The Development of a Fuzzy Model and Usability Test of a Recommended Interface Design for Mobile Phones for Elderly Users

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Abstract—The purpose of this study was to examine a range of flexible user interface designs for mobile phones with the aim of locating and addressing the limitations reported by elderly users. Accordingly, a fuzzy model drawing on a range of variables was developed from an age/vision impaired related data set for the development of a variety of basic design elements for user interfaces. The model was tested to assess the preciseness and accuracy of its functions, achieving a Mean Absolute Error (MAE) close to 0 and an Effectiveness Index (EI) close to 1, giving the model a high value for effectiveness. A subsequent usability test of the generated design interfaces using four types of mobile phones (18 screens in all) was conducted among 25 elderly users with vision impairment. The findings showed that the size and shape of both numeric and function buttons was a significant factor in assessing phone usability both for communication and for social media use, as was text and number size, although, significantly, the latter was qualified by screen size. Recommended numeric and dial function button sizes are 15.6mm and 16.2 mm, text and numbers sizes are 14 and 25 points, respectively. Square-shaped buttons with rounded-edge buttons are the most suitable for elderly users, as is a background in a light shade, with texts and icons in dark colors. The model demonstrates that it is possible to design user interfaces with particular groups in mind such as the elderly and vision-impaired, in order to enhance mobile phone usability for these groups.

Keywords—fuzzy model development, user interface design, mobile phone application, elderly mobile phone users, usability

1 Introduction

Society is aging worldwide. The world's population of elderly people more than doubled between 1980 and 2017, and is forecast to duplicate by 2050 [1]. These valuable people face many challenges in modern daily life. One lies in the use of technology in the face of visual impairment. Although specialized training courses, especially computer-based training, may help find ways to compensate for visual field loss, loss of vision can never be recovered perfectly [2]. Elderly users, particularly those with visual impairment, will continue to have specific difficulties in using technology. This applies especially to what is currently the most economically accessible device, the mobile phone [3]. According to a 2011 survey of the use of technology devices by Walker and Masnard [4] involving 2,947 elderly participants in 23 countries, 87% of the participants used mobile phones. In Thailand, a full-fledged 'ageing society' in 2021, the National Statistical Office [5] revealed that over 80% of elderly Thai people used mobile phones for communication. Moreover, among all applications available, 89.8% of Thai elderly people also spent their time on their phones on social media. Within this figure, 91.5% of elderly users chose to use LINE [6], a free application for smartphones as well as tablets and PCs, for instant communication by voice, video, image or text.

However, a problem faced by these elderly users is that user interface designs (UIDs) for these devices are intended to cover all age groups of users [7]. They therefore may not meet the needs of specific groups of users such as the elderly and/or vision impaired. While users are expected to be able to adjust aspects such as the size of the operation buttons and typefaces of a device's operating system (OS) themselves [8], it may not be easy or even possible for elderly users to manually adjust the complex settings on their mobile phones [9], especially as one of the most significant problems reported in relation to the components of mobile phones for elderly users relates to the phone's touch screen [10], including 'buttons,' text and menus [11]. This problem includes elements of design such as size, shape, and color [11,12].

This study draws on Artificial Intelligence in order to come up with a user interface design for mobile phones that has the flexibility to meet the physical and cognitive requirements of elderly users, particularly those with visual limitations, in order to improve their experience of using a mobile phone device. A fuzzy model was developed to identify feature selection and create fuzzy rules for designing appropriate user interfaces on mobile applications and social media applications by focusing on components of application and design that would enable the elderly to use an interface at its highest level of *efficiency* and *effectiveness* while meeting their *satisfaction*, the three aspects of the ISO 9241-11 usability standard. The model scored highly when tested for these three usability indicators, allowing recommendations to be made to application developers.

2 Literature

Artificial Intelligence (AI) is the attempt to design machines, particularly computer systems with processors and memory, which can simulate human intelligence, act rationally and autonomously, and can learn [13]. A strong AI would be a computerized system that had 'a mind.' While this is proving challenging for computer scientists to develop, their efforts to develop such systems have already been beneficial in many fields involving complex decision-making such as medical science, economics, geology [14], general technology development, and the environmental sciences, where AI techniques enable modelling by drawing on a range of different methods, often in combination, including case-based reasoning, rule-based problem-solving involving machine learning, the creation of artificial neural networks to mimic the way human brains operate and 'genetic' algorithms to mimic natural selection, 'multi-agent' systems in which components are placed into networks within which they interact, and fuzzy set theory [15].

