ORIGINAL ARTICLE

Heuristic Evaluation of Digitized PGMI Assessment in Mammography Screening

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ABSTRACT

Introduction: Mammography screening provides one of the best possible ways to improve image quality to optimally visualize the breast for diagnosis purposes. The current mammography screening using Perfect, Good, Moderate, Inadequate (PGMI) assessment is done manually on paper-imposed issues due to inability to reproduce and retrieve the data which are crucial for image quality management. Therefore, this study proposed to develop a digital PGMI assessment-based platform tool for assessment image quality in digital mammography images. **Materials and Methods:** The platform tool called MAMMOScreen and evaluated by three evaluators who have experienced in software development using heuristic evaluation by answering the heuristic questionnaire in a Google form to rate the severity of usability problems. **Results:** The results show that the severity rating scale of MAMMOScreen is 1 (cosmetic problem), which indicates that the repair problem was given a low priority. However, for the visibility of the system status, the repair of MAMMOScreen has a high priority. The redesign then takes into account the high priority problems and the recommendations of the evaluators. **Conclusion:** MAMMOScreen is the first platform tool for PGMI assessment that provides results based on user input and can document PGMI results to fully review previous information. The introduction of a digital evaluation using platform tools has the potential to provide efficient reproducibility and minimize potential errors.
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INTRODUCTION

Breast cancer is the most commonly reported cancer in women, with a high incidence rate in Malaysia with an age-standardized rate (ASR) with per 100,000 populations of 34.1 between 2012 and 2016 compared to 31.1 between 2007 and 2011 [1]. The statistics from the Ministry of Health (MoH), Malaysia showed that the percentage of late stage three and four diagnoses in Malaysia increased from 43.2% in 2007-2011 to 47.9% in 2012-2016 [2]. 5-year survival rates for women diagnosed with third- and fourth- stage breast cancer is 60% and 23%, respectively, much lower than those diagnosed with first- and second- stage cancer, which are 88% and 81%, respectively [3]. Early detection and treatment of breast cancer can help to reduce the mortality rate at lower cost and with less complex interventions [2]. Thus, the burden of breast cancer brought on by late presentation may be lessened by the use of preventive measures, such as mammography screening [3].

Policy development in Malaysia regarding breast cancer was reviewed and results were related to the raising awareness about mammography screening especially in the rural area, increasing accessibility of mammography screening facilities and improving reporting processes between doctors and national cancer registry to down-staging breast cancer [1]. However, the policy did not include the process for image quality assessment or PGMI assessment after mammography screening as part of key steps in the policy development.

There are two approaches for cancer screening: which aims to find and remove premalignant tumors; and early detection of invasive cancer that is still in an early curable stage [4]. Hence, mammography screening must provide the best possible image quality to optimally visualize the breast for diagnosis. Therefore, there is an image quality assessment guideline, such as, MoH created Quality Assurance Programme (QAP) for radiology department, including mammography [5], to ensure the production of high-quality images for the detection of abnormalities associated with breast cancer [6].

Radiographers expected to produce mammogram images of good diagnostic quality while providing care for their patient at the same time [7] because failure clinical image quality is usually associated with the cancer occurrence [8]. Therefore, the novice and experienced radiographers may need to attend continuing education for PGMI assessment at an approved institute, for example, mammography Continuing Medical Education (CME) to improve their understanding of image quality assessment and improve their hands-on experience. However, the courses are not compulsory and are offered to interested radiographers. In addition, many CME courses are related to the basic position in mammography and radiation risks rather than image quality assessment. The lack of exposure towards image quality assessment and the current method of evaluating the image with the PGMI method is done manually on paper may be difficult to reproduce, execute and tedious [9]. The limitations to handling hard copy of mammography images compared to the evaluation of the images, and manual data entry of PGMI assessment have a potential of risk of errors in transferring manual assessment results into the computer, which requires double checking of most data [10].

Therefore, one of the best solutions is to provide radiographers with digitised PGMI assessment for mammogram image quality assessment, which can relieve the burden on radiographers who struggle with manual assessment. The platform tool also can be integrated into the CME course that are mainly focused on PGMI assessment, so that radiographers can learn direct hands-on training on PGMI assessment using the digitalized PGMI assessment.

