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ORIGINAL RESEARCH

PALLA: Palpation Suit for Breast Cancer Examination

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Abstract
At a time when communication is advancing rapidly, sight and hearing have progressed to the extent that we can witness or hear events occurring on the other side of the world. However, tactile communication, equally crucial, has not reached the same level of advancement due to its subtlety and complexity, still harboring gaps that require further knowledge for development. The PALLA breast cancer examination tool, presented in this research, aims not only to address these gaps but also to alleviate concerns for women uncomfortable with direct breast contact during examinations. Various sensor technologies, including pressure generation and mass detection to monitor lymph nodes and breasts, along with surface abnormality sensors, have been employed to support the development of this tool, encouraging individuals to undergo breast cancer examinations promptly, given its status as the leading cause of female cancer mortality. In addition to the innovative features of the PALLA breast cancer examination tool, the evaluation results underscore its significant potential impact on improving breast cancer examinations. Finally, we conclude the research and give the future research direction.

Keywords Breast cancer · Wearable medical devices in healthcare · Touch communication · Haptics · Sensors

Introduction

The incorporation of advanced emerging technologies has gained widespread popularity in the medical field, aiming to elevate diagnostics, treatment, and overall healthcare processes, as studied by Paternò and Lorenzon [19], Siriborvornratanakul [24], and Nagi et al. [16]. In the context of the provided passage, this phrase suggests the integration of cutting-edge technologies, as proposed by Kittipongdaja and Siriborvornratanakul [11], to tackle challenges in medical communication, particularly those associated with touch, as presented by Quezada et al. [20] and Liu et al. [14]. Communication has been a pivotal force throughout history, attaining unprecedented significance in the modern era through the integration of diverse technologies and knowledge. While our senses have made remarkable strides in overcoming past limitations, achieving near perfection in hearing and seeing, the intricacies of communication through touch pose ongoing challenges despite dedicated efforts by experts and developers to propel advancements in this domain.

Acknowledging these persistent gaps, the present study endeavors to bridge them by developing a prototype communication tool tailored to the concerns of both female patients and doctors during clinical breast examinations (CBE)—a nearly ubiquitous medical procedure. The anxiety, embarrassment, and tension commonly experienced by patients, especially those over 20, due to the necessity of exposing part of their bodies during the examination, act as a catalyst for the creation of an innovative breast cancer examination tool. This tool utilizes non-contact communication technology to address the challenges associated with direct physical

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contact during CBE, thereby fostering a more encouraging environment for women to undergo this vital examination without reservations.

In the creation of our groundbreaking prototype tool, PALLA, dedicated to breast cancer examination, we draw upon the realms of haptic communication, touch imitation, and various sensor technologies, coupled with expertise in cancer detection. The PALLA suit is complemented by an additional device—an artificial breast—through which doctors input touch information. This touch data is then transmitted to the PALLA suit, enabling it to replicate the pressure applied by the doctor to marked points. Simultaneously, the PALLA suit relays diverse resistance data and detects abnormalities through its installed sensors. This real-time information is promptly sent back to the doctor, facilitating an instantaneous diagnosis without the need for direct physical contact during the breast examinations conducted by medical professionals.

Hence, this paper introduces a prototype breast cancer examination tool that employs non-contact communication technology to mitigate concerns and encourage women to undergo examinations without apprehension. The development of our innovative PALLA breast cancer examination tool incorporates expertise in haptic communication, touch imitation, various sensors, and cancer detection. Alongside the PALLA suit, an additional device—an artificial breast—allows the doctor to input touch information. This data is then transmitted to the PALLA suit, enabling it to replicate the pressure applied by the doctor to marked points. Simultaneously, the PALLA suit relays diverse resistance data and detects abnormalities through its installed sensors, providing a real-time diagnosis without the necessity for direct physical contact. During breast examinations facilitated by our innovative PALLA prototype tool, doctors utilize an artificial breast device to input touch information. This tactile data is then transmitted to the PALLA suit, allowing it to replicate the pressure applied by the doctor to specific marked points, ensuring a comprehensive and accurate examination experience. Simultaneously, the PALLA suit relays real-time information, including diverse resistance data and detected abnormalities through its installed sensors, thereby enabling doctors to conduct thorough and precise breast examinations without the need for direct physical contact.

