A REVIEW OF THE CURRENT TRENDS AND FUTURE DIRECTIONS OF CAMERA BARCODE READING

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ABSTRACT

Modern mobile phones or smartphones have become a pervasive and affordable device for users at different levels of age around the world. Smartphones equipped with many useful sensors, including camera, barometer, accelerometer, and digital compass. The sensors on smartphones attracted researchers and developers to develop mobile applications (apps) and study the potential use of the sensors to support daily life activities. Unlike other types of sensor, the smartphone camera has been underutilized. Analysis of the literature suggested that smartphone camera mainly serves for personal and social photography. Practically, a smartphone camera can be used as an imaging device for reading a barcode. Although barcode has been used for identifying products and items, the use of a smartphone camera as a reading device has not been explored thoroughly. Further, scholarly resources describing the fundamental knowledge of smartphone camera barcode reading is not available in the literature which could be the reason contributed to slow research progress of the domain. Therefore, this study aims to review the current trends and future directions of smartphone camera for barcode reading. Specifically, the study reviews the literature on the types of applications that are currently available and run on the standard mobile platform for reading a barcode. It also analyzes the necessary components that made up barcode reading apps. Further, the review identifies technical and non-technical issues that are critical for the development of the apps. The contributions of this work are twofold, first, it provides the fundamental knowledge on the building blocks of camera barcode reading apps, and second, it explores the issues in the current camera barcode reading apps that could encourage exploration towards addressing the issues. Practically, the findings could spark new research ideas to address the current issues related to the use of smartphone camera for barcode reading in the near future.

Keywords: *Bar codes, Communication Systems, Mobile Phones, Mobile Telecommunication Systems, Sensors*

1. INTRODUCTION

The International Telecommunication Union (ITU) reported that there were more than 4.3 billion mobile broadband subscriptions at the end of 2017. It has grown more than 20% annually since 2012 [1]. Statistics also reported that there are 5.135 billion unique mobile users in January 2018, with 68% penetration rate and 56% of access to the web was made using smartphones and tablet computers [2]. This trend shows that people use smartphones and tablet computers as a device to perform everyday computing tasks in the same way as they used desktop computers [3]; except people use them on the go. This new paradigm is called mobile computing [4]. The hardware and network advancements replaced desktop computing where smartphones and tablet computers play a significant role in people's life [5]. Smartphones allow users to access to web content through two common approaches; (i) mobile web applications that display the content through mobile browsers and (ii) native applications that install a copy of the code on the phone [6]. Web apps and mobile apps are always used to refer to these two approaches respectively. Dominant smartphone performance and capabilities have increased demands on mobile applications. Consequently, mobile application development emerges as a new discipline due to the economic and scientific factors the technology offers [7].

Modern mobile phones or smartphones are a versatile gadget that can be used as a camera, video player, music player, navigation tool, and mini personal computer; beyond a device for voice call

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and text messaging. The gadgets also come with many sensors such as a digital camera, accelerometer, digital compass, gyroscope, a global positioning system (GPS), and microphone which make possible of new mobile applications (apps) design to support human daily life activities. The sensors enable the development of apps in various domains including healthcare, environmental monitoring, and transportation that consequently created an area of research called mobile phone sensing [8]. Unlike other types of sensor, the built-in camera has been underutilized for mobile sensing [9, 10]. Therefore, there is a need to explore the potential use of the camera in supporting human daily life activities.

The technology used for smartphone cameras has improved significantly over the past decade. Smartphone with a digital camera is also available to consumers at an affordable price which increases the worldwide penetration as mentioned earlier. In truth, smartphones have replaced the role of the conventional cameras in which it caused a devastating effect on the camera and photo equipment industry [11]. The trend suggested that consumers highly use smartphones for taking photos. A survey by InfoTrend [12] in 2015 showed that more than 70% of users used their smartphone for taking photos every day as compared to the standard camera. Further, it was estimated that 1.2 trillion photos were captured using smartphone cameras in 2017. It can be concluded that smartphone camera serves as an essential tool for personal photography.

The rapidly growing and high demand for mobile apps has attracted researchers to extend studies on any potential area of smartphone [13]. It includes studies related to the use of smartphone cameras as an imaging device for reading a product barcode. Many barcode reading apps have been developed to help users in finding further information from the product barcodes especially for food items. Such information includes nutritional information, ingredients, special dietary needs and much more. There are also apps that are intended to improve users' quality of life such those developed for elderly care and visually-impaired people. Mobile apps also developed to help users to manage their home food inventory to reduce waste due to expired and unconsumed food. Mobile apps that use smartphone cameras for reading product barcode have also been extended its functionality to a personal shopper tool. Users scan the product barcode, and the mobile applications compare the product prices from the nearby local stores and as well as online stores. Then, the apps would suggest the store that offers the lowest price of the same item. These are among the examples of smartphone barcode reading apps that are currently available.

These are the examples of camera barcode reading apps available to users to facilitate their daily life activities. The uses of camera barcode reading for supporting daily life activities has never been analyzed and reported in the literature up to the point when this work was carried out. Therefore, there is a need for a source that reveals all possible uses of the camera barcode reading apps in a comprehensive manner to benefit the researchers, developers, and users. It is one of the current limitations of the existing studies that this work intends to address. Apart from the limitation, this work intends to address other limitations from the context of system development literature. Since the invention of the mobile phone camera, researchers investigate and enhance the way how the apps work to improve usefulness and ease-of-use of such apps. However, from the theoretical perspective, there is a lack of studies analyzing the fundamental knowledge pertaining to the system architectural components that built up the apps. Taking this limitation into consideration, this work analyses the main components that are necessary for developing camera barcode reading apps. On the other hand, the current literature on camera barcode reading lacks an analysis of technical issues and challenges of developing such apps. This analysis could help to create new areas of research that facilitate developers in producing high-quality apps that satisfy the users. In conclusion, there is a need for a review work that reports the findings in a comprehensive manner to fill the gaps in the domain.

Based on the limitations found in the literature as explained in the previous paragraph, the work aims to review the current trends and future directions of camera barcode reading apps. The following research questions (RQ) were formulated to guide the work presented in this paper:

RQ1: How a barcode symbology works?

RQ2: What are the domains in which barcodes can be used?

RQ3: What are the components of the architecture for a smartphone camera barcode reading app?

RQ4: What are the challenges of using a smartphone camera for barcode reading?

The remaining of the paper is divided into six sections answering the four RQ stated earlier.