MATERIALS AND METHODS

Research flow

This project decided to use the PGMI assessment criteria and their classification published in the MoH QAP. First, a thorough literature review was conducted to gather information on the design principles of user interface (UI) and its requirements. Then, the content of the software tool, MAMMOScreen must be identified to determine all criteria and their categorization as Perfect, Good, Moderate, and Inadequate for PGMI assessment. Next, the MAMMOScreen operating system was created to provide a storyboard for the design of UI (user interface). Upon completion of the UI design, the Heuristic Evaluation (HE) was conducted to evaluate the performance of MAMMOScreen and determine the process for redesigning MAMMOScreen based on evaluators' recommendation.

UI design

The UI design is done with a MATLAB R2022b App Designer. MATLAB App Designer provides support for reading DICOM files. The App Designer has a function of 'drag and drop' visual components and automatically generates the object-oriented code that specifies the app's layout and design to program its behavior. The design is performed using a computer equipped with a 12th generation Intel® Core™ i7-1255U CPU with 8 GB RAM and the 64-bit Windows 11 operating system. All PGMI criteria and PGMI classification for two CC (craniocaudal) views and two MLO (mediolateral oblique) were not modified or changed.

The framework was divided into three categories which are user, input and output. The user must import the mammogram image and do the PGMI assessment for each view. Then, the output needs to produce five estimated suggested ratings for PGMI classification where four suggested rating for each view and one suggested rating for combination of those four views for one patient. Finally, the results can be exported in PDF and saved on the computer.

Heuristic Evaluation (HE)

This project used HE which involved three evaluators with experienced software development from Universiti Teknologi Malaysia (UTM) with postgraduate student from School of Computing, who had work experience in software development within three years as evaluator A. A senior lecturer from Biomedical Engineering department as evaluator B, who have experienced more than three years in research work. A postgraduate student from Biomedical Engineering department as evaluator C, have no more than three years experience in research work. Each evaluator needs to answer a heuristic question provided in Google Form where each question has a 5-point Likert scale (1=strongly disagree to 5=strongly agree) and one question for recommendation. The question for HE is adopted by 10 usability heuristic [11] and 18 usability problems [12] as shown in Table I. The evaluators need to evaluate the performance of MAMMOScreen before answering the questions provided.

Severity Rating (SR)

To get the severity rating for each usability problem (SR_{UP}), usability heuristic (SR_{UH}) and total severity rating score SR_t for MAMMOScreen are by using the equation in (1), (2) and (3) below respectively [12].

$$SR_{UP} = \frac{4(x1) + 3(x2) + 2(x3) + 1(x4) + 0(x5)}{N} \quad (1)$$

Where:
SR_{UP} = Severity rating for each usability problem
x1,x2,x3,x4,x5 = Evaluators choice in Likert scale for each question
N = Total number of evaluators

$$SR_{UH} = \frac{\sum_{i=1}^{k} a_i}{n} \quad (2)$$

Where:
SR_{UH} = Severity rating for each usability heuristic
k = Last value of usability problem

Table I Heuristic evaluation questionnaire

10 Usability Heuristic	18 Usability Problems
Visibility of system status	There is notification
Match between system and the real world	Easy to understand The menu name is easy to understand
User control and freedom	Each menu corresponds to a function
Consistency and Standards	The symbols are consistent Title of appropriate content
Error prevention	The size of the icon is easy to remember Icon according to function
Recognition rather than recall	Easy return to previous function Menu positions are easy to remember
Flexibility and efficiency of use	Easy to search Menu positions are easily accessible
Aesthetic and minimalist design	Consistent menu shape Consistent theme and font selection
Helps user recognize, diagnose, and recovers user	There is an error message Shows what to do
Help and documentation	There is a help menu User does not lose data

i = First value of usability problem
a = SR_{UP}
n = Total number of usability problem in each heuristic usability

$$SR_t = \frac{\sum_{j=1}^{m} y_j}{p} \quad (3)$$

Where:
SR_t= Total of severity rating for MAMMOScreen
m = Last value of usability heuristic
j = First value of usability heuristic
y = SR_{UH}
p = Total number of usability heuristic

Then, the data calculated from equation (1), (2) and (3) above was compared with the severity scale [13] to indicate the scale of the severity for the MAMMOScreen software. The severity scale was rated from 0 to 4, with 0 indicating that the problem was not a usability problem at all, 1 indicating as a cosmetic problem, 2 indicating as a minor usability catastrophe, 3 indicating as a major problem, and 4 indicating as a usability catastrophe.

