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***Abstract*—The rapidly increasing elderly population in many developed and developing countries poses great challenges to elderly care systems. To alleviate the problem of a shrinking workforce to deliver elderly care, using mobile intelligent assistants to lessen the caregivers' workload becomes a promising solution. However, the friendliness of such mobile assistants, which is seldom measured in a quantitative manner, may hinder their acceptance by the elderly users. In this paper, we propose a formalized systematic approach named Elderly Friendliness Evaluation Methodology (EFEM) to measure the elderly friendliness of any product, service or system. Furthermore, we apply EFEM to evaluate the elderly friendliness of five commercial mobile assistants and three prototypes. The comparison results show that the commercial assistants are less elderly-friendly than the prototypes. The high Elderly Friendliness Scores (EFSs) achieved by the prototypes suggest that they are highly likely to be well accepted by elderly users.**

I. Introduction

Due to the increased life expectancy around the globe, the number of persons aged 60 or above is expected to increase from 901 million in 2015 to 2.1 billion in 2050 [1]. This situation is more challenging in certain countries, e.g., one in four persons in Singapore will be aged 65 or above by 2030, up from one in eight in 2016 [2]. The rapidly increasing elderly population poses great challenges to both individual households and the society, mainly due to the declining ratio of the number of healthcare professionals over the number of elderly. To alleviate the problem of a shrinking workforce to deliver elderly care, using mobile intelligent assistants to lessen the caregivers' workload becomes a promising solution [3]. Among all intelligent assistants, mobile ones are the most pervasive kind thanks to the high penetration rate of smartphones (e.g., 83% among senior Singaporeans [4]) and the fact that many people always keep their smartphones within reach. However, most existing mobile assistants are not designed for, hence not friendly to, the elderly users.

Human Factors considerations play an important role in improving the friendliness of a product, service or system. Design models have been proposed in the literature to achieve high elderly friendliness [5], [6], [7]. However, these models focus more on design principles rather than evaluation. Furthermore, they may only focus on certain aspects among the broad range of Human Factors considerations. Therefore, in this paper, we propose a formalized comprehensive approach, named Elderly Friendliness Evaluation Methodology (**EFEM**), to systematically measure the Elderly Friendliness Score (**EFS**) of any product, service or system. Furthermore, we apply EFEM to quantify EFSs of eight mobile assistants and provide comparisons with discussion.

The eight mobile assistant candidates evaluated in this paper consist of five commercial ones and three prototypes (see Section III). Please note that Apple's Siri, Google's Now, and Microsoft's Cortana, which may be the most widely known and used mobile assistants, are not evaluated in this paper. Without doubt, these three assistants demonstrate state-of-the-art technologies in the field of human language understanding, dialogue generation, online information retrieval from large databases, etc. However, their primary functionalities are to provide more efficient information retrieval and more natural ways for user interactions, rather than proactively providing companionship, sending reminders, and promoting a healthier lifestyle to the users. Thus, we do not consider them as purposely designed for providing assistance in Activities of Daily Living (ADLs).

We compute the EFSs of the eight mobile assistant candidates based on EFEM and compare the results with discussion. It is shown that the commercial assistants are less elderly-friendly, probably because they were purposely designed for working adults. On the other hand, the high EFSs achieved by the prototypes suggest that they are highly likely to be well accepted by elderly users.

The contributions of this paper are mainly three-fold:

1) We propose a formalized systematic approach named EFEM to measure the elderly friendliness of any product, service or system. Specifically, EFEM consists of 86 key considerations across 22 Human Factors aspects. It may be used not only as an evaluation method, but also as a comprehensive guideline during the design and re-design phases.
2) We conduct a brief survey on eight mobile intelligent assistants that are designed to serve the users in their everyday life (five commercial ones and three prototypes). Moreover, we apply EFEM on the eight assistants to compare their elderly friendliness in a quantitative manner.
3) EFEM can be customized to exclude any non-applicable Human Factors aspects (e.g., "Haptics and controls" is excluded when evaluating mobile assistants), which makes it suitable to evaluate the elderly friendliness of all types of products, services and systems. Readers may follow the approach delineated in this paper to evaluate

the elderly friendliness of other products, services or systems.

The rest of the paper is organized as follows. We review the literature of elderly friendliness evaluations in terms of Human Factors considerations and propose EFEM in Section II. We briefly introduce the eight mobile assistant candidates in Section III. We delineate our approach of applying EFEM to evaluate the elderly friendliness of mobile assistants and compare the results in Section IV. We conclude this paper and propose future work in Section V.