Section 2 reveals the method for conducting the review. Then, Section 3 describes how barcode can be read by the smartphone camera which answering RQ1. After that, Section 4 reports the domains that camera barcode reading apps are implemented which corresponds to RQ2. Section 5 explains the findings for RQ3 which cover the components and architecture for a camera barcode reading app. RQ4 is answered in Section 6. Finally, the concluding remark is presented in Section 7.

2. METHOD

The aim of the paper is to review the current trends, and future directions in the use of smartphone cameras as a barcode reading device guided by the four RQ stated in the previous section. The review was conducted following the method used by Siswanto et al. [14]. The work started by searching scholarly articles indexed in Google Scholar. The search terms include "barcode reading apps", "barcode scanning apps", "1-D barcode applications", "mobile phone barcode", "mobile phone linear barcode" and "smartphone barcode". The results of the search on Google Scholar returned more than ten thousand documents in various forms including books, theses, patents, articles in journals, articles in proceedings, book chapters. and technical reports. Then, the documents were manually filtered, and relevant documents were selected to be included in the review. Full-text of the relevant documents were further searched for content analysis. The filtering process discarded patents and books. Further, the scope of the work is limited to camera barcode reading used by users in facilitating their daily life activities. Other uses of camera barcode reading such as those used in scientific and clinical studies are beyond the scope of this work. The searching results reveal that the earliest study on camera barcode reading was published in 2004, consistent with the introduction of the camera mobile phone. Therefore, the range of years for the published scholarly documents was set between 2004 to 2018. In total, 50 documents were selected and reviewed. Table 1 summarizes the types and the number of documents included in the review. The complete lists of the documents are listed in Table 2.

Table 1: Types of documents included in the review

Types of documents	Number of documents
Articles in journals	18
Articles in conference proceedings	21
Chapter in books	8
Technical reports	2
Thesis	1
Total	**50**

Table 2: List of authors and its references

Kulyukin and Zaman [15]	Deng and Cox [16]
Kalnikaitė, et al. [17]	Kutiyanawala and Kulyukin [18]
Dorman, et al. [19]	Tekin and Coughlan [20]
Rocholl, et al. [21]	Mira [22]
Daraghmi, et al. [23]	Mira, et al. [24]
Wachenfeld, et al. [25]	Ebling and Cáceres [26]
Gallo and Manduchi [27]	Engelsma, et al. [28]
Sörös and Flörkemeier [29]	Karpischek, et al. [30]
Sörös [31]	Farr-Wharton [32]
Von Reischach, et al. [33]	Simmonds and Nipper [34]
Son and Shin [35]	Järvinen [36]
Franco, et al. [37]	Karpischek and Michahelles [38]
Byrd-Bredbenner and Bredbenner [39]	Karpischek, et al. [40]
Chen, et al. [41]	Neal, et al. [42]
Junaini and Abdullah [43]	Amran, et al. [44]
Kassim, et al. [45]	Kulyukin and Zaman [46]
Järvinen [36]	Kulyukin, et al. [47]
Dunford and Neal [48]	Yahaya, et al. [49]
Dunford, et al. [50]	Jethjarurach and Limpiyakorn [51]
Venkataram and Purama [52]	Razak and Katuk [53]
Maringer, et al. [54]	Hernández, et al. [55]
Karpischek [56]	Piedra, et al. [57]
Rouillard [58]	Zamberletti, et al. [59]
Farr-Wharton, et al. [60]	Jadhav and Bhatia [61]
Budde and Michahelles [62]	Gallo and Manduchi [63]

We analyze and discuss the content of the documents with the intention to provide readers with the state of its current research and development. Specifically, we intend to analyze the different purposes of apps that used smartphone cameras as a product barcode reading device. Further, we are also interested in studying what the software and hardware components that built-up the

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apps and the possible instances of the components that developers may select are. Finally, we study the literature on the issues that are faced by users, developers, and researchers towards a successful implementation of smartphone barcode reading apps.

3. AN OVERVIEW TO BARCODE SYMBOLOGY

This section provides the findings to the first research question (RQ1), specifically on "How a barcode symbology works?" It describes the history of barcode and its building block. Further, it discusses the devices used for reading the barcodes, and current implementations of the barcode in human daily life. Finally, the section elaborates how a smartphone camera reads a barcode printed on the label of items and consumer products.

The use of smartphones as a reading device for consumer product barcodes has been the focus of many research and development projects for a long time [15]. Consumer awareness and demand for detail product information open new opportunity for mobile technologies to fulfill consumers' needs [17]. The consumer product is just one example of a domain that uses barcode symbology. Since the last century, the barcode is a common identifier for handling consumer products within retail businesses. Specifically, barcode reading involves merchants' point-of-sale (POS) systems [64] where it helps the merchants in their sales and inventory processes. Reading barcode from retail products at the check-out counter is a lot faster and less error in preparing invoice and receipts compared to the use of keyboard to manually enter the product code to the POS system. The POS and barcode are very convenient and improves customers' shopping experience.

A barcode symbology stores an identifier (i.e., barcode data) that uses a special reader or optical scanner to extract and obtain it. Barcode symbology has two categories: one-dimensional (1D) and two-dimensional (2D) barcode [65]. These two categories describe barcode data representation. The 1D barcode contains parallel lines with varied thickness; while 2D barcode has two-dimensional patterns with more data contained per unit area. Figure 1 shows the two barcodes symbology.

(a) 1D barcode *(b) 2D barcode*

Figure 1: Example of 1D and 2D barcodes

2D barcodes are the recent development that evolves together with the introduction of smart devices. However, these systems are not compatible with 1D barcodes [19]. Further, the majority of consumer products have 1D barcode label either the Universal Product Code (UPC) or European Article Number (EAN) standard which is known as Global Trade Item Numbers (GTIN) since 2005 [21]. GTIN is specified and distributed by a worldwide regulatory organization called Global Standards One (GS1) in which its members are the governing agencies from each country in the world. GS1 manages the system for identifying goods, services, assets, and locations worldwide. GS1 provides an efficient numbering system to trade items that can assign a unique identification number and as well as supplementary information such as best before date, serial number and batch number [66].

GTIN comes in the form of 1D barcodes printed on product packaging [67]. Before 2005, UPC was the barcode standard used in the United States, while EAN-13 was used in European countries and commonly used worldwide. The EAN-13 barcode represented the identifier in a sequence of thirteen digits, and UPC barcode consisted of twelve digits [23, 68]. In January 2016, a new release of GS1 specification had renamed EAN-13 to GTIN-13 and UPC to GTIN-12 [66]. Other GTIN standards include GTIN-8 and GTIN-14. In this section, we specifically focus the discussion on GTIN-13 as it is being used widely especially for consumers' products. The series of numbers for GTIN-13 is represented in the form of a 1D barcode and printed on products' cover.

