AN OPTIMIZED CONTEXT-AWARE MOBILE COMPUTING MODEL TO FILTER INAPPROPRIATE INCOMING CALLS IN SMARTPHONE

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This thesis is dedicated to my beloved parents, Ali Davoudi and Shahla Kabiri, who always give me positive energy with constant and unconditional love and encourage me to go on every adventure, especially this one.

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ABSTRACT

Requests for communication via mobile devices can be disruptive to the receiver in certain social situation. For example, unsuitable incoming calls may put the receiver in a dangerous condition, as in the case of receiving calls while driving. Therefore, designers of mobile computing interfaces require plans for minimizing annoying calls. To reduce the frequency of these calls, one promising approach is to provide an intelligent and accurate system, based on context awareness with cues of a callee's context allowing informed decisions of when to answer a call. The processing capabilities and advantages of mobile devices equipped with portable sensors provide the basis for new context-awareness services and applications. However, context-awareness mobile computing systems are needed to manage the difficulty of multiple sources of context that affects the accuracy of the systems, and the challenge of energy hungry GPS sensor that affects the battery consumption of mobile phone. Hence, reducing the cost of GPS sensor and increasing the accuracy of current context-awareness call filtering systems are two main motivations of this study. Therefore, this study proposes a new localization mechanism named Improved Battery Life in Context Awareness System (IBCS) to deal with the energy-hungry GPS sensor and optimize the battery consumption of GPS sensor in smartphone for more than four hours. Finally, this study investigates the context-awareness models in smartphone and develops an alternative intelligent model structure to improve the accuracy rate. Hence, a new optimized context-awareness mobile computing model named Optimized Context Filtering (OCF) is developed to filter unsuitable incoming calls based on context information of call receiver. In this regard, a new extended Naive Bayesian classifier was proposed based on the Naive Bayesian classifier by combining the incremental learning strategy with appropriate weight on the new training data. This new classifier is utilized as an inference engine to the proposed model to increase its accuracy rate. The results indicated that 7% improvement was seen in the accuracy rate of the proposed extended naive Bayesian classifier. On the other hand, the proposed model result showed that the OCF model improved the accuracy rate by 14%. These results indicated that the proposed model is a hopeful approach to provide an intelligent call filtering system based on context information for smartphones.

ABSTRAK

Permintaan untuk berkomunikasi melalui peranti mudah alih boleh menganggu penerima dalam keadaan tertentu. Sebagai contoh, panggilan masuk yang tidak sesuai boleh meletakkan penerima dalam keadaan berbahaya, seperti menerima panggilan semasa memandu. Oleh itu, pereka antara muka pengkomputeran mudah alih perlu merancang untuk meminimumkan panggilan yang boleh memberi gangguan. Untuk mengurangkan kekerapan gangguan ini, satu pendekatan perlu diperkenalkan untuk menyediakan sistem pintar dan tepat berdasarkan kesedaran konteks dengan isyarat dalam konteks penerima yang membolehkan keputusan dimaklumkan ketika menjawab panggilan. Keupayaan pemprosesan dan kelebihan peranti mudah alih yang dilengkapi dengan sensor mudah alih menyediakan asas bagi perkhidmatan dan aplikasi kesedaran konteks yang baru. Walau bagaimanapun, sistem pengkomputeran mudah alih kesedaran konteks diperlukan untuk mengurus kesukaran pelbagai sumber konteks yang memberi kesan kepada ketepatan sistem, dan cabaran sensor GPS yang menggunakan banyak tenaga yang memberi kesan kepada penggunaan bateri telefon bimbit. Oleh itu, mengurangkan kos sensor GPS dan meningkatkan ketepatan sistem penapisan panggilan bagi konteks semasa adalah dua tujuan utama kajian ini. Oleh itu, kajian ini mencadangkan satu mekanisme penyetempatan baru bernama Peningkatan Hayat Bateri dalam Sistem Kesedaran Konteks (IBCS) untuk menangani masalah sensor GPS dan mengoptimumkan penggunaan bateri sensor GPS dalam telefon pintar selama lebih dari empat jam. Akhir sekali, kajian ini mengkaji model kesedaran konteks dalam telefon pintar dan membangunkan struktur model pintar alternatif untuk meningkatkan kadar ketepatannya. Oleh itu, model pengkomputeran mudah alih konteks kesedaran yang baru bernama Penapisan Konteks yang diOptimumkan (OCF) dibangunkan untuk menapis panggilan masuk yang tidak sesuai berdasarkan maklumat konteks penerima panggilan. Dalam hal ini, pengelas *Naive Bayesian* lanjutan yang baru dicadangkan berdasarkan pengelas *Naive Bayesian* dengan menggabungkan strategi pembelajaran tambahan dengan pemberat yang sesuai pada data latihan baru. Pengelas baru ini digunakan sebagai enjin inferensi kepada model yang dicadangkan untuk meningkatkan kadar ketepatannya. Keputusan menunjukkan bahawa peningkatan kadar ketepatan 7% didapati dengan pengelas Bayesian baru ini. Sebaliknya hasil yang dicadangkan menunjukkan bahawa model OCF meningkatkan kadar ketepatan sebanyak 14%. Hasil ini menunjukkan bahawa model yang dicadangkan merupakan pendekatan yang diharapkan untuk menyediakan sistem penapisan panggilan pintar berdasarkan maklumat konteks untuk telefon pintar.

