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A New Smart Mobile System for Chronic Wound Care Management

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ABSTRACT Nonhealing wounds pose a major challenge in clinical medicine. Typical chronic wounds, such as diabetic foot ulcers and venous leg ulcers, have brought substantial difficulties to millions of patients around the world. The management of chronic wound care remains challenging in terms of precise wound size measurement, comprehensive wound assessment, timely wound healing monitoring, and efficient wound case management. Despite the rapid progress of digital health technologies in recent years, practical smart wound care management systems are yet to be developed. One of the main difficulties is in-depth communication and interaction with nurses and doctors throughout the complex wound care process. This paper presents a systematic approach for the user-centered design and development of a new smart mobile system for the management of chronic wound care that manages the nurse's task flow and meets the requirements for the care of different types of wounds in both clinic and hospital wards. The system evaluation and satisfaction review was carried out with a group of ten nurses from various clinical departments after using the system for over one month. The survey results demonstrated high effectiveness and usability of the smart mobile system for chronic wound care management, in contrast to the traditional pen-and-paper approach, in busy clinical contexts.

INDEX TERMS User centered design, smart mobile system, chronic wound care management, human computer interaction.

I. INTRODUCTION

Over 13 million people worldwide suffer from chronic wounds every year. The annual cost for chronic wound treatment exceeds 15 billion dollars [1]. If a chronic wound goes unhealed for a long time, it will distinctively worsen the quality of life of both the patient and his/her family, resulting in the spread of infections or even life-threatening complications, such as sepsis [2]–[4]. The effective diagnosis, treatment and management of chronic wounds are of profound importance in clinical practice. However, the causes of chronic wounds and the factors influencing wound healing are quite complex and diverse [5]. In the process of chronic wound diagnosis, treatment and management, doctors and nurses need to have an overall understanding as well as complete medical records, effective management and timely monitoring of the patient's general physical conditions, laboratory examination reports, fractional wound assessment and treatment.

In contrast to recent rapid developments in clinical information systems such as hospital information system (HIS), electronic medical record system (EMR) and laboratory information system (LIS), wound care management still lack an effective digital solution. With only pen and paper, the measurement, assessment, monitoring and management of numerous patients' chronic wounds are cumbersome, which affects doctors' and nurses' daily work efficiency noticeably. Although a chronic wound care management digital solution is expected by doctors and nurses, it is not an easy task to complete, as it involves in-depth observation and understanding of the complex process and requires domain knowledge of the clinical practice, as well as suitable information technologies, including artificial intelligence

technologies such as automatic image measurement and deep learning, which makes it a challenging inter-disciplinary research-and-development topic.

In order to develop a smart chronic wound care management system, interviews with head nurses were conducted to gather general requirements of wound care in the first place. Then contextual inquiries in clinics and wards were carried out to clarify different chronic wound care tasks, operation flow, existing problems, potential needs and wounds diversity in clinical practice. Later, a novel smart mobile system solution for wound measurement, assessment, record, monitoring and management was proposed using the user participated design approach. Human computer interactive flow and relevant user interface were designed and developed through iterative cognitive walkthrough with wound care nurses.

The main contributions of the paper are as follows:

1) It summarizes the nurse's general requirements in the process of wound care as precise and contactless smart wound size measurement, standard and complete wound assessment, wound healing monitoring and hassle-free wound case management.
2) It reveals the tasks flow, existing problems and potential needs in current wound care process in both clinic and ward scenarios. It classifies 5 types of wound with different measurement and assessment requirements.
3) It proposes a smart mobile system for chronic wound care management, created by user-participated design, to ensure that the system's functions and work flow meet the needs of clinical practice. Through cognitive walkthrough with nurses and iterative design, a human–computer interface, including UI features, UI layout, and UI flow, has been designed and developed.
4) Finally, through presentation, prototype trial and satisfaction evaluation feedback from wound care nurses in different departments in Xiangya Hospital Central South University China, the clinic effectiveness of the system has been demonstrated.

The rest of this paper is organized as follows: Section II gives an extensive review of related work, pointing out that current systems lack of consideration of the overall nurse operation in the whole wound care process and wound diversity; Section III is the functionality study which presents the general requirements through the interviews with head nurses in wound clinic department of the hospital; Section IV presents the wound care process tasks and operation flow, discusses the existing problems and needs in clinic and ward scenarios; Section V presents the new smart wound management system featuring automatic wound measurement, assessment, monitoring and management, with illustration of its user participated design and iterative cognitive walkthrough processes; Section VI presents a system evaluation feedback of ten wound care nurses from different departments in hospital through the prototype trial; Section VII concludes the current work and discusses further research directions in the future.

II. LITERATURE REVIEW

A. PROBLEMS AND CHALLENGES IN WOUND CARE

The definition of a chronic wound from the Wound Healing Society is a wound that fails to progress through the normal phases of wound healing. In clinical practice, chronic wounds usually refer to wounds that fail to heal or shows no tendency to heal over 1 month under medical treatment [6].