RESULTS

PGMI evaluation

Figure 1(A) shows the help menu on the left side of the MAMMOScreen that is able to present a manual for MAMMOScreen, manual of original PGMI assessment from QAP [5] and example of PGMI assessment image from BSA [14] in PDF file. Furthermore, there is also a function called Hyperlink that enables the user to open a webpage on their computer. Figure 1(B) shows the middle part in the main window of MAMMOScreen that has the "Patient Name" and "Radiographer Name" text area, "Date Picker" and "Upload image" button. The user was able to type in the white box and the date picker was able to collect the patient's and radiographer's name on a particular day when performing the PGMI assessment. The "Upload image" button was designed to import only from the DICOM, "*.dcm" format file. The directory file enabled the user to choose any folder and file in their computer and imported in the MAMMOScreen as shown in Figure 1(D). The MAMMOScreen is able to display the image in full regardless of the DICOM format image size. Hence, even if the size of the computer screen is smaller than the original DICOM format size, MAMMOScreen can display the image perfectly without cutting any part of the image and lower the risk of making a mistake during PGMI assessment due to the part of the breast being cut off.

For PGMI assessment tabs, each selected dropdown option will show their own category for each criterion after the user clicks on the "Result" button as shown in Figure 1(C). The result for the breast image is displayed on the bottom of the criteria. The suggested rating for the image view is classified from the combination of the all nine criteria and the user was able to assess the PGMI category for each criterion. This method is able to give the user to observe which criterion achieves the "Perfect" category and which criterion that needs more improvement. For example, criteria number 4 "Good compression" is under Inadequate category, which is that the user knows that Right CC image is required to repeat mammogram screening due to inadequate compression.

During PGMI assessment, there will be a risk of error to overlook some of the criterion. Then, the confirmation dialog box would appear after the user clicked on the "Result" button. The confirmation dialog box would alert the user to make sure all criteria were chosen during PGMI assessment. This will make sure the user can double check if all criteria are chosen so that it can lower the risk of users making mistakes during PGMI

assessment. The disclaimer written in red under the "Result" button was "Reminder: Suggested rating is not an official final result for the image". The disclaimer is to give users a reminder that the suggested rating is not necessary to follow due to there will be some changes made if the result from discussion with the radiologist is different from MAMMOScreen. Next, there will be a "Save" and "Reset" button to enable the user to save the PGMI assessment in PDF file in their computer in any folder while the "Reset" button will enable the user to delete all information that user already put in the box for PGMI assessment. This action will be easier for the next PGMI assessment and to not make the user confused with the previous PGMI assessment. Then, after the user done the PGMI assessment for four breast images, the results for each breast image will be transferred to the "Final rating" window and the results from left CC, right CC, left MLO and right MLO would produce one result for one patient in "Final Rating".

Heuristic Evaluation

From Figure 2, the graph shows that the first usability problem, which is the "There is notification" has the highest SR score among the other usability problems. With the score of 4, which means it is "Usability catastrophe" according to the severity scale table shown in Table III. Followed by the usability problem of "Easy to return to previous function" and "Easy to search" have a score of 3 which is a "major usability problem". Then, from Figure 3, for the usability heuristic, the "Visibility of system status" has the highest score which is 4, while the other usability heuristic have a score of 0, 1, and 2 which are there is "no usability problem at all", "cosmetic problem" and "minor problem" respectively. The total of SR score is 1.7 which can be rounded off to 1, which is in the category of cosmetic problem. This means the problem repairs for MAMMOScreen are given low priority.

