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Internet of Things: A Survey for the Individuals' E-Health Applications

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Abstract

In today's world, the Internet of Things (IoT), which is a fairly new technology, has become a popular topic for discussion. Meanwhile, the increasing demand for personalized healthcare with the assistance of new technologies has created new applications called e-health IoT applications; however, researchers are still attempting to find its applications, therefore they have not been able to focus on comparing these applications. We have aimed at understanding the benefits of e-health IoT applications in comparison to one another. Therefore, this study is an attempt to provide a list of e-health IoT applications for individuals and to prioritize them. The Fuzzy Analytical Hierarchy Process (FAHP) method has been used, which is a method for Multi-Criteria Decision Making (MCDM) and a useful tool for prioritizing multiple alternatives based on criteria. Eight important criteria, based on a comprehensive literature review and experts' opinions, were determined. Then, by using the FAHP method, the weight of each criterion was calculated. As a result, seven applications identified for individuals were prioritized based on the weight of each criterion and the score of each application in each criterion. Health Effectiveness, Empowerment, Safety, Privacy, and Peace of Mind are the most important criteria in e-health IoT applications for individuals; Cost Saving, round-the-clock Access, and Time-Saving are in the next levels of importance. The results also show that Chronic disease management, Medication reminders, Health monitoring, Air quality, Fall detection, Sleep control and Fitness were respectively ranked as first, second, third, fourth, fifth, sixth and seventh among the IoT applications.

Keywords: Internet of Things (IoT); Health IoT application; Healthcare Devices; Electrical Healthcare (E-Health).

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Introduction

To gain a competitive advantage, successful organizations and governments need to pay more attention to their people (Safari, Abdollahi & Ghasemi, 2012).In developing countries, employee health is one of the concerns of policymakers (Fritzen, 2007). Having healthy people in the community increases the chance of having a healthy workforce (Gebbie, Merrill & Tilson, 2002). Due to the effects of healthcare on longevity and wellness, there has always been a curiosity in this field. The 21st century has seen significant changes in population demographics', and individuals are also living longer (UN, 2006). The challenges caused by the aging of the population are prompting modern healthcare to improve efficiency and transform from career-centric to patient-centric (Pang et al., 2015). Meanwhile, how to improve an individual's health through using new technologies has become an increasingly popular topic for discussion and this has resulted in the necessity to take on a strategy to address the issue.

In addition, health services need to be handled in-home (WHO, 2008), with individuals taking more responsibility towards their health and well-being. Using Information Technology has made significant changes in all aspects of life. One area, which has been transformed by technology's enabling approach, is health services. The use of IT tools in the health domain in various countries has enhanced the quality of health services and also decreased healthcare costs (Majlis Research Center, 2009). It has been discussed by the National Information Council (2008) that the betterment of human health and wellness is the vital aim of any economic, technological and social development. The Internet has revealed new types of technologies have transformed the world considerably and have had a significant effect on everyday life (Bargh & McKenna, 2004). The recent decade has also introduced a new technology based on Information and Communication Technology (ICT), which is believed to be the next revolution in this field (Chui et al., 2010; Ghasemi et al., 2016; Gubbi et al., 2013; WEF, 2015; Zarei et al., 2015). As a result, in different industries and applications, there is a rising interest in utilizing the IoT (Li et al., 2012). This technology is not a second Internet, but rather a network of things, each of them embedded with sensors that are connected to the “Internet”. The true value of this technology can be enhanced by sharing the data of these interconnected devices (IEEE, 2015). Designing and developing new types of businesses, startups, and applications has been made possible through the IoT (e.g., see Jasper, 2015). Furthermore, the number of published papers in this field has significantly increased as well (DaXu et al., 2014). The IoT, as a successor of IT, is an information realm of considerable development and new opportunities (Paschou et al., 2013).

It has been mentioned that there have been almost 9 billion connected devices in 2013, and that figure will likely increase to 24 billion devices by 2020 (Gubbi et al., 2013). The IoT makes possible the collaboration and communication between individuals and things, and also between things themselves. In this regard, IERC (2015) states that this technological paradigm has been connecting anyone, anything, any service, and any network at anytime and anyplace. Kortuem et al. (2010) believes that the IoT as a phrase enforces the idea of a global infrastructure of networked things.

The IoT, by enabling objects to communicate with each other, opens up new and exhilarating methods for research and business (Miorandi et al., 2012); supporting the aforementioned remarks about the IoT enabling businesses and industries, commentators claim that it has a significant potential to be used in healthcare (Zarei, Jamalian & Ghasemi , 2017; Atzori et al., 2014; Chui et al., 2010; Da Xu et al., 2014; Gubbi et al., 2013; He et al., 2014; Jara et al., 2011a; Luo et al., 2010; Miorandi et al., 2012; Perera et al., 2014; Tsai et al., 2014; Vermesan et al., 2013; Xu, 2002; Zarei et al., 2016; Zheng et al., 2011).

Accordingly, the World Health Organization (WHO), Healthy Cities Network, and related national networks have identified a great number of cities around the world that benefit from and utilize the IoT, are aiming to improve the health and wellness of their citizens (Boulos and Al-shorbaji, 2014). Predictions show the IoT could affect healthcare services' transformation and their cost-efficiency (Moosavi et al., 2015, Rahmani et al, 2018).In this respect, some researchers have explored IoT applications in the health area (Bandyopadhyay & Sen, 2011; Dohr et al., 2010; Khan et al., 2012; Vermesan & Friess, 2014), but prioritizing applications based on the needs of individuals has been neglected. Boulos and Al-shorbaji (2014) have pointed to health applications for individuals utilizing this technology. Boulos and Al-shorbaji (2014) argue that smart cities enabled by this technology have better opportunities of becoming healthier. Similar to other novel technologies, the IoT has used a form of new, related notions for explaining the future of healthcare, such as the following phrases: Pervasive Healthcare (P-Health), Ubiquitous Healthcare (U-Health), Mobile Healthcare (M-Health), Electrical Healthcare (E-Health), Telehealth, Telemedicine, and etc. (Pawar et al., 2012).