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LIST OF ABBREVIATIONS

AI   -   Artificial Intelligence

GPS   -   Global Positioning System

WWW   -   Word Wide Web

NB   -   Naïve Bayesian

PBN   -   Practical Body Networking

ANN   -   Artificial Neural Network

IT   -   Information Technology

FFT   -   Fast Fourier Transform

WLAN   -   Wireless Local Area Network

IOS   -   Internetwork Operating System

API   -   Application Program Interface

PIN   -   Personal Identification Number

KNN   -   K-th Nearest Neighbor

PCA   -   Principle Component Analysis

LBS   -   Location Based Service

CBL   -   Circle Based Localization

IDE   -   Integrated Development Environment

DFT   -   Discrete Fourier Transform

SPSS   -   Statistical Package for the Social Science

UTM   -   Universiti Teknologi Malaysia

OCF   -   Optimized Context Filtering

IBCS   -   Improved Battery Life in Context Awareness System

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CHAPTER 1

INTRODUCTION

1.1 Introduction and Motivation

In the past few years, the mobile device and mobile services markets have been affected by the strong emergence of smartphones. A smartphone is a mobile phone built on mobile computing platforms, which offers hi-tech computing ability and connectivity options. As a result, its memory and processing features are also boosted (Gan, 2018). A majority of new mobile devices are equipped with Internet connectivity, Global Positioning System (GPS), wireless local area network (WLAN)-based sensors, and other novel capabilities which have been integrated to support the users' social or individual activities (You et al., 2018).

New smartphones employ a kind of operation system that enables them to have new versions of mobile services. Notably, the number of these services for smartphones has been growing rapidly. In reality, smartphones are increasingly being equipped with operating systems that have similar complexity with those on desktop computers (Sherman and Craig, 2018). This tendency makes smartphone operating systems liable to a lot of threats that are also faced by desktop operating systems.

The availability of rich real-time information and smartphones' sensors coupled with the capabilities of the mobile computing platforms present an ideal platform for delivering context-aware information systems. Context-aware computing is aimed to make mobile devices smarter by giving them the ability to recognise and interpret the surrounding environment, as well as to react proactively and intelligently (Hwang, 2014).

Context plays an important role in universal computing. For example, context is crucial in location-based services (Bao et al., 2015; Champiri et al., 2015; Zhu et al.,

2015). Context awareness is considered the most prominent approach in the progress of smartphone devices (Elina Jaakkola et al., 2015). In particular, it has produced more privacy-driven applications in smartphones (Gamecho et al., 2013; Nogueira et al., 2017; Offen et al., 2016). This comparison vividly leads to privacy service possibility in mobile information systems (Schaub et al., 2015). Context-aware services make it possible for recipients to receive only the information that they are interested in. As a matter of fact, this system enhances the intelligence of mobile devices in figuring out and recognising the environment, in addition to responding intelligently (Perera et al., 2014; Vaizman et al., 2017).