Related Work

Breast Cancer

Breast cancer stands out as one of the most prevalent cancers globally and holds the unfortunate position of being the most common cancer affecting women. Lima et al. [13] highlighted a concerning trend in the rise of breast cancer mortality worldwide across various regions and age groups. Notably, the increase in breast cancer incidence is pervasive across all age groups, with the highest rates observed in women under fifty, persisting in many regions even when accounting for declining birth rates. According to 2017–2019 data from the National Cancer Institute [17], the annual rate of new breast cancer cases in women reached 128.3 per 100,000 individuals, with a death rate of 19.9 per 100,000 individuals. The escalating incidence of breast cancer, even with its potential for early detection, is a significant concern, as emphasized by ElKorany et al. [6]. Furthermore, Cardoso et al. [3] provide a comprehensive overview of the utilization of artificial intelligence (AI) in supporting breast cancer care, shedding light on the evolving landscape of technological interventions. In addition, Liu and Kurc (2022) conducted a noteworthy analysis of slide image data for breast cancer using deep machine learning techniques, contributing valuable insights to the field.

Touch Communication Technologies

Touch plays a pivotal role in social communication, and recent years have witnessed a surge in research utilizing touch communication technologies, as presented by Kerdvibulvech [10]. Jensen et al. [8] provided an overview of the trends in haptic communication, focusing on co-manipulation works between humans. Li et al. [12] introduced a double-loop control approach for edge-learning-enabled realistic touch through a remote haptic display. Nunez et al. proposed a feedback method employing a wearable device to convey holistic touch illusions. Raisamo et al. [21] emphasized various technologies for interpersonal touch communication, highlighting vibrotactile stimulation as a cost-effective and easily integrated option. Thermal methods, utilizing Peltier elements, and non-contact approaches, including ultrasound, were also explored. Affective touch communication technology, exemplified by the Force Jacket introduced by Delazio et al. [5], demonstrated the application of pneumatically actuated air cushions to deliver forces and vibrotactile sensations for a nuanced haptic experience.

Sensors, vital for health monitoring in continuous healthcare, have shown significant promise in detecting diseases promptly. Kavitha et al. [9] illustrated that compact wearable sensors can aid in the early detection of breast abnormalities, contributing to improved health outcomes. The study emphasized the importance of sensors in monitoring various parameters such as temperature, skin thickness, shape, color changes, size, and nipple changes. The sensor modules, including detection, preparation, correspondence, and power supply, work synergistically to collect and transmit data remotely. Fernandes and Jiang [7] noted that during clinical breast examinations (CBE), doctors heavily rely on tactile feedback to identify irregularities indicative of breast cancer.

To facilitate proper training, a proposed sensor employing a capacitor structure with patterned dielectric elastomer layers tracked the normal pressure and location of a doctor's hand on the breast during palpation.

Our PALLA breast cancer examination tool brings forth innovative features that set it apart from prior studies by Altunkurek et al. [1], Dadsetan et al. [4], Sanni et al. [23], and Balijepally and Mullick [2]. Primarily, it introduces a pioneering approach by proposing an indirect contact breast cancer examination tool ingeniously designed within sports bras. This design not only prioritizes functionality and effectiveness but also places a significant emphasis on enhancing comfort, addressing a critical aspect often overlooked in traditional examination tools. By incorporating the breast cancer examination tool seamlessly into sports bras, we aim to create an environment that promotes ease and convenience for women undergoing examinations, potentially encouraging more individuals to participate in regular screenings.

Secondly, our tool goes beyond conventional methods by acknowledging the inherent limitations of breast self-examination, particularly in the context of diagnosing cancer. Understanding the complexities involved in accurate diagnosis, our approach leverages haptic communication technology. This enables real-time interaction and diagnosis by medical professionals, ensuring a higher level of accuracy in detecting abnormalities or potential signs of breast cancer. The incorporation of haptic communication not only enhances the precision of the diagnostic process but also opens avenues for future adaptability and refinements in patient care plans based on evolving medical insights and technological advancements. This dual focus on user comfort and diagnostic accuracy positions our PALLA as a cutting-edge and patient-centric solution in the realm of breast cancer examinations.