Studies of traditional clinical wound care practice [7], [8], [9] have revealed the major factors that affect the efficiency of wound diagnosis and treatment as follows:

1) Precise measurement of wound size;
2) Complete records of wound assessment and treatment;
3) Effective management for personalized wound cases.

The traditional method for wound size measurement is to place a wound ruler near the wound to measure its length and width [10]. This requires the wound ruler be sterilized well, otherwise it may increase the risks of cross infection among patients. Furthermore, the placement of the wound ruler and its distance to the wound may not be consistent, which may cause human errors in wound measurement and assessment.

Measuring the area of wound is a challenging issue. A traditional approach proposed is to count blocks in square centimeters by placing transparent grids on top of the wound [11]. But this approach has two drawbacks: the first drawback is its granularity could not be scaled down to millimeter due to practicality in block counting, the second one is that close or even contact the grid to the wound will be needed for precise reading, but this might disturb wound healing process.

In terms of wound care records, the wound assessment and treatment processes are normally described by nurses in hardcopy or typed into computers. However, the quality of recorded contents are normally subject to personal understanding and convenience of the wound care nurse on duty, which might affect the care quality of following processes carried out by the same nurse or other nurses while they need the previous wound care records [12].

From the data volume point of view, hundreds of wound care cases are treated every day in each large general hospital like Xiangya Hospital in China. However there is no effective wound care management solutions available to address this issue systematically. Huge amount of unorganized wound data including pictures and handwriting wound care records including assessments and treatments are generated daily in the wound clinic for out-patients and various wards for in-patients. It has been regarded a very challenging and time consuming issue for nurses working on wound healing monitoring and wound case management thus directly affect the quality of wound care for patients [13], [14].

B. DIGITAL SOLUTIONS FOR WOUND CARE MANAGEMENT

There are various technological solutions to address the challenges and problems in wound care in clinical practice.

For smart wound size measurement, digital camera photography [15], Android system photography [16], and other

similar technologies have implemented contactless wound measurement approaches by photo capture. However, little consideration has been given to the instability and imprecision of manual operation; thus, these technological solutions are of low usability (e.g., effectiveness, efficiency, user satisfaction) [17]. For example, when nurses measure a wound by a captured photo, the capture distance to the wound needs to be consistent or estimated precisely to compensate for the contactless wound size measurement, which are difficult to achieve in clinical practice.

To reduce the negative impact of human errors in human–computer interaction and to improve operation efficiency and clinical effectiveness, new hardware systems have been applied in a series of smart solutions but with high price tags. For instance, auto diagnostic scans [19], 3D photography [20], laser Doppler measurement [21] and others can measure the wound length, width, area and depth precisely in one shot by contactless capture of a single wound at a random distance. However, these solutions are not only expensive but also have functional flaws in covering multiple-wound cases, which limit their application in clinical practice.

In wound assessment and wound case management, a mobile nursing system machine based on integrated platform can support the complete wound assessment recording and effective wound case management [22]. Unfortunately, due to its heavy weight and large size, it is not easy for nurses to carry out quick and flexible wound care measurement, assessment, monitoring and management practices across scenarios in both the ward and the clinic.

From the studies above, it is clear that a good and usable wound care management system would need sufficient consideration of easy and effective human–computer interaction and patient wound diversity in practice. It is very important to have nurses and patients involved in the design and development process to create a smart mobile system for wound care management, as it must feature a user-centered interactive design for efficient and effective wound measurement, assessment, monitoring and management, covering different types of wounds in the wound care process under ward and clinical scenarios.

III. USER-CENTERED DESIGN METHODOLOGY FOR INTERACTIVE SYSTEM DEVELOPMENT

User-centered design (UCD) is a well-appreciated methodology in applied ergonomics for interactive system design and development. Traditional UCD focuses on rapid prototyping and usability tests of interactive systems [23], [24]. UCD has been applied widely in consumer product fields of the Internet and mobile applications in the past 20 years [25]. UCD has also evolved and improved by integrating multidisciplinary methods and tools with proven effectiveness in real-world practice. For instance, methods such as contextual inquiry [26], user interviews [27], user need analysis [28], and task analysis [29] can clarify current task operation and flow, existing problems and potential needs under different user interactive situation. User participatory design [30], cognitive walkthrough [31] and iterative design [32] that actively involve users in the design of human–computer interactive system appear to be effective approaches for developing user interfaces that meet user expectations.

In contrast to traditional approaches that put emphasis on a single interactive product and its user interface, the smart mobile system developed for chronic wound care management takes advantages of the "Internet of Things" (IoT), big data, mobile technology and human–computer interaction technology to provide integrated patient-centered care across scenarios (such as the clinic and the ward), across platforms (such as Android and iOS), across devices (such as desktop computers, tablets and smart phones), and across services (such as patient medical history collection, wound measurement, assessment, monitoring and management).

