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A Systematic Review on Smartphone Skin Cancer Apps: Coherent Taxonomy, Motivations, Open Challenges and Recommendations, and New Research Direction*

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Objective: This research aims to survey the efforts of researchers in response to the new and disruptive technology of skin cancer apps, map the research landscape from the literature onto coherent taxonomy, and determine the basic characteristics of this emerging field. In addition, this research looks at the motivation behind using Smartphone apps in the diagnosis of skin cancer and in health care and the open challenges that impede the utility of this technology. This study offers valuable recommendations to improve the acceptance and use of medical apps in the literature. *Methods*: We conducted a comprehensive survey using the keywords "skin cancer," "apps," and "Smartphone" or "m-Health" in different variations to find all the relevant articles in three major databases: Web of Science, Science Direct, and IEEE Xplore. These databases broadly cover medical and technical literature. *Results*: We found 110 articles after a comprehensive survey of the literature. Out of the 110 articles, 46 present actual attempts to develop and design medical apps or share certain experiences of doing so. Twenty-eight articles consist of analytical studies on the incidence of skin cancer, the classification of malignant cancer or benign cancer, and the methods of prevention and diagnosis. Twenty-two articles comprise studies that range from the evaluative or comparative study of apps to the exploration of the desired features for skin cancer detection. Fourteen articles consist of reviews and surveys that refer to actual apps or the literature to describe medical apps for a specific specialty, disease, or skin cancer and provide a general overview of the technology. *New research direction*: With the exception of the 110 papers reviewed earlier in results section, the new directions of this research were described. In state-of-the-art, no particular study presenting watermarking and stenography approaches for any type of skin cancer images based on Smartphone apps is available. *Discussion*: Researchers have attempted to develop and improve skin cancer apps in several ways since 2011. However, several areas or aspects require further attention. All the articles, regardless of their research focus, attempt to address the challenges that impede the full utility of skin cancer apps and offer recommendations to mitigate their drawbacks. *Conclusions*: Research on skin cancer apps is active and efficient. This study contributes to this area of

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research by providing a detailed review of the available options and problems to allow other researchers and participants to further develop skin cancer apps, and the new directions of this research were described.

Keywords: Skin cancer; apps; smartphone; m-Health; watermarking; stenography.

1. Introduction

The interest in the topic of skin cancer has grown over the past few decades because of the excessive damage caused by this type of disease and its widespread incidence. Skin cancer has two basic types: malignant and benign. The proportion of people with different types of skin cancer has been increasing in recent years.[13] The incidence rate for melanoma has increased significantly. Therefore, melanoma has received considerable attention from the public health field, medical prevention campaigns, and the cancer research field. Melanoma is considered one of the deadliest types of skin cancer and accounts for approximately 75% of deaths worldwide.[13] The main reason for skin cancer injuries that largely affect the epidermal layer of the skin is due to prolonged sun exposure. Malignant melanoma (MM) is considered one of the types of cancer that requires stupendously expensive treatment, but the cure rate is approximately 95% only if this cancer is diagnosed and treated early.[36]

Several software developers have recently become interested in the development of skin detection applications. Many technologies are currently used in the medical field; however, research in this area focusses on the use of mobile technology (i.e., smartphones or mobile phones) to detect skin cancer.[49] Many developers show an increasing interest in creating computer vision algorithms that work in the mobile environment because of the mobility and portability of smartphones. Consequently, smartphones have offered a good environment for the development of various new-generation applications that use computer vision algorithms. The development of smartphone apps for the segmentation of dermoscopic images to examine skin cancer would be beneficial in the diagnosis of melanoma in terms of cost, time, and reliability.[51] Smartphones are mobile devices that are smarter than the earlier generations of cellular phones, which are commonly known as feature phones. This smart feature is due to the close resemblance of smartphones to personal computers (PCs). Smartphones possess substantial computing power, several connectivity options, advanced operating systems, full Internet access, and the ability to install and run third-party apps. This ability extends the versatility and utility of smartphones, given that they offer users new ever-evolving functions. However, smartphones are not only scaled-down versions of PCs but also more portable compared with laptops. This scenario introduces the notion of context to smartphones in terms of location, ambience, and user actions. Accordingly, the progress in smartphones has improved health sciences and people's awareness of the importance of having healthy lifestyle.[53]

The camera feature in smartphones is an innovative development that has been incorporated into a low-cost smartphone-based intelligent system to allow people to take images whenever and wherever. Smartphone cameras can help people in remote areas and poor and developing countries because they can be used to scan, analyze, and make regular skin examinations anywhere.[2] An app that runs on a smartphone with a camera could take pictures of skin abnormality. The image of the lesion could be sent from the smartphone to a central server/computer, which would use color and symmetry-based analysis based on artificial intelligence (AI) algorithms to classify the image as benign or malignant. Such a system has been designed to provide a fully functional feature-rich software application with a simple graphical user interface to analyze skin images.[28] This paper aims to elucidate research efforts, such as those mentioned earlier that have taken place in response to the new and disruptive technology, map the research landscape from the literature onto a coherent taxonomy, and discover the key features that characterize this emerging line of research, as well as the new direction of this research will propose and describe in detail.