Nowadays, mobile phone as a mobile communication has facilitated global interaction and connection among users. Nevertheless, incoming calls in unsuitable moments can be interruptive to the social environment or present duty; they also cause interruption, awkwardness, and embarrassment for the call receiver (Rosenthal *et al.*, 2011). Sometimes, incoming calls can also lead to an increased level of stress or mistakes. They may even put the receiver in a dangerous condition, as in the case of receiving calls while driving (Oviedo-Trespalacios et al., 2017).

In the middle of the evolving movement, intelligent context-aware mobile computing systems to filter inappropriate incoming calls have obtained rising recognition as an emerging technology for novel generation of mobile devices. These systems interact with unsuitable incoming calls by sensing clues about the situational context of the users and allowing expected interaction between the caller and callee. In fact, these systems could decrease unsuitable calls by identifying the context of the users and select a more appropriate moment to call (Guangxing and Qingsheng, 2011; Zhu et al., 2015).

With the embedded sensors in today's mobile phones such as accelerometer and GPS sensor, the user's context can be sensed and estimated to some extent using machine learning techniques. Zhu et al. (2015) stressed the importance of accuracy for context-aware mobile computing systems. They suggested that the systems need to take a more practical approach in their performance to predict and adjust the requirements of their users, instead of being static and waiting for user's commands.

Nonetheless, planning and developing context-aware mobile computing models to filter inappropriate incoming calls in a reasonable, predictable, accurate and timely way pose a huge engineering challenge (Elina Jaakkola et al., 2015). Even though the development of this kind of systems have made significant progress, there are insufficient methodologies and tactics on how to intelligently model and implement these systems with a high accuracy rate that have to manage sizable amounts of context information in the mobile phone.

On other hand, context-aware mobile computing systems needed to manage the challenge of energy-hungry and context sensors limitations in mobile phones. Context-aware location-based applications have become increasingly popular on smartphones over the past years. The dynamic utilization of these frameworks and systems cause the device's battery to deplete because of their powerful location-sensing operations. In the current context-aware mobile computing systems, location context plays an important role (Böhmer et al., 2014; Offen et al., 2016; Razzaque and Clarke, 2016), which is mostly obtained by GPS sensor. GPS is broadly utilized for the location-based service (LBS) of mobile phones. This sensor significantly increase the power consumption of mobile phones due to its substantial overhead calculation (Carroll, 2017). Cell tower-based localisation (CBL) could be an option to achieve LBS in energy-effective way; however, its appropriation is constrained because of the low positioning precision.

Lack of the location context information could lead to inaccuracy of these context-aware systems (Sarwat et al., 2015). Additionally, GPS sensor could decrease smartphone's battery life to less than nine hours (Man and Ngai, 2014). When the battery power is reduced at a fast rate from the permanent process of multiple sensors on the smartphone, especially the GPS sensors, the inconvenience of frequent battery recharge often outweighs the advantage of using these systems. Hence, a new mechanism to optimize the energy consumption of GPS sensor and manage the GPS sensor limitation in these systems is inevitable.

1.2   Background of Study

Context-aware computing research is stated by ubiquitous computing, which was created by Want et al. (1995). It had also been discussed as pervasive computing, that is a computing standard to make different computing devices accessible all through the surrounding environment and successfully imperceptible to the users. Several researchers studied "context" (Balan et al., 2014; Cao et al., 2018; Elina Jaakkola et al., 2015; Galar et al., 2015) since Schilit et al. (1994) first introduced it.

The definition of context awareness as stated by (Bao et al., 2015; Dey, 2018) is used to comprehend the environment, as well as the basics of context awareness and smartphone's sensors. This information covers the sensors of smartphone like GPS and accelerometer, and user activity such as driving or studying. In addition, using AI techniques and new localization systems in current context-aware systems can help in understanding the phenomenological view of context, which depends on user's context information.