In GTIN-13, the thirteen digits are group into three parts, GS1 company prefix, item reference, and a check digit. Figure 2 shows the allocation of digits for both GTIN-13 and GTIN-12. GS1 company prefix consists of the first six digits to which GS1 member organization or the governing agency in a country assigned it. The next six digits represent the item reference which is assigned and given by the respective owners or manufacturers of

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a product. The last digit is for the check digit used to ensure the barcode readers correctly obtain the first twelve numbers. Figure 3 shows the method for checking the numbers for exact composition. The numbers in odd position must be multiplied by one, and the numbers in even position must be multiplied by three. Then, sum up the multiplied values in each position. Finally, select the nearest higher number multiple of ten and subtract the sum value from the number. The remainder should be equal to the check digit. Figure 4 shows an example of calculation for the check digit.

GTIN-13												
N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13
Multiply value in each position by												
1	3	1	3	1	3	1	3	1	3	1	3	
Accumulated results = sum												
Subtract sum from the nearest equal or higher multiple of ten = check digit												

Figure 2: The digit allocation of GTIN

	GS1 Company Prefix						Item Reference						Check Digit
GTIN -13	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13
GTIN -12	0	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12

Figure 3: The process for calculating the check digit

9 556231 110229

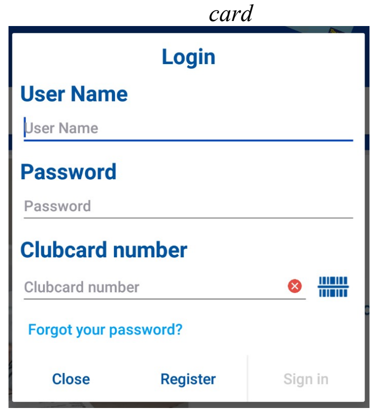
GTIN-13												
9	5	5	6	2	3	1	1	1	0	2	2	9
Multiply value in each position by												
1	3	1	3	1	3	1	3	1	3	1	3	
9	15	5	18	2	9	1	3	1	0	2	6	
9+15+5+18+2+9+1+3+1+0+2+6 = 71												
80-71 = 9												

Figure 4: An example of calculating the check digit

The GTIN-13 and GTIN-12 are called EAN/UPC family barcode used in retail products. There are other barcode standards such as GS1-128 and ITF-14 used in logistics and transportation, clothing industry, and healthcare as product identifiers [69]. The 1D barcode was not limited to consumer products as governing by GS1. For example, the barcode is available in the library for recording book catalogs and circulations. Printed utility bills also used barcode as an identifier. Retail businesses created a loyalty card for their customers and used the barcode as an automatic identifier for capturing the customer's detail. Figure 5 shows an example of a loyalty card that used barcode and used the barcode number to log in the mobile app.

(a) The front side of the card

(b) The rear side of the card



(c) Barcode reading for login the mobile app

Figure 5: An example of a barcode printed on a loyalty card and used for login the mobile app.

A particular device, called a barcode reader (or barcode scanner) is used to capture the barcode printed image. The barcode readers are available in three forms; (i) pen type readers, (ii) laser scanners, and (iii) LED scanners [25]. The pen type reader is the simplest and less expensive device for reading the barcode. The tip of the pen is a photodiode and light that will return a waveform when it is pulled horizontally across the lines in the barcode. Similarly, the laser scanner uses a laser beam and mirror to capture the reflected intensity of lines in the barcode instead of the photodiode. LED scanner which is also known as a charge-coupled device (CCD) uses hundreds of tiny lights sensors to measure the intensity of ambient lights from the lines. Then, it generates digital representations of the barcodes.

Pen, laser, and LED scanners are already mature technology for barcode reading. Researchers are currently investigating the potential of a digital camera as an emerging technology for barcode readers. The technology for digital cameras has improved a lot compared to a decade ago. Current digital cameras can capture images at a higher image resolution and produce high-quality images. Further, the dedicated digital camera now has built-in wireless and cellular network communication which make them a smart device. Modern mobile devices mostly contain a digital camera. Both dedicated digital cameras and smartphone cameras have the potential to be used as a barcode reader. Camera-based readers have recently gained much attention due to the reason that they are capable of capturing good quality images [25, 27]. Further, great smartphones penetration has fostered camera-based app development that could benefit users. It includes the use of smartphone cameras for barcode reading.

The process of reading barcode information using smartphone cameras involves two necessary steps that capture the barcode image and decode the image into a series of numbers. During the process of capturing a barcode image; the whole barcode lines should be visible to the camera lens. It is a significant step in the barcode reading process as it determines whether the camera correctly captures the barcode. A viewfinder window and a scan line and are the elements that help users to locate barcode when a smartphone camera is triggered. Figure 6 shows an example of a view-finder window; the lighter color of the middle square box and the red scan-line in a smartphone app that scans the barcode printed on a drink bottle.

Figure 6: An example of a scan-line and a view-finder window in a barcode reading app.

Then, barcode localization algorithms are utilized to obtain sharp barcode image as camera-based readers often produce blurry images. It could be due to the fixed-focus camera; the camera is too close to the barcode or small barcode image that causes the camera to focus on the background [29]. When the camera successfully captured the barcode image, it is passed to a barcode decoder to obtain the series of product identifier [31] for product lookup. Product lookup based on barcode information is useful for consumers particularly for getting additional product-related information that is not available on the product packaging, reviews by other consumers or comparing prices [23]. In the early introduction of a phone camera, barcode reading apps were still immature. Von Reischach, et al. [33] evaluated eleven 1D barcode reading mobile apps in 2010 and concluded that most of them were not applicable yet with slow barcode recognition process that explained the low adoption of mobile 1D readers. They suggested improvements concerning the speed in reading the barcode, reliability in giving the correct barcode number, interaction in a simple manner, and feedback after a successful reading. The speed of barcode reading has been a growing research area in which researchers developed many techniques to capture fast and accurate barcode data.

4. SMARTPHONE BARCODE READING APPS

This section provides the findings to the second research question (RQ2) on “What are the domains in which barcodes can be used?” There is an emerging interest among app developers to explore the potential of smartphone cameras as a barcode reader with the aim to improve users’ quality of life. Smartphone camera can be an input device for automatic reading of the barcode number which eliminates typing. Hence, it provides a faster way to input the numbers and reduces errors. Smartphone barcode reading apps scan the barcode of items or products using the built-in camera, translate the lines into a barcode number and perform a lookup from the associated database [70]. Then, the apps will render additional information about the items or products on the smartphone screen. The extended roles that the apps perform are varied. Among them is the role of a digital diary or a personal assistant that reminds the users about events such as medicine intake and grocery shopping. The apps are also programmed using artificial intelligence techniques to provide recommendations to users based on users’ conditions or behaviors. Then, users get useful information tailored to their needs.