Based on the multi-disciplinary UCD methodology, and according to the characteristics of the smart mobile system for wound care management, this section presents the product development process, including research, design and implementation, as shown in Figure 1.

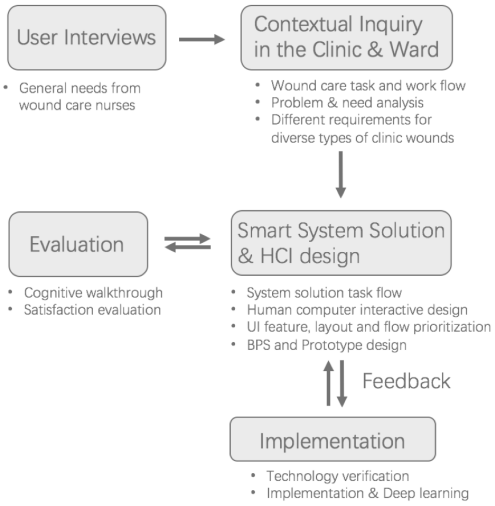


FIGURE 1. User-centered mobile smart system design and implementation process for chronic wound care management.

First, general clinic requirements for smart chronic wound management were collected through in-depth user interviews of nurses in the wound clinic. Then, the chronic wound care task operation and work flow were identified with detailed investigation of problems in the existing manual process and future needs in clinical and ward scenarios through contextual inquiry.

Based on the studies above, a smart mobile system design solution for chronic wound care management was developed involving wound care nurses to ensure that the human–computer interactive operations and the work flow of the smart mobile system met the needs of daily wound care work in the clinic and the ward.

Furthermore, through cognitive walkthrough with wound care nurses and iterative design, the UI features of the smart

mobile system were enriched, and UI layout, flow and prototypes were designed and prioritized in developments.

Finally, by carrying out user satisfaction evaluation among nurses from different clinical departments, the smart mobile system and human–computer interface design was proved applicable and effective in clinical practice.

IV. FIELD WORK IN CLINICAL PRACTICE

A. USER INTERVIEW AND GENERAL REQUIREMENTS

In-depth interviews with nurses of general requirements for the smart mobile system for chronic wound care management was carried out and described as follows, also shown in Figure 2.

1) Contactless smart measure of wound size (length, width, area) and wound bed tissue composition;
2) Recording of the complete wound assessment records;
3) Wound assessment rating and wound healing monitoring along the dates;
4) Efficient wound case documentation and management of wound pictures, measurement, assessment and treatment recording for both clinic and ward patients.

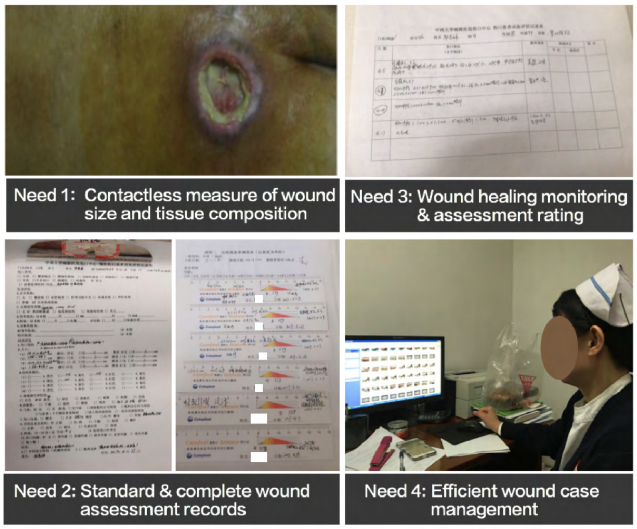


FIGURE 2. User in-depth interview and summary of requirements.

B. CONTEXTUAL INQUIRY AND TASK ANALYSIS

Based on the general user requirements from in-depth interviews, contextual inquiries and participatory observations of the wound care processes in the clinic and ward were carried out in the wound clinic.

Six major tasks were identified after the inquiries and analyses (as shown in Figure 3), corresponding to existing problems and potential needs:

1) Medical history interview is important but time-consuming: Every time before wound diagnosis, measurement, assessment and treatment, nurses need to go through a brief interview for patient medical conditions, current and previous illness, general disease and treatment, relevant surgery, examination report and laboratory test results. During the interview, the nurse quickly records the wound's dimensions on a paper wound ruler. In the time-critical working hours in the wound clinic, this process is time-consuming. Moreover, sometimes patients cannot remember the result of the laboratory test in details, which affects the efficiency of wound diagnosis, assessment and treatment.
2) Previous wound review is necessary but inconvenient: The wound dressing is replaced once a week, and the dressing might be adjusted by taking the previous wound status and treatment into consideration. However, it is not convenient for nurses to review the previously recorded wound status pictures and assessment data in the less organized mixed clinic and ward patient wound cases on a PC and digital camera.
3) Wound measurement and assessment are not precise or comprehensively recorded: The current wound measurement is usually done by a disposable paper ruler with assessment results written on it. The wound size cannot be measured precisely, and the assessment record is subjective, casual and lacks completeness.
4) Wound treatment recording is important but occasionally neglected: Although clinical nurses are required to record wound treatment only when there is a wound status change, it is easy to forget to take this record during time-critical clinic working hours.
5) Wound healing monitoring records are hardly useful for clinical professionals to identify tendencies: To monitor the wound healing tendency, the paper