AI technology utilizes algorithms or precise sets of instructions to respond to human instruction. Fuzzy logic, a development of fuzzy set theory first demonstrated by L.A. Zadeh in 1965, is one of the techniques used in AI studies. Unlike sets in classic theory (so-called crisp sets), which are binary, fuzzy set members are 'fuzzy,' like human thinking, with indeterminate boundaries because of uncertainty about where boundaries exist. Fuzzy sets approach the measurement of things by 'scaling' [16]. They therefore provide 'a mathematical tool to deal with uncertainties' [17]. Models using fuzzy logic can take into consideration conditions that are 'vague or not precisely defined' [18], allowing the solving of problems where vagueness of information emerges [19]. Fuzzy logic is therefore ideal for modelling decision-making or solving problems where uncertainty occurs [20]. It allows 'the study of vagueness:' whenever uncertainty emerges this theory allows models to be 'constructed to represent and process' specified problems [21]. This ability to handle vague or imprecise information makes fuzzy systems one of AI's 'strongest techniques' [15].

Developments in mobile technologies such as phones and other portable internet connectable devices in conjunction with developments in AI have increased the 'application scenarios' for AI enormously [22]. Scholars are already envisaging future smart 6G networks that will make the Internet of Everything (IoE) a reality for mobile device users [23]. AI assisted mobile phones already allow wallet-less shopping, convenient vaccination/health status display, smart home and health care management [22]. AI, including fuzzy logic, is being used to develop applications and mobile devices that are useful for those with visual impairment, including the elderly. Harum et al., for instance, have used AI technology and smartphone application technology such as the Digital Daisy Book Reader to develop a multi-language interactive book reading device that can be used by the visually impaired to 'read' information in public places [24]. Conversely, mobile apps for smartphones are increasingly being developed to help users manage a huge range of human needs, from finding ways for dysarthic children (children with a neurological disorder that damages their ability to speak) to communicate using 'daily usable conversation terms' [25], to encouraging inveterate online texters to find more polite ways of communicating [26]. Mobile phones are being developed as 'fall detection system' sensors 'trained' to detect 'falling in any direction' from common activities such as walking or jogging [27]. Bratić et al. have also used a fuzzy logic-based model to evaluate the readability of handwritten font sizes on small devices such as mobile phones, finding that some font types in some sizes are more readable than others [16]. Clearly, AI is already widely used in smartphone technology, and likely to become more so as phones learn to automatically carry out tasks that are important to users [28]. Applying AI techniques can conceivably generate a more-personalized and adaptive service to users, if AI designers incorporate the needs of user, along with product development, principles, and processes [29]. Nevertheless, regardless of the sophistication of the application, older mobile phone users generally choose a mobile phone for its apparent usability, based primarily on its functional attributes [30]. Unless the targeted customers for these wonderful services find the basic functions of mobile phones easy, comfortable, and satisfying to use, these applications will fail to be embraced. Therefore, it is important to understand the basics of what elderly people require to make mobile phones easier and more satisfying to use. AI is therefore increasingly being applied to test the usability of mobile devices. This is becoming even more important since it has been recognized that high levels of human-machine integration can in effect reduce user autonomy, limiting the appeal and usability of some designs for vulnerable user groups such as the elderly [29].

However, although studies on the usability of particular *applications* for mobile phones have burgeoned, basic function usability (the hardware of devices) has not kept pace with developments in smart-phone technology, or with the needs of aging populations. In 2005, Ziefle and Bay reported that although older adults were very interested in and willing to use new devices, they found the usability of the designs was not adequate to their needs or abilities [31]. In 2014, Kamel Boulos et al. argued for the development of application operability standards and certifications for mobile phones, since apps that were 'perfectly usable by a younger person' could be unmanageable for older or disabled persons with different usability needs, and increasing age combined with increasing complexity of interfaces in mobile phones were factors that resulted in poorer performance [32]. Yet, in 2020, Jiang et al., still found that current smartphone user interfaces, specifically those for camera use, were not optimized for users over 50 years of age, although this age group was a much greater user of mobile phone cameras than younger phone users. Many interviewees thought there were too many functions, and routinely relied only on a few, even when aware of others [33]. Huang's 2020 'state-of-the-art review' also found that application designs for mobile phones were much more constrained by the physical limits of the devices than for PCs and larger devices, but designers were not factoring this into their application designs. Nor were usability studies keeping up with later mobile phone actions such as swiping and pinching touchscreens [34]. In general, although existing guidelines and checklists for designers had increased in complexity as mobile phones shifted from feature phones to smartphones and increased in complexity, there were many usability dimensions in relation to age-friendly design that were still not well covered. Factors affecting usability for older people that had been identified by scholars were also still not being picked up by existing guidelines, while the guidelines themselves were becoming so complex in their efforts to cover many more dimensions and categories that they risked being unusable. Nor was there recognition that age-related guidelines were not static: the technological skills of older users were increasing over time as middle-aged users aged, even as the usual physical limitations of age (memory loss, failing eyesight, loss of dexterity and hand control) remained much the same [35]. To date, design technologies have tended to treat the elderly, including those with visual impairment, as 'passive receivers' [36], with limited recognition of their specific needs.