This section identifies various apps that utilized smartphone cameras as a barcode reader. It focuses on smartphone apps for reading 1D GTIN barcodes printed on consumer products. The main aim of the section is to review smartphone barcode reading apps that support daily human life activities and further synthesize the architectural software design of the apps. Software architecture illustrates the structure and component of a modern system as well as the interactions between the subsystems that make up the whole system so that the system can be designed in the best possible way [71]. Software architecture is also a mental model which depicts the system at the high level of abstraction that is vital for software development process including understanding, reuse, development, evolution, analysis, and management [72]. Consequently, developers can deliver useful software with acceptable performance and reliable [71].

Researchers and developers proposed diverse types of apps utilizing smartphone cameras as a barcode reading device. The apps are beneficial for diverse groups of smartphone users including elderly and visually impaired people. A simple search from Google Play Store using the keyword “barcode scanner” returns hundreds of apps from various categories covering both 1D and 2D barcodes. It portrays a growing interest among developers to utilize smartphone cameras as a barcode reader. Generally, software (including mobile apps) development is difficult because the process is complicated and understanding how a system also works a challenge [73]. It is even harder if developers must start from scratch. Thus, a generic architecture for smartphone barcode reading apps would assist the new developers to understand the apps or to reuse the existing components for other newly developed apps. It will support the developers and allows them to produce apps in a shorter time. Indirectly, it will significantly benefit users as more functional smartphone barcode reading apps are available for their usage.

Developers have developed smartphone barcode reading apps to facilitate users is getting detail information from the barcode. There is a growing demand from consumers who would like to access additional information on particular products using their mobile phones [67]. The additional information includes recipes, usage tips and the ideal amount of food consumption [74]. It is also a necessity for consumers with special dietary needs such as people who suffer from chronic disease, have an allergy reaction to certain foods, and have religious and cultural restrictions [19, 39, 41, 53, 75]. People with special dietary needs, especially those with religious food restrictions. For examples, MyMobiHalal 2.0 [43] and MyHalal [45] assist Muslim consumers in checking whether the foods are halal compliant. Other than that, the apps can also be used to promote healthy habits and practices on food management such as TIVIK [76], FoodSwitch [48, 50], and healthWise [52]. A study by Maringer, et al. [54] found that 24 smartphone barcode reading apps for food nutritional information are available from Google Play Store and Apple’s App Store in 2018. Seven of the smartphone apps namely MyFitnessPal, FatSecret, Virtuagym Food, Lifesum, Lose It!, Yazio, and SparkPeople reached more than a million downloads and had exportable food data which could help users to get information faster from the food label. The apps also serve as a way to find a product review by other consumers [17, 56].

Another innovative use of smartphone camera and the barcode is for pantry and fridge inventory tools [58, 60]. Fridge and pantry are available at home for storing food supply for the week or month. The process starts by listing the food needed for the household and buying them from the grocery store or online shops. Users might forget which food items are still available in the pantry or the fridge and which are reaching the expiry date. Users can use smartphone cameras as a tool for managing food inventory in their fridge and pantry to avoid food waste. Expired food products are a waste to the environment and food sustainability [60]. Thus, developers utilized smartphone cameras and the barcode printed on the product label to create apps that assist the users in monitoring food in their fridge or pantry. Notification can be sent to them to remind them of foods that are going to expire soon. Then, it may also suggest recipes on how to cook with those ingredients. The apps can be a tool for grocery shopping. It could remind users of the food items that are running out of stock soon in the fridge or pantry. FridgePal [60] and Pervasive Fridge [58] are examples of these apps.

Smartphone cameras and barcode can serve as a tool for getting product reviews from other consumers. Crowdsourcing is also a way of getting information about products. Reviews from other consumers are useful in deciding on buying products such as implemented in Product Empire [62]. Product Empire motivates users to capture the product barcode and supply information about the product. The crowdsourced information aims to create an open product repository that could benefit users and app developers. A similar concept is also applied in FoodSwitch [48]; a food barcode reading apps that allow users to supply missing food information. Users uploaded more than one million photos of food items contributing to more than 100,000 new products added to the database reported in 2017. The crowdsourced information complements the missing product information that users need. The barcode reading function for crowdsourcing facilitates the input process and could encourage more participation from users as compared to the manual of keyboard input. The other possible usage of smartphone camera for barcode reading includes a price comparison offered by different retailers [16, 77]. Further, smartphones could also be used as a barcode reader to assist visually impaired people to get product information at the supermarket by giving audio information [18, 20]. Older adults may also get benefit from the device when it is used to help them in their intake of medication [22, 24]. Table 3 summarizes the domains of implementations for camera barcode reading adds and descriptions of the relevant apps.

Table 3: Barcode reading apps and the relevant domains of implementation

References	Domain of Applications	Description of the application
[26, 28, 30, 62]	Price comparison	*ShopSavvy* is a mobile application that allows users to use their smartphone camera and scan consumer product barcode and get the product prices from different online retailers or local stores. Users can find the lowest price offered in the market and obtain updates on price changes for the products in the list.
[62, 78]	Crowdsourcing product repository	*Product Empire* is a mobile game application that encourages players to capture photo and barcode information of products. Players will be rewarded with virtual currency, and they can broadcast their achievements through the social network. It is a way to attract new players which indirectly will increase the product data in the repository.
[22, 24]	Elderly care	*TUMEDICINA* is an application that provides verbal instruction when barcode information on medication packaging is scanned using smartphone cameras. The aim of the system is to assist elderly patients to use multiple medications safely.
[58]	Home food inventory management	*Pervasive Fridge* is an application that aims to avoid food waste by sending a reminder of food expiry dates stored in the fridge or cupboards. It uses smartphone camera and voice command to capture GTIN barcodes and validity dates. Reminders will be sent through alarm set on the calendar, email, and text messages.
[32, 60]	Home food inventory management and Recommender system	*Fridge Pal* is an application that helps users to manage their groceries in the fridge, freezer and pantry by recording their barcode using smartphone camera. The application keeps track of the food inventory and suggests recipes to the users based on the list of groceries recorded in the application database.
[34]	Online gift registry	*GiftScroll* is a mobile application that allows users to manage their "wish list" gift for events such as wedding and baby shower. The list can be created by scanning the product barcode from shops, and the wish list can be distributed to friends and family members.
[16]	Price comparison	*LiveCompare* is a mobile application that enables price comparison of grocery items through participatory sensing. Users scan the barcode image of the price tag and upload it to a central repository, then; the application will provide the price of the same item from nearby stores.
[77]	Price comparison	*Ubira* is a mobile application that shows the price list of a product offered by online and offline stores when a user scans the barcode of a product. It also allows users to add the price of a product if it is not on the list.
[36]	Product information system	*TIVIK* is a project that developed a mobile application that allows users to manage their food intake based on product barcode information. When users scan the barcode, they will be provided with food nutritional information.
[28]	Product information system	*Shop Social* is a mobile application that allows users to scan barcodes and search product information and relevant video from the user's social graph.