Utilizing the IoT for e-health makes many prospects possible for enhancing outcomes and giving individuals a greater sense of well-being by improving healthcare systems (Lake et al., 2014), so the e-health field is a key beneficiary of this novel paradigm (Sebestyen et al., 2014). E-health IoT solutions connect information, individuals, devices, processes, and contexts to enhance the results (Lake et al., 2014). The IoT can be used in healthcare systems to build a new e-health generation (Atzori et al., 2010; Said & Tolba, 2012). Smart devices that are now connected – formerly passive and not connected –offer a great amount of information that can be applied to make actionable decisions and considerably affect healthcare conditions (Lake et al., 2014). Undeniably, the key power of this technology is related to the major effects on different aspects of users' daily life. From the individual's point of view, the apparent effects of IoT are evident in e-health, as an example of potential application (Atzori et al., 2010). In the e-health domain, there are some cases of connecting health devices on the Internet to carry out some remote health services such as remote health monitoring and elderly peoples' supervision (Sebestyen et al., 2014). These devices can be utilized for a permanent observation of a person's vital signs – such as electrocardiograms, blood pressure, and temperature – for monitoring or remote health evaluations (Lin et al., 2009; Sebestyen et al., 2012). Hence, digital health enables individuals to take care of their health conditions and have an active part in their well-being (Boulos & Al-shorbaji, 2014).

It is noteworthy that due to the principle – number 29 – of the constitution of Iran, to achieve sustainable development, healthy people play a central role; also, protecting and improving human health requires an efficient health system (Majlis Research Center, 2009). The concept of sustainability comprises the combination of environmental, social, and economic criteria to get long term economic viability (Haghighi, Torabi & Ghasemi, 2016). Based on the Twenty-Year Vision of Iran, which is the basis of formulating the general policy plans, health and all its determinants are subjected as well. The Twenty-Year Vision describes the health of an Iranian as health, welfare, food, social security, equal opportunities, better distribution of income, and family foundation; being away from poverty, corruption, and discrimination; and taking advantage of the favorable environment (IHIO, 2015).

Due to all of these components, equal health for individuals is the primary aim of the public sector in Iran. The characteristics of Iran's health system oblige the development of IT in the health domain and its implementation as an effective e-health system (Nasiripour et al., 2012). Therefore, the scope of government activities in the field of IT, particularly e-health in the IT master plan document of the country in the field of public services, legislative, policy, and the development of software and hardware infrastructure, has been set. It has been indicated in this document that the public sector is not the beneficiary, but it has a supporting, coordinating, and monitoring role in the framework of healthy competition and creating opportunities that are accessible to all sections of society (Majlis Research Center, 2009).

Iran Telecommunication Research Center (ITRC), as a subgroup of the Iranian Ministry of I.C.T, has introduced a project called “The Internet of Things Research, Market and Industries”. Regarding the emergence of IoT and the ever-increasing importance of e-health IoT applications for individuals (Leister et al., 2014; Savola & Abie, 2013; Swiatek & Rucinski, 2013), the current study, as a part of this project, aims to prioritize e-health IoT applications for individuals. Prioritization of these applications is based on the eight identified criteria. For the research methodology part of the survey, FAHP has been used, which is known as a common decision-making method for weighing the criteria (Cho & Lee, 2013; Lee et al., 2014; Tan et al., 2014; Tavana et al., 2013). This method has widely been used in prioritizing technologies, especially in the field of health (Kahraman et al., 2015; Jain & Rao, 2013; Büyüközkan & Çifçi, 2012; Zhang et al., 2011). Therefore, the main aim and contribution of the research can be recognized as identifying e-health IoT applications and also identifying criteria for prioritizing these applications. Therefore, the following questions have progressively been discussed:

1. What are the priorities of e-health IoT applications for individuals?

For answering this question, we must attempt on answering the following questions:

1.1. What are thee-health IoT applications for individuals?

1.2. What are the effective criteria for prioritizing e-health IoT applications for individuals?

1.3. How important is each of these criteria?

Health IoT Applications

IoT is opening marvelous opportunities for several new applications that promise to improve the quality of individuals’ lives (Hu et al., 2011; Iera et al., 2010; Xia et al., 2012) with the help of smart assistance systems to increase safety (Mattern & Floerkemeier, 2010) and offering “connected health/care” services via an improved availability of quality health information (Boulos & Al-shorbaji, 2014).

The related IoT technologies, such as smart components, sensors, and etc., have been developed rapidly and considerably extended. As a result, the number of IoT applications has expanded (Broll et al., 2009; Li et al., 2011). The health-related IoT services, which are pervasive and personalized, have accelerated the evolution of health services from career-based to patient-based (Klasnja and Pratt, 2012; Liu et al., 2011; Plaza et al., 2011). As a promising solution, the health IoT has promising prospects (Pang et al., 2015). Alagoz et al. (2010) claim that the future applications of tomorrow’s mobile information and communication technologies will include health care practices. Gradually changing expectations from traditional healthcare to personalized healthcare services have extended the needs and introduced opportunities for automated applications. Attempts in this field can be seen in e-health in the form of pervasive healthcare apps (Ranjan & Varma, 2012; Touati & Tabish, 2013, Subasi et al, 2018) that allow patients to stay at home more instead of being hospitalized with the help of monitoring sensors and devices (Boulos and Al-shorbaji, 2014).