Breast Cancer Examination System

PALLA, a prototype breast cancer examination tool, was developed to simulate early-stage breast cancer screening by mimicking palpation without direct contact with patients. To address concerns about the reproducibility of the experience, we have incorporated a comprehensive evaluation protocol that outlines specific steps and criteria for assessing the PALLA breast cancer examination tool. This protocol includes detailed instructions on replicating the simulated palpation process, utilizing the Palpation Suit, Breast Pad, and PALLA Application in a controlled environment. By providing explicit guidelines and criteria, we aim to enhance the reproducibility of the evaluation experience, ensuring transparency and facilitating accurate assessments of the tool's performance. PALLA consists of three components as follows:

(1) Palpation Suit—it receives real-time signals and generates pressure following the doctor's commands from the Breast Pad, then sends the data back to the PALLA Application.
(2) Breast Pad—it simulates palpation without direct contact with the patient and sends signals to the Palpation Suit.
(3) PALLA Application—it serves as a dashboard for viewing the results of the sensors in the Palpation Suit.

Palpation Suit

Design of the suit: The Palpation Suit is designed in the shape of a sports bra that is comfortable and stretchy for patients. Sensors are placed inside to generate pressure and collect data. Figure 1 shows our designed Palpation Suit prototype for patients.

Sensors: The Palpation Suit consists of seven sensors: 1. Thermochron iButton for breast temperature, 2. Haptic sensing technology for breast stiffness, 3. Position sensor and a pressure sensor for hard spots or lumps in the breast, 4. Polymer-coated fabric sensor for breast movement, 5. Sodium sensor for breast sweat monitoring, 6. Silicon image sensor for skin irritation, 7. Epidermis sensor for skin swelling.

Breast Pad

The round pad is designed for simulating palpation for doctors. Figure 2 illustrates the presented Breast Pad prototype for doctors. It is connected with a haptic sensor, a position sensor, and a pressure sensor. It also serves as a controller to receive the doctor's commands to apply pressure in different positions.

Fig. 1 Palpation Suit prototype for patients

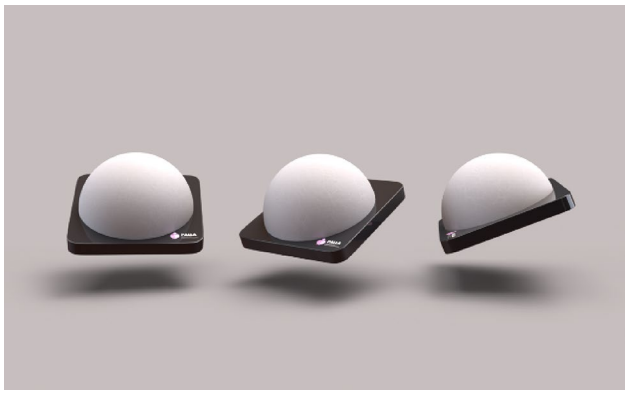

Fig. 2 Breast pad prototype for doctors

PALLA Application

The application to manage, set, and display the data. It is connected to the hospital's database to display the information about the treatment history and visualize the data in easy-to-understand graphics as a dashboard for the examination, including the recording of the examination data, which is stored as a history in the hospital database. Figure 3 depicts our PALLA application and interface while using the prototype system. The dashboard of our PALLA application serves as a comprehensive interface for managing, configuring, and presenting data. Linked to the hospital's database, it provides an intuitive visualization of treatment history and examination data, allowing for seamless recording and storage within the hospital's database.

Discussion

In the evaluation of the PALLA system among medical instrument users, doctors and nurses emphasized the importance of meticulous examination procedures to ensure accurate results in breast cancer detection. They highlighted the significance of proper attire and hygiene among healthcare providers, as well as the necessity for thorough explanation of the examination process to alleviate patient concerns. The presence of a nurse or third party during examinations was deemed essential to create a comfortable and secure environment for patients. Furthermore, medical personnel emphasized the crucial role of accuracy in examination tools, particularly in replicating palpation pressure and mimicking breast tissue characteristics. Any limitations in accuracy could lead to potential inaccuracies in diagnosis, underscoring the importance of precision in medical instruments designed for breast cancer examinations.

Conversely, the evaluation among adolescents undergoing breast cancer examinations shed light on the decision-making process and experiences surrounding breast examinations. Participants highlighted the influence of family history and recommendations from trusted sources in their decision to undergo examinations. Upon arrival for appointments, they expressed feelings of concern and embarrassment, emphasizing the need for clear instructions and support from

Fig. 3 The proposed PALLA application

healthcare providers. The desire for a breast examination tool offering real-time visualization of the examined area emerged as a common theme among participants, reflecting their apprehension and desire for reassurance during the examination process. Additionally, concerns regarding unfamiliarity with palpation techniques, particularly with male doctors, underscored the need for innovative solutions such as the PALLA bra to enhance patient comfort and confidence during breast examinations. Overall, the evaluation results underscored the potential value of the PALLA system in addressing the diverse needs and concerns of individuals undergoing breast cancer examinations, highlighting its potential to improve patient experiences and diagnostic accuracy in clinical settings.