Context data infrastructure for context-aware mobile computing models had been studied comprehensively by researchers over the last recent years. The researchers had been mostly aiming at the outcome of interruption, realization, context sensing and accurate result (Böhmer et al., 2014; Guangxing and Qingsheng, 2011; Miraoui et al., 2013). They mainly had focused on gaining a comprehension of how to manage the inappropriate incoming calls in mobile phone accurately.

Phithakkitnukoon and Dantu (2010) offered a context-aware mobile computing model known as ContextAlert. Their objective was to designed a new model that senses the user's context information and accurately arranges the smartphone alert mode to filter inappropriate incoming calls. An overview of ContextAlert model is illustrated in Figure 1.1.
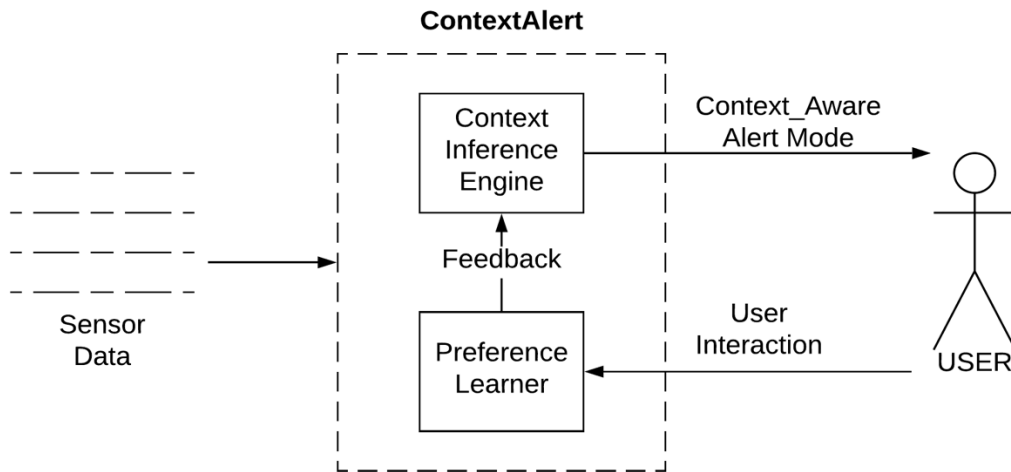
Figure 1.1   ContextAlert Overview (Phithakkitnukoon and Dantu, 2010)

In their model, K nearest neighbour classifier was considered as a learning mechanism that kept a continuous adaptive rate for new learning. Three incoming call alert options were considered in their model: interruptible by ringtone (vehicular mode), uninterruptible by ringtone, and interruptible by ringtone (non-vehicular mode). By utilizing data that were gathered from human subjects, their model was evaluated in many situations. They demonstrated that the proposed model acted well and yielded accurate results.

Furthermore, Miraoui et al. (2013) proposed a context-aware incoming calls' indication based on context information of callee in the mobile phone in order to automatically and accurately configure incoming calls based on the context information of user in order to increase the usage comfort of the device. Their method contained a specific context to seek for the nearby known context information and modify the service indication of incoming calls in a similar way. They considered reference contexts by enumerating typical contexts for smartphones: battery charge level, nearby, time, date, noise, localization, occupation and light. These contexts can be detected utilizing different types of sensors: some can be recognised straight from the proper physical sensor (time, noise, light, etc.) and others can be logical sensors (occupation).