[38, 40]	Product review	*My2cents* is a mobile application that allows consumers to share their opinion on products with friends and social network. Consumers are also able to share their opinion with the product owners.
[19]	Recommender system	The researchers developed an application that uses the mobile phone camera for scanning the GTIN-12 code on packaged foods for monitoring food intake especially on the amount of calories consumed by a user. It helps obese users to manage their calorie intake to get a healthy diet.
[42, 50]	Recommender system	*Food Switch* as a mobile phone application that provides consumers with food nutrition information with color coded (red, amber, green) to indicate the nutritional contents of the foods. The application supports users' selection of healthier choices when shopping for food.
[52]	Recommender system	*healthWISE* is an application that allows a user to scan food product barcode to obtain nutritional information on calories intake that a user consumes. Users are suggested to exercise when the calories intake is exceeding the required amount.
[44]	Recommender system	*User Profile Based Product Recommender* is a mobile application that provides personalized recommendations to users based on their religion and medical condition.
[46, 47]	Special dietary needs	*Persuasive NUTrition Management System (PNUTS)* is a mobile application that aims to improve consumers' awareness of food nutritional labels. Consumers scan food barcode, and the application will provide the nutritional information of the corresponding products.
[23]	Special dietary needs	*Preferences Monitoring* is an application that assists users to check the ingredients of food products based on their GTIN-13 barcode. Users predefine their profile and diet preferences e.g., religious restriction (Muslim, Hindu, Judaism, etc.) or allergy reaction or calories-based diet, and the system will notify whether the scanned food is suitable for the users' preferences.
[49]	Special dietary needs	The researchers developed a mobile application that facilitates Muslim consumers to verify either food products were Halal certified. Consumers scan the product barcodes, and the application will look up the Halal database from the Halal authority. Consumers will be notified whether the food products are Halal certified.
[45]	Special dietary needs	*MyHalal* allows Muslim consumers to verify and recognized the information of products and confirmed their Halal status in real time which has access to its database while they do shopping.
[43]	Special dietary needs	*MyMobiHalal 2.0* is a mobile application that helps Muslim consumers to verify the Halal status of food products based on their barcode information. The halal status is obtained from halal authority database.
[20]	Visually impaired users	The researchers developed a mobile application that assists a visually impaired user to get information on products from their barcode. Users will be presented with audio information of the products when product barcodes are scanned.
[51]	Visually impaired users	The researchers developed a mobile application for Thai blind users. The application helps blind users to locate barcode application on the product cover via text-to-speech technology. Once the barcode is located, it will be decoded, and information about the product is also presented to the users through text-to-speech technology.

5. THE ARCHITECTURE OF SMARTPHONE BARCODE READING APPS

This section provides the findings of the third research question (RQ3) on "What are the components of the architecture for a smartphone camera barcode reading app?"

In the context of smartphone barcode reading, the software architectural design layouts the components and communications between the components that make up the app. However, the architecture for smartphone barcode reading apps is limited in the literature. Therefore, there is a need for discussing the architecture for smartphone barcode reading apps to support developers in developing the apps. Further, the apps involve communication with a sensor which may need external services or components that make the apps more challenging to develop than the usual mobile

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apps. Hence, academic papers and technical reports on smartphone barcode reading apps are reviewed to pinpoint the components that make up the apps.

The process of using smartphone cameras for barcode reading involves a few steps. First, the users must activate the barcode reading app. Some apps have a personalized system interface in which different users will get different information based on their needs and condition [24], where their profiles are available in the database [44]. Personalized information and user profile can be obtained using social network credentials such as Facebook and Twitter [56]. Hence, the social login interface sometimes provided in smartphone barcode reading apps as a user authentication technique accessing the user profiles. Specific apps provide the main menu or interface where the users can choose among other few functions such as modifying the setting and review past activities. Other apps may automatically trigger the smartphone camera once the apps are activated.

Second, the users should hold a smartphone camera on the printed barcode and align the viewfinder window (i.e., the barcode frame) on the printed barcode horizontally. A scan line will appear and read the barcodes. In the case that the scan line does not appear, the users need to keep aligning the viewfinder window on the barcode. A barcode localization algorithm [18, 29, 31] perform this process. Third, the barcode decoder will translate the lines into a series of numbers and performed a validation process. It passes the correct barcode numbers to other modules of the apps for extended data lookup and manipulation. If the incorrect barcode numbers are retrieved, the apps should be able to ask the users to align the smartphone camera on the barcode again. Finally, the barcode extended modules should be able to render the information on the smartphone screen to the users. Figure 7 shows a flowchart for the general process of the smartphone barcode reading apps.

Analysis of the smartphone barcode reading apps has revealed the architecture of such systems. The apps in specific studies (such as [23], [19], [52], [76], [43], [53]) were analyzed to find similarities between them and the core components that made up the apps. The generic architecture for the smartphone barcode reading apps is presented in this paper to highlight the essential components and the flow of communication between them. The architecture comprises of four essential components namely; (i) a smartphone camera, (ii) an application programming interface (API), (iii) an application server and, (iv) a product barcode database.

A smartphone camera is a built-in rear camera of smartphones for capturing images. It is a type of sensor equipped in the modern smartphone. The smartphone camera is used to capture the barcode image printed on the product label. It needs a barcode reader API; software modules developed by third-party programmers integrated into other apps. API facilitates the communication of the smartphone camera with the whole structure of the barcode reading apps [74]. Further, the barcode reading API reduces the developers' programming effort to construct the barcode reading modules; hence making the work more convenience [3].

Smartphone barcode reading apps require an application server to host the program and perform the logic and business operations of the apps. It is the component of the apps that interact with users' smartphone and other external components such as the product databases through a communication network. It is also the component that maintains users' information and activities including logs. The application server is the brain of the app that processes the input and produces the intended output to the users. A product barcode database is a repository that stores product information including the barcode, the product name, the brand, and the manufacturer. The program or code resided on the application server will perform product lookup from the product barcode database according to the decoded barcode information. Figure 8 shows the overall architecture, the components, and the communication flow of smartphone barcode reading apps.