2. Methods

The most important keyword in the area covered by this paper is "apps." However, in our search for apps, we exclude non-m-Health applications, such as those found on personal digital assistants or PDAs, and non-apps, such as SMS used by conventional mobile phones. In addition, we consider all health-care-related areas that focus on skin cancer and research in this field but limit our scope to literature in the English language.

2.1. *Information sources*

We undertook a comprehensive survey to find all the articles related to the subject of skin cancer apps by searching on the best and most reliable databases: (1) the Science Direct database, which offers access to science, technical, and medical journal articles; (2) the IEEE Xplore library of technical literature in engineering and technology; and (3) the Web of Science (WoS) service, which indexes cross-disciplinary research in the sciences, social sciences, arts, and humanities. This selection covers medical and technical literature and provides a broad view of the efforts of researchers in a wide but relevant range of disciplines.

2.2. *Procedure of study selection*

The procedure for the selection of the relevant studies includes searching the literature sources based on two iterations, namely, screening and filtering. The first iteration excluded duplicates and irrelevant articles by scanning the titles and abstracts. The second iteration filtered the articles after a thorough full-text reading of the screened articles. Both iterations applied the same eligibility criteria.

2.3. *Search*

We conducted this research from the beginning of 2015 to 2016 using the search engines Science Direct, IEEE Xplore, and WoS and entered various keywords into their search boxes. We used a mix of keywords that contained the terms "skin cancer," "m-Health," "healthcare," "smartphone," and "apps" in different variations combined by the "OR" operator. Figure 1 shows the exact query text.

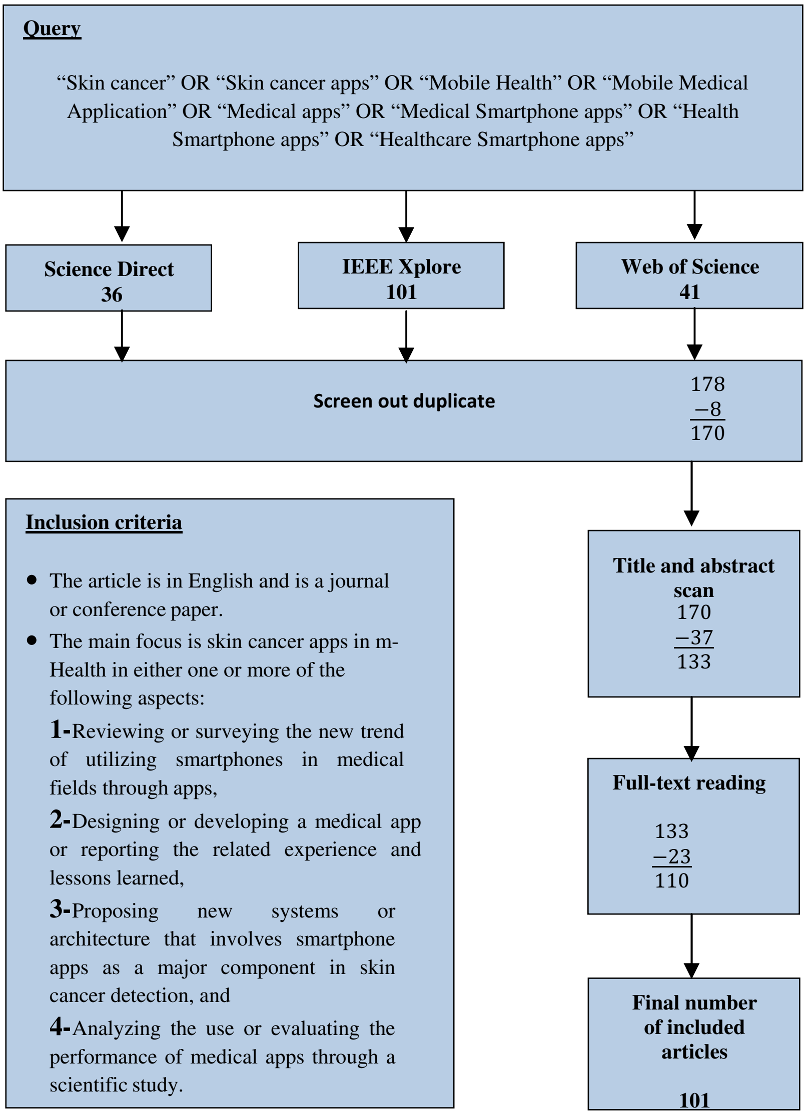

Fig. 1. Flowchart of study selection, which includes the search query and inclusion criteria.

The search excluded book chapters and other types of reports and instead focussed on journal and conference articles given that these two avenues most likely include up-to-date and proper scientific works relevant to our survey related to the developing trend of m-Health.

2.4. *Inclusion and exclusion criteria*

Articles that met the criteria in Fig. 1 were included in the review. We set an initial target of mapping the scope of research on skin cancer apps onto a general and coarse-grained taxonomy of four categories (see Fig. 1 bottom left). These categories were derived from a pre-survey of the literature without constraints. Google Scholar was used to obtain a first taste of the landscape and directions in the literature. After the removal of duplicates, some articles were excluded in both iterations if they did not fulfill a set of inclusion criteria. The exclusion criteria are as follows: (1) the article is non-English; (2) the focus is on a specific aspect of smartphone use, such as social networking; and (3) the target is skin cancer diagnosis with m-Health technology rather than smartphone apps specifically.