E-health IoT Applications for Individuals

The results of the existing potential and ability of IoT in various applications are listed in Table 1. In the following sections, seven identified e-health IoT applications for individuals will be presented and discussed.

Table 1. E-health IoT applications for individuals

Applications	The Author(s)
Chronic Disease Management	Bandyopadhyay and Sen, 2011; Bui and Zorzi, 2011; Chen, 2012; Dohr et al., 2010; Istepanaian and Zhang, 2012, Jara et al., 2011a; Leister et al., 2014; McCullagh and Augusto, 2011; Savola and Abie, 2013; Vermesan and Friess, 2014.
Air Quality	Bandyopadhyay and Sen, 2011; Bellavista et al., 2013; Boulos and Al-shorbaji, 2014; Song et al., 2014; Steele and Clarke, 2013; Zanella et al., 2014.
Health Monitoring (monitoring of vital functions)	Atzori et al., 2010; Bandyopadhyay and Sen, 2011; Bui and Zorzi, 2011; Chen, 2012; Da Xu et al., 2014; Diaz et al., 2012; Gubbi et al., 2013; Istepanaian and Zhang, 2012; Jara et al., 2012; Khan et al., 2012; Kramp et al., 2013; Leister et al., 2014; McCullagh and Augusto, 2011; Milenković et al., 2006; Song et al., 2014; Steele and Clarke, 2013; Swan, 2012; Swiatek and Rucinski , 2013; Vermesan and Friess, 2014; Thierer, 2014.
Medication Reminder	Atzori et al., 2010; Bandyopadhyay and Sen, 2011; Chen, 2012; Dohr et al., 2010; Istepanaian and Zhang, 2012; Khan et al., 2012; Thierer, 2014.
Fitness	Khan et al., 2012; Steele and Clarke, 2013; Swan, 2012; Swiatek and Rucinski, 2013; Thierer, 2014; Vermesan and Friess, 2014.
Fall Detection	Amendola et al., 2014; Bui and Zorzi, 2011; Caporusso et al., 2009; Song et al., 2014; Vermesan and Friess, 2014.
Sleep Control	Amendola et al., 2014; Steele and Clarke, 2013; Swan, 2012; Thierer, 2014; Vermesan and Friess, 2014.

Chronic Disease Management Applications

Chronic diseases can be related to lung problems, heart disease, diabetes or arthritis (Lorig et al., 2000) which are all increasing. Many elderly people have more than one chronic illness (King et al., 1998). A report predicts that deaths related to diabetes will double between 2005 and 2030 (WHO, 2015). Various researchers have claimed that the IoT can be suitable for managing chronic diseases and empowering elderly people (McCullagh and Augusto, 2011). Chronic disease management is significant for the self-management of an individual’s health, and IoT plays a major role in this (Ali et al, 2018).

Health Monitoring Applications

IoT’s main goal is to monitor and control things through the Internet (Rohokale et al., 2011). Therefore, it can be considered as one of the most inspiring application fields is health monitoring (Subasi et al, 2018). The identification, sensing, and communication capabilities of this technology let different things such as people, medical tools, etc., to be monitored by Wearable Wireless Sensor Network (WWSN) devices (Alemdar & Ersoy, 2010). Several body sensors can monitor vital signs (Jovanov et al., 2005), therefore, wearable health monitoring gadgets allow individuals to precisely monitor changes in their vital signs and offer feedback to maintain an optimum health condition (Milenković et al., 2006).

Air Quality Applications

It has been discussed that the IoT can be utilized to improve the efficiency and effectiveness of many important metropolitan and national environmental programs that help control air quality (Bandyopadhyay & Sen, 2011). For example, communication equipment can be prepared to connect health applications running on the devices of joggers to the infrastructure, in this case, individuals can always find the healthiest pathway for outdoor activities (Zanella et al., 2014).

The importance of e-health IoT applications – air quality applications – is that some cities in Iran have a considerably level of high air pollution. For example, Tehran's air pollution exceeds air quality standards during many days each year (WHO, 2011), which is a reason for both morbidity and mortality (Naddafi et al., 2012). Shiraz another large city in Iran is also among the ones with a high level of air pollution (Gharehchahi et al., 2013).

Fitness Applications

Fitness, an application field helpful for a huge market interested in exercising, provides immediate performance feedback about an individual's heart rate, body temperature, oxygen uptake, and aerobic and anaerobic exercise (Swan, 2012). There are various fitness products on the market which calculate exercise, steps and other data (Vermesan & Friess, 2014). Therefore, connected objects that make self-tracking possible during everyday life will improve the fitness and physical wellbeing of individuals.

Fall Detection Applications

Various studies have concluded that falling on the ground is the most significant threat for elderly people, causing irretrievable bone damage and even death (Auvinet et al., 2011; Qian et al., 2008; Rougier et al., 2011). So, the instant treatment of people wounded by falling is critical. Vermesan and Friess (2014) argue that fall detection applications can assist elderly or disabled people to even live independently. Healthcare is a repeatedly cited field that the IoT can be used in (Fok et al., 2011), with being one of its specific aspect. In this issue, Luo et al. (2012) discuss designing a quick, fall alarm system for the elderly. Furthermore, the most important point of fall detection is that in many cases wounded victims are unconscious; smart sensors for fall-detection (Ng, 2012), as the main part of this technology, can assist in these cases.

Sleep Control Applications

Sleep quality is a serious issue because it is crucial for learning, memory processes, and performance (Dewald et al., 2010). Given the importance of sleep quality, sleep pattern capturing products are noteworthy. According to Steele and Clarke (2013), some wristband sensors are currently available for this aim. For example, Fitbit measures sleep duration and wellness (Skiba, 2013), or wireless sensors located across the mattress provide data accessible via an app on a smartphone by sensing small movements, like breathing, heart rate and large movements during sleep (Vermesan & Friess, 2014).