3 Research hypothesis

The purpose of this study was to generate and test a model flexible user interface design application for mobile phones with the aim of addressing usability limitations reported by elderly users of mobile phones. In developing a fuzzy model for this purpose, the hypotheses were:

1. [W]hen the value of the Mean Absolute Error (MAE) of the fuzzy model for designing user interface applications for mobile phones gets close to 0 and the Effectiveness Index (EI) gets close to 1, the three aspects of usability according to ISO 9241-11 (efficiency, effectiveness, and user satisfaction) for a user interface application on a mobile phone would be at a high level.
2. User-testing this model for efficiency, effectiveness and user satisfaction would provide viable usability recommendations of a high level to be made to application developers.

4 Methodology

Most user interface designs are designed to meet the general needs of all ages of users. This results in usage problems and dissatisfaction for specific groups, such as elderly users [7]. Therefore, the usability of such interface designs should be evaluated. Although Nielsen [37], Sharp et al. [38], and Quesenbery [39] explain usability from different perspectives and it seems that usability can be tested in different ways, there is general agreement over five key principles of usability: task efficiency; easy to learn; rate of error; memorability; and satisfaction. The International Organization for Standardization has reduced these to three key principles in their ISO 9241-11 usability standard: efficiency, effectiveness, and satisfaction [40, 41]. These are the principles this study utilizes to measure the usability of the recommended interface designs. The research procedure for the study was divided into two parts. The first entailed the development of the fuzzy model. The second entailed the usability evaluation of the model.

4.1 Research tools

The research tools for the study covered three areas:

1. Research instruments for the data collection procedure: Data collection was implemented using data collection computer software as a research tool, drawing on information supplied by surveying/interviewing a preliminary group of participants. This included their responses to a list of 40 questions divided into 15 multiple-choice questions (demographic and human factors) and 25 estimation-scale questions (designed for self-adjustment).
2. Research instruments for the fuzzy model development process: The tools included in the process of developing the fuzzy model included the Waikato Environment for

Knowledge Analysis: WEKA version 3.6, the Matrix Laboratory: MATLAB version R2014a, and the Development Application for Data Collection.

3. Evaluation tools: In evaluating usability, the following research tools were used: android smart phones with a screen size of 5.5 inch; a development mobile phone application (dial screens); and a usability evaluation of proposed user interface designs on mobile phone and social media applications by a smaller cohort of elderly users.

4.2 Population and samples

The sample size for the development of the fuzzy model was 200 elderly people. This was determined by factor analysis that suggested that the sample size should be at least five times the number of variables [42]. The target population were people aged 55 and over who resided in Thailand in the Mueang District of Nakhon Ratchasima Province and in the Bangkok area. Snowball sampling was used, and the participants had to voluntarily provide their personal information. A survey method was employed, combined with interviews to put participants at their ease.

The usability testing sample totaled 25 elderly users, 11 males and 14 females who were selected by purposive sampling that specified that the samples needed to be people between 60-69 years of age with impaired vision conditions who had experience of using a mobile phone for one year or more. In this regard, too, the participants selected for this study were to voluntarily provide their personal information. These elderly participants had the following specific characteristics: they were aged between 60-69 years old; they had the experience of using a mobile phone for a period of one year or more; and they had eye conditions that impaired their vision.

4.3 Development of the fuzzy model

The development of the fuzzy model was divided into three steps: preparation of input data; development of the fuzzy model; and evaluation of the fuzzy model for preciseness and accuracy prior to it being used for designing the mobile phone interface for the elderly users. In defining the groups of variables required for the model, input data was obtained from a feature selection of demographic characteristics and human factors as outlined below. To determine membership patterns, 14 variables were selected by dividing these factors into two parts: clear data of nine variables; and fuzzy data of 5 variables. Output data, on the other hand, was obtained from the program data and components of mobile phone applications and social media applications to set the membership patterns of 25 variables that could be divided by their usage into five display screens, including: 8 variables of dial screen; 5 variables of call logs screen; 4 variables of chat room screen; 4 variables of timeline menu screen, and 4 variables of post screen.

The data used to generate the input set for the model was obtained from a collection of demographic and human factors of the 200 elderly people recruited as described in section 4.1 and 4.2. Overall, this set consisted of 15 data inputs or variables consisting of age (X1), biological sex (X2), education (X3), eye problems (vision condition (X4), spectacles wearing (X5), eye diseases/disorders (X6), blue vision (Cyanopsia) (X7), color discrimination (X8), and eye measurement (X9)), screen size (X10), experience of using mobile phone (X11), technological experience (X12), memorization techniques/methods (X13), and memory (memory efficiency (X14), and memory effectiveness (X15)). The set excluded hearing conditions since the data collection showed that there were only two participants diagnosed with hearing disorders. The factor of hearing was eliminated from the data set for greater conciseness of the research and so that the specified codes met the research objectives in relation to visual impairment.