FIGURE 3. Task flow and potential problems in clinic and ward scenarios.

wound rulers, with hand-written patient information and wound assessment results on top, are passed on a sheet to get an overview of the wound status change. The nurse picks up the recorded wound assessment items to fill in a wound assessment rating sheet along with the date. Each assessment item is rated with a corresponding rating score. By calculating and comparing the overall assessment score and each assessment item score, the wound healing tendency is estimated. The higher the score, the severer the wound status is, hence the more urgently the nurse's attention is needed. There is no doubt that the current wound healing monitoring task is neither easy to carry out nor efficient to detect the wound healing tendency.

6) Wound case management: The wound status and paper wound ruler, written with patient information and wound assessment results, are recorded in photos and stored in a file-oriented database. Since it is less organized, when a search for certain type of wound case or review of a patient wound status is needed, the nurse has to browse through each photo among hundreds or thousands of wound cases to pick up the right one, obstructing the wound case management work.

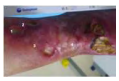
In comparison to the task flow and problems in the wound clinic, the chronic wound care process in the ward is slightly different in tasks 1, 4, and 5, described as follows:

1) Ward patient wound care request: The nurses in the wound clinic receive requests for ward patient wound care from doctors in different clinical departments. When the nurses notice the request, they need to review the patient's medical history and relevant examination and test results carefully. Since the doctor's request, patient medical history, test results, ward and bed number information and more can only be viewed on the computer, nurses experience delays and inconvenience when they visit the ward to address the wound care request.
2) Wound treatment recording: In most cases, the status of the chronic wounds of a patient in the ward who needs wound care is much more severe than that in the clinic. Thus, recording the wound treatment process is compulsory every time, regardless the status change of the wound in healing process.
3) Wound care report: In addition to the monitoring of the wound healing status, the nurse works on patients' wounds in the ward is required to report on the wound diagnosis, assessment and treatment for each individual case. It is time-consuming and tiring for the nurse to write the wound care report in the ward after hard work.

C. WOUND CLASSIFICATION FOR CARE MANAGEMENT

The contextual inquiry and participatory observation revealed that the wounds of different characteristics have different requirements for wound management. Table 1 shows 5 different major types of wounds in clinical practice from the care management perspective, which are considered in system design and development.

TABLE 1. Wound classifications.

Type of Wound	Complexity in Measurement	Example
Single open wounds	Changing and irregular shape in the wound healing process makes the measurement difficult in terms of consistency and precision.	
Multiple open adjacent wounds	Multiple wounds need individual identification and measurement; multiple measurements need to be recorded separately.	
Wounds with sinuses/fistulae	The length and angle of any undermining sinus/fistula must be measured by probing the wound with a cotton bud.	
Post-operative wounds with stitches	The total length of post-operative wound stitches might exceed the overall length of the paper ruler, which affects the precision of measurement.	
Wounds of rare case	Unable to measure with traditional methods.	

1) Single open wounds: Common chronic wounds such as ulcers. Every wound must be measured, and its length, width, depth and tissue composition must be recorded.
2) Multiple open adjacent wounds: Several wounds near each other. Wounds must be numbered/identified first (e.g., in an order from up to down, from outside to inside). Then, the size of each wound must be measured and recorded separately under different identifications.
3) Wounds with sinuses/fistulae: In addition to the general wound size to be measured, the length and angle of any undermining sinus/fistula must also be measured by probing the wound using a cotton bud.
4) Post-operative wounds with stitches: In addition to general wound size and undermining sinuses/fistulae, the total length of post-operative wound stitches must also be measured and recorded.
5) Wounds of rare cases: For wounds on irregular curved surfaces, e.g., the face, or those that are located intensively over the whole body, e.g., a skin disease, the nurse describes the wound status in words instead of regular wound measurement and assessment.

V. INTERACTIVE SYSTEM WORKFLOW AND USER INTERFACE DESIGN

By taking the general user requirements, potential problems and needs of wound care in the clinic and the ward into consideration, a smart mobile system solution for chronic wound management was proposed. Nurses were involved to confirm that the system functions would work in wound care practice without major problems. Through cognitive walkthrough with nurses and iterative design, the human–computer interface in the system work flow was confirmed