The evaluation of the PALLA system by medical staff and patients yielded valuable insights into its potential impact on breast cancer examinations. Medical professionals emphasized the importance of meticulous examination procedures to ensure accurate results, highlighting the necessity for proper attire, hygiene, and thorough explanation of the examination process to alleviate patient concerns. They also underscored the critical role of accuracy in examination tools, particularly in replicating palpation pressure, as any discrepancies could lead to inaccuracies in diagnosis. Conversely, patients, particularly adolescents undergoing breast cancer examinations, welcomed the introduction of the PALLA system as a means to alleviate anxiety and discomfort during the examination process. They expressed appreciation for the opportunity for real-time visualization of the examined area, which could offer reassurance and improve their overall experience. Patients also highlighted the desire for greater awareness and understanding of the examination process, particularly regarding palpation techniques. Overall, both medical staff and patients recognized the potential of the PALLA system to transform breast cancer examinations, offering enhanced comfort, accuracy, and patient satisfaction. These findings underscore the importance of further research and development to refine and enhance the effectiveness of the PALLA system in clinical settings.

Participants

The careful selection and categorization of participants in this study significantly enriched the depth and breadth of insights gathered regarding breast cancer examinations and the evaluation of the PALLA system. By intentionally dividing participants into two distinct groups, comprising medical instrument users and individuals undergoing breast cancer examinations, the study ensured a multifaceted exploration of perspectives and experiences relevant to the research objectives. The inclusion of medical professionals, such as doctors and nurses, alongside adolescent patients undergoing examinations, provided a comprehensive understanding of both the clinical and patient-centered aspects of breast cancer detection. Furthermore, deliberate efforts to diversify participant demographics, considering factors such as age, gender, and professional background, enhanced the representativeness of the sample and contributed to the contextualization of findings within broader societal and healthcare contexts. While participant demographics were primarily selected in Bangkok for logistical reasons, the findings are anticipated to offer valuable insights applicable beyond geographical boundaries, underscoring the significance of the study's participant selection process in enriching the comprehensiveness and relevance of the research outcomes. Thus, this research involved eight participants, divided into two groups as follows: 1. The group of medical instrument users, comprising doctors and nurses, consisted of three individuals. 2. The group of individuals who participated in breast cancer examinations (teenagers) included five people.

In detail, a total of eight participants were involved, categorized into two distinct groups. The first group comprised medical instrument users, including doctors and nurses, with three individuals in this category. These three participants are both male and female. The second group consisted of individuals undergoing breast cancer examinations, specifically teenagers, totaling five participants. Even though we specifically selected for teenagers, the ages of each participant vary from a minimum age of thirteen to a maximum age of 17. These five participants are also both male and female. We selected the participants' ages and background information as diverse as possible. It is essential to note that the diversity within these groups, including factors such as age, gender, and professional experience in the case of medical staff, could have influenced their perspectives and experiences during the evaluation of the PALLA system. However, we only selected the participants' demographics in Bangkok where we are, as we needed to conduct in-depth interviews physically. In selecting the participants for this study, deliberate efforts were made to ensure diversity within the groups to capture a wide range of perspectives and experiences relevant to breast cancer examinations and the evaluation of the PALLA system. For the group of medical instrument users, comprising doctors and nurses, individuals were chosen based on their varying levels of professional experience, specialties, and backgrounds to provide comprehensive insights into the clinical aspects of breast examinations. Similarly, for the group of individuals undergoing breast cancer examinations, specifically teenagers, efforts were made to include participants with diverse backgrounds, including factors such as socioeconomic status, educational attainment, and cultural influences, to represent a broad spectrum of experiences and perspectives among adolescent patients. While the participants' demographics were selected primarily in Bangkok for logistical reasons, the findings of the study are expected to provide valuable insights

applicable to broader contexts within the field of breast cancer detection and healthcare provision.