The output variables, as presented in Table 1, were set with code using the Correlation-based Feature Selection (CFS) method with the Waikato Environment for Knowledge Analysis (WEKA) version 3.6 to select criteria from the input variables of demography and human factors that were an appropriate fit for the output variables, that is, for the application and components of mobile phone and social media applications.

Table 1. Output variables of components and elements of interface design on mobile phone and social media application

No.	Variable	Code	Screen	Application	No.	Variable	Code	Screen	Application
1	Display Number Size	A1	Dial	Mobile Phone	14	Message Size	C1	Chat Room	Social Media
2	Button Del Size	A2			15	Message Shape	C2		
3	Pad Number Size	A3			16	Status Size	C3		
4	Pad Number Shape	A4			17	Sticker Size	C4		
5	Number Size	A5			18	Header Size	D1	Timeline Menu	
6	Text Size	A6			19	Icon Size	D2		
7	Button Phone Shape	A7			20	Color	D3		
8	Button Phone Size	A8			21	Label Size	D4		
9	List Name Size	B1	Call Logs		22	Text Size	E1	Post	
10	Call Logs Size	B2			23	Picture Size	E2		
11	Picture Logs Size	B3			24	Label Size	E3		
12	List Name Picture Size	B4			25	Icon Size	E4		
13	List Name Picture Shape	B5							

The development of the fuzzy model consisted of the following four steps:

1. A fuzzy membership function was used to determine the numbers of fuzzy members of the input variables and the output variables obtained from the data set preparation. A cluster analysis using the K-fold cross validation technique was used by identifying K = 10. Also, Hartigan's rule was used to determine the appropriate number of groups of fuzzy members [43]. This 'rule of thumb' suggests that 'when clusters are well separated, then for $K<K^*$, where K^* is the "right number" of clusters, a $(K+1)$-cluster partition should be the K-cluster partition with one of its clusters split in two' [44].
2. A fuzzy set imported the input variables and the output variables from the above process of creating a membership function. Matrix Laboratory: MATLAB R2014a was used to determine an appropriate equation or graph of the fuzzy set for each variable. All variable values were represented in numbers prior to being substituted in graphs. The variables were further coded into linguistic variables by modifying various data to be consistent with other variables in the graphs. All variables were treated in the same pattern in this step.
3. A fuzzy rule-base is a set of fuzzy rules created from the relationship between the input variables and output variables in the fuzzy sets, and is used as a knowledge

base. The redundancy of the rules was removed using computer software. Then, the rules data were recorded in the MATLAB program as a fuzzy rule base.

4. Fuzzy inference interpreted the inferring process based on the fuzzy knowledge base to obtain the result of the design value. Again, the MATLAB program was used in accordance with the fuzzy rule base to control fuzzy knowledge inference to design the components and elements of mobile phone and social media applications.

This process of creating a fuzzy system to design user interfaces for elderly users of mobile phones and social media applications is illustrated Figure 1.

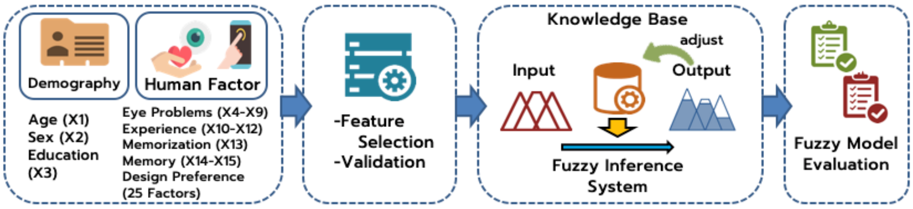


Fig. 1. The process of creating a fuzzy system to design the elderly user interface

4.4 Evaluating the fuzzy model and testing usability

For the fuzzy model evaluation, the data was divided into two sub-sets of data consisting of, first, a training data set for the system to learn (70% of the data), and second, a test data set for validating the accuracy of the results from the system's learning (30% of the data). These two sets of data were used to assess the preciseness and accuracy of the fuzzy model's functions. The value of the Mean Absolute Error (MAE) was further analyzed to assess the similarity between the estimated and actual values to identify an Effectiveness Index (EI) for reassessing the accuracy of the estimation. When the Mean Absolute Error (MAE) of the fuzzy model for designing user interface applications for mobile phones got close to 0 and the Effectiveness Index (EI) got close to 1, usability was considered at a high level.

Usability testing then evaluated the user interface design of existing mobile phone and social media applications obtained from the fuzzy model by grouping the dial screens into one of four types, based on display size, delete button size, numeric button size, number size, text size, button shape, and call/dial button size. There were eighteen possible combinations of these, providing a total of eighteen screens for testing. The participants came from the usability testing group specified in section 4.2. The experiment required participants to use mobile phones with an Android operating system and which had a screen size of 5.5 inches, as presented in Figure 2.