2.5. *Data collection process*

All included papers with their corresponding initial categories were compiled from various sources to a single Excel file to simplify the further steps in our analysis. Several full-text readings resulted in a large collection of highlights and comments on the surveyed works and a running classification of the articles into a refined taxonomy. All comments were saved in the body of the texts (depending on each author's preferred style, either in hard or soft copy versions). The main findings were summarized, tabulated, and described. Sets of relevant information were saved in Word and Excel files, which include a full list of articles; their respective source databases; summary and description tables; categorization tables based on medical specialties, purposes, review sources, target platforms, and audiences; and various related figures. These datasets are provided in the supplementary material as a complete reference for the results described next.

3. Results

The initial query search resulted in 178 articles published in 2011–2016: 36 articles from Science Direct, 101 from IEEE Xplore, and 41 from WoS. Only eight articles were duplicates across all three libraries. After the scan of the titles and abstracts, 37 further articles were excluded, thereby resulting in 133 papers. The full-text reading resulted in the exclusion of 23 additional articles. The 110 articles in the final set were read thoroughly for developing a general map of the research conducted on this emerging topic.

Out of the 110 articles, 46 (41.81%) articles focussed on the development of various AI algorithms and actual attempts to develop or design medical apps that aid in the prevention and early detection of MM. Twenty-eight (25.45%) articles included analytical studies on the incidence of skin cancer, the classification of malignant cancer or benign cancer, and the methods of prevention and diagnosis. Twenty-two (20%, 22/110) articles consisted of studies that range from the evaluative or comparative study of apps to the exploration of the features desired for the skin cancer detector process. Fourteen (12.72%) articles comprised reviews and surveys that referred to actual apps or the literature that describes medical apps for a specific skin cancer or other diseases or provides a general overview of the technology.

We observed the aforementioned patterns, captured the general categories of articles, and refined the classification into the literature taxonomy, as shown in Fig. 2. We distinguished several subcategories in the main classes, although overlaps emerged. The following sections describe the observed categories and provide simple accompanying statistics.

3.1. *Development and design studies*

Given the growing interest in the topic of skin cancer, we found that most of the articles (46/110) involved the medical community and obtained some descriptive statistics to understand this field. We ascertained that the largest percentage of articles described the development and design of various methods and techniques used to detect and diagnose skin cancer.

References 2, 5, 7, 8, 12, 24, 26, 29, 30, 42, 43, 46, 56, 57, 78, 79, 93 and 109 focussed on diagnosis and detection using various techniques, such as skin cancer of epiluminescence microscopy and micro-machined millimeter-wave (mm-wave), in addition to those used for image segmentation in the diagnosis of skin cancer as either melanoma or non-melanoma. The second largest proportion of articles described the development and design of smartphone applications for skin cancer. References 28, 38, 40, 45, 51–55, and 85 reported that the disease is diagnosed by taking an image of the area directly affected using a smartphone camera. These applications are platforms to help patients and physicians in the rapid detection of skin cancer instead of waiting for traditional clinical detection. Few articles described the development of some devices used in the detection of skin cancer in detail. References 3, 15, 18, 20, 23, 48, 50, 66, 83 and 93 stated that the devices are used in conjunction with a computer-aided diagnosis (CAD) system as a platform to analyze the data sent by the sensors for the detection of malignant tumors of the skin. References 87 and 105 presented an extensive study on the relationship between vitiligo skin cancers to show how to detect skin cancer with this type of disease. References 97 and 108 showed an interest in some companies that have developed novel synthetic compounds and drugs, such as HDAC5, HDAC6, and 6 h, to treat skin cancer due to the sudden rise of skin cancer incidence globally. Reference 64 provided a comprehensive and systematic description of the risk of exposure to large amounts of ultraviolet (UV) radiation among young adults, which can lead to skin cancer. Reference 72