Medication Reminder Applications

Aging people are often major consumers of various medicines (Linjakumpu et al., 2002). They frequently have trouble remembering the drug's dosage and consumption schedules. Also, elderly individuals often have a continuing need for medical treatment and, as a result, consuming a variety of medications, which can prove confusing. To help this problem, Jara et al. (2014) have designed a system based on the IoT for drug recognition and the monitoring of medication, which works as a medication reminder and checker. Consequently, the IoT in the health domain can help reduce harmful occurrences for patients, such as taking the wrong medication or dosage at the wrong time (Atzori et al., 2010).

Beneficiary Criteria for Prioritizing E-Health IoT Applications for Individuals

In this study, we need to define the criteria to prioritize e-health IoT applications for individuals based on these criteria. Therefore, based on to the comprehensive literature review, some criteria have been extracted. The list of the selected criteria can be found in Table 2. In the following sections, the importance and application of each selected criterion will be discussed based in this paper's aim and scope.

Table 2. E-health IoT criteria

Criteria	Author(s)
Empowerment	Boulos and Al-shorbaji, 2014; Dohr et al., 2010; Khan et al., 2012; McCullagh and Augusto, 2011; Swan, 2012; Thierer, 2014; WHO, 2012.
Time Saving	Sehgal et al., 2012; Thierer, 2014.
Cost Saving	Jara et al., 2011b; Swan, 2012; Thierer, 2014.
Safety	Bandyopadhyay and Sen, 2011; Dohr et al., 2010; Thierer, 2014.
Health Effectiveness	Bughin et al., 2010; Khan et al., 2012; Thierer, 2014.
Peace of Mind	Dohr et al., 2010; Gale and Sultan, 2013.
Round-the-clock Access	Nag and Mukhopadhyay, 2014; Swan, 2012; Wan and Tang, 2007.
Privacy	Mohammadzadeh et al., 2018; Bazzani , et al., 2012; Savola et al., 2012.

The Empowerment Criterion

Personalized care, all over the health system and an individual's lifetime, makes health care accessible even at home, not just the hospital, by focusing on prevention, self-management and so forth. It also makes it easier to get guidance and support from peers (WHO, 2012). In this case, it is said that individuals will be empowered by the assistance of new technology in the health domain (WHO, 2012). Besides, Swan (2012) believes this technology promises to enhance health outcomes. For example, the IoT helps individuals have more control over their lives (Thierer, 2014); therefore, the empowerment criterion is completely suitable and also necessary for measuring the effect of empowerment of each e-health IoT application for individuals.

The Time Saving Criterion

Previously, the importance of time in both organizations and individuals' lives has been discussed and also approved (Britton & Tesser, 1991; Macan, 1996). The capability of networking devices opens up opportunities to build up new applications (Sehgal et al., 2012). By automating routine tasks made possible by connected devices and applications, consumers using them are able to free up their time (Thierer, 2014).

The Cost Saving Criterion

With the aid of IoT technologies, consumers can make health care purchasing decisions directly, which may oblige more price rationalization (Swan, 2012). These technologies help people live less costly and more efficient (Thierer, 2014). The potential reason is that IoT health solutions allow for carrying out the patients' therapy in their homes, instead of the hospital (Jara et al., 2011b). Accordingly, the cost-saving criterion is valuable and also meaningful.

The Safety Criterion

One of the most important aspects of our lives is related to safety. Individuals desire to be healthier; technologies help them to get better and safer environments essential for curing, taking care of aging individuals and other patients, and preventing accidents or injuries (Chen, 2012). The IoT technologies help people live more comfortably, safer and healthier (Thierer, 2014). It also enhances the safety of elderly people in assisted living (Dohr et al., 2010).

The Health Effectiveness Criterion

Healthcare combined with other related technologies improves the effectiveness, access, efficiency, and quality of the processes used by patients in order to enhance their health condition (Sundmaeker et al., 2010). For example, the body sensors of patients constantly inform doctors about a change in an individual health status, so they can adjust the therapy of their patients accordingly (Bughin et al., 2010) or implantable wireless devices can be utilized to store health records, which could save a patient's life in emergencies (Sundmaeker et al., 2010). In fact, the IoT is able to discover more applications in the health sector for saving lives (Khan et al., 2012).

The Peace of Mind Criterion

Peace of mind as an important aspect of people's health – especially the elderly – has attracted a lot of attention (Gale & Sultan, 2013). Dohr et al. (2010) discuss how the IoT helps assisted living, which brings peace of mind for patients. By using tele-technology in healthcare, users' peace of mind, life quality, enhanced empowerment, and self-management can be increased (Gale & Sultan, 2013).

The Round-the-Clock Criterion

The importance of ‘anytime, anywhere, and by any network’ monitoring in health is unquestionable. Enabled by IoT's omnipresent identification, sensors, and communication capabilities, all things in the healthcare systems (individuals, tools, medicine, and etc.) can be traced and/or monitored on a 24/7 basis (Wanand Tang, 2007). More detailed 24/7 quantified monitoring enabled by this technology is guiding individuals to a more profound perception of the world (Swan, 2012).

Privacy

Privacy has always been an important right for individuals. Therefore, it has to be closely considered. It has been discussed that the privacy of the involved stakeholders in the IoT is affected by its technical architecture (Gürses et al., 2006). The right to privacy can be measured as a fundamental and undeniable human right, or as a personal right or possession (Weber, 2010). Furthermore, privacy is highlighted in healthcare information systems (Savola et al., 2012).

The Conceptual Model of Research

A hierarchy structure was used in this research, which aims to prioritize e-health IoT applications for individuals. The structure develops a Fuzzy AHP – Analytic Hierarchy Process –model based on alternatives and criteria that have been derived from the research literature presented in Figure 1.