As shown in Figure 1.2, each context was defined by composing few elements and they allocated the proper rate to each context information element. Apart from

that, they also determined the form of delivery for the incoming calls' indication service. Once the smartphone noticed new context information, it searched the ten general contexts of information for the most related context and adjusted the service call indication accordingly. Their method can be offered in diverse forms of mode: vibration, ring tone and divert to voicemail.
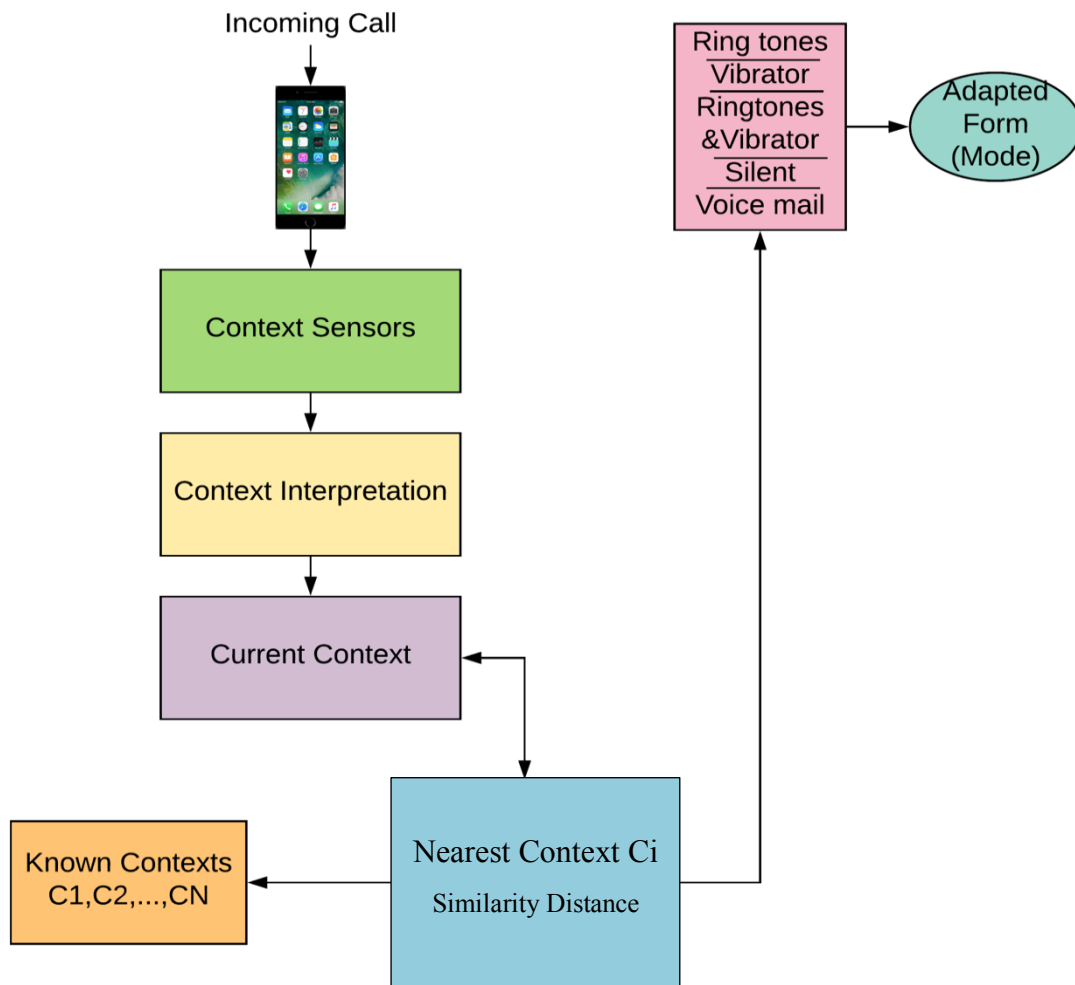
Figure 1.2   Operation of the Context-Aware Incoming Calls' Indication Approach (Miraoui et al., 2014)

In other hand, many researchers on context aware mobile computing systems mainly focused on the inference of user's unseen information which cannot be achieved explicitly. They usually used users' location information as one of the major contexts, which is obtained from a GPS sensor. Nevertheless, GPS sensor cannot work in indoor area, thus indoor-location information is unavailable in existing works on context awareness. The lack of indoor-location information prevents the accurate

inference of hidden information. In addition, collecting GPS context from smartphones significantly causes power consumption and reduces battery lifetime (Cho and Yu, 2019). Hence, high battery consumption of permanent GPS localization is a huge challenge for context-aware mobile computing systems in mobile phones.