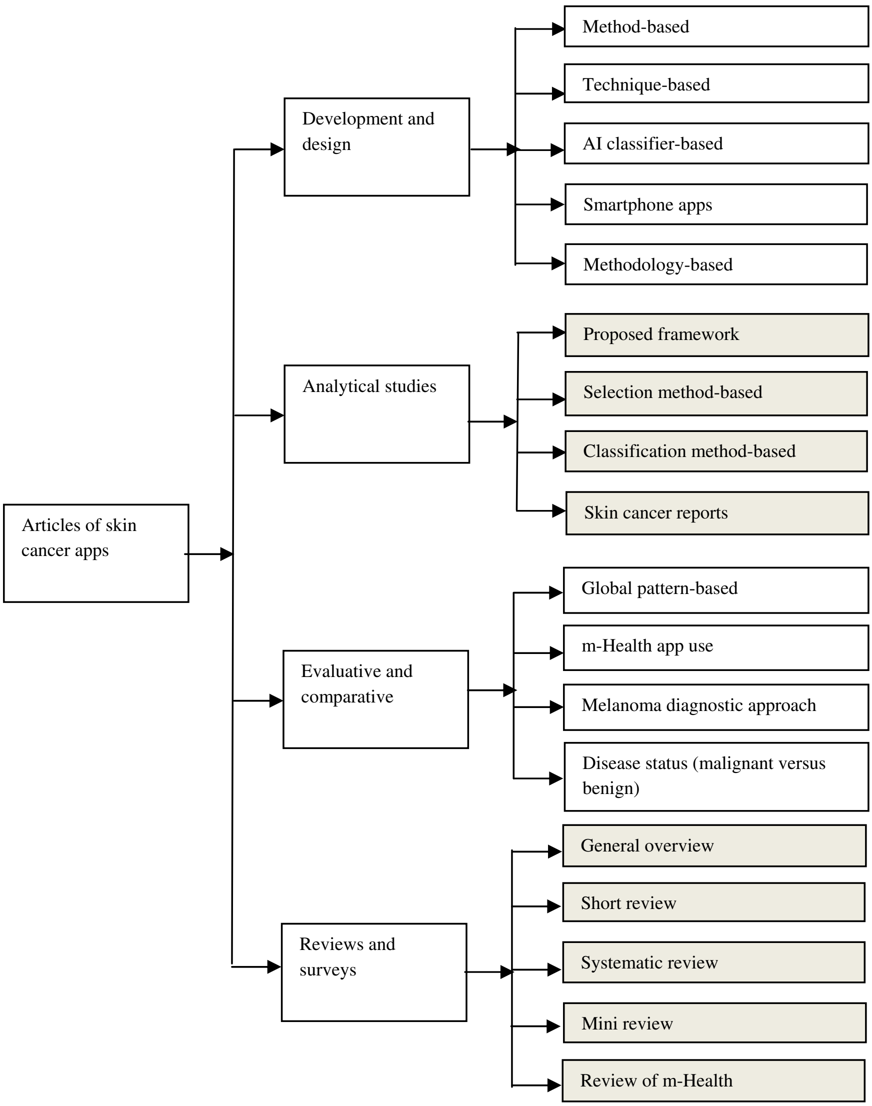

Fig. 2. Taxonomy of research literature on skin cancer apps.

referred to new strategies developed to overcome abnormal skin pigmentation. In addition, this reference provided details on how complex facial defects caused by non-melanoma skin cancer (NMSC) can be treated by applying a non-cultured autologous epidermal cell (NCAEC) application to improve the color of aesthetically displeasing areas caused by burn scars, melanocytic nevi, and vitiligo. However, Ref. 74 investigated the role of exogenous and endogenous cannabinoids in mouse skin cancer, and the results confirmed the use of exogenous cannabinoids for the treatment of melanoma but did not support the use of the endogenous cannabinoid system in the pathogenesis of skin cancer. Reference 76 described a text intervention that is effective in inducing significant improvement in sun protection to prevent skin cancer.

3.2. *Analytical studies*

The second largest category of articles (28/110) comprised analytical studies that attempted to classify various tumors that infect the skin.

References 1, 4, 11, 16, 27, 34, 36, 39, 44, 47, 96 and 99 provided a comprehensive analysis of the various methods, classifications, and tools used in the detection of skin cancer. References 67, 92 and 101 analyzed NMSC and highlighted the importance of regular care in terms of medical dermatology for the patient population and the importance of periodic inspection for this type of skin cancer. References 60, 62 and 65 provided an analytical description of patients who are injured due to exposure to UV and presented discretionary ratios for people with skin cancer in some countries. References 88 and 90, on the causes of cancer, conducted a detailed analytical study on young people who use tobacco and indoor tanning beds and exposed to UV radiation through outdoor sun tanning and work. References 88 and 90 helped the participants achieve a significant reduction in tobacco use using a multi-pronged comprehensive approach based on social norms and values for a long time; the authors conducted a detailed analytical study on the causes of skin cancer. Young people who use tobacco are commonly exposed to the risk of lung cancer when they use tanning beds, which area source of UV radiation. Moreover, tanning bed users may probably incur prolonged sun exposure, which further increases their skin cancer risk. References 73 and 94 focussed on families with a history of melanoma, especially the carriers of mutations in the CDKN2A gene or MC1R genotype that are considered a significant factor in the diagnosis and evaluation of the disease risk during the developmental stages of a malignancy. Reference 21 focussed on the two-dimensional scanning resolution of a micro-machined mm-wave based on a combination of high resolution and high sensitivity, which is important for the diagnosis of early-stage melanoma. Reference 81 showed that Erk and P38 play a crucial role in the cancer-promoting effect of capsaicin on carcinogen-induced skin cancer in terms of inflammation and concluded that skin cancer patients must pay considerable attention to their daily diet. Reference 82 discussed a variety of preventative measures specific to women that can reduce the chance of being diagnosed with skin cancer as well as current detection methods and future treatment options. Reference 91 presented an analytical study by the Cancer Institute of New South Wales on public education regarding skin cancer and the role of mass media campaigns, which were found to lead to a positive rate of return on the investment in terms of prevention in New South Wales, Australia. Reference 102 applied imaging cycle microscopy to analyze the immune contexture in human skin cancer by CD8 T lymphocytes. Reference 107 applied microscopy imaging to analyze the immune contexture in human skin cancer cells and examined the possible effect of enzymes, which may lead to cell damage and death in some cases.