Methodology

An in-depth interview was used as a tool to obtain detailed information about the participants. In this study, the methodology employed involved conducting in-depth interviews with participants to gather detailed information essential to the research. The interviews were structured to cover various aspects related to breast cancer examinations, including the decision-making process, experiences during examinations, and perceptions of the PALLA system. Participants were asked open-ended questions to encourage comprehensive responses and insights. The interviews were conducted in person to allow for direct interaction and facilitate a deeper understanding of participants' perspectives. Specific questions focused on participants' attitudes towards breast examinations, factors influencing their decision to undergo examinations, experiences during the examination process, and perceptions of the PALLA system. Additionally, participants were encouraged to share any concerns or suggestions regarding breast cancer examinations and the potential role of innovative technologies like the PALLA system. The methodology aimed to elicit rich and nuanced data to provide a comprehensive understanding of the topic and inform the development and refinement of breast examination tools. In employing the methodology of in-depth interviews, the study aimed to delve deeply into participants' attitudes, experiences, and perceptions regarding breast cancer examinations and the PALLA system. The interviews were meticulously structured to cover a broad spectrum of topics, ensuring a comprehensive exploration of the subject matter. By asking open-ended questions, participants were encouraged to provide detailed insights, allowing for a nuanced understanding of their perspectives. Conducting the interviews in person facilitated direct interaction, enabling researchers to probe further into participants' responses and gain a deeper comprehension of their viewpoints. Throughout the interviews, particular emphasis was placed on understanding the decision-making process surrounding breast examinations, the challenges and concerns faced during examinations, and the potential benefits of innovative technologies like the PALLA system. Overall, the methodology employed sought to capture rich and diverse data to inform the development and enhancement of breast examination tools, ultimately aiming to improve the patient experience and diagnostic accuracy in clinical settings.

Results

This part is to disclose the results of the tests on our prototype, PALLA, Palpation Suit for breast cancer examination. The results are divided into two parts as follows:

(1) The cohort of users utilizing medical instruments.

The recommendation emphasizes the importance of breast self-examination (BSE) as the primary control method for individuals over twenty years of age, given the rarity of abnormalities in this age group. For women aged forty and above, a clinical breast examination (CBE) by a doctor is advised. Patients typically have the flexibility to choose their examining doctor, especially if they have a prior relationship or have scheduled an appointment.

Preparation for the examination is crucial, and healthcare providers, including doctors and nurses, guide patients on necessary steps beforehand. The examining doctor is expected to maintain proper attire, maintain clean fingernails, and assess the mental well-being of patients, recognizing the common concerns and anxieties, particularly among younger patients. Additionally, doctors are mandated to thoroughly explain the examination processes. During the examination, whether conducted by a male or female doctor, the presence of a nurse or a third party is mandatory to ensure a comfortable and secure environment for the patient.

Hence, when an instrument or tool is developed for examination, as depicted in Fig. 4, it signifies a significant medical advancement resulting from a meticulous examination process to achieve the utmost accuracy in results. This advancement offers the benefit of facilitating informed decision-making for individuals seeking a breast examination, thereby reducing the risk of disease. The crucial aspect lies in the accuracy of the instrument, understanding the palpation system, and correctly replicating the pressure weight in comparison to the doctor's normal pressure. Limited accuracy could lead to inaccuracies in the initial examination.

Another vital component is the material that mimics the breast, serving as a fundamental tool for the doctor to conduct the examination in lieu of the real breast. In the past, concerns from teenage female patients were prevalent, often inquiring about having a female doctor for the examination. Some patients exhibited visible anxiety and tension during the examination, even when only the palpable area was exposed. Certain individuals requested a blindfold to alleviate anxiety, while others struggled to answer the doctor's questions due to heightened worry. However, the availability of an alternative, more accurate examination tool proves advantageous for the person undergoing examination.

(2) The cohort undergoing breast cancer examination (adolescents).

They mentioned that the decision to undergo a breast cancer examination often stems from family influence. Individuals with a family history of breast cancer are motivated to get checked regularly to ensure their well-being. The choice of where to undergo the examination is typically guided by recommendations from trusted hospitals or referrals from family members.