II. Elderly Friendliness Evaluation Method

Studying user friendliness has always been a major topic in ergonomics, an important sub-field of Human Factors research. However, over the last decades, many Human Factors evaluations on user friendliness were studied on a broad scale, such as universal principles and guidelines [8], [9], without specifically targeting the elderly users. In the mean time, some elderly-specific evaluations only focused on certain aspects, such as familiarity [10], [11] or curiosity [12], without having a comprehensive model. On the other hand, although some design models have been proposed to achieve high elderly friendliness [5], [6], [7], they are not generic to all products, services and systems. Even though quantitative evaluations of elderly friendliness are desirable and essential to estimate acceptance by the elderly users without conducting large-scale trials, there are few tools available in the literature or on the market. Easy-to-use evaluation tools, such as the Age-Friendly Brands App[1], provide predefined questions for users to rate the product, service, or system and then provide an overall score. However, we find these tools may not be flexible (e.g., user cannot easily exclude irrelevant evaluation categories) and comprehensive enough (i.e., the evaluations may not cover a wide range of considerations).

To devise a flexible and comprehensive evaluation method to quantitatively assess the elderly friendliness of a product, service or system, we propose the Elderly Friendliness Evaluation Methodology (EFEM), which possesses the following two major advantages over existing evaluations:

1) We did a thorough literature view on the existing evaluation scales and principles across different perspectives and points of entry, based on which we can ensure the comprehensiveness of EFEM to cover a wide variety of evaluations. Specifically, EFEM consists of 86 key considerations across 22 Human Factors aspects.
2) EFEM is a quantitative evaluation method, which provides an intuitive score at the end of the evaluation process. Moreover, EFEM is flexible enough to exclude non-applicable categories. For example, "Haptics and controls" is irrelevant to intelligent assistants residing in mobile devices and can be easily excluded (see Section IV).

The 22 Human Factors evaluation categories covered by EFEM are listed as follows: (i) display visibility, (ii) legibility, (iii) readability, (iv) compatibility, (v) comprehension, (vi) feedback, (vii) visibility, (viii) constraints, (ix) consistency, (x) error prevention and recovery, (xi) individualization, (xii) learnability, (xiii) memorability, (xiv) audibility, (xv) haptics and controls, (xvi) safety, (xvii) affectiveness, (xviii) persuasiveness, (xix) curiosity, (xx) information organization, (xxi) task organization, and (xxii) help and documentation. Each category consists of 2 to 6 corresponding evaluation criteria and there are 86 criteria altogether. Due to the page limitation, we refer readers to the online document[2] for more details on the descriptions of the 22 evaluation categories and the specifics of the 86 criteria.

[1]URL: https://www.age-friendly.com/brands/

TABLE I: Correspondence between elderly friendliness score (EFS) and elderly friendliness grade

Elderly Friendliness Score (%)	Elderly Friendliness Grade
$[90, 100]$	Excellent
$[80, 90)$	Very good
$[70, 80)$	Good
$[50, 70)$	Poor
$[30, 50)$	Very poor
$[0, 30)$	Unacceptable

Let object o denote the product, service or system to be evaluated using EFEM. After identifying the number of relevant evaluation categories m_o, where $m_o \leq 22$, which are applicable to o, we can compute the Elderly Friendliness Score *EFS* of o using the following formula:

$$\mathit{EFS}(o) = \sum_{i=1}^{m_o} c_i \sum_{j=1}^{n_i} d_{i,j} s_{i,j} \cdot 100\%, \tag{1}$$

where c_i denotes the coefficient associated with the ith category, n_i denotes the number of criteria in the ith category, $d_{i,j}$ denotes the coefficient associated with the jth criterion in the ith category, and $s_{i,j}$ denotes the score obtained by object o for the jth criterion in the ith category.