3.3. *Evaluative and comparative studies*

Several studies (22/110) on skin cancer apps have attempted to participate in the new trend to evaluate and compare these apps and involved mostly professionals from health-care disciplines.

References 9, 13, 25, 32, 33, 35 and 58 compared different techniques and methods for the classification of skin cancer according to local and global strategies for the detection of melanomas using different classification methods. References 41, 49 and 85 specifically evaluated the m-Health system using smartphones, which are seen as an innovative and convenient modality for providing medical consultations for people with skin cancer. References 22 and 37 presented new devices for skin cancer diagnosis: a micro-machined millimeter wave with a high-resolution microwave measurement probe and a non-invasive based on a resonance microwave reflectometry device. These imaging studies used an artificial dielectric skin model to show the possibility of obtaining a high contrast resolution for small cancerous tumors at the early stage of skin cancer. References 59 and 95 used a logistic regression model to evaluate the odds of NMSC after adjusting for skin type, sun exposure history, and the indication of NSAID use. A different focus was adopted by Ref. 61, which evaluated how effectively HIV predisposes albinos to skin malignancies. This reference confirmed that albinos make poor use of free and available antiretroviral therapy services provided by health-care centers. Reference 68 evaluated the impact of early detection on the risk and prevention of skin cancer for golfers and golf course workers. A comparative study was undertaken by Ref. 69 on the performance of malignant skin lesions in the head and neck for basal cell carcinoma (BCC) and the trunk for squamous cell carcinoma (SCC); dermatofibrosarcoma protuberans; skin secondaries from the stomach, breast, and lung; mycosis fungoides; and MM to compare the pattern of skin malignancies in Dammam Medical Complex in Saudi Arabia with that in other parts of the world. Reference 89 presented the results of a comparison of the tumor burden in trisomic mice for two groups of Ts1Rhr trisomic mice (Ts mice) and euploid (WT mice). The use of the trisomic mouse model to study the genetics of people with Down syndrome extends the understanding of the mechanisms that underlie the protection against and susceptibility to different forms of cancer. Reference 100 evaluated the effect of indoor tanning for the majority of the population based on their exposure to indoor tanning, especially young and middle-aged people. This reference verified that indoor tanning is harmful to health regardless of the location; thus, the proliferation of indoor tanning devices in all locations should be discouraged. Reference 103 presented an assessment of the cumulative incidence, tumor burden, and risk factors for skin cancer among patients who had undergone a lung transplant.

3.4. Reviews and surveys

The final and smallest set of articles (14/110) in our taxonomy consisted of reviews and surveys of the literature about skin tumors and apps.

References 6, 10, 70 and 71 provided a review of the most important implementations of techniques and methods for the classification of skin cancer in the detection of skin melanoma and non-melanoma. References 77, 80 and 104 were specifically considerably focussed on the issue of peripheral leukocyte telomere length, skin physiology, and various surgical and non-surgical treatment modalities available for the management of skin cancers associated with the risk of a cutaneous melanoma and NMSC. References 63 and 106 reviewed the work on the link between tanning bed use and skin cancer, specifically the biological effects of UV radiation exposure, which is associated with cutaneous malignancy and indoor tanning. References 84 and 110 focussed on in-depth reviewing of the state-of-the-art m-Health services and applications proposed by various developers. Reference 19 presented a short review of the experimental results and clinical experience acquired in the autofluorescence diagnosis of benign, dysplastic, and malignant skin neoplastic tumors. Reference 75 presented a review of 101 melanoma reports from different laboratory specialists' skin multidisciplinary team meetings, core data items, and free text. Reference 98 conducted a systematic review and a meta-analysis of coffee intake level and the risk of MM by referring to cohort and case studies.

Figure 3 shows the relationship between the number of articles that have been collected from the literature and the years of publication of those articles. The chart illustrates a clear contrast to the number of studies presented on the subject of our research. Therefore, consideration should be given on this contrast, notes outstanding to the target objective of this study should be extracted, and the study in