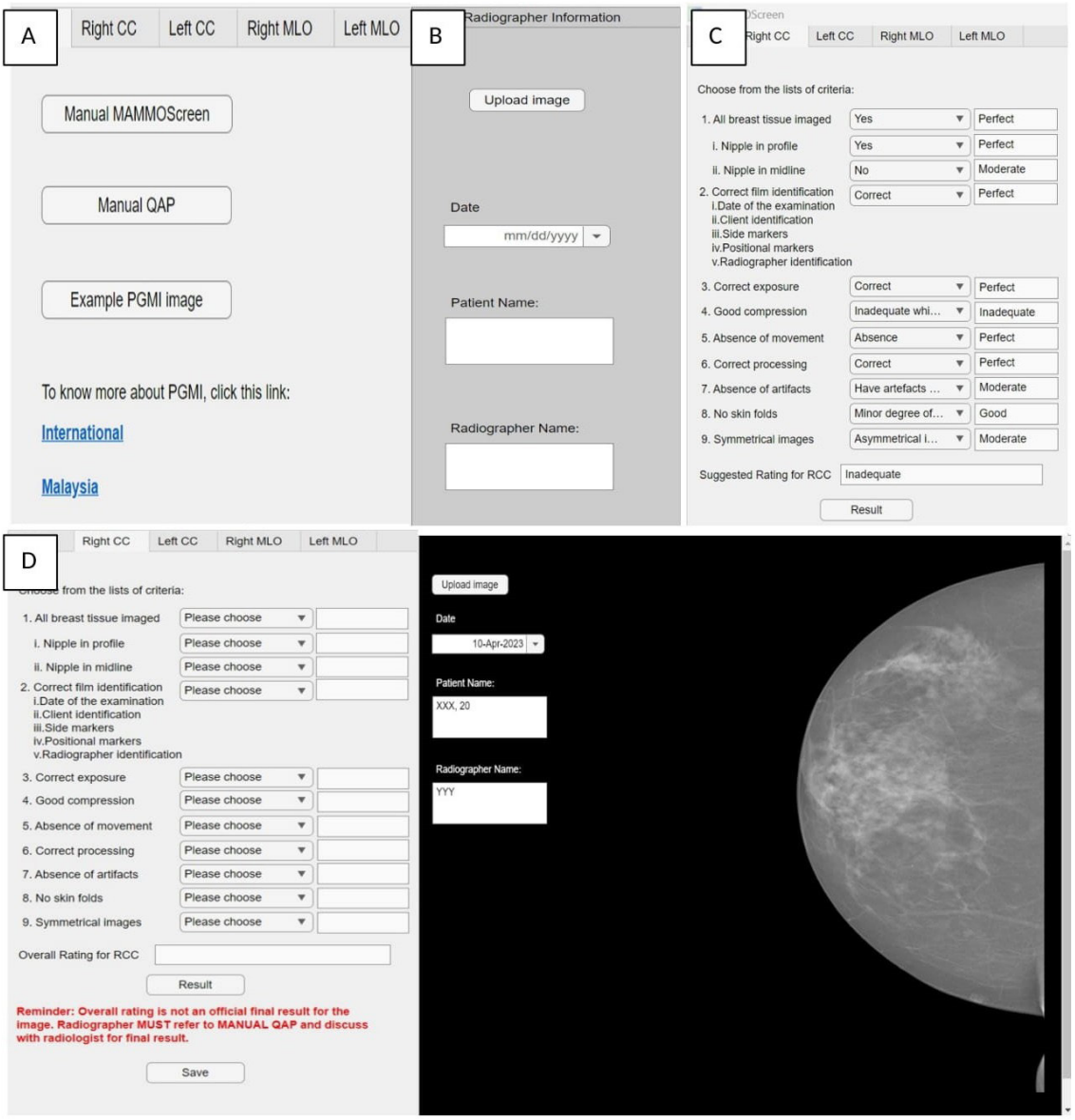

Fig. 1: Screenshots of the MAMMOScreen window with (A) help tab, (B) patient and radiographer information tab, (C) Right CC tab and (D) image imported in MAMMOScreen

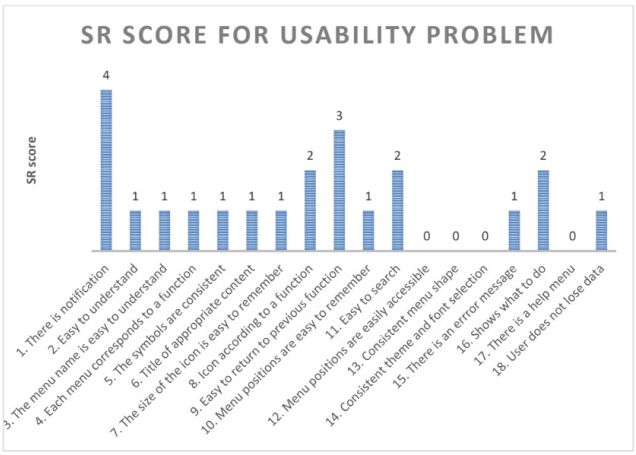

Fig. 2: The graph of severity rating for usability problem.