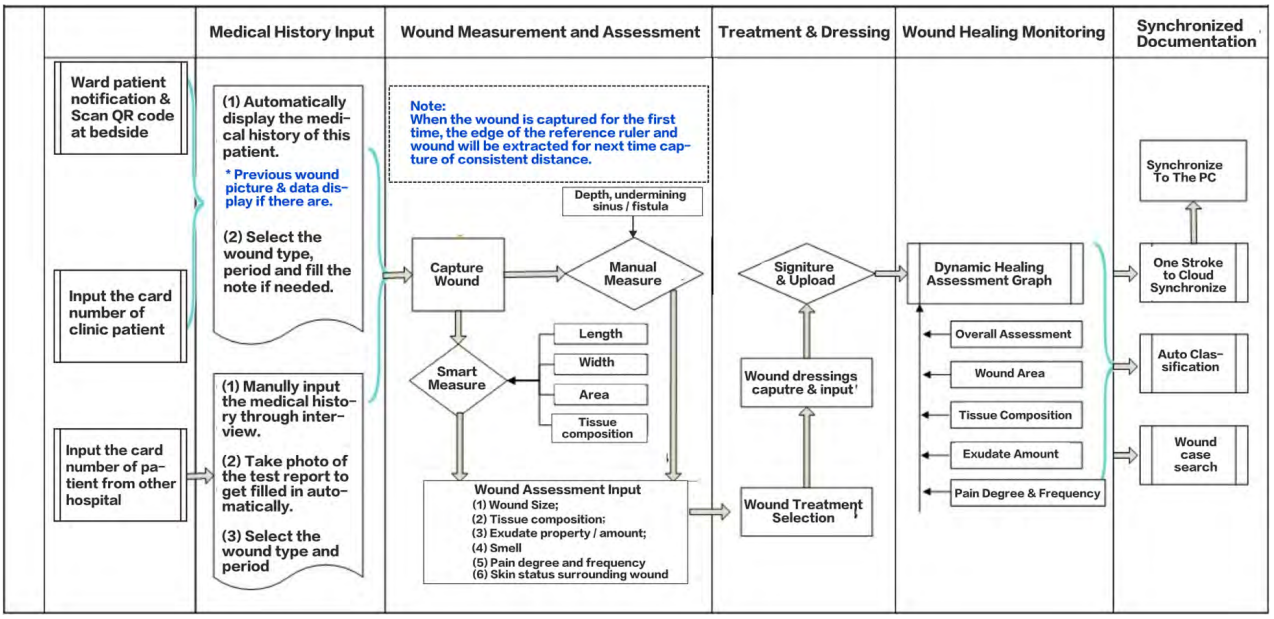


FIGURE 4. Interactive work flow of the smart mobile system for chronic wound care management.

to meet nurses' expectation and to improve the efficiency and effectiveness of current clinical practice, as shown in Figure 4.

For existing patients already registered in the EMR system of Xiangya Hospital, by scanning the barcode or inputting the patient number on the interface of the smart system in the tablet, the patient's basic information, the summary of medical records and the examination/test results will be shown directly, which normally include previous diagnosis, general disease and treatment, surgery name, and wound care-related laboratory examination or test results, such as hemoglobin, serum albumin, blood glucose, secretion culture, white blood cells, blood platelets, and procalcitonin, if needed. The patient's previous wound status pictures, assessments and treatment records can also be viewed if they were recorded before in this system, as shown in Figure 5.

The quick review function of patient medical history and wound care record with straightforward tablet operation could shorten the traditional interview and record time in the clinical scenario and provide effective references for following wound diagnosis and treatment.

For patients who transfer from other hospitals and have no previous medical records or examination reports in Xiangya Hospital, the basic medical history information form needs to be filled in manually by nurses through interview. The examination/test results can be filled in automatically by taking a photo of the examination report sheets using OCR technology.

For ward patients, the notification of a wound care request sent by a doctor displays as a headline running notification in the tablet to prompt the nurses to address it on time. If the nurse does not check the request timely, notifications are listed under the ward patient category, with the number of requests highlighted in the headings.

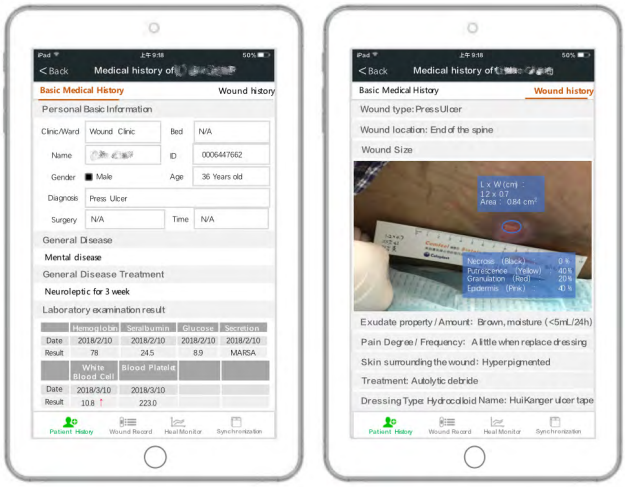


FIGURE 5. Patient's medical record, wound history capture and display.

When the nurse checks the ward patient information, the ward and bed numbers of this patient are also displayed, helping the nurse to organize her work with multiple wound care requests one by one in different departments.