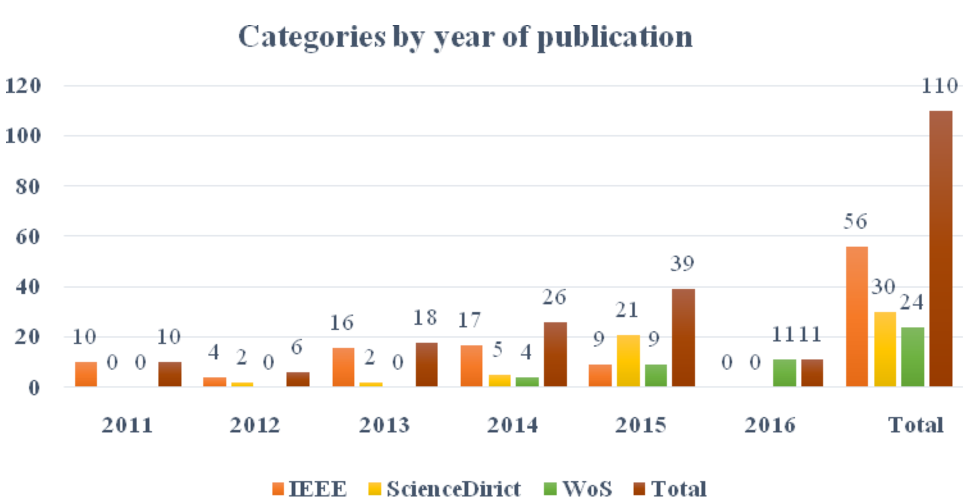

Fig. 3. Number of included articles in different categories by year of publication.

this field should be expanded. The present research targeted three engines: IEEE, Science Direct, and WoS, for basic research. These engines are the most reliable sources of research. This study has adopted 110 articles from various sources: 56 articles from IEEE Xplore, 30 from Science Direct, and 24 from WoS. These sources provided different studies from various international journals, which included studies on the applications and tools in skin cancer to help physicians and patients.

Figure 4 provides a breakdown of the four broad categories of our taxonomy by the number of articles and database searched. This chart includes all articles dependent in this study. This chart shows a relationship between the sections of articles and subdivisions within this study: development, design, review and survey, analysis, evaluation, and comparison. A total of 110 articles were adopted from various sources in this study. The chart presented varying proportions among these articles. Forty-six articles are under the development and design category, 14 articles are under the review and survey category, 28 articles are under the analysis category, and 22 articles are under the evaluation and comparison category.

Figure 5 provides a clear picture of the distribution of subcategories within the taxonomy based on the database searched. The taxonomy consists of three basic sections: development and design; analysis, evaluation, and comparison; and review and survey. This chart displays a ratio of varying studies used in this research through subsections of titles in the taxonomy. These subsections represent the direction for many future studies in this field. Accordingly, these studies may be a starting point for many researchers in their future studies. The above-identified subcategories could suggest directions for many future studies in the field of skin cancer apps. These are discussed in more detail in the following section.

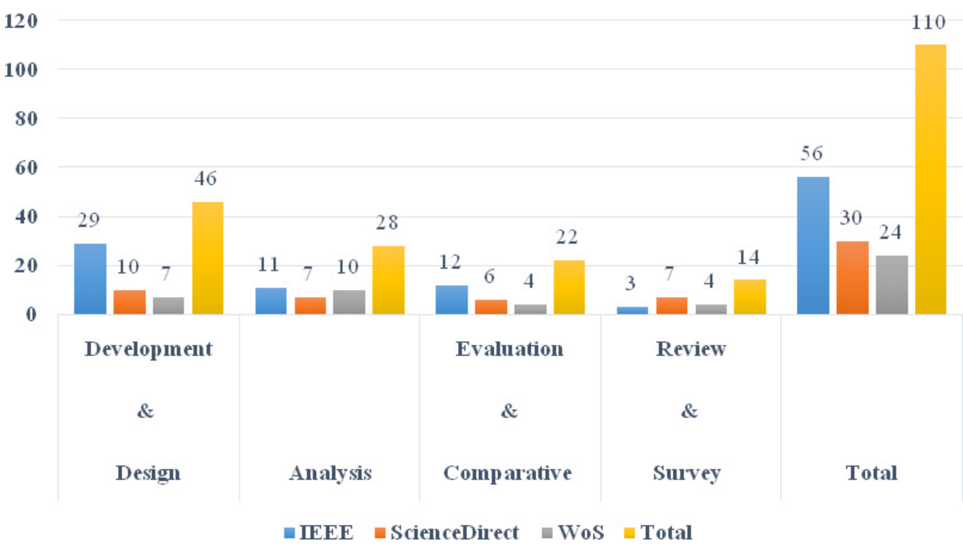

Fig. 4. Number of included articles by main category of article and database source.