Furthermore, a GPS-Accelerometer-Compass localization technique was designed by Vo et al. (2016). This new technique depended on utilizing the low-energy compass and accelerometer sensors and utilized the GPS sensor infrequently for management. Their result showed that the proposed technique had an exponential saving in mobile phone's battery life with a linear loss in accuracy as compared to GPS accuracy. Plus, they assessed the effect of the different parameters on the energy-accuracy trade-off. The proposed technique is illustrated in Figure 1.3.
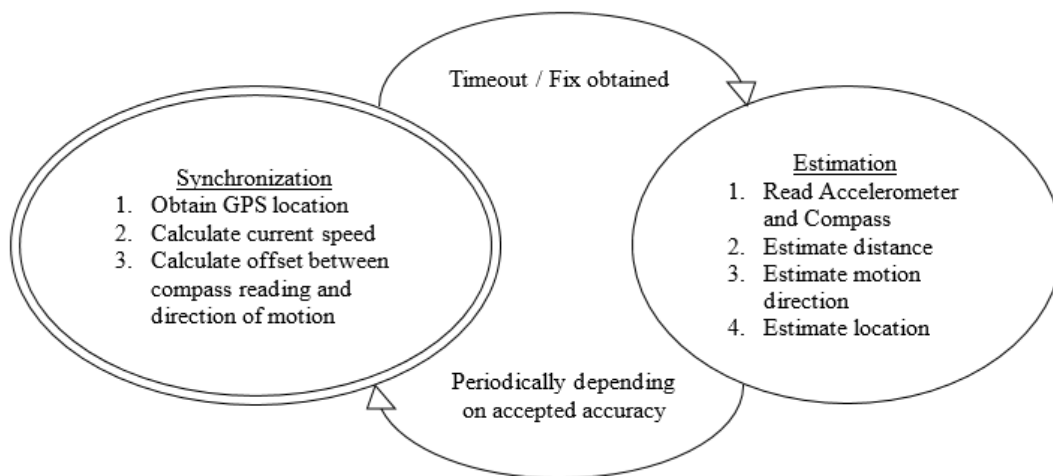
Figure 1.3   GPS-Accelerometer-Compass Localization Technique Overview (Vo et al., 2016)

As shown in Figure 1.3, the location estimator requested the accelerometer and compass continually to determine the direction of the tracked object and the displacement and speed along this direction. This is combined with the previous location estimate to provide the new location estimate. Periodically, based on a present value, the GPS is queried to obtain a better location estimate and the current estimate is set to the GPS location. The GPS is also used to determine the initial position and

velocity. The frequency of synchronization with the GPS represents a trade-off between energy-consumption and error in localization.

1.3   Problem Statement

Nowadays, smartphone plays a significant role in people's life but sometimes it comes with a price in terms of inappropriate incoming calls and interruptions. Users regularly need to make the decision to ignore or answer incoming calls based on not only their accessibility but also the benefits derived from the incoming calls by considering the context information of the user and the call content. For example, a mobile application can identify that the user is driving and block the incoming calls to avoid interruption. When the system is accurate enough, sensing and context inference stay unnoticed.

In order to achieve the continuous satisfaction of changing contexts, the development of this type of systems requires intelligent and accurate mechanisms (Afzal et al., 2018; Böhmer et al., 2014). Nevertheless, when system performance is inaccurate or faulty, users may not realize the underlying behaviour (Bulej, 2019). There have been remarkable models towards intelligent filtering incoming calls in context-aware mobile computing systems such as ContextAlert (Phithakkitnukoon and Dantu, 2010) and SmartNoti (Oh et al., 2015) models. However, their result indicated that they were not accurate and not optimized enough to infer user's context information in smartphone. The ContextAlert model achieved 90.5% and the SmartNoti models only achieved 80 % accuracy rate. This can lead users to mistrust, misuse, or even abandon the system. This lack of accuracy may be countered by having a new intelligent method based on the AI techniques that is more accurate for the context-aware mobile systems (Corea, 2018; Offen et al., 2016). Accuracy is the key to such systems that have to intelligently distribute and manage large amounts of information (Böhmer et al., 2014; Grandhi and Jones, 2015; Lim et al., 2016). Even though there have been notable steps towards intelligent distribution methods and approaches on context-aware mobile computing models, the methodologies on how to

model and implement these systems intelligently with high accuracy rate in smartphones are still lacking.