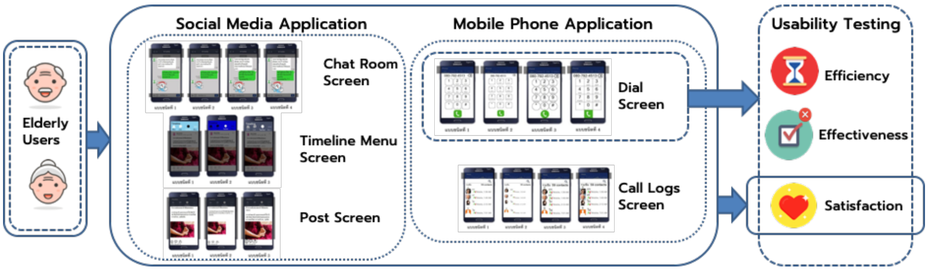


Fig. 2. Usability testing of elderly users

As shown in Figure 3, participants were asked to press the number button according to randomly given numbers on the mobile phone. The provided 10-digit numbers of each set were different each time, ranging from 0 to 9. To simulate actual usage situations, the sample group could press the delete button to edit a number. Participants were also able to take a break and/or cancel the test as needed. The observations of the researcher and interviews with the participants were also included in the usability assessment.

Fig. 3. Mobile phone application: dial screen type 1-4

The research focused on the actual daily use of the applications on the mobile phones and assessed the level of user satisfaction with the interface design according to the three aspects of usability specified by ISO 9241-11, effectiveness, efficiency and satisfaction. According to the ISO, effectiveness is 'fundamental as it is about achieving the intended goal(s)', while efficiency is about resources like the time and effort users need to expend to achieve their goals [45]. Deficiencies in both can make users unsatisfied and frustrated with their experience with mobile phones, and choose not to use them despite the many benefits they might offer. In this study the three aspects were measured as follows:

1. Efficiency was evaluated by lead time - the amount of time the user spent on the work process was counted from the beginning to the complete end to measure the usability of user interface [46].

2. Effectiveness was measured by the degree of work performance [46] from calculations based on those used in Chiou et al. [47]. Work performance related to the ability to accomplish desired tasks.
3. Satisfaction was evaluated by the average satisfaction of the elderly users with the user interface of the mobile phone applications and social media applications, using a Likert scale with the values of means and standard deviation.

To summarize, in this study, as a result of initial research into participants' experiences with mobile phones across a range of factors, and the development of a model assessing mobile phone features in relation to those factors, three areas, namely efficiency, effectiveness and satisfaction with four different types of mobile phone applications in relation to dial screens were tested and evaluated in terms of display size, delete button size, numeric button size, number size, text size, button shape, and call/dial button size.

5 Results and discussion

5.1 Summary of experimental results and discussion of fuzzy model development

Fifteen factors were initially selected from the list of demographic characteristics and human factors of the target group of 200 participants, however, only 14 factors were directly relevant to the study, regardless of X1. The results of the analysis of this data showed that the three most significant factors relating specifically to the use of mobile phone applications included X5 (spectacles wearing), X7 (blue vision or Cyanopsis), and X13 (memorization techniques/methods). The two most significant factors for the use of social media applications were X10 (screen size) and X13 (memorization techniques/methods).

From the findings, X13 proved to be an important factor perceived by the users on both mobile phone applications and social media applications, because when users have learnt certain techniques for memorizing what to do, they quickly become at ease with a user interface and recognize the required ways to move their fingers. This result was consistent with Jastrzembski and Charness [48] and Slavicek et al. [49]. However, both these studies also mentioned that elderly people appeared to need to spend longer time thinking during their physical movements than people in younger age groups. This suggests that elderly mobile phone users either needed to be allowed more time to move by the device, rather than having the device force them to try to move themselves more quickly, or that basic moves to engage with the phone needed to be simpler, easier and easy to remember. One way of addressing these needs, is to make basic navigating clearer and easier to see, thereby making it quicker to recognize and memorize for elderly users. If users are struggling just to locate and press the right buttons, they will always need more time than the device would want to give them.

In evaluating the fuzzy model for designing the mobile phone interface for the elderly users, the data obtained from the 30% of samples set aside to test the model produced the desired results for MAE and EI, indicating a high level of usability. This allowed the evaluation results of the fuzzy model for the output variables to be divided into five screen styles from testing data based on 66 samples.

The subsequent fuzzy model development for a mobile phone application with 13 variables showed a total of 780 rules while social media applications with 12 variables showed a total of 644 rules. The fuzzy rules for designing both mobile phone and social media applications thus came to 25 variables, resulting in a total of 1,424 rules.