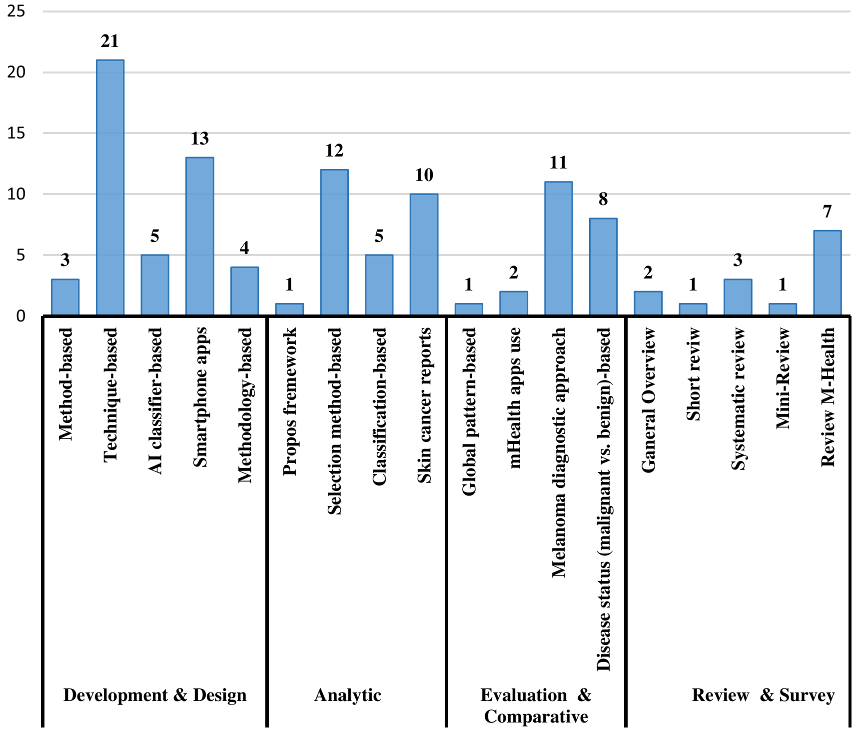

Fig. 5. Distribution of subcategories in the taxonomy.

4. Discussion

This study aims to provide an update on the infrastructure of skin cancer apps and highlight research trends that deal with this topic. Our comprehensive survey focusses on previous articles on the subject of skin cancer applications rather than the applications themselves. In addition, we provide a taxonomy of articles related to this topic to assist researchers.

A taxonomy developed based on the literature can provide several benefits. A taxonomy of published works imposes organization on a set of publications. A new researcher who is interested in the trend of skin cancer apps may be overwhelmed by the large number of publications written on the topic when no organizational structure exists and fails to gain a proper sense of the actual activities in this field. Various articles treat the topic from an introductory perspective, others examine a selected number of existing apps, and some involve developing the actual apps. Providing a taxonomy helps sort the different works and activities collected from the literature into a meaningful, manageable, and coherent framework. A taxonomy can also provide researchers with important insights into a topic in several ways.

First, a taxonomy can be used to identify potential directions of research in a given subject. This work on the taxonomy of skin cancer apps affirms that researchers are interested in urging their peers and users to focus on this type of application, which drives a new trend in this area. Other research paths identified in this taxonomy include evaluating current apps or sharing the experience of developing actual apps. Secondly, a taxonomy allows researchers to detect gaps in the literature on a particular subject. Mapping the works on skin cancer apps highlights the weaknesses and strengths in the research coverage.

Regarding the articles reviewed in this study, the developed taxonomy shows that some groups of individual apps receive significant attention in terms of review, evaluation, and analysis, and considerable development efforts in this field are based on integrated solutions and frameworks in conjunction with the surveys of the literature based on an adequate representative sample. Our taxonomy highlights some of the fundamental aspects of skin cancer apps, such as privacy and flexibility, which have received considerable attention from researchers compared with traditional technologies. Researchers working on an area of interest adopt a certain taxonomy by developing a common language through which future works are shared and discussed. For example, for skin cancer apps, these works could take the form of a development paper, a comparative study, or an overview.

The articles included in the review are discussed in the following sections to conduct research on skin cancer applications that diagnose malignant tumors, the challenges that users of this technology face, and some basic recommendations to avoid these issues.

4.1. *Motivations*

Skin cancer detection applications used in the smartphones are considered a promising and important area of research. This section reports some of the characteristics of the literature, which we grouped into categories according to certain benefits based on the references to aid further discussion, as shown in Fig. 6.

4.1.1. *Motives related to skin cancer detector/diagnostics*

The proposed WR-22 device has the potential to be used for fast tissue inspection during surgery by specialist doctors.[3] This device is easy to fabricate and provides a low-cost solution for fast and accurate skin cancer detection. The THz tissue method is an efficient technique for the analysis in skin cancer diagnostics.[4] This method has a sub-picosecond resolution and provides information on the phase of the reflected signals by measuring short pulse reflectance from the interfaces. Moreover, a CAD system has been used to diagnose skin cancer, which finds the location of a lesion, and estimate the probability of the disease.[6] The epiluminescence microscopy seven-point checklist can be used to describe the malignancy of a lesion,[8] which allows less experienced observers to achieve high diagnostic accuracy. The automation of skin