For simplicity, in this paper (see Section IV-B for other assignment suggestions), we equally assign c_i, i.e.,

$$c_i = 1/m_o, \tag{2}$$

and similarly, we equally assign $d_{i,j}$, i.e.,

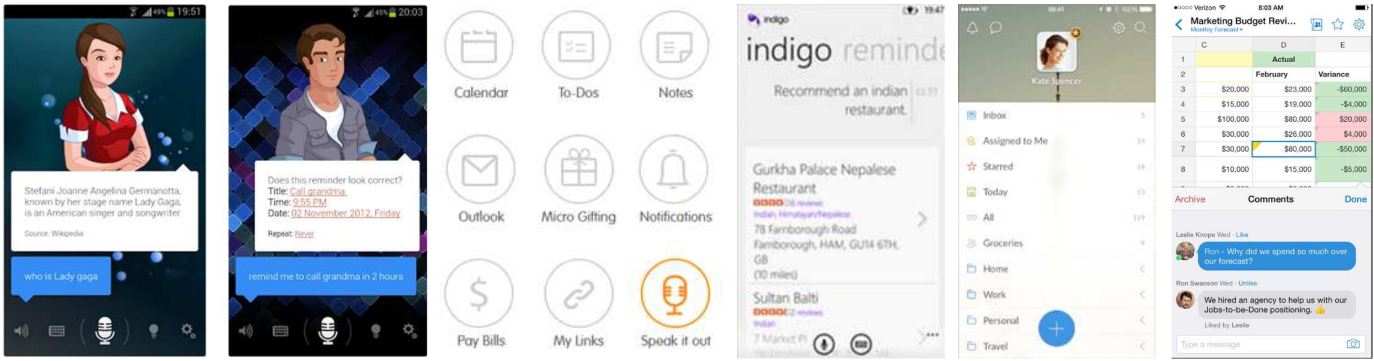
$$d_{i,j} = 1/n_i. \tag{3}$$

Moreover, to ease the effort in evaluations, $s_{i,j}$ is assigned using the following intuitive means:

$$s_{i,j} = \begin{cases} 0, & \text{if the criterion is not satisfied,} \\ 0.5, & \text{if the criterion is partially satisfied,} \\ 1, & \text{if the criterion is satisfied.} \end{cases} \tag{4}$$

Besides providing an exact score $\mathit{EFS}(o)$, EFEM also assigns a grade associated with the evaluation result based on heuristic mappings to provide an overall view of the object being evaluated. The mappings are shown in Table I.

[2]URL: https://www.dropbox.com/s/4rpkwxfxdhhvf21/EFEM.pdf?dl=0



(a) Speaktoit (b) 24me (c) indigo (d) Wunderlist (e) Quip

Fig. 1: User interfaces of the commercial mobile assistants. (a) Two of the many avatars used in Speaktoit. Left: information inquiry. Right: reminder service. (b) Functions provided by 24me. (c) Illustration of indigo's recommendation function. (d) Wunderlist's function list. (e) Illustration of sharing spreadsheets among team members using Quip.

III. Mobile Intelligent Assistants

Mobile personal assistant apps are pervasive on today's handheld mobile devices. Many such apps require access rights to the user's calendar, contact list, email accounts, etc., so that they can assist in both work and leisure aspects. These mobile intelligent assistants are mostly designed to assist the working adults by means of providing reminders and keeping records. In the past few years, we have observed an emerging trend of using intelligent virtual assistants to accompany the elderly and provide all-round care to them [3], [13].

There is a common stereotype that the elderly are not receptive to advanced technological gadgets. However, although less confident than younger people, elderly who have experience using modern gadgets generally hold more positive attitudes and greater confidence [14]. If computers (extensible to smartphones) are modified according to the specific needs of the elderly with simpler interfaces that follow natural mental concepts, the elderly can benefit much from them [14]. Moreover, the usage of Internet, computers, and social network service platforms among the elderly has been increasing over the past decade [15]. Therefore, deploying intelligent agents in smartphone and computer platforms is a feasible and practical way to assist the elderly in their daily life.

In Section III-A, we briefly introduce five popular commercial mobile personal assistants. In Section III-B, we briefly introduce three mobile intelligent assistant prototypes developed at the Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY), Nanyang Technological University, Singapore.

A. Commercial Mobile Intelligent Assistants

Speaktoit[3] supports quite a variety of services, each provided in a separate tab with a unique avatar appearing in the background (see Fig. 1(a)). Although it seems that Speaktoit provides a bundle of assistants, all of them may use the same underlying engine when delivering different types of services.

[3]URL: https://assistant.ai/

24me[4] supports a total of nine functions (see Fig. 1(b)). However, it seems unintuitive to separate the speech understanding function from the others.

indigo[5] provides fewer functions, namely Social Networks (mainly connecting to Twitter), Restaurant Recommendations (see Fig. 1(c)), Search Engines, Email Accounts, and Get Musical.