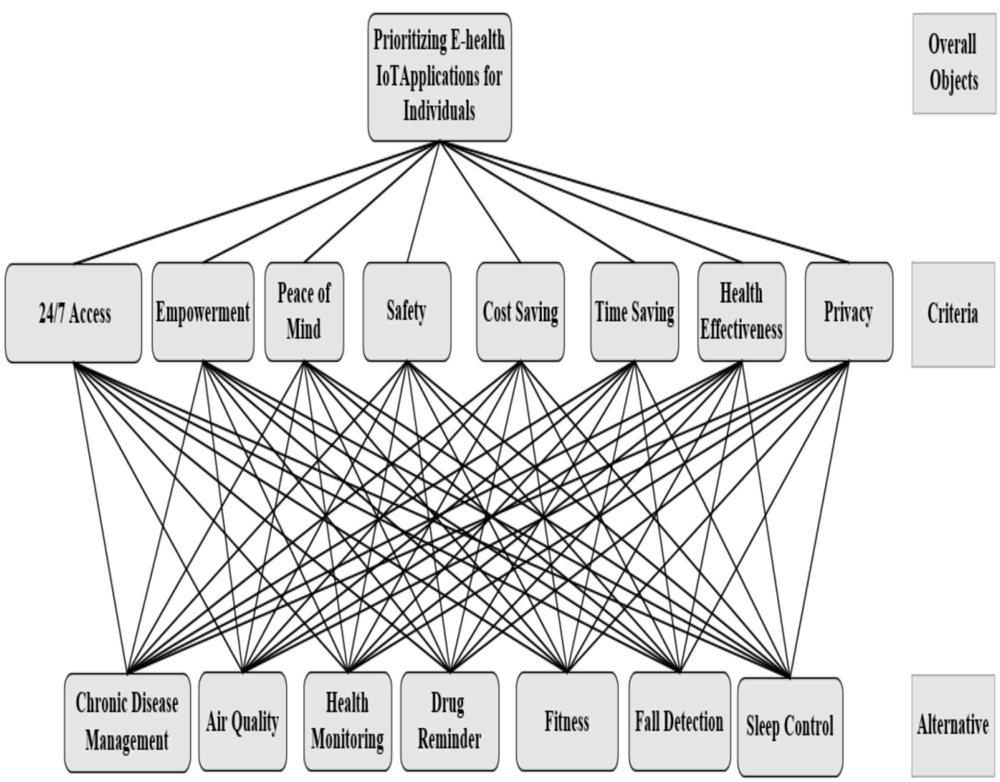

Figure 1. The hierarchical structure of Fuzzy AHP

Materials and Methods

In this study, eight criteria have been used for the evaluation of e-health IoT applications for individuals. Due to the existence of several criteria and alternatives, MCDM methods have been used. These methods of decision-making have two general categories including "Quantitative" (Anderson et al., 2015) and "Qualitative" (Liao et al., 2015).

Among quantitative ones, the method of Analytic Hierarchy Process (AHP), as one of the most accurate methods for weighting criteria and prioritizing alternatives, is well-known.AHP is a flexible, robust and simple method to make decisions. It is used when conflicting decision criteria makes it difficult to choose between alternatives (Triantaphyllou, 2000; Saaty, 1988; Saaty, 2008; Zahedi, 1986).

Hence, based on our main aim, AHP is great for completing the research. However, the classic method cannot fully reflect the style of human thinking. In other words, the AHP is broadly used to answer MADM issues. However, due to the ambiguity and uncertainty in verdicts, a brittle, pair-wise comparison with a classical AHP may be incapable of properly representing the decision-makers' thoughts (Ayağ, 2005).

Albeit, the distinct scale of AHP has the benefits of simplicity and ease of use, it is not adequate to consider the uncertainty related to the mapping of one's insight. Therefore, fuzzy logic is also introduced into the pair-wise comparison to deal with the insufficiency of the classic one, stated as FAHP. Furthermore, this method is an efficacious tool to handle the fuzziness of the existing data in determining the preferences of diverse decision variables. The comparisons made by experts are represented in the format of Triangular Fuzzy Numbers (TFNs) to structure fuzzy pair-wise comparison matrixes (Ghodsypour & O'Brien, 1998).

FAHP, often called the extent analysis method, was presented by Changin 1996 and is the basis of the calculations in this article (see Chang, 1996). Based on this method, after identifying the criteria and alternatives – Figure 1-9 pair-wise comparison questionnaires were distributed. One questionnaire was used to measure the importance or relative weight of the criteria. Also, eight questionnaires were used to determine the weight of each alternative in each of the eight criteria separately. The output of this part as a decision matrix has been used for prioritizing-health IoT applications for individuals with the FAHP method. Figure 2 describes the scenario of the paper and also the method as a part of this scenario.