From the evaluation of the average absolute deviation of the fuzzy model for designing the user interface of the mobile phone applications, it was found that output variables had the least absolute deviation value, or highest value of the phone application based on some part of the hypothesis, for the following nine variables: A1(Display number size), A2 (Delete Button size), A3 (Number Pad size), A5 (Number size), A6 (Text size), B1 (List name size), B2 (Call log size), and B3 (Call log icon size). There were four output variables that did not meet the hypothesis, consisting of A4 (Pad number shape), A7 (Phone button shape), B4 (List Name picture size) and B5 (List Name picture shape).

The results also showed that seven output variables had the highest average absolute deviation of social media applications, consisting of C1 (Message size), C3 (Status size), D1 (Header size), D2 (Icon size), D3 (Color), E1 (Text size), and E3 (Label size), within the hypothesis provided. On the other hand, it was found that there were five output variables of C2 (Message shape), C4 (Sticker size), D4 (Label size), E2 (Picture size), and E4 (Icon size), with lowest-to-zero average absolute deviation relative to size. Therefore, it can be determined that the fuzzy model for designing in terms of size allowed with the highest average absolute deviation, included 14 variables out of a total of 25 variables of mobile phone and social media applications.

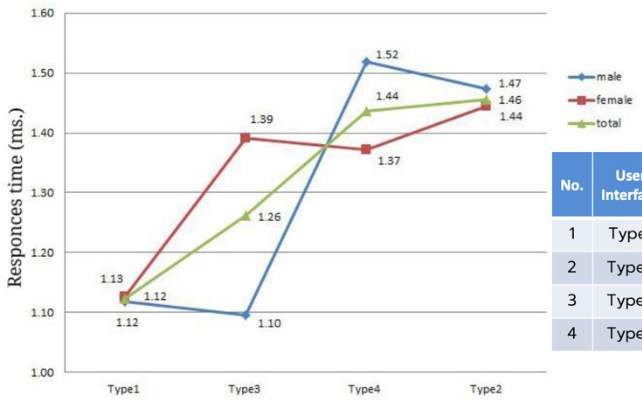
When considering the results based on the effectiveness index of the fuzzy model for designing the user interface for mobile phone applications, it was found that five output variables consisting of A2, A3, A5, A8 (Phone button size) and B1 had the highest effectiveness index of mobile phone applications which partially supported the hypothesis. On the other hand, there were eight output variables consisting of A1, A4, A6, A7, B2, B3, B4, and B5 which did not fit the hypothesis. Moreover, there were three output variables for designing the user interface for social media applications consisting of C1, E1 and E3 that fitted the given hypothesis because of their high effectiveness index to 1, while there were nine non-hypothetical variables consisting of C2, C3, C4, D1 (header size), D2, D3, D4, E2, and E4 (icon size). These size-related variables were functions that resulted in the highest effectiveness index among eight variables out of a total of 25 variables of both mobile phone and social media applications, whereas the variables relating to shape were functions resulting in a low effectiveness index.

The results in this study lead to the conclusion that size was the most significant variable for users of mobile phones for both phone and social media applications. Therefore, size should be the main focused when designing appropriate user interfaces for elderly users. However, shape was also a factor that needed improvement, although this may have been due to limitations in the number of participants in this study. If these limitations were eliminated by having a greater number of participants or by using a greater number of artificial intelligence techniques, the results of a similar study could produce a higher MAE and EI.

5.2 Summary of experimental results and discussion of usability testing

The results of the usability evaluation of the user interface design for mobile phone and social media applications for elderly users, found that both male and female users perceived that user interface Type 1 had the highest level of efficiency and effectiveness because this user interface design featured buttons that were twice the size of its number size. These results were in accordance with Hoober and Berkman [50], who also found that the button size should be twice the size of the data. As illustrated in Figure 4, male elderly users using interface Type 4 showed low efficiency and effectiveness in line with the earlier results, while elderly females using interface Type 2 showed low efficiency and effectiveness.