Wunderlist[6] is similar to 24me in terms of interface design. However, Wunderlist provides more types of services such as sharing files among team members, using hashtags to add more context to the to-do list, etc. Moreover, Wunderlist clearly separates work and personal services (see Fig. 1(d)).

Quip[7] aims to support collaborative team work more than individual productivity. For example, it enables team members to easily share their files and work in progress (see Fig. 1(e)).

All five commercial mobile assistants shown in Fig. 1 basically focus on improving work productivity or providing personal leisure activity recommendations. Although none of them is specifically designed for elderly users, it is quite intuitive to figure out that Speaktoit may be better accepted by such users than the other assistants, due to its spacious layout design, use of self-explanatory icons, large fonts and line space, etc. Nonetheless, the aforementioned intuitive reasons are far inferior to a formalized quantitative assessment. Later in Section IV, we apply EFEM to evaluate the EFSs of these five commercial mobile assistants.

B. Mobile Intelligent Assistant Prototypes

As its name suggests, the smart butler Alfred (see Fig. 2(a)) provides all-round tender care through frequent natural interactions (i.e., speech and touch). Its context panel (upper left portion) displays peripheral information. It provides various functions via their respective buttons in the function panel (right portion). The interaction panel (lower left portion)

[4]URL: http://www.twentyfour.me/
[5]URL: http://www.helloindigo.com/
[6]URL: https://www.wunderlist.com/
[7]URL: https://quip.com/

(a) Alfred (b) Florence (c) Misa

Fig. 2: User interfaces of the mobile assistant prototypes. (a) Smart butler Alfred is recommending physical exercise to the elderly user. (b) Virtual nurse Florence agrees with Alfred and is trying to persuade the user who did not wish to follow the advice. (c) Mobile intelligent silver assistant Misa retrieves the user's schedule.

delivers all types of messages, such as reminders, recommendations, small talks, etc., and receives the user responses through button presses. More details about Alfred can be found in [3], [16], [17].

Although the original version of virtual nurse Florence (see Fig. 2(b)) resides in a home computer, it can easily be implemented in smartphones as it was developed using the Unity3D platform. As its name suggests, Florence specializes in promoting healthy lifestyles and providing health-related recommendations to the elderly. It naturally interacts with the elderly through speech and touch. Its most unique features is the use of a computational model for adaptive persuasion. More details about Florence can be found in [3], [17], [18].

In our prior work [17], both Alfred and Florence are enabled to assess the well-being of an elderly occupant living in a smart-home environment through a situation awareness model, which manages the sensory inputs collected from various sources (both built-in and mobile). As shown in Figs. 2(a) and 2(b), Alfred and Florence can work together seamlessly.

The mobile intelligent silver assistant Misa adopts an open architecture approach, which allows multiple reusable services to be integrated onto a single platform while maintaining high extensibility for future open services. As such, Misa is able to provide personalized services to care for the fundamental aspects in elderly users' lives, including health, exercise and activity management. The reasoning processes in these services are supported by a healthcare domain knowledge base and user models for implicit user modelling. More details about Misa can be found in [19].

As mentioned previously, all three prototypes shown in Fig. 2 were purposely designed for elderly users to help them cope with reduced physical and cognitive capabilities, provide emotional support, and promote social engagement. It may appear obvious that these prototypes are more elderly-friendly than the commercial assistants shown in Fig. 1. Nonetheless, without quantitative evaluations, we cannot directly jump to this conclusion. Therefore, in the following section, we evaluate the prototypes using EFEM and compare the results to those of the commercial assistants.

TABLE II: Overall EFSs and grades of mobile assistants

Name	EFS (%)	Grade	Name	EFS (%)	Grade
Commercial			**Prototype**		
Speaktoit	69.88	Poor	Alfred	80.63	Very good
24me	61.03	Poor	Florence	72.70	Good
indigo	45.51	Very poor	Misa	71.38	Good
Wunderlist	53.77	Poor			
Quip	60.16	Poor			
mean	**58.07**	**Poor**	mean	**74.90**	**Good**
std	9.07		std	5.00	

IV. Evaluation of Mobile Intelligent Assistants

Among all the 22 Human Factors evaluation categories introduced in Section II, only "Haptics and controls" is identified as not applicable to mobile intelligent assistants. Haptic devices for elderly are usually used for physical rehabilitation purposes. In terms of mobile devices, different amount of pressure applied by the users on the screen is not quantified as a form of haptic inputs and on the other hand, vibration of the mobile devices (one type of haptic outputs) is not suggested to avoid accidents such as dropping the phone on the ground. Therefore, m_o (see (1)) for mobile assistants is 21 and thus, $c_i = 1/21$. The EFSs and the corresponding elderly-friendliness grades of the eight mobile assistants introduced in this paper are listed in Table II. Furthermore, the EFSs in each Human Factors evaluation category are listed in Table III.