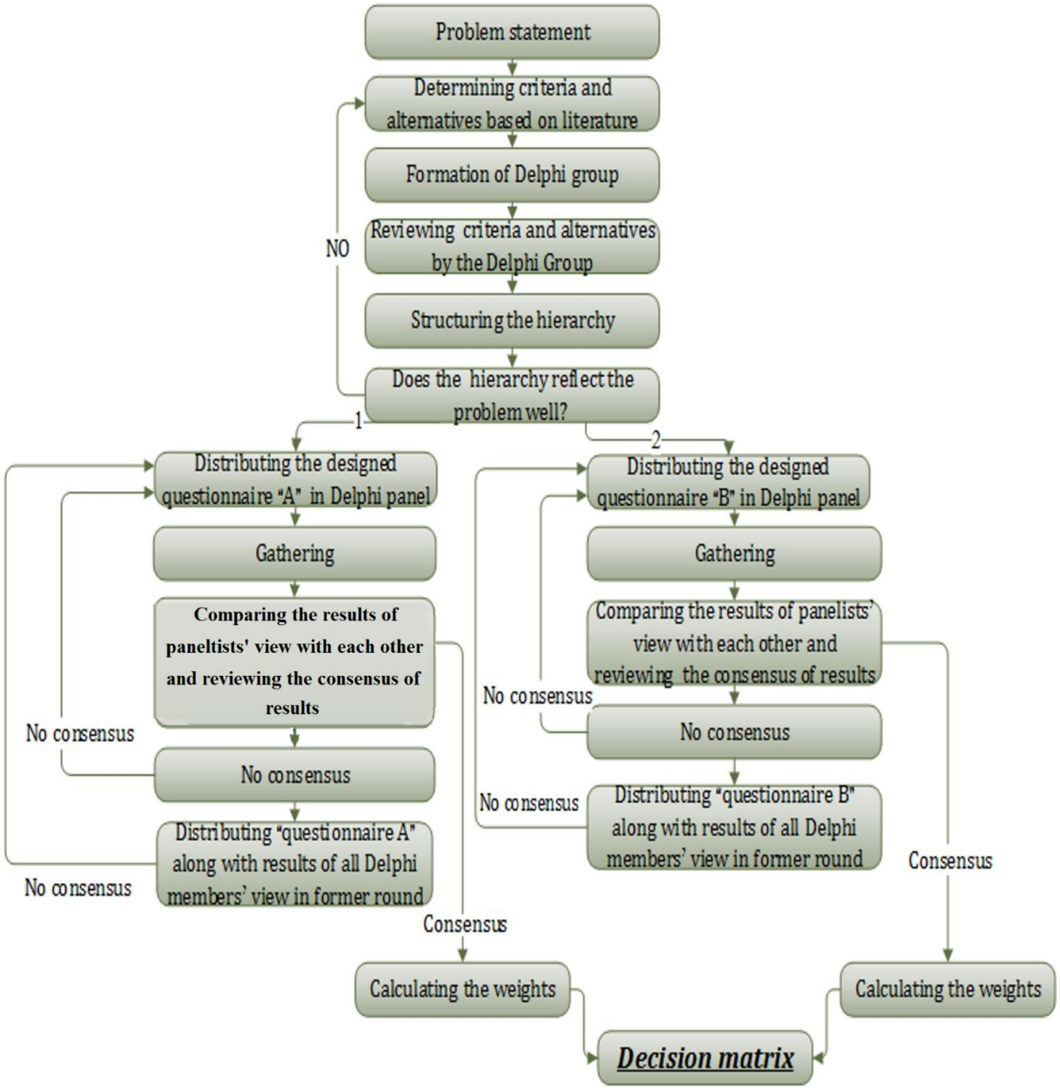

Figure 2. Scenario of the paper

Fuzzy Analytic Hierarchy Process (FAHP)

Decision making is one of the key competencies of managers and there are various tools for it (Mahbanooei, Gholipour & Abooyee Ardakan, 2016). AHP model is a multiple attribute, decision-making method that was introduced in the early 1970s by Saaty (see Saaty, 1998). In 1996, a Chinese scholar named Chang (1996) introduced FAHP based on extent analysis method. In fact, this method was developed based on AHP and fuzzy logic (Büyüközkan et al., 2011). Remarkably, the calculation of this method to achieve criteria weight and prioritize e-health IoT applications for individuals has been done based on Chang (1996) method. These steps are:

Step 1: Drawing the hierarchical structure of FAHP.

Step 2: Defining fuzzy numbers in order to make pair-wise comparisons.

Step 3: Formation of a pair-wise comparisons matrix using fuzzy numbers.

Step 4: Calculating the S_i for each pair-wise comparison matrix rows.

S_i is a triangular fuzzy number that is calculated from the following equation:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad [1]$$

In this equation, "i" Indicates the row and "j" represents the column number. M_{gi}^{j}, in this equation is a triangular fuzzy number. Other values in relations are calculated as relations (2) to (4):

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad [2]$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad [3]$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad [4]$$

In the equations above the relations l_i, m_i and u_i are respectively the lower limit, medium limit and upper limits of the fuzzy numbers.

Step 5: Calculating the extent analysis of S_i with regard to each other. Generally, if $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two fuzzy triangular numbers, based on relationship (5), the extent analysis of $M_1$is defined with respect to M_2:

$$V(M_2 \geq M_1) = hgt(M_2 \cap M_1) = \mu_{M_2}(d) = \begin{cases} 1 & \text{if} \quad m_2 \geq m_1 \\ 0 & \text{if} \quad l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{other} \end{cases} \quad [5]$$

On the other hand, the Strength of a triangular fuzzy number compared to other K numbers of triangular fuzzy numbers is obtained from the equation:

$$V(M \geq M_1, M_2, \dots, M_k) = V[(M \geq M_1) \text{ and} (M \geq M_1) \text{ and} \dots \text{and } (M \geq M_k)] = \min V(M \geq M_i) \quad [6]$$

i=1,2,3,..,k

Step 6: In this step in Chang's method (1996), the weights of criteria and alternatives are calculated in the pair-wise comparison matrix. For this purpose, the equation (7) is used:

$$\acute{d}(A_i) = \min V(S_i \geq S_k)$$
$$k=1,2,3,..,n,\ k \neq i \quad [7]$$

It is worth noting that the method of Chang (1996) eliminates some of the criteria and the importance of some of the criteria will be ignored and zero weight is given to them by using the equation (7). Thus, instead of using minimum values to determine the weight of criteria and alternatives, the average value according to equation (8) will be used. In this way, unlike Chang method, no criterion will be eliminated. This change is our innovation on Chang method.

$$\acute{d}(A_i) = \text{average}\, V(S_i \geq S_k),\ k=1,2,3,..,n\ ,\ k \neq i \quad [8]$$

After this step, other the steps are also based on Chang method (1996). So the non-normalized weight vector will be as equation (8):

$$\acute{W} = (\acute{d}(A_1), \acute{d}(A_2), \ldots, \acute{d}(A_n))^T \quad i=1,2,3,..,n \quad [9]$$
$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T i=1,2,3,..,n \quad [10]$$

Step 7: Calculating the final weight vector. To compute the final weight, the calculated weight vector in the previous step should be normalized with the help of equation (9). Other steps of FAHP method for prioritizing alternatives are similar to the classic one (Chang, 1996).