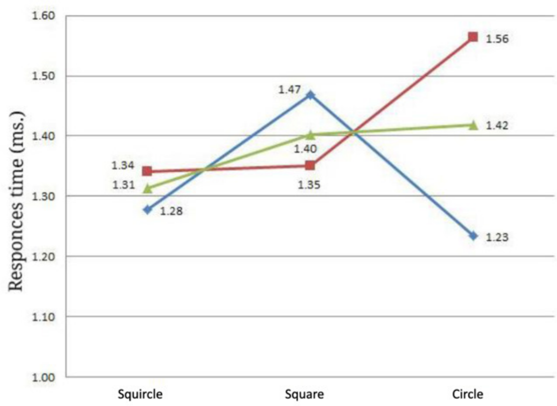
Considering the overall efficiency of the user interfaces, user interface Type 1 had the highest usability efficiency. On the other hand, user interfaces Type 1 and Type 2, as shown in Figure 4, showed slightly different efficiency in terms of lead time. The results of this study were in accordance with a previous study by Chotivinijchai [51] that suggested that tablet screen size affected time efficiency as perceived by elderly users. Neither user interface Type 3 nor 4 conformed to the hypothesis. Problematically, the sample group advised that they were not experts in using mobile phones. This response was consistent with the study by Pak and McLaughlin [52] that revealed that elderly users were likely to blame themselves and their limitations for inefficiencies, rather than considering the design of user interface to be ineffective or unfriendly to users. This response, if widespread, is likely to mean that mobile phones will continue to have design shortcomings in relation to this group of users because there will be no consolidated product dissatisfaction expressed by this group of users.



No.	User Interface	Efficiency		
		M	F	Avg
1	Type1	1.10	1.13	1.12
2	Type3	1.10	1.39	1.26
3	Type4	1.52	1.37	1.44
4	Type2	1.47	1.44	1.46

Fig. 4. The results of the efficiency evaluation of user interface types 1-4

When evaluating the user interface efficiency in terms of button shape, it was found that square-shaped buttons with rounded edges were most preferred, while all round/circular shaped buttons were found to be the least efficient. When considering effectiveness, it was found that the buttons with a square shape and rounded edges were ranked high for both efficiency and effectiveness, while the circular shape buttons were ranked low in both in a similar direction. When considering the biological sex of the users, it was found that males used the circular buttons with the highest efficiency, while females use the rectangular buttons with rounded edges with the highest efficiency, as shown in Figure 5. The evaluation results also showed that the rounded rectangular buttons for female elderly users showed the least efficiency, a finding that contradicted Han et al. [12]'s study, which found that female users were more likely to prefer curves or circles, while male users tended to prefer square-shaped or edgy buttons, as illustrated in Figure 5.



No.	Button Shape	Efficiency		
		M	F	Avg
1	Squircle	1.28	1.34	1.31
2	Square	1.47	1.35	1.40
3	Circle	1.23	1.56	1.42

Fig. 5. The results of the efficiency evaluation of button shape

In summary, the evaluation results of elderly users' satisfaction with the user interfaces found that male users expressed the highest satisfaction for dial screen and post screen Type 1, as shown in Figure 6, while dial screen Type 1 provided the highest satisfaction rating for both male and female users.

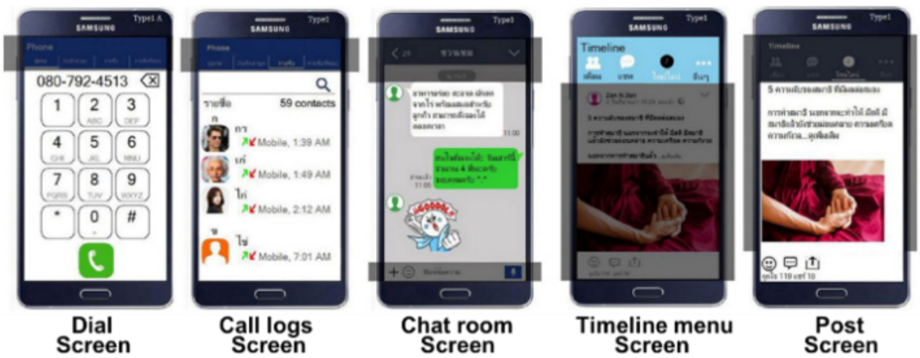


Fig. 6. User interface design screen: type 1

The sample group's satisfaction with the call logs screen Type 2 was at the lowest level. When summarizing the results of the overall user satisfaction evaluation on all screens, it was found that the sample group had the highest level of satisfaction for user interface Type 1, while user interface Type 2, shown in Figure 7, provided the least satisfaction to the sample group.