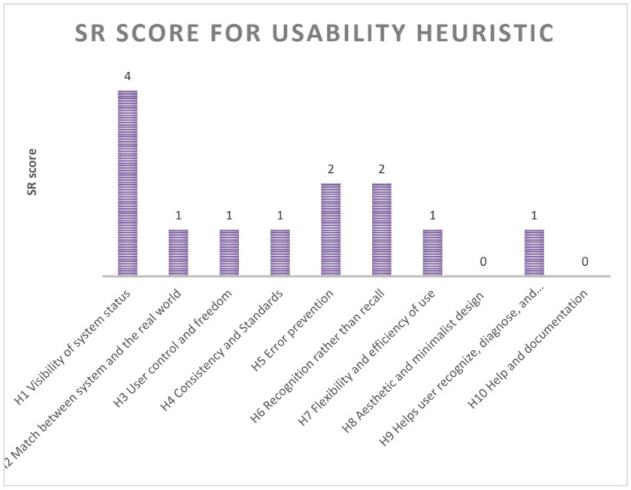

Fig. 3: The graph of severity rating for usability heuristic

The recommendation(s) result in Table II describes several opinions for example, evaluator A, mentioned about to put icon in the system button or to show certain functionalities. Evaluator B recommends to amend the function of confirmation dialog box and the arrangement of user interface layout, to specify the steps or flow in using the MAMMOScreen, add label to the image, link the data of patient information to one table, and suggest to have a reset all button. Lastly, evaluator C suggests to have an undo button, to improvise the user interface layout, enable import existing data function, can save data for repeat patients and put additional information such as, patient's age, gender and radiographer signature.

Redesign MAMMOScreen

From HE results, the usability problems of "There is notification" has severity scale of 4 (usability catastrophe), meanwhile "Easy to return to previous function" has severity scale of 3 (major problem). Those two usability problems are needed to be repaired due to high priority. The redesign process will include mentioned usability problems and relate with the recommendations from the evaluators. From the original MAMMOScreen, the only notification available is when clicked on the "Result" button.

However, the notification dialog box always appears every time the result button is pushed regardless of whether the boxes for each criterion are empty or not. Evaluator B commented that "popup window 'please make sure all boxes are filled up' appeared even though all boxes have been filled up". The dialog box was modified to appear when any box under the PGMI tab menu is empty as shown in Figure 4(A). For example, if PGMI category box 6 is empty, the notification will appear "Please do not leave box 6 empty". If PGMI category box 7 is empty, the notification will appear "Please do not leave box 7 empty". If both boxes 6 and 7 are empty, then the notification dialog box will appear both at the same time.

Next, evaluator B commented that "Step in using this software is not clear, such as, need to fill up patient information prior to fill up the form.". The notification dialog box was added to the import image button. The notification dialog box would appear after the image imported into the MAMMOScreen successfully as shown in Figure 4(B). From the original MAMMOScreen, the "Reset" button was changed to "Delete" button. Another notification dialog box was added to the "Delete" button. The confirmation dialog box will appear every time the user clicks the "Delete" button to ensure the user want to proceed or not as shown in Figure 4(C). If the user clicked the "OK" button, the input data will be deleted, meanwhile if the user clicked the "Cancel" button, the window will return back to the previous action but the input data in the boxes will stay.

The MAMMOScreen version 2 named as MAMMOScreenV2 was redesigned with the addition of icons on the button instead of text. Figure 4(D) shows the differences of user interface layout from before and after the heuristic evaluation. The main differences of the user interface layout in MAMMOScreenV2 are the presence of icons.

Evaluator A recommended adding icons into the user interface design. Evaluator B and evaluator C suggested having an additional function which is "undo" and "redo" button and "Reset all" button respectively. The redesign process has added the "undo" and "redo" button with the arrow backward and forward as its icon and "Reset all" button with the arrow circle as its icon. When there is an icon, the tooltip function can be helpful to provide a descriptive information of the button. For example, the "result" button with the description box appeared to describe the button as shown in Figure 4(E). The tooltip will display on the screen after a short pause when the pointer is at the button. Evaluator B recommended that "more manageable for the user, if menu bar for the Right CC, left CC, right MLO and left MLO is put under 1 menu named with suitable title, for example "image analysis", or "PGMI form"". Then, after taken evaluator B recommendation into consideration, the layout was change with two tabs menu consists of PGMI form and Final rating as shown in Figure 4(F).