Data Collection

To reach a pair-wise comparison matrix with the FAHP method, the Delphi method was used; this approach is very common and also useful (Cho & Lee, 2013; Joshi et al., 2011; Kim et al., 2013). According to Dalkey and Helmer (1963), Delphi is a useful communication tool between groups of experts, which simplifies formulating the votes of group members. Wissema (1982), emphasizing the importance of the Delphi method, mentions it as a way to reach an agreement on the prospects of the technologies.

In this regard, firstly a team for executing and supervising the implementation of the Delphi method was formed in ITRC. Due to the limited number of experts, the snowball method (as a non-probability sampling method) was used for the statistical population of the study. Finally, the Delphi panel was formed with a combination of 6 experts familiar with the IoT and e-health. To check the validity of the content, criteria and identified alternative were sent to the Delphi panel.

By reviewing the literature, numerous applications were discussed in addition to the seven ultimate applications that have been selected by the Delphi group – which the definitions of these applications have been argued in detail in the literature. Some of these applications include “sportsmen care,” “medical fridges,” “patient surveillance,” “ultraviolet radiation,” “hygienic hand control,” “dental health,” and “physical activity monitoring for aging people” (See e.g., Vermesan & Friess, 2014).

Based on the experts' opinions about the IoT applications, the “sportsmen care” application has been seen as a subset of “fitness.” The panel group's reason for this decision has been that if a person exercises for wellbeing and fitness and needs IoT applications for taking care of him/her while exercising, then this application can be seen as a branch of “fitness”. The “physical activity monitoring for aging people” and also “patient surveillance” has been recognized as subsets of the “health monitoring” applications.

After conducting the first review by the panel members, the “efficiency” criterion was segregated into “money-saving” and “time saving” criteria. Furthermore, “dental health,” medical fridges,” “hygienic hand control,” and finally “ultraviolet radiation” as e-health IoT applications for individuals were not approved by the panel members, so they were removed from the list of our alternatives.

On one hand, the reason behind removing these applications has been that the level analysis for this paper is based on the individual applications. On the other hand, the Delphi panel experts' opinion has been that the audiences of these applications are health centers and hospitals. So, these applications were ignored in the study by the panelists. Besides, they aren't meaningful applications for individual use at the present time in Iran.

In the end, the decision matrix with eight criteria and seven alternatives was confirmed by members. Next, the first questionnaire was sent to members of the panel. The results of the responses from the first round were sent to the members. They completed questionnaires and pair-wise comparisons again. This was repeated five times to reach the pair-wise comparison matrix, and the results were used as an input of calculations in the FAHP method.

Results

The findings related to the weight of the criteria are represented in the following: First, the accepted questionnaire, which was formulated with the aid of fuzzy language and fuzzy numbers for pair-wise comparison of criteria, was given out. According to the results of FAHP, weights were calculated, which in Figure 3, the priority of importance and also weights are shown.

For drawing a decision matrix, determining the score of alternatives in each criterion is needed. So, after collecting eight questionnaires of agreed pair-wise comparisons for each criterion, the relative scores of each of the e-health IoT applications compared to each other were determined in each criterion. Then, the score of each alternative in each of the criteria is calculated by using of FAHP, and decision matrix was obtained as seen in Table 3.