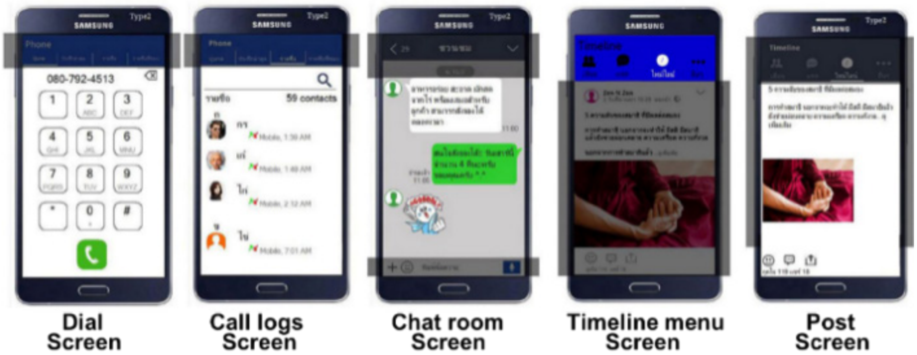


Fig. 7. User interface design screen: type 2

From the evaluation results, it can be concluded that the participants were highly satisfied with the mobile phone application call screen Type 1, because the number buttons were in the size of 15.6 mm and call buttons were in the size of 16.2 mm, both of which were the most suitable size for visibility and user interface usability. The results are consistent with Jin et al. [53] who found that 16.51 mm buttons were acceptable if the screen had limited space. Participants were also satisfied with the rounded edges of rectangular button shapes since this shape was unlikely to cause confusion while in use. Moreover, having an appropriate size of button gave users a pleasant feeling when using them, which conforms with the study by Looijesteijn [54] that mentioned that the rounded shape of buttons made users feel as if a phone was more useable.

In terms of the color used for the screen for the social media application, it was found that participants were highly satisfied with Timeline menu screen Type 1 because of its light background color and dark text colors, making it easier for users to see it more clearly and more comfortable to use. On the other hand, the participants were less satisfied with Timeline menu screen Type 2 because the figures and text lost their sharpness because of the dark background colors. Thus, Timeline menu screen Type 2 was perceived as not as clear as Timeline menu screen Type 1.

Furthermore, the results showed that participants were less satisfied with the chat room screen of the social media application on Types 3 and 4, which contained a text size of 16-points, because the messages were too large for the 5.5-inch mobile phone screen. On the other hand, the participants were highly satisfied with the 14-point text size on the chat room screens of Types 1 and 2. These findings were not consistent with the findings of Kamollimsakul et al. [55], whose study had found that elderly users were more satisfied with 16-point font and less satisfied with a 14-point font. However, Kamollimsakul et al.'s study was conducted on computer screens, rather than on the screens of mobile phone devices. Thus, while these results seem contradictory, the findings point to the importance of the context in which a font size is used. A large font on a small screen requires the user to carry out other actions such as scrolling that are not required on a larger device, significantly increasing effort and therefore reducing efficiency and user satisfaction. In addition, the subsequent layout and spacing of text in different size fonts can have a significant effect on overall text layout. As Sribhurapa [56] and Loharjun [57] both noted, text layout and font design of content, including spacing, should be appropriate to the space available. Whatever the available space is, it is important that the text be clearly seen, with the least amount of effort. Therefore, application developers should focus on the designing the font size of both text and numbers not only in relation to the layout and spacing but also in relation to the display screen size. When the text is too large, the layout of content and spacing become inappropriate: the layout of the overall screen is unbalanced and will therefore be inefficient. Text and numbers should be sized in order to be properly balanced within the display screen of a particular device to maximize user satisfaction.

6 Suggestions

The specific group under investigation in this study was elderly people aged 60-69 years who had lower than normal or impaired vision and who had used a mobile phone for communication or for social media for one year or more. Based on the preferences they indicated in this study, user interface design specifications for mobile phones that best suit their needs require the following considerations:

1. A 15.6-mm numeric button and a 16.2-mm dial button with 14-point text size and 25-point number size on 5.5-inch mobile phones are most suitable for elderly users with the qualifications mentioned above. The dial button should be slightly larger than the numeric button to enable them to be easily distinguished. The number size should be larger than the text size for better reading.
2. A square button shape with rounded edges is most suitable for elderly users with the qualifications mentioned above. Large circular button shapes should be avoided as they are perceived as filling the overall display screen in ways that are confusing, as these kinds of circular buttons are perceived as tightly attached to each other. Likewise, the large size of square-shaped buttons encourages the perception that the buttons fill up the display screen, especially when the edges of the buttons are close to each other with no clear boundaries or spaces. This makes elderly users unsure about the implications of using a button. The ideal design of the button shape should be a rounded rectangular shape. This was especially favored by female users.
3. The background color of the timeline menu screen should be in light colors such as a light blue, with the text and icons in a dark color such as black to be suitable for elderly users who have the aforementioned qualifications. If the timeline menu screen background color is dark, such as dark blue, it must be used with light or white text or icons so that the contrast color choices make the text and objects clear to see. However, ideally, the background should be in light colors while the text and icons should be in a dark color.

The suggestions from this study, which used fuzzy model development to design and test user interfaces for mobile phones, are that current user interfaces not only can be adjusted for elderly users in line with the specifications used for the input variables of the fuzzy model, but they should be. By drawing on a user group's data-base, the fuzzy model generated here will enabled designers to take a user-centered approach to the development of user interface designs, as an alternative to designing from the generalized perspective of the developer. Therefore, data specific to particular user groups, which can be collected and inserted into the model with research tools and artificial intelligence systems, as was done here, can be used to contribute to the development of appropriate user interface designs that meet the needs of groups that need usability to be maximized.

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