After reviewing or completing the medical history record, the nurse can go to the wound record user interface for wound measurements, assessments and treatment records.

The wound assessment user interface offers complete information to be recorded from assessments, which includes the wound status pictures before and after wound debriding, the wound location, the wound size, the wound bed tissue composition, the exudate situation photos and exudate properties, the exudate amount, the smell of the wound, the pain degree and frequency, and the skin status surrounding the wound.

The wound size and wound bed tissue composition is to be filled in automatically after the nurse takes photos of the wound.

After the nurse taps to take a photo, a dialogue of wound type selection displays, which covers most chronic wound cases in clinical practice, as shown in Figure 6.

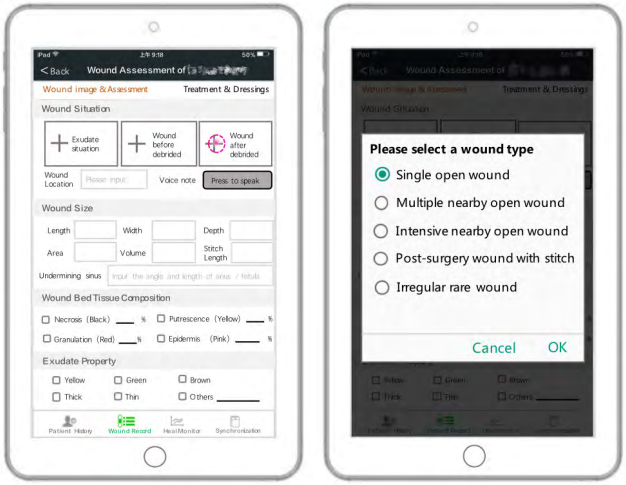


FIGURE 6. Wound assessment user interface and wound classification dialogue.

Before taking the photo of the wound for the first time, the nurse needs to stick a 1cm tape with printed red, yellow and blue color blocks on the same plane surface of the wound. The main objective of using such a tape with standard color blocks is to provide reference and ensure consistency in automatic imaging processing in wound surface tissue composition color recognition and wound size measurement.

After the nurse selects the corresponding wound type and takes the photo of the wound, the user interface next displays simple instruction hints for smart measure operations, as shown in Figure 7.

For a single open wound, the hint message tells the nurse to draw a rough circle around the wound, as shown in the left part of Figure 7. Then, the rough circle adapts to match the edge of the wound automatically. When the circle matches the edge of the wound precisely, the nurse wound taps ''Smart measure'' to generate the length, width, and tissue composition of the wound, as shown in the right part of Figure 7.

For multiple open wounds, the hint message tells the nurse to draw a rough circle around each wound, according to the numbering rule in clinical practice. If the hints are not clearly understood, the nurse can tap ''Numbering order'' highlighted in red to see the guidance. Basically, according to clinical practice, the rule to number the wound in order is from top to bottom and from outside to inside.

For post-operative wounds with stitches, the hint message tells the nurse to draw a circle around the wound first and to then draw along the stitches from the beginning to the end. If the automatically captured wound edge is not correct, the nurse needs to manually adjust the outlined edge of

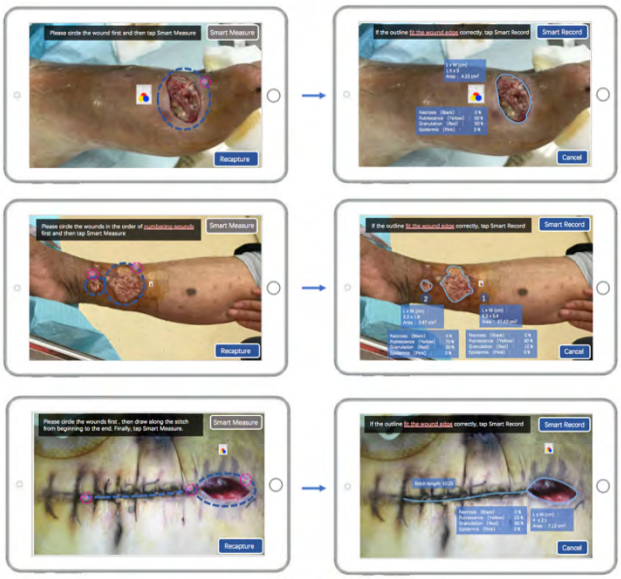


FIGURE 7. Different UI features and UI flows for different wounds.

the wound, then tap ''Smart measure'' button to calculate the wound size and wound bed tissue composition.

After smart measurement, the nurse can tap ''Smart record'' to get these measured wound size and wound bed tissue compositions recorded into the page of wound assessment.

In order to offer consistent image quality and quick operation, outline of the color block stick near the wound in the first capture would display in the viewfinder for reference of subsequent wound captures from the same distance and angle, as shown in Figure 8.