Notably, context-aware mobile computing systems needed to manage the difficulties of multiple sources of context that effect on the performance of the systems, and the challenge of energy-hungry context sensors that effect on the battery consumption of mobile phone. Location context plays an important role in a majority of these systems (Böhmer et al., 2014; Capurso et al., 2018; Guangxing and Qingsheng, 2011; Miraoui et al., 2013; Sarker et al., 2016), which is mostly obtained by GPS sensor. However, GPS sensor's limitation in the indoor environments and high-power consumption of permanent localization are a huge challenge in these systems (Leick et al., 2015; Oshin et al., 2012). Further, users may prefer to turn the GPS sensor off to avoid letting the mobile phone's battery run all the way down (Liao et al., 2016). In the absence of the location context information, the accuracy of the these systems could significantly fall off (Davoudi et al., 2014a; Noh et al., 2012). Therefore, a new localization mechanism to provide the location context in any circumstances and decrease the battery consumption of GPS sensors in context-aware mobile computing systems is inevitable and necessary to improve users' trust in such system for smartphone.

Accordingly, reducing the cost of GPS sensor and increasing the accuracy of current context-aware call filtering systems are two main challenges as mentioned previously. This study leads to identification of criteria from previous researches and aims to solve these problems through developing a new model based on AI techniques to increase the accuracy rate of context-aware mobile computing models and designing a new localization mechanism to decrease the GPS battery consumption of permanent localization to the current context-aware call filtering models to prevent mistrust and misuse of the users.

1.4   Research Objectives

In this thesis, four objectives had been outlined as follows:

(a)   To propose a new context-aware mobile computing model to filter inappropriate incoming calls in smartphones.

(b)   To propose an extended naïve Bayesian classifier to increase the classification accuracy rate.

(c)   To design a new localization mechanism to optimize the battery consumption of the GPS sensor in the proposed model.

(d)   To evaluate the performance of the proposed model based on accuracy rate and battery consumption

1.5   Research Questions

This research is guided by these four questions:

(a)   How to filter inappropriate incoming calls in smartphones?

(b)   What are to propose an extended naïve Bayesian classifier to increase the classification accuracy rate?

(c)   How to design a new localization mechanism to optimize the battery consumption of the GPS sensor in the proposed model?

(d)   How is the performance of the proposed model in terms of accuracy rate and battery consumption?

1.6   Scope and Limitations

Three categories of context could be taken into account, namely user context, terminal context, and communication network context; this research focuses on the context of the user. Nevertheless, all of these categories could be mixed when needed.

This research is focused on the following scopes:

    (i)   Context-aware call filtering systems to deal with call interruption

    (ii)   Context-aware mobile computing models

    (iii)   Smart phone's accelerometer sensor

    (iv)   GPS localization techniques to optimize the battery consumption of GPS sensor on smart phones.

The deliverables of this system will benefit all smartphone users who are concerned about inappropriate incoming calls. This research excluded users with experience or technical expertise in such systems. Plus, the users were not required to have an understanding of the context-aware interruption system operations. Instead, they only need to focus on the contexts of their incoming calls and their activities. Plus, this study aimed to understand the factors and sensors that influence on decision making in filtering incoming calls.

This research had several limitations in terms of mobile phone's abilities and specifications, amount of test data available, and duration of the test. Furthermore, it was challenging to identify the user context for meeting the objectives and figure out the sensors that can provide the required information reliably.