A. Discussions on EFSs

As expected, the commercial mobile assistants obtain lower grades (four poor and one very poor) than the prototypes (one very good and two good). The difference between the two groups is quantitatively measured as $74.9\% - 58.07\% = 16.83\%$. Delving into the Human Factors categories (see Table III) to explain the difference, we find that generally speaking, the commercial ones do not obtain competitive scores on "Curiosity" (i.e., stimulates the users' curiosity

TABLE III: EFSs in each Human Factors evaluation category

ID	Speaktoit	24me	indigo	Wunderlist	Quip	mean (std)	Alfred	Florence	Misa	mean (std)	difference
i	0.800	0.500	0.200	0.400	0.800	0.54 (0.26)	1.000	0.700	1.000	0.90 (0.17)	0.36
ii	0.750	0.833	0.667	0.583	0.583	0.68 (0.11)	0.833	0.667	0.750	0.75 (0.08)	0.07
iii	1.000	0.833	0.500	0.833	0.833	0.80 (0.18)	1.000	0.833	1.000	0.94 (0.10)	0.14
iv	0.800	0.800	0.700	0.800	0.900	0.80 (0.07)	1.000	1.000	1.000	1.00 (0.00)	0.20
v	1.000	0.833	0.500	0.500	0.500	0.67 (0.24)	1.000	0.833	0.833	0.89 (0.10)	0.22
vi	0.700	0.800	0.800	0.800	0.800	0.78 (0.04)	0.900	0.700	0.800	0.80 (0.10)	0.02
vii	0.750	0.750	0.500	0.625	0.625	0.65 (0.10)	1.000	0.750	0.750	0.83 (0.14)	0.18
viii	0.300	0.200	0.200	0.200	0.300	0.24 (0.05)	0.500	0.300	0.100	0.30 (0.20)	0.06
ix	1.000	1.000	0.833	0.833	1.000	0.93 (0.09)	1.000	1.000	1.000	1.00 (0.00)	0.07
x	0.500	0.333	0.333	0.333	0.333	0.37 (0.07)	0.500	0.333	0.333	0.39 (0.10)	0.02
xi	0.125	0.000	0.125	0.125	0.750	0.23 (0.30)	0.000	0.250	0.125	0.13 (0.13)	-0.10
xii	0.500	0.667	0.333	0.667	0.500	0.53 (0.14)	0.667	0.667	0.333	0.56 (0.19)	0.02
xiii	1.000	1.000	0.500	0.500	0.250	0.65 (0.36)	1.000	1.000	0.750	0.92 (0.14)	0.27
xiv	1.000	1.000	1.000	1.000	1.000	1.00 (0.00)	1.000	1.000	1.000	1.00 (0.00)	0.00
xv	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
xvi	0.400	0.400	0.400	0.300	0.300	0.36 (0.05)	0.600	0.500	0.400	0.50 (0.10)	0.14
xvii	1.000	0.167	0.167	0.500	0.667	0.50 (0.35)	1.000	1.000	0.833	0.94 (0.10)	**0.44**
xviii	0.000	0.000	0.000	0.167	0.167	0.07 (0.09)	0.333	0.333	0.833	0.50 (0.29)	**0.43**
xix	0.875	0.500	0.250	0.250	0.500	0.48 (0.26)	1.000	1.000	0.875	0.96 (0.07)	**0.48**
xx	0.600	0.600	0.300	0.300	0.600	0.48 (0.16)	0.900	0.600	0.700	0.73 (0.15)	0.25
xxi	0.875	1.000	0.750	0.875	0.625	0.83 (0.14)	1.000	1.000	0.875	0.96 (0.07)	0.13
xxii	0.700	0.600	0.500	0.700	0.700	0.64 (0.09)	0.700	0.800	0.700	0.73 (0.06)	0.09

for attraction and attention), "Affectiveness" (i.e., provides a pleasing experience to the users), "Persuasiveness" (i.e., provides proper persuasion and incentives), and various sensory-related categories such as "Display visibility", "Readability", "visibility", etc. All the aforementioned categories play an important role in reducing the barriers of using intelligent assistants residing in mobile devices to assist the elderly in their daily life and provide appropriate care. As shown in this instance, EFEM can help identify the Human Factors categories in which major differences exist.