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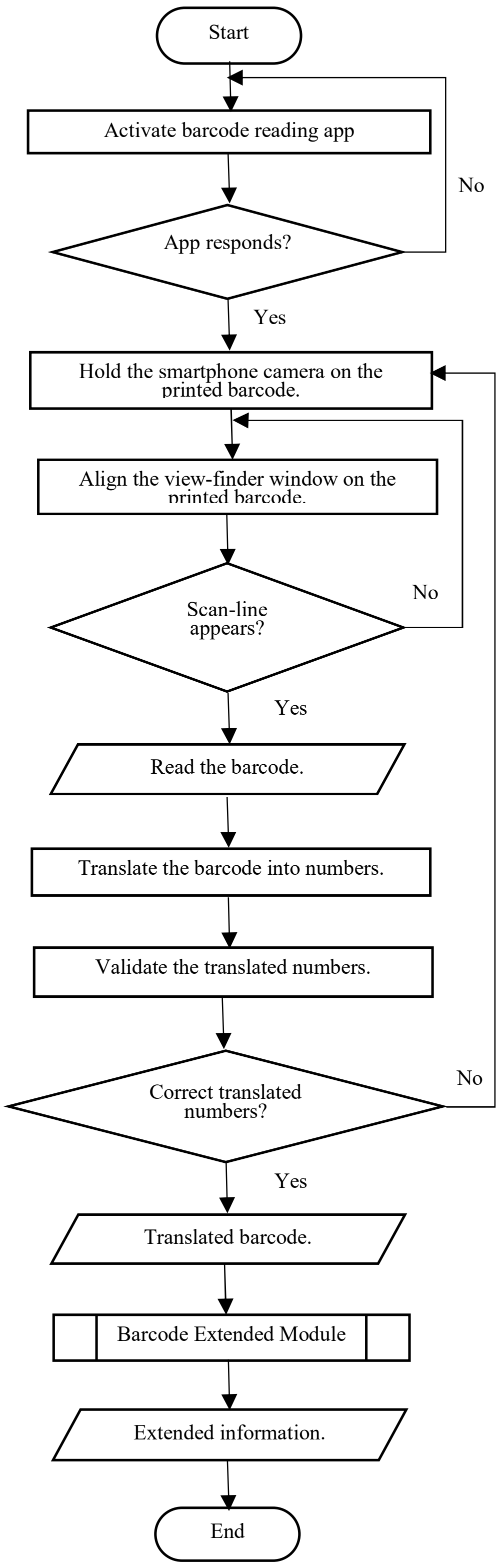

Figure 7: The process of using smartphone barcode reading apps

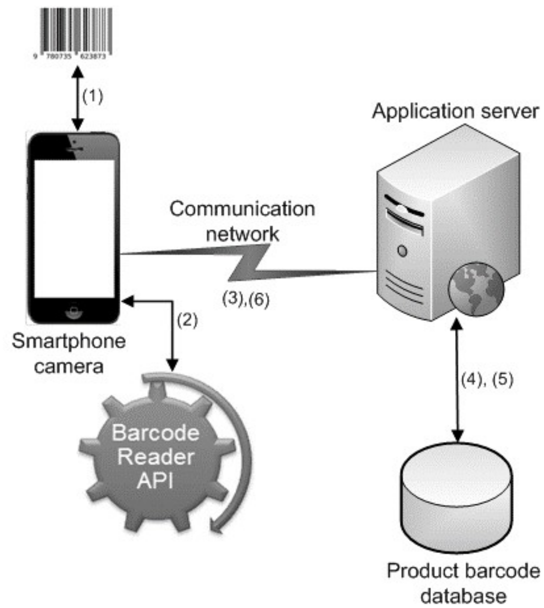

Figure 8: Generic architecture for smartphone barcode reading apps

From Figure 8, the architecture for smartphone barcode reading app replicates the three-tier client-server architecture [55, 57, 79]. In this architecture, a smartphone is a client which requests a service from an application server. The client should have installed and run a native mobile app. When the server received the request, it will process the request and send another request to the product barcode database following the original request by the client. The server responds to the client request upon receiving a response from the product barcode database. An API for barcode image recognition is the additional component that performs image recognition and processing of the barcode. Communication between the components in the architecture is performed in a sequence as follow:

(1) A user activates the app and points the smartphone camera on a product barcode.

(2) The app calls barcode reader API. The API performs barcode localization and decoding and returns barcode identifier number to the app installed on the smartphone.

(3) The app sends the identifier number to the application server.

(4) The application server processes the request by sending it first to the product barcode database to retrieve the intended product information.

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(5) The product barcode database returns the requested product information to the application server.

(6) The application server performs further processes such as recommending actions, recipes, set the alarm, and then returns the results to the app. The user gets the result through text message, email, alarm, calendar, and others.

As explained in the previous paragraph, barcode reader API performs barcode image recognition and decoding. The examples of barcode reader API are ZXing, Bartoo Toolkit, ZBar, Google Barcode API, and Scandit. A comparison of barcode reading tools has also been made earlier by Reischach [33] involving first barcode libraries, APIs, and software development kits (SDK) that were available before 2010. The barcode reader APIs are available as open-source or proprietary. Table 4 lists some of the standard barcode reading API and SDK.

Table 4: Barcode reading API and SDK

Types of barcode reader API	Name	Description
Open-source API	ZXing [15], [51], [44], [59], [29], [45], [30], [56], [49], [33], [21], [40], [38], [62], [16]	ZXing (pronounced as "zebra crossing") provides barcode image processing library implemented in Java. It performs image recognition process on the barcode and returns barcode number identifier without communication with a server.
	Batoo Toolkit [33], [23], [56]	Batoo Toolkit is an automatic 1D barcode recognition tool developed by a group of researchers at ETH, Zurich Germany.
	ZBar [61], [21], [40], [38]	ZBar is a barcode reader API that can capture barcode images of video streams, image files, and raw intensity sensors. It supports EAN-13/UPC-A, UPC-E, EAN-8, Code 128, Code 39, Interleaved 2 of 5 and QR Code.
	Google Barcode API/ ML Kit [80]	An API for the mobile app developed by Google that can recognize and translate 1D and 2D barcodes and works in any orientation.
Proprietary API	RedLaser SDK [38], [40], [29], [26], [63], [17], [30], [15], [56]	SDK that provides developers with code that can perform barcode reading on images or voices for Android and iOS platforms. It has been discontinued since 31 December 2015.
	Scandit Barcode Scanner SDK [29], [67], [56]	SDK that provides high-performance speed and accuracy for enterprise barcode reading. The SDK is available on many platforms including iOS, Android, Windows, Linux, Google Glass, Xamarin, Cordova, and Titanium.
	i-nigma Barcode Reader SDK [19]	SDK that provides barcode reading functionality using the camera of all major mobile platforms. It allows developers to integrate the SDK into their apps for several types of apps.