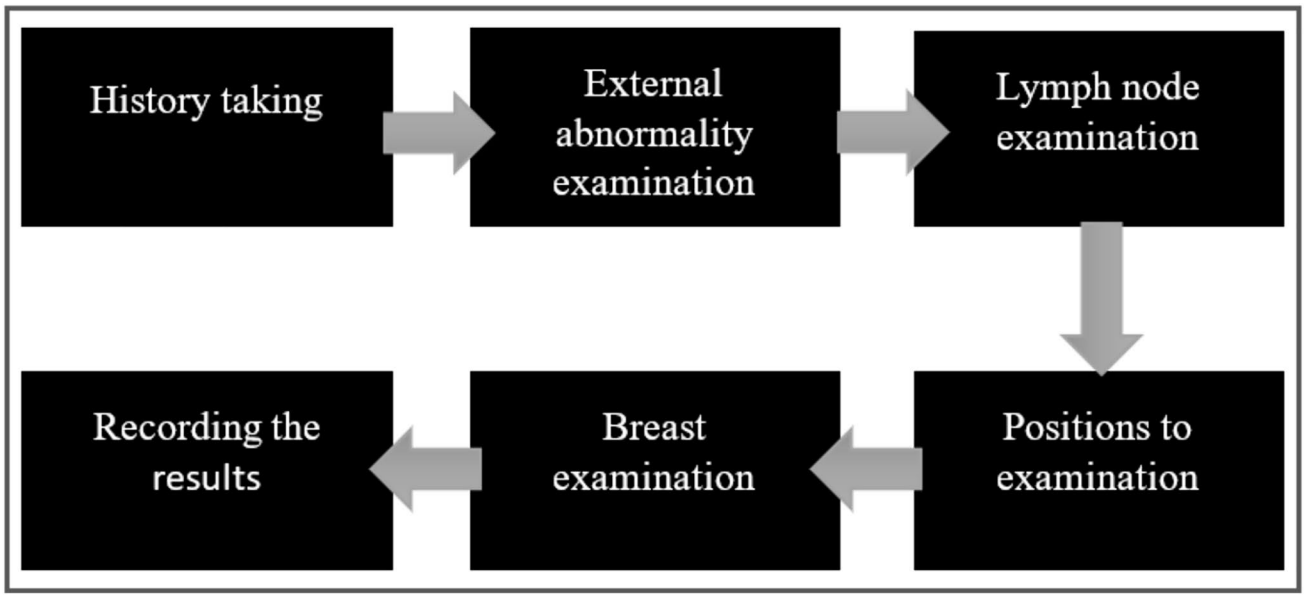

Fig. 4 Breast cancer examination procedures

When they initially opted for a breast examination, they lacked awareness of the examination process. Their knowledge was limited to knowing the appointment details, including the examining doctor's name and the option to choose a female doctor. Upon arriving for the appointment, they experienced moments of concern and embarrassment as they changed into examination gowns and removed their bras while awaiting the doctor. Once in the examination room, a nurse provided instructions on positioning, offering a cloth for coverage. The doctor then conducted palpation, explaining any abnormalities if detected. For those without issues, an annual checkup was recommended. In cases of concern, further appointments were scheduled for examinations involving medical instruments like ultrasound or mammography.

The participants expressed a desire for a breast examination tool that could provide real-time visualization of the examined area, alleviating anxiety during the process. This concern extended even when the examining doctor was female. The unfamiliarity with palpation techniques, particularly with male doctors, added to their apprehension. Consequently, they saw potential value in the PALLA bra as a medical instrument for breast examination, expressing a willingness to pay for its use, particularly if it could offer accurate results.

In evaluating the PALLA system, medical staff emphasized its potential to revolutionize breast cancer examinations by offering a more precise and comfortable experience for patients. They highlighted the importance of proper attire and cleanliness during examinations, underscoring the necessity for doctors to maintain professionalism and ensure patient comfort. Moreover, medical personnel emphasized the significance of accurately replicating palpation pressure, as any discrepancies could lead to inaccuracies in diagnosis. The introduction of the PALLA system was seen as a significant advancement in medical technology, providing a standardized and reliable tool for breast examinations. Additionally, medical staff expressed enthusiasm for the real-time visualization capabilities of the PALLA system, recognizing its potential to enhance diagnostic accuracy and patient reassurance during examinations.

On the other hand, patients, particularly adolescents undergoing breast cancer examinations, welcomed the introduction of the PALLA system as a means to alleviate anxiety and discomfort during the examination process. They appreciated the opportunity for real-time visualization of the examined area, which could offer reassurance and improve their overall experience. Patients expressed a desire for greater awareness and understanding of the examination process, particularly regarding palpation techniques and the role of medical instruments like ultrasound or mammography. The availability of the PALLA system was perceived as a valuable addition to breast cancer screening, with patients expressing a willingness to utilize the system and even pay for its use if it could provide accurate and reliable results. Overall, both medical staff and patients recognized the potential of the PALLA system to transform breast cancer examinations, offering enhanced comfort, accuracy, and patient satisfaction.