Table II Recommendation(s) from three evaluators

Evaluator	Recommendation(s)
A	Q*8: The icon presence.
B	Q*1: Pop-up window 'please make sure all boxes are filled up' appeared even though all boxes have been filled up. Q*2: • Step in using this software is not clear, such as, need to fill up patient information prior to fill up the form. • The arrangement of the layout, can be improved. • There is no label in image either it is Right CC etc. This may lead to mistakenly read wrong image. Q*3: It is more manageable for the user, if menu bar for the Right CC, left CC, right MLO and left MLO is put under 1 menu named with suitable title, for example "image analysis", or "PGMI form". Q*18: • Mixing data may happen because the patient information, image uploaded and the information from the form are not linked with each other. Suggest to save all the results in table that can be exported to excel file. • Suggest to have reset all button.
C	Q*2: the name button and upload arrangement Q*9: Suggest to have undo button Q*18: • Can import saved data for repeat patient. • Add more information for example, patient's age, gender and radiographer signature

Table III **The severity scale and its descriptions [13]**

Severity scale	Descriptions
0	The "problem" was not a usability problem at all.
1	Cosmetic problem.
2	A minor problem.
3	A major problem.
4	Usability catastrophe.

Next, under the tab menu PGMI form has another four tabs menu with Right CC, Left CC, Right MLO and Left MLO. In the original MAMMOScreen, the save button was simply generated from the pdf file of the screen window just like a mobile phone takes a 'screenshot'. Even though the MAMMOScreen able to capture the data and save, the saved data is not editable because the type of the data is in picture format. Then, it is quite difficult for users to rearrange and not practical. Evaluator B commented 'Mixing data may happen because the patient information, image uploaded and the information from the form are not linked with each other. Suggest to save all the results in table that can be exported to excel file'. Hence, redesign included the tabulated result for patient details as shown in Figure 4(G). Two icons were added which are import and export excel files. Evaluator C recommended 'import saved data for repeat patient'. With the button import excel file, this function enables the excel file in directory to be imported inside the tabulated results. The Export Excel File button not only allows you to save the data to a "*.csv" file, but also can edit and rearrange the results.

DISCUSSION

This project addresses two interconnected research problems in the field of mammogram image assessment and evaluation. Firstly, the current method of evaluating mammogram images using the PGMI is manual, difficult to reproduce and execute. This limits scalability and introduces potential errors and inconsistencies. The identified research problem underscores the need for a more efficient and standardized evaluation process for assessing mammogram images using the PGMI. The reliance on manual assessment on paper introduces the potential for human error and inconsistency, which can impact the reliability and validity of the results. Lastly, previous research image quality assessment has predominantly focused on two criteria within the PGMI assessment, which is criterion 1, a) nipple in profile [15], b) pectoral muscle [16], c) inframammary fold [17], for criterion 8 which is skinfold [18], while neglecting other crucial criteria. While the existing research has provided valuable insights into breast positioning and skin fold evaluation, other crucial criteria within the PGMI assessment have received limited attention. This limitation restricts the findings of the category of image quality that can effectively evaluate the full spectrum of criteria.

By addressing these interconnected research problems, this study aims to contribute to the improvement of mammogram image assessment and evaluation practices. To the best of our knowledge, this is the first software developed based on PGMI assessment of mammogram image. Functionalities of MAMMOScreen was compatible with DICOM image breast, able to read input for all criteria from user selection and display the output either four categories which are Perfect, Good, Moderate and Inadequate and able to save the results in table and import or export result data in excel file. Development of the application presented was by enabling to include full criteria of PGMI assessment.

In terms of severity scale, the software achieved good usability performance demonstrated by low severity scale of 1 (cosmetic problem). Cosmetic problems mean there can be a space of improvement in the software design regarding the appearance but do not change its basic functionality. Cosmetic problems may not need to be fixed unless there is extra time available in the project [19]. From the results, heuristic evaluation identified