In addition, context acquisition remains as an issue because of the existence of a considerable gap between aspects that can be sensed and the actual situation in social interactions and people's minds. For instance, is somebody quiet because they are deep in thought or are, they about to make a mathematical breakthrough.

1.7 Research Significance

The significances of this research are outlined as follows:

(i) An optimized context-aware mobile computing model named Optimize Context Filtering (OCF) that can sense users' context information to provide a service to synchronise the incoming calls with users' daily life is proposed. The service reduces the frequency of annoying calls in smartphone, for example, it blocks an incoming call while the user is driving.

(ii) The multiple sensors embedded in smartphones which are more accurate in finding users' context information were applied instead of the various sensors attached to different parts of users' body.

(iii) A new localization mechanism named Improved Battery Life in Context-aware Systems (IBCS) that provides the location context information to the proposed model in any circumstances as well as optimizes the battery consumption of continuous GPS localization is designed.

(iv) An extended Naive Bayesian classifier is developed based on the Naive Bayesian classifier, which is more accurate and suitable for the proposed model in smartphones.

1.8 Thesis Outline

In Chapter 1, A brief introduction of context information, smartphone's features, call interruption and context-aware computing models is provided. It also outlines the necessity for filtering incoming calls, the current challenges and the appropriate approaches to do so. In these regards, the problem statement and research objectives of this research are addressed. In chapter 2, smartphone capabilities are

inquired and reviewed. Next, an elaboration on call filtering systems and context-aware mobile computing models which were concerned about interruption is conducted. Notably, the necessity of location information and accuracy in context-aware mobile computing model systems are discussed. In this regard, the new localization techniques which were concerned on battery consumption are reviewed. Secondly, the existing context-aware computing models are studied and compared. After reviewed the current models, two models which were meet this research objective are selected and studied further. Then, current model's methods are studied to determine the best method to manage context information. As a result, the Naive Bayesian classifier is shown as the promising AI technique for context-aware mobile computing model to deal with interruptions. However, to overcome its weaknesses, a brief review of new techniques and boosting methods are reviewed.

In chapter 3, the methodology of the proposed model that includes the research design, research procedure, research activities, and operational framework is described. Further, data collection process is also described. The process flow of the research was developed according to the established methodology of an optimized context-aware mobile computing model- Optimized Call Filtering (OCF)- to filter inappropriate incoming calls in smartphones. In addition, a new mechanism named Improved Battery life in Context-aware-system (IBCS) is designed to optimize the high battery consumption of Global Positioning Sensor (GPS) localization in the context-aware mobile computing systems. Finally, a new extended Naive Bayesian classifier is developed as an inference engine to achieve a higher accuracy rate and better performance in the proposed model. Finally, the assumptions and limitations of this research are discussed.

In chapter 4, the optimized call filtering (OCF) model is developed based on the closest model to the research objectives, namely SmartNoti model (Oh et al., 2015). In this regard, the context follow diagram and data follow diagram of OCF model is presented. In addition, the OCF Data-Flow model is offered based on the notion that systems can be modelled as a visualization of the data interaction that the overall system. Finally, pseudo code of Extended Naïve Bayesian Classifier is presented. In chapter 5, the proposed localization mechanism (IBCS) is evaluated in three different

smartphones to measure its performance based on battery consumption. Apart from that, the users' impression on call filtering systems is also analysed. Next, outlines of an extensive study are conducted to evaluate the impact of the new extended Naive Bayesian classifier on accuracy rate. Lastly, the proposed model is evaluated and compared with SmartNoti model (Oh et al., 2015) based on the accuracy rate. Finally, in chapter 6, objectives of this research been outlined the novel contribution of this thesis and differences between this work and other previous works is described. Lastly, future works are recommended.

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Appendix F

LIST OF PUBLICATIONS

Davoudi, K. V., et al. "Improved Battery Life for Context Awareness Application in Smart-Phones." (2014).

Davoudi, Vahid, et al. "Improved Indoors Location Awareness Architecture in Mobile Phones." Advanced Science Letters20.10-11 (2016): 2078-2081.

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