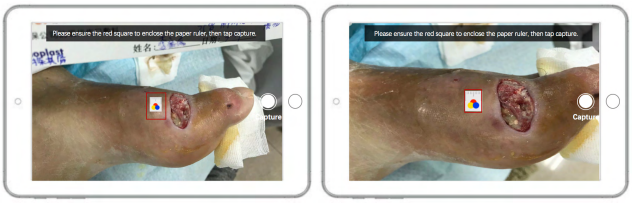


FIGURE 8. Smart reference for subsequent wound capture.

In the wound assessment, with the exception of the smart measure and recorded part, the left part is to be checked by the nurse manually, as shown in Figure 9.

After checking the wound assessment items, the nurse can tap the treatment and dressing menu to input the treatment record, which includes wound debriding methods and washing liquid.

After that, the nurse takes a photo of the wound dressing and its package. Using OCR technology, the words of type and dressing name on the dressing package are extracted and filled automatically into the system for confirmation with ease.

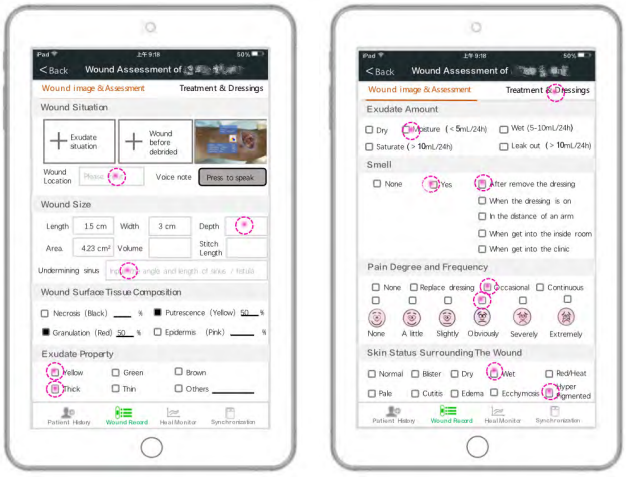


FIGURE 9. Smart and manual wound assessment inputs.

Finally, the nurse can tap the check box if this wound treatment is complex and needs to be reviewed and confirmed by the head nurse. Once this process is completed, an updated wound healing monitoring curve and corresponding wound care report could be generated.

In the wound monitoring user interface, previously smart and manually recorded assessment items will be displayed in the form of a rating curve. Different assessment items, such as wound area, exudate amount and tissue composition, could all be shown on the curve accordingly. This provide an efficient overview of the wound healing monitoring process, as shown in Figure 10.

FIGURE 10. Monitoring curve of wound healing.

In the synchronization interface, various wound photos, assessment items and treatment records are organized in different layout views according to the nurse's preference:

1) Severe wounds flags to call for the head nurse's attention;
2) Wound types including press ulcer, diabetes foot, and so on;
3) Patient name in alphabetical/PinYin order;
4) Wound record date/time.

The classified document can also be synchronized to the PC from the cloud sever on demand through user verification.

VI. PROTOTYPE TRIAL AND USER SATISFACTION EVALUATION

To validate the applicability and effectiveness of the smart mobile wound care management system and evaluate the usability of the system HCI user interface in real practice, a group of 10 wound care nurses with 2 nurses each from 5 clinical departments (i.e. Urinary Surgery Department, Dermatology Department, Neurology Department, Endocrinology Department and Orthopedics Department) of Xiangya Hospital were invited to carry out a one week prototype trial with about 200 cases in total, as shown in Figure 11.

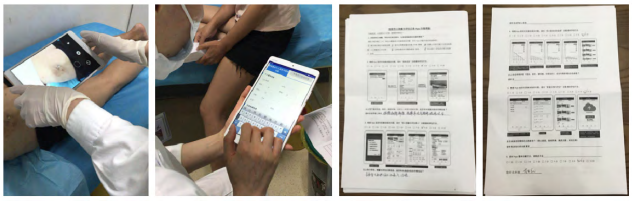


FIGURE 11. Prototype trial by nurses and feedback forms used.

After the prototype trial, the efficiency and convenience of all major task operations in the wound care process were compared between the new work experience with the prototype and the past work experience (as shown in Table 2). It is clear that the efficiency of the task operation and the performance of the care were significantly improved by cutting the time of each task in the normal work flow.

TABLE 2. Comparison of the prototype trial results with the past.

Task operation and flow in wound care process	Past UX	Current UX
Clinical patient medical history interview	5 minutes	<1 minute
Wound history review	Slow	<1 minute
Ward patient wound care request check patient information & history review	Time consuming	Instant
Wound measurement and record	Imprecise	Precise
Wound assessment and record	Imprecise	Standard
Wound treatment and dressing record	Incomplete	Complete
Wound healing monitoring graph	10 minutes	<1 minute
Ward patient wound care report	10 minutes	3-5 minutes
Wound case synchronization	Impossible	<1 minute
Wound case documentation	Time consuming	<1 minute

In the task of clinical patient medical history interview, it previously took approximately 5 minutes to inquire and to review the patient medical history and examination results. Now, when the patient number is input or scanned, the medical history and examination result of this patient display,

together with previous wound assessment and treatment history record.