Limitations

We crafted our PALLA in the form of a sports bra, recognizing potential limitations related to size and shared use. Since breast examinations require the removal of the patient's clothing, necessitating direct skin contact, there is a consideration of the implications of such exposure. Additionally, certain components incorporated into PALLA may have implications for individuals at risk of specific conditions. Despite these considerations, all participants expressed admiration for the prototype, citing its aesthetics and user-friendly design as appealing features. However, they did express concerns regarding the accuracy of the device and the associated costs.

Conclusion and Future Work

We have observed that doctors follow clear and detailed procedures for breast examinations, utilizing not only their hands but also the fingers' pads, which apply varying levels of pressure categorized into three depths: superficial for subcutaneous tumor detection, middle for tumors in the breast's midsection, and deep for tumors near the pectoral muscles. The insights gathered from this observation will contribute to the ongoing refinement and enhancement of our prototype.

This study underscores the critical importance of breast cancer examinations, given that it stands as the leading cause of cancer-related mortality in women. In response to this, we have conceptualized and developed PALLA, a palpation suit for breast cancer examinations, incorporating touch communication technology, diverse sensors, and other relevant knowledge, aiming to advance the medical field. Notably, our study emphasizes the advantage of PALLA, whereby doctors can conduct examinations without direct contact with patients' breasts. This holds particular significance for individuals undergoing examinations for the first time, providing them with a more comfortable experience. However, it is essential to note that PALLA remains a prototype, and our commitment to further research and development is imperative to enhance its effectiveness. We anticipate that the findings of this study will prove valuable for those interested in pursuing further advancements in this domain. In the evaluation of the PALLA system by medical staff and patients, thorough attention was given to various aspects crucial for enhancing the effectiveness and acceptability of the breast cancer examination tool. Medical professionals underscored the importance of meticulous examination procedures, emphasizing the need for accurate replication of palpation pressure and the detection of breast tissue abnormalities. They highlighted the significance of proper attire, hygiene, and clear communication during examinations to alleviate patient concerns and ensure a comfortable and secure environment. Moreover, the real-time visualization capabilities of the PALLA system were acknowledged as a valuable feature that could enhance diagnostic accuracy and patient reassurance. On the other hand, patients, particularly adolescents undergoing breast cancer examinations, expressed appreciation for the potential of the PALLA system to alleviate anxiety and discomfort during the examination process. They emphasized the desire for real-time visualization of the examined area and highlighted the importance of familiarity and comfort with the examination techniques and examining personnel. Overall, the evaluation revealed promising insights into the potential of the PALLA system to address the diverse needs and concerns of both medical staff and patients, highlighting its role in improving the overall experience and accuracy of breast cancer examinations.

As we look forward, one avenue for future work involves an in-depth exploration of user experiences and feedback regarding the PALLA prototype. Conducting usability studies and collecting qualitative data from both medical practitioners and patients will provide valuable insights into the real-world applicability of our technology. Additionally, further research could delve into refining the design and functionality of PALLA, addressing any concerns raised during the initial testing phase. Exploring collaborations with medical institutions for large-scale trials and extending the technology to cover a broader spectrum of breast-related examinations are also avenues for future investigation. Continuous efforts in research and development will be pivotal in transforming PALLA from a prototype into a reliable and widely adopted tool in the realm of breast cancer examinations. Moreover, looking ahead, an intriguing avenue for future work involves exploring the integration of Artificial Intelligence (AI) technologies, as studied by Rasrichai et al. [22], to enhance the artistic aspects of breast cancer awareness campaigns. By leveraging AI algorithms, we could generate visually compelling and emotionally resonant artworks that effectively communicate the importance of regular breast cancer examinations. Collaborations with AI artists and designers could lead to the creation of impactful visual content, incorporating elements of empathy and awareness. Moreover, employing AI-driven techniques for data visualization might offer innovative ways to present complex medical information related to breast health, fostering better understanding and engagement among diverse audiences. As we continue our commitment to advancing healthcare through technology, the fusion of medical expertise, AI creativity, and visual communication holds

promise for more comprehensive breast cancer awareness initiatives in the future.

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Availability of Data and Materials The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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