The type of application servers as in the generic architecture depends on the programming and mobile device platforms. Nowadays, there are many options for developers to choose from for the application servers especially the one provided by cloud service providers. Developers and app owners can omit the complexity of choosing the right hardware, software, infrastructure and platform for hosting and running their app. Cloud service providers provide the solution more efficiently and user-friendly at an affordable price [81]. The increase in mobile subscribers has emerged a recent technological trend called mobile cloud computing (MCC) [82, 83]. In MCC, centralized computing platforms located in clouds took over the role of data processing and storage from mobile devices [84]. Apps can be deployed quickly without the need for enterprises to invest in physical servers and other infrastructure. In other words, MCC enables mobile app providers and users to exploit computing resources available at the cloud when they are needed [85].

Barcode reading apps also require a product barcode database for getting further information

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about the products. The barcode in POS is linked to product name and price for informing customers about the price of the product. At the check-out counter, merchants prepare an invoice which states the list of items, their quantity and the corresponding price which derived from their database. Merchants' database contains product information such as the product identifier number, product name and description, its' unit price and quantity for tracking the merchants' inventory and sales. In the retail business, product barcode links to the price and quantity of products in the store. By searching its barcode number from product database providers over the Internet, users obtain basic product information such as product name, general description and brand's owner.

As GS1 governs GTIN; the organization provides a public service name Global Electronic Party Information Registry (GEPIR) that gives access to necessary contact information for companies that are members of GS1. Anyone can search the owner of a GTIN barcode and retrieve the company's address and contact person. However, for the public used, GEPIR does not provide information about the product name and brand, as well as additional information like the ingredients and nutritional information for food products. By searching its barcode number from product database providers over the Internet, users obtain necessary product information such as product name, general description and brand's owner.

Karpischek, et al. [67] analyzed publicly available sources of GTIN product databases used by customers to access additional product information through barcode reading apps. The sources include codecheck.info, amazon.com, Google, affili.net, openean.kaufkauf.net, GEPIR, and SA2 WorldSync. Although the information for a barcode obtained from the public sources is less accurate, they are useful for the developers and users to get extended information from the product barcode. Currently, free product databases for smartphone barcode reading apps are limited. Therefore, many developers encourage user-generated database entries [54]. Table 5 lists the available public GTIN product databases for product lookup using the barcode. The app developers could also use this product database for product lookup from smartphone barcode reading apps. There are also commercial product databases which can be bought or subscribed to from the providers such as Semantics3, Scandit, and MyNetDiary.

Table 5: List of product databases for GTIN

Database Name	Description
Global Electronic Party Information Registry (GEPIR) [86], [67], [56]	GEPIR is a web-based app that provides facilities to obtain contact information for brand owners of a GTIN barcode.
Product Open Data (POD) [87]	A product database initiated by the Open Knowledge Foundation that provides information on GTIN barcode based on brands and brand owners.
Open Product Data [88]	A product database and API by Open Data Soft that stores GTIN, brand owners, and nutritional information.
Open EAN/GTIN Database [56], [67], [30]	A web-based app, database, and API that allow the user to look up the product database and it returns product names, manufacturers, and country of origin. The app is available in the German language.
Barcode Database [59]	A web-based app that allows users to lookup a barcode and it returns product information of the given barcode
UPC Index [89]	A web-based app that provides a database to look-up UPC barcode for users. The app returns product information for the barcode number.
Codecheck [62], [38], [40], [30], [67], [56]	A German web-based app that returns product name and description when users look up for a barcode number.
Barcode Lookup [90]	A product database where the owners collect the information from various retailers and allow public users to contribute new product information to the database.
International Barcodes Database [91]	A web-based product database that provides information about products using the product barcode.

The architecture for smartphone barcode reading apps discussed in this section provides fundamental knowledge to app developers and research on the components needed to develop such apps and how the components interact with each other.

6. DESIGN AND IMPLEMENTATION CHALLENGES

This section provides the findings of the fourth research question (RQ4) on "What are the challenges of using a smartphone camera for barcode reading?" The analysis of the literature suggested five design and implementation challenges faced by the developers in developing the camera barcode reading apps.

The development of smartphone barcode reading apps seems to be simplified and less complex; thanks to the services provided by MCC that allows a cheap solution for mobile app development, as well as API for barcode image localization and recognition. Although the use of smartphone cameras for barcode reading is a low-cost approach towards supporting human daily life activities; there are a few challenges that regularly discussed by researchers in this domain of study. The challenges involve technical and non-technical aspects of the development and implementation. The technical aspect refers to the technical capability of smartphones as an imaging device whereas the non-technical aspect covers the factors that influence the success of the apps including support for the infrastructure. This section analyses the challenges of using smartphone cameras for barcode reading to exhibit the urgent need for further research and opportunity for exploring enhancements of the technology. The papers and report from academic databases and search engines are analyzed to pin out the challenges highlighted by the developers and researchers in developing smartphone barcode reading apps. Analysis of the literature suggested five primary challenges of using a smartphone camera for barcode reading; (1) blurry barcode image, (2) camera alignment constraint, (3) high battery energy consumption, (4) limited custom barcode databases, and (5) limited access to barcode databases. The following paragraphs explain these challenges.

Blurry barcode image. The built-in camera of smartphones nowadays has been significantly improved concerning its capability to produce good photo images. The cameras come with many features such as image stabilization, bright lens and optical zoom for higher quality photography. However, locating and decoding blurry barcode images is the most common problem involving smartphone cameras [21, 29, 56]. In the early days of smartphone cameras, many of them had low-grade lenses that lack focusing capability; the primary cause for blurry images [27]. Those cameras usually have a fixed focus lens because they did not develop for macro photos. The cameras tend to produce blurry images because they have a limitation in the distance between camera and object [21]. A blurry image also caused by small barcode image size, reflections [43], poor lighting conditions, or out-of-focus smartphone distance [23]. The blurry image could delay the barcode image localization and decoding. Resolving the blurry barcode image scanned using a smartphone camera is an emerging research area. Researchers improved the image recognition algorithms to capture a clear and sharp barcode image. Further, the image should be able to capture very quickly as soon as the users hold smartphone camera on a barcode. The techniques include edge detection for barcode reconstruction, methods based on peak detection, and blind deconvolution [61].