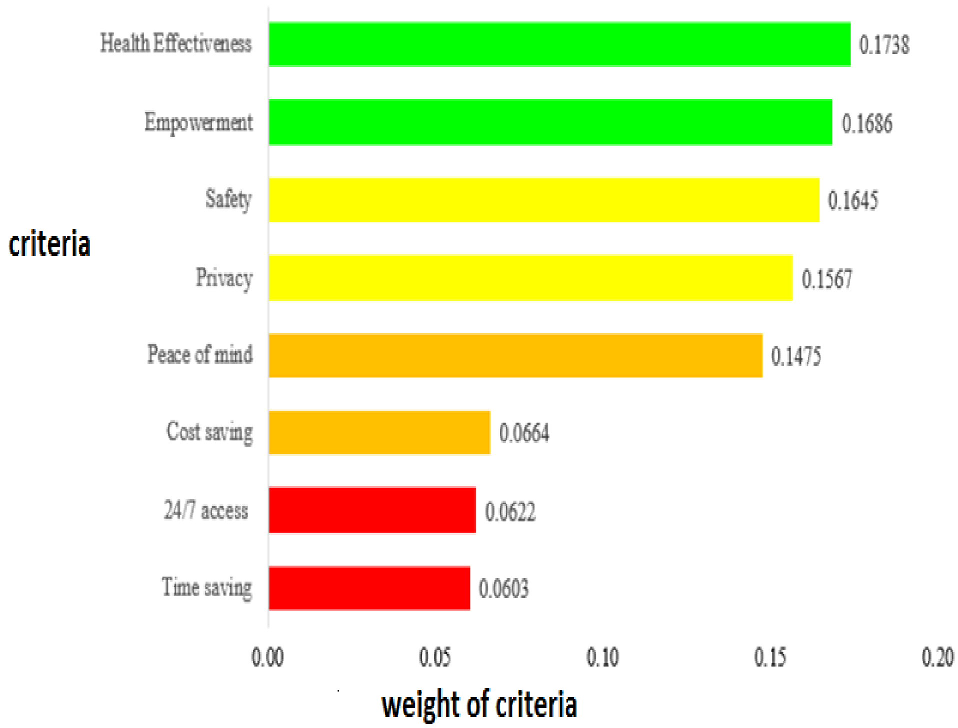

Figure 3. The results for Weight of criteria

Table 3. The decision matrix

	24/7 Access	Empowerment	Peace of Mind	Safety	Cost Saving	Time Saving	Health Effectiveness	Privacy
Chronic Disease Management	0.2160	0.2212	0.1743	0.2212	0.2188	0.1747	0.2206	0.0665
Air Quality	0.1689	0.1169	0.1549	0.1227	0.2102	0.1095	0.1622	0.1989
Health Monitoring	0.2246	0.1898	0.2149	0.1839	0.1991	0.1808	0.2206	0.0571
Medication Reminder	0.0700	0.2063	0.2035	0.2303	0.1086	0.2083	0.1835	0.1372
Fitness	0.0321	0.0632	0.0307	0.0329	0.0856	0.0771	0.0315	0.1425
Fall Detection	0.1633	0.1394	0.1452	0.1432	0.1464	0.2145	0.1126	0.1989
Sleep Control	0.1251	0.0632	0.0765	0.0658	0.0313	0.0351	0.0692	0.1989

According to the weights obtained for the criteria in Figure 3, the score and priorities of each of the alternatives by using the FAHP is also calculated which can be seen in Table 4, respectively.

Table 4. Score and priorities of each of e-health IoT applications for individuals in Iran

Alternatives	Rank	Score
Chronic Disease Management	1	**0.1866**
Air Quality	4	**0.1532**
Health Monitoring	3	**0.1793**
Medication Reminder	2	**0.1802**
Fitness	7	**0.0607**
Fall detection	5	**0.1520**
Sleep control	6	**0.0879**

Discussion

Based on the results of the research, the five most important criteria for prioritizing e-health IoT applications for individuals according to criteria weights were identified as Health Effectiveness (0.1738), Empowerment (0.1686), Safety (0.1645), Privacy (0.1567), and Peace of mind (0.1475). Also, it is notable that cost saving with a weight of (0.0664), 24/7 Access with a weight of (0.0622), and Time-Saving with a weight of (0.0603) were among the least important criteria.

In Table 4, ranked results obtained by the method of FAHP show that the priority of e-health IoT applications according to the weights of the identified criteria are as follows: “Chronic Disease Management,” “Health Monitoring,” “Medication Reminder,” “Air Quality,” “Fall Detection,” “Sleep Control,” and “Fitness.”

Conclusion

Health is one of the social concerns of the world that, in Iran as a transition country moving from a factor-driven economy to an efficiency-oriented economy, has been a subject of interest for policymakers and regulators. Recently, national research centers in Iran, including ITRC, have put the implementation of IoT technologies in the field of health on their agenda, and at the ministerial level of the country, well-done infrastructure works are in progress. Due to the high volume of healthcare consumers, e-health IoT applications at different levels of businesses and corporations, government, universities, research institutes, and especially citizens (individuals) can be studied. The aim of this study is to prioritize these applications for individuals in Iran.

Based on the literature review, areas of Chronic Disease Management, Air Quality, Health Monitoring (vital signs monitoring), Medication Reminder, Fitness, Fall Detection, and Sleep Control cover a wide range of applications of the e-health IoT for individuals. To achieve a priority, the benefits of these applications for individuals were identified as criteria for decision making. According to the research literature review, these criteria consist of round-the-clock Access, Empowerment, Privacy, Peace of Mind, Safety, Cost Saving, Time Saving, and Health Effectiveness. For weighing criteria and determining the relative scores of alternatives compared with each other, in each criterion, the FAHP method, one of the techniques most common in multiple attribute decision making, was chosen.

The findings have shown that priority of e-health IoT applications according to the weights of the identified criteria are as follows: “Chronic Disease Management,” “Health Monitoring,” “Medication Reminder,” “Air Quality,” “Fall Detection,” “Sleep Control,” and “Fitness.”

The results have focused on the IoT technology in regard to developing e-health IoT applications for both policymakers and business owners; policymakers by concerning individual's health to reduce some of the health problems of citizens in Iran with the help of this technology, and on the other hand, business owners with investments and more detailed feasibility studies on applications with higher priority. The results of this research improve our knowledge about IoT technology in the health sector and also encourage innovative use cases of this new technology in the health field for individuals in Iran.

Conflict of interests

Furthermore, this study has had some limitations which should be pointed out. For example, the given priorities will be more suitable for the Iranian folks as their health status has significant differences from developed countries. Although our method to evaluate and prioritizing e-health IoT applications in the health sector is completely suitable for others, it seems the results are under the influence of the public health situation in Iran. Also, research about applications in different scenarios such as hospital healthcare, home healthcare, and smart city is recommended.

In addition, we highly recommend some future and further researches in the following areas; as Iran is a transition country, this study has been carried out due to the economic situation, health status and health issues of Iranian people at the individual level and also according to the existing infrastructure in the country.

The generalization of the results to other countries should be done cautiously and a separate study is better to be carried out according to the economic, technological and health status of other countries. It is also suggested to investigate the public health impact on the prioritization by researching countries with different levels of development.

In this study, in order to structure the decision matrix to measure the effectiveness of health, time-saving and cost-saving, accurate measurement has not been done and the criteria have just been measured according to experts' opinions. So doing experimental investigations to evaluate the effectiveness of these applications seems to be necessary. In addition, the cost-benefit analysis could be useful from the point of view of cost and time.

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