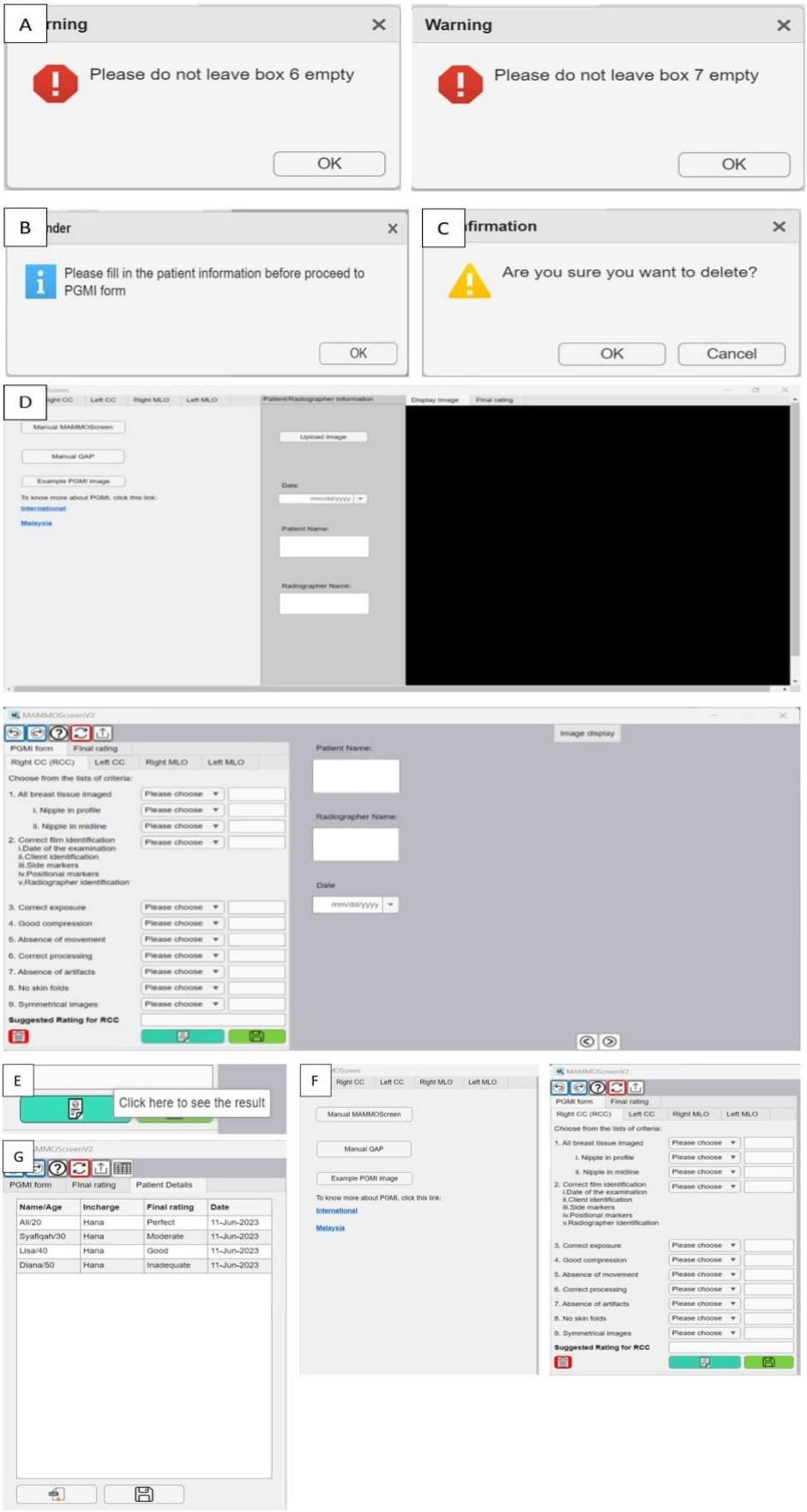

Fig. 4: Screenshots of the MAMMOScreen window. (A) Warning pop-up box. (B) Reminder pop-up box. (C) Confirmation pop-up box. (D) Differences between original and second version of MAMMOScreen window. (E) Tooltip function (F) Added icon and layout change (G) Tabulated data with export and import excel button.

"visibility of system status" has catastrophic problem while other heuristics were identified as minor problem, cosmetic problem and no problem, according to the rating scale. The result indicated that MAMMOScreen software has good interaction between UI and the users [20].

Furthermore, even though the functions such as notification, documentation and the arrangement of user interface layout were implemented in MAMMOScreen, the evaluators mentioned the problems need to be modified. Other study also presented the same problems from evaluator recommendations which are that they comment on the appearance and operation of the user interface need some modifications [21].