Furthermore, as shown in Table II, none of the prototypes achieves the "Excellent" grade, which means there is still much room for improvement. Specifically, the prototypes obtain the lowest scores on "Individualization", "Constraints" and "Error prevention and recovery". However, all the commercial mobile assistants also obtain low scores on these categories that the differences are merely -0.1, 0.06 and 0.02, respectively (see Table III). This similar level of low attainment may suggest that the design considerations of these Human Factors categories may not be easily fulfilled due to the nature of the product being evaluated. For example, all the prototypes fail the last criterion of "Individualization" (i.e., $s_{11,4} = 0$, see (4)) about "Allows flexibility in interface setup". Mobile assistant apps seldom allow the users to alter their layout or remove certain components. Nonetheless, the EFS of each criterion enables us to find certain functions of the prototypes that can be easily improved with a fair amount of effort for better elderly friendliness. For example, the failed criteria $s_{12,3}$ and $s_{22,3}$ can be simply improved by providing tutorials and wizards to guide the users during first use ("Learnability") and comprehensive manuals and documentations ("Help and documentation"), respectively.

B. Other Notes on Applying EFEM

In the previous subsection, we compared and discussed the main differences between the commercial assistants and the prototypes in terms of their EFSs. In this subsection, we provide some notes on applying EFEM on other products, services or systems.

In this paper, EFEM is shown to be flexible in the sense that non-applicable evaluation categories can be easily excluded (see (1)). For other evaluations, the coefficients associated with the categories (c_i) may be assigned based on their respective importance rather than equally assigned (see (2)). For example, for a physical rehabilitation device for the elderly, the "Haptics and controls" and "Safety" categories are far more important than others such as "Audibility". Furthermore, EFEM is also flexible to be adjusted according to certain specific user groups by altering the coefficient values associated with the corresponding criteria ($d_{i,j}$, see (3)). For example, if the targeted users are dementia patients, the coefficient associated with "Protecting users from potential psychological risks" in the "Safety" category should be assigned with much higher importance than the other criteria in the same category.

Similarly, to apply EFEM, one simply needs to follow each criterion of each category to assign the corresponding score ($s_{i,j}$, see (4)) to perform the evaluation. This systematic approach can be further improved by implementing an Excel spreadsheet template or a dedicated web page to facilitate the evaluation process.

In this paper, we compared the EFSs of eight intelligent assistants of the same nature. i.e., residing in mobile devices and providing assistance and recommendations. However, comparison of different products, services or systems of different nature may not be fair. For example, the virtual escape exergame (VEE) [20], which is a serious rehabilitation game designed to help the elderly exercise their motor and cognitive capabilities using Kinect (for non-intrusive motion detection), has an EFS of 83.46%. Although it is technically correct to state that VEE is more elderly-friendly than all the mobile intelligent assistants because VEE obtains a higher score, VEE may not necessarily be better accepted by elderly users. It would be fairer to compare the EFS of VEE to those of other exergames of the same nature.

EFEM may not only be used to compute the EFSs: it can also be used as a guideline or a checklist to improve a prototype even before running pilot studies with elderly users. Based on the scores obtained in each Human Factors evaluation category, it is quite intuitive to figure out which aspects of the prototype should be improved.

V. Conclusion

In this paper, we proposed a formalized systematic yet flexible approach, named Elderly Friendliness Evaluation Method (EFEM), to measure the elderly friendliness of any product, service or system. Moreover, we apply EFEM to evaluate eight mobile intelligent assistants. Other than comparing and discussing the Elderly Friendliness Scores (EFSs) of the mobile assistants, we further outline how to apply EFEM for other evaluations and how to use EFEM as a generic design guideline or a checklist for improvements.

In Human Factors terms, EFEM is regarded as a "usability inspection" method rather than "usability testing" which requires running pilot studies with test users. Going forward, we plan to recruit elderly users to get their views on the mobile assistants and compare their opinions with EFSs.

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