In the task of dealing with the ward patient wound care request and the medical history review, it previously took a relative long time to check the request manually. Now, once the request is sent by the doctor, the nurse will receive the notification instantaneously.

Previously, wound measurement and recording were not precise due to manual operation inaccuracies. Now, in every capture of the wound, the distance and angle is consistent, and the measurements are relatively precise.

Previously, wound assessment and recording were imprecise and incomplete. Now, the standard assessment record can be completed in less than a minute.

Previously, the tasks of wound dressing and treatment records were easily forgotten by the nurse. Now, when the nurse submits the assessment, if the treatment record is not filled in, the nurse will be reminded to complete it.

The task of generating a wound healing monitoring graph and ward patient wound care report used to take approximately 10 minutes to complete. Now, when the assessment data are uploaded, the wound healing monitoring graph and report are generated within a second.

The tasks of wound case synchronization and documentation, previously due to the complexity of manual operations, were often left unorganized. Now, when the wound case is uploaded, it is automatically documented and synchronized.

The user satisfaction survey for different system functions and related human–computer interface based on feedbacks from wound care nurses in different clinical departments is summarized in Table 3.

TABLE 3. User satisfaction survey results.

Category Number	System function & HCI design	Satisfaction Evaluation
1	Patient medical and wound history review	7.4 / 10
2	Ward patient wound care request display	7.4 / 10
3	Wound measurement & assessment record	8.5 / 10
4	Wound treatment and dressing record	8.5 / 10
5	Wound healing monitoring graph	8.8 / 10
6	Ward patient wound care report	8.8 / 10

The survey result shows that the new smart mobile system has achieved high level user satisfaction and proven its effectiveness in clinical practice.

In addition to the positive feedback on the system, nurses also made some constructive comments to be considered for future improvements:

1) For the patient medical history user interface: Drug allergies need to be highlighted; latest test results of patients should notify the nurse and be checked by the nurse before wound care treatments; contact information of patients need to be shown in handy places to help nurses following up the wound recovery status of every patient discharged from the hospital.
2) For the wound record user interface: If a patient receives a general-body treatment, the patient's general-body status and treatment need to be recorded briefly; after a ward patient receiving the wound care by the nurse, in addition to the care record uploaded, a notification of the wound assessment results should be sent to the doctor in charge for future reference.
3) For the wound healing monitoring user interface: The patient's pain degree and pain frequency ratings need to be monitored as well; the final result of the wound healing (e.g. fully recovered, degeneration, no change) need to be recorded in the case.
4) For the data synchronization user interface: To support severity and urgency ranking, the wound case under each category needs to be ranked from top to bottom according to the assessment rating score. The higher the score, the more severe the wound status is and the higher the ranking of the wound case under each category.

VII. CONCLUSION AND FUTURE WORK

To develop a highly usable mobile wound care management system for nurses and doctors, this paper provides a systematic review on the general requirements of wound care in clinical practice. By analyzing the daily task flow, the existing challenges and the needs in current wound care processes, a new smart mobile system for chronic wound care management is designed and developed. This system provides a practical solution to address the major challenges in general wound care processes, which include precise wound measurement, wound healing monitoring, standard and comprehensive wound assessment and integrated wound case management in the existing clinical information system context of general hospitals. The system applies an iterative-design approach with user inputs and feedbacks to ensure the system's functions and work flow fitting into real clinical practice. The system's effectiveness is validated through presentation, prototype trial and satisfaction evaluation feedback from 10 wound care nurses from different clinical departments of Xiangya Hospital Central South University China.

In addition to the wound care management functions provided by the current prototype system, new features and further technical improvements will be made for smarter and better wound care management in the future:

1) Smarter technologies for wound care management: improvement of the precision of wound edge detection to optimize the human–computer interaction efficiency using big data and AI techniques. In some cases, the wound edge is obscure, similar to the skin color surrounding the wound, which might result in imprecise recognition of the wound edge. In these cases, the nurse needs to adjust the wound edge manually, which increases the error rate due to manual operation and lowers the interaction efficiency. In the future, with big data of wound images and related literal descriptions, it is possible to achieve better wound edge recognition and extraction using better deep learning algorithms.

2) More intuitive HCI design: In addition to existing technical solutions for smart measurements and assessments, the wound care nurses' user experience could be further improved by applying new HCI techniques such as voice and speech recognition, face recognition in the wound care system. However, the feasibility and usability of new techniques should be tested in complex clinic and ward environments before final integration.
3) Optimized visual design for user experience: The current prototype system was developed with a priority of functions and features, UI layout and workflow confirmation. Visual design optimization will be carried out in the next stage. Nurses will be involved in user-participatory design to develop and prioritize the visual elements for easy recognition, improving the human–computer interaction usability in the long run.

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