Camera alignment constraint. Localization is a primary process in barcode image reading as mentioned in the preceding paragraphs. To locate barcode image using smartphone cameras, users must align and focus the camera lens on the center of barcode image for obtaining a complete scan line for the camera to successfully read the bars [15, 46]. The camera lens and the viewfinder window must be in vertical or horizontal focus on the barcode frame. A standard LED barcode reading device can easily do it where it retrieved barcode image at any orientation. However, it is not the case with smartphone cameras used for barcode reading. It is hard to achieve the correct alignment of the barcode image because focusing on the barcode image frame always result in a blurry image [31]. There is a need for investigating the method to obtain fast and correct alignment during smartphone barcode reading. It is among the primary performance measure for smartphone barcode reading apps that could lead to user acceptance and satisfaction. Aligning smartphone camera to obtain the correct frame for the barcode is a cumbersome task for users. A good barcode reading API or the barcode localization algorithms should be able to read the barcode from any orientation and acquired the correct barcode image quickly. It requires a proper image recognition technique and a localization algorithm for reading the barcode so that it only reads the barcode image while discards other background objects.

High battery energy consumption. Section 4 has discussed that smartphone barcode reading apps utilize MCC infrastructure where the back-end server and product database server accessed through mobile networks. It involves overhead concerning energy and bandwidth [92]. Smartphones use high energy for reading barcodes because more power needed to operate the camera [23]. Further, communication between smartphones with cloud servers (both application servers and product databases) consumes a high amount of battery energy. High battery usage has limited smartphones processing capability [21] which become a challenge for mobile apps. An empirical study on the energy consumption of more than 400 Android apps [93] showed that access to the Internet and the use of camera consumed more than 50% of smartphones' battery energy. Surprisingly, invoking API in Android SDK consumed higher energy (85%) compared to only 2% of energy consumption for developers'-written code. In general, smartphone barcode reading apps require a high amount of battery energy for its operation and communication. Smartphone apps that consume high battery energy may not be a favorable choice for users as they highly rely on the device for other purposes as well. Therefore, further research that works towards resolving high battery consumption by smartphone is needed. It should be specifically focused on the image localization algorithms and could cover simplification of the overall communication of the components in the architecture.

They have limited custom barcode databases. The previous section also discussed the architecture of smartphone barcode reading apps that contains product barcode database as one of its vital components. Apps such as those comparing prices of a product could use the existing retailers' POS system for getting access to the product's price. However, other apps require a custom product database that supplies specific information more than just the product name and description. General product databases do not provide enough information rather than very general information that is available on product packaging. Other apps than POS that utilize product barcode somehow need to develop a database to allow the apps to work properly, consequently benefits users. Depending on the type of apps, the product database should include basic information about products such as product name and its description, brand's owner with additional information that suits the types of apps and users' needs. For example, an app for home food inventory system requires additional information on production date or expiry date. The food recommendation systems require information on nutritional facts and ingredients so that the engine can propose menu or diet plan based on the nutritional facts and ingredients. To date, there is no public source of product master data for consumer goods which are accessible, complete, and suitable for multiple purposes of mobile apps [67]. On the other hand, populating the product database with custom information requires much effort and is time-consuming because there are millions of consumer products with a barcode on the market worldwide. It is the major non-technical problem for smartphone barcode reading apps. Food manufacturers and retailers might also get the benefit since the quality of the food data retrieved from nutrition apps might have a strong influence on users' behaviors future shopping [54].

Limited access to barcode the database. Access to the public source of product databases is another non-technical problem that may limit the benefit of such systems and become a constraint to the app developers. Many of the product databases are available in a web-based system where users must key in the GTIN associated with a product barcode through a web interface. Users must key-in the number in the space provided, and a particular prevention system that distinguishes human from machine input (i.e., CAPTCHA) [94] embedded in the system. This mechanism does not allow access to websites' data from other external apps. It makes the product data unavailable for barcode reading apps. In another scenario, product databases appear in various formats including MS Excel sheet, XML documents, and text file. A standard query may not be able to access multiple shared product data due to inconsistency in the data types and formats of the data source. Hence, a flexible web service that can overcome this problem is required to support appropriate query and communication protocols.

7. CONCLUSION

This paper reviewed the topic related to the utilization of smartphone camera for barcode reading with the aimed to synthesize the generic architecture for the apps and highlight the challenges faced by the app developers in developing the apps. The reviews reported in this paper derived from the academic papers and reports that are available from the academic search engine. Therefore, it may have a bias towards the research perspective rather than technical and programming aspects of smartphone barcode reading apps. Further, it only focused on the use of camera barcode reading apps designed to facilitate human daily life activities. Nevertheless, the outcomes of the review reported in this paper provided fundamental knowledge about smartphone camera barcode reading apps. It is a useful source for researchers and developers to understand the components that built up the apps. Furthermore, the constraints faced by the developers in developing the apps demonstrate the existing gaps in the area and shed light on the need for further investigation for future works.

Analysis of the challenges in smartphone barcode reading apps has brought forward the potential areas of research and developments. There are many gaps in the domain that require further studies and investigation. This paper highlighted the potential future research that could be beneficial for the developers and the users of barcode reading apps. In the context of the computer science field of study, there is a growing interest among researchers to improve the barcode image localization algorithms to achieve better performance in capturing the barcode image. The performance measures include speed and accuracy. Another potential area of research for smartphone barcode reading is the investigation of methods or techniques to conserve the battery power; hence, achieving energy-efficient apps. Research and development could also be carried out for the development of a multipurpose product barcode database that could be customized based on the developers and users' need. Further, there is also a need for developing web services that could connect various product database providers that are available in different formats.

In the context of human-computer interaction, the use of a smartphone camera for barcode reading could have an impact on the users' behaviors. A deep study could be established to provide evidence on the use of smartphone barcode reading apps on purchasing behavior or company sales. Further, investigations could also be carried out to see the impact of the apps on users' behaviors towards their diet planning and health conditions. Another example of the study perhaps is the impact of smartphone barcode reading on the users' behavior towards reducing food waste. Finally, the usability and acceptance of the studies could be carried out to evaluate the effectiveness of the apps in assisting the elderly to manage their daily medication intake. The human-computer interaction studies will provide empirical evidence on the usefulness and impacts of barcode reading apps on users, hence will significantly benefit them.

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