As the software includes functionalities for presenting images and collecting user inputs, it may also be used for educational purposes for radiographers [22]. From the qualitative data, radiographers enable to discover the flaw of DICOM images related to PGMI criteria. Furthermore, radiographers can improve their understanding of PGMI criteria by using different breast images, however it requires dedications, motivations and consistency monitoring over time [7]. Although there is a controversy regarding the PGMI criteria due to its subjectivity [23], thus the understanding of PGMI criteria descriptions is important due to there will be a risk of ambiguity for radiographer [24]. By training the PGMI with the software may lead to significant improvement in image quality assessment, subsequently increasing the motivation within the team members [7].

Furthermore, there is some modification in terms of notification, addition of icons, addition of other user interfaces such as reset all function, undo and redo function and result documentation. In the first version of MAMMOScreen, the design does not include any icon at all. Then, the redesign of MAMMOScreen was added with several icons. With the presence of icons rather than text, the design looks more user friendly, intuitive and more easy to identify [25]. However, the redesign MAMMOScreen does not undergo another heuristic evaluation, which means that there will be a possibility the user misinterprets the button function or uses it wrongly [20]. Common problem in designing UI is including the unfamiliar icons [20], nevertheless, with addition of tooltip function on the button, it can reduce possible screen clutter caused by control captions and descriptive information [26]. It can lower the risk that can cause user frustration and dissatisfaction.

In addition, the problems in using the MAMMOScreen was mentioned in recommendations. From the evaluator's assessment, the steps in using the MAMMOScreen is not clear, even though the MAMMOScreen already provides a manual in PDF file. The solution provided to the problem is by adding notification during the task. The notification will act as a reminder to do the certain steps prior to another step but not necessary to follow [27].

According to the human-computer interactions (HCI) to the user interface design, they found the proportions are based on the user's attention to the appearance and shape (68%), function (55%), colour matching (45%) and interface layout (28%) [28]. However, none of the evaluators recommends improving the colour combination in the user interface design. These results align with the findings in another study that reveals the most important factor in designing which is clarity rather than beautiful appearances [29]. Nevertheless, colour combination is one of the factors that cannot be neglected. By engaging with people's feelings, harmonious colour combinations can generate a balance in visual experience [30].

While this project has provided valuable insights and addressed important research problems, there are several limitations that should be acknowledged. The main limitation of this project is heuristic evaluation is highly based on the experience of evaluators in software development. The evaluators did not have work experience in the field of usability. Furthermore, it is also important to highlight that the recommendations from the evaluators may not be relevant to the end users of MAMMOScreen. Thus, future research could consider combining both heuristic evaluation and system usability scale to test the usability from evaluators who have experience in usability or human factor evaluators [31] and end users. Another limitation is the current PGMI assessment used in this project is neither reliable nor valid, due to the fact that many of the descriptors are subjective [32]. Furthermore, UK guidelines for mammographic screening stated that PGMI is no longer an acceptable method to assess image quality [6]. Thus, other countries have implemented its own version of PGMI classification such as Slovenia [23] and Norway [33]. Hence, future research could consider applying a modified PGMI version from Malaysia that can integrate with MAMMOScreen that is suitable for Malaysian's clinical practice guidelines.

CONCLUSION

In summary, this project has successfully addressed several important research problems in the area of mammography image assessment. The introduction of a digital evaluation method for PGMI assessment has the potential to provide efficient reproducibility and minimize potential errors. In addition, this project has expanded the scope to cover all relevant criteria within the PGMI assessment for Malaysian guidelines, resulting in a more comprehensive and accurate assessment of image quality. The evaluator point of view on the usability of MAMMOScreen has had a significant impact on the development of a software application that provides practical benefits in terms of standardized

procedures, documentation, and data management for breast imaging.

However, the PGMI assessment may have great impact on the image quality because it was fully depended on the subjectivity on the assessment, so the method to evaluate the image may need to adjust by change the evaluator by instead of one person in charge, change to two or three persons to evaluate the one mammogram images. The objective assessment in PGMI also greatly improved the efficiency such as angle and length of pectoral muscle, posterior nipple line, ect.

Although this study has provided valuable insights, it is important to acknowledge its limitations. The usability findings are limited to evaluators with experience in software development and a specific usability problem. MAMMOScreen has some development potential for further improvement. Future research should therefore consider a combination of evaluators and end users, as well as the reliability of the current PGMI assessment in Malaysia.

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