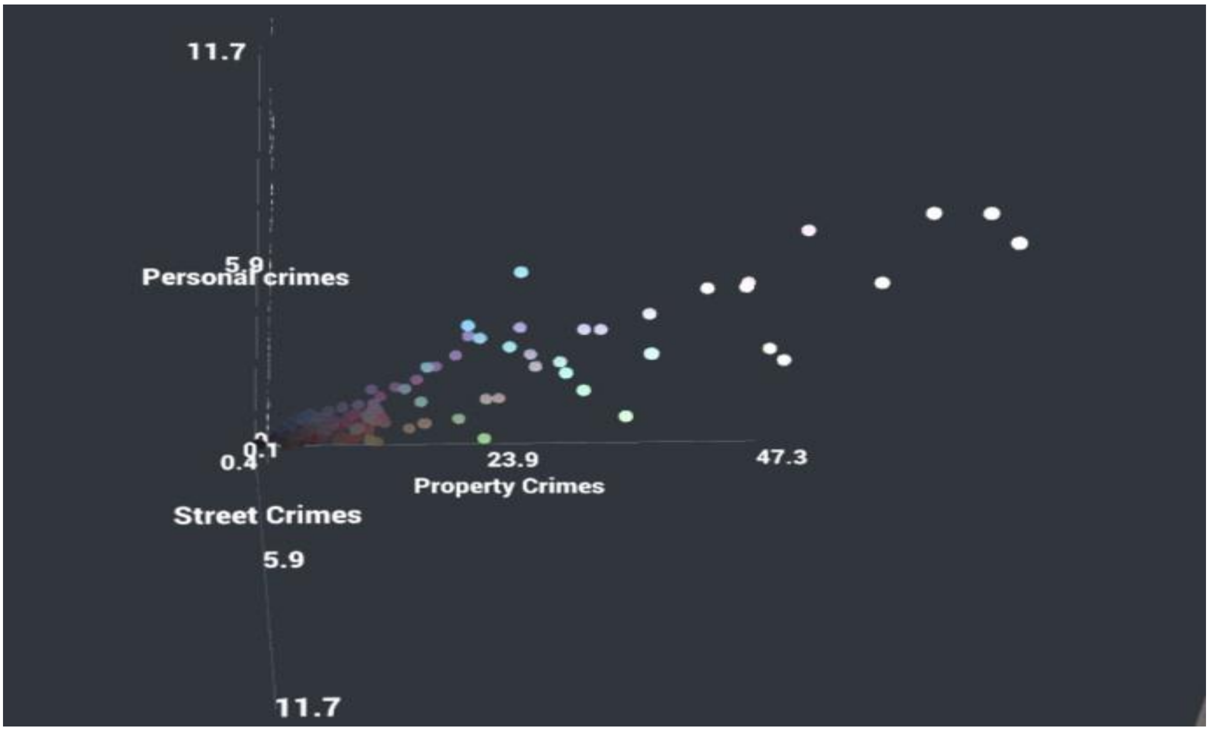


Figure 7. View from Street crime (y-axis)

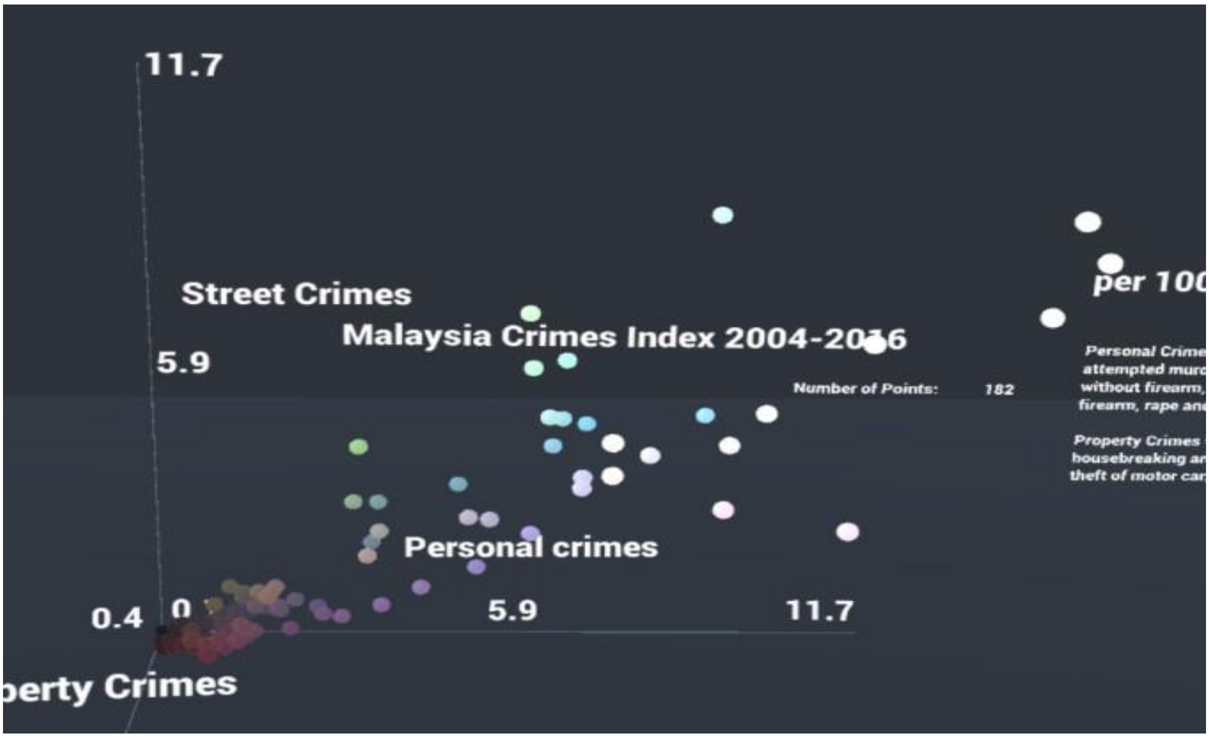


Figure 4 is the first display of scatter plot once the image target is being detected by the mobile phone camera. On the right side of the dataset label "Malaysian Crime Index 2004-2016" consists of the list of crime categories under personal and property crime. Street crime can occur in the public area which includes personal and property crime. Figure 2 depicts the top view of the AR scatter plot showing the (x, y, z) label responding towards the camera position by facing upwards.

Figure 5 illustrates the view from the property crime (x- axis) display, showing that crime rates are mainly below an average value of 23.9, as the darker colour of data balls indicates lower cases of crime. The maximum points are 47.3 cases with a lighter or brighter colour of data balls plotted. Figure 5.3 illustrates the view from personal crime (z-axis) display showing that crime rates have mainly a lower value where data balls are grouped together with a darker colour which indicates lower cases of crime. Maximum points are 11.7 cases with a brighter colour of data balls plotted.

Finally, the third axis in Figure 7 depicts the view from street crime at the (y-axis), showing that crime rates are mainly below the average value of 5.9 where the data balls colour is darker, indicating lower cases of crime. The maximum points are 11.7 cases with a lighter or brighter colour of data balls plotted.

Conclusion

To conclude, AR data visualisation in mobile applications has achieved its objective in solving the limitation of 2D screen data visualisation technique. Furthermore, it is a finished product that can be launched or deployed anytime and only requires users to launch the application to view a complete graph by highlighting important values within the dataset without any complexity.

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