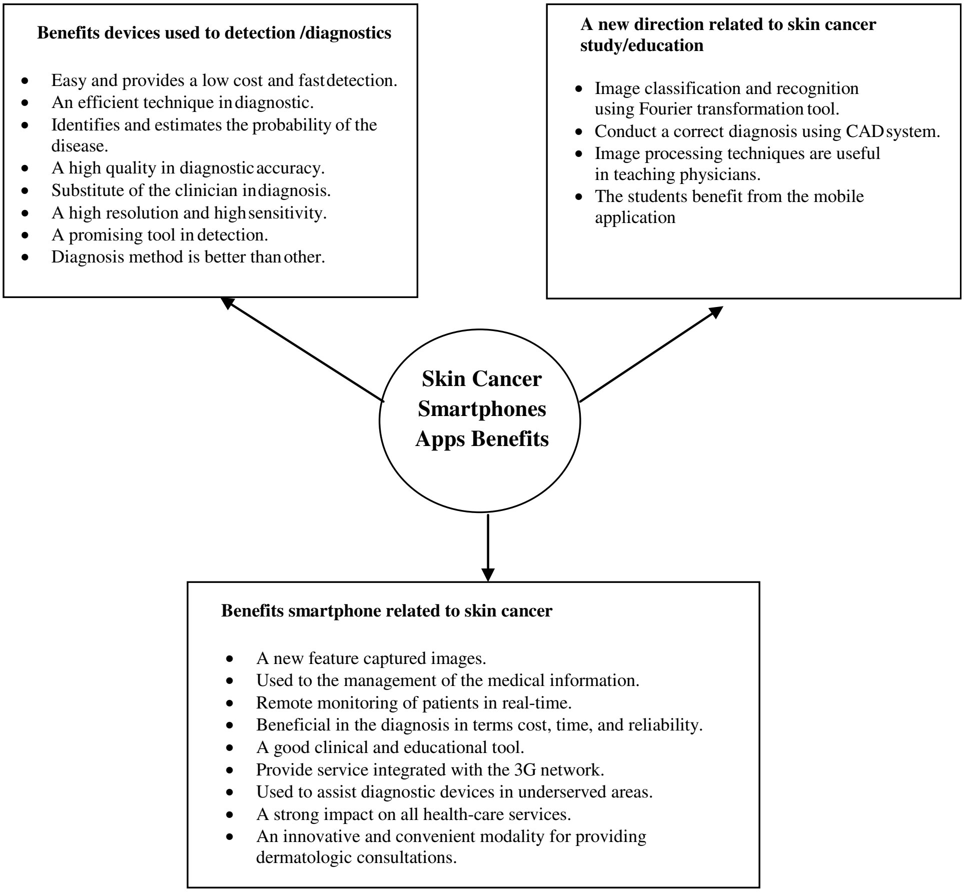

Fig. 6. Benefits categories for smartphone applications based on skin cancer.

cancer detection is designed to reduce the false positive or false negative clinical diagnosis by adding a quantitative observation to the "clinical eye observation."[10] The automated skin cancer system is well suited as a substitute for the clinician in melanoma diagnosis. The finite-difference time-domain method is utilized to detect local variations in the electrical properties of the skin tissue due to the presence of anomalous cells.[18] Using such method allows one to retrieve information about the growth rate of possible melanomas and monitor the risk. Another work presented a two-dimensional scanning resolution technique that combines high resolution and high sensitivity, which are important for the diagnosis of small, early-stage skin tumors.[21] Dynamic thermal imaging with a properly standardized methodology has been proposed and is considered a promising tool for detecting skin cancer.[78] The Roebuck SCAN tool was developed to identify and prevent skin cancer and meet the educational needs of a state council of nurse practitioners.[93] This tool is highly adaptable to different populations who have various levels of clinical competency. The real-time Raman spectroscopy method can be used for vivo (living body) skin cancer diagnosis with the most conservative multivariate statistical methods in the fingerprint region[96] and is equivalent to or better than other diagnostic aids.

4.1.2. *Motives related to skin cancer apps*

A new feature to capture color variation and border irregularity has been proposed for smartphone-captured images.[46] Smart mobile phones have been used in the management of the medical information of patients, such as medical health record access, appointment management, and prescription management, and this technology is considered acceptable.[49] A new m-Health platform called C-SMART was proposed for the remote monitoring of patients in real time.[50] A mobile framework for segmentation dermoscopy images to examine skin lesions through the Windows phone and Android environments may be beneficial in the diagnosis of melanoma in terms of cost, time, and reliability.[51] A mobile-based system developed for Android that uses by a supervised classification method allows the user to capture images using a smartphone camera or load images from a mobile gallery for skin lesion analysis.[52] Mobile phone technology serves as a clinical and educational tool by health-care providers and facilitates patient adherence to treatment and diagnostic requirements.[54] The mobile medical service model has been proposed to integrate medical services with the 3G network. This model works as a new medical approach with the traditional medical treatment and hospital management modes.[55] Smartphones can be used to assist diagnostic devices in routine skin screening in underserved areas and in developing countries, particularly in West Africa, where health-care infrastructure is limited.[56] m-Health applications can have a strong impact on all health-care services, such as hospitals, care centers, and emergency services, especially for the elderly, disabled, and chronically ill.[84] Mobile teledermatology through cellular phones is considered an innovative and convenient modality for providing dermatologic consultations for skin cancer screening.[86] Smartphone apps available only for Apple users have been presented, which aim at minimizing the diagnostic delay experienced by people with melanoma, which may be significantly associated with mortality.[110]

4.1.3. *Motives related to skin cancer study/education*

The use of the Fourier transformation tool has been proposed for studying melanoma lesions, given that it would be useful in image classification and melanoma image recognition.[1] The CAD system provides information, which allows dermatologists to extract proper feature selection methods for making a correct diagnosis of melanoma.[6] Image processing techniques can be used to distinguish melanoma from Clark nevus lesions that are benign, which is useful for teaching physicians to differentiate lesions.[16] Being involved in the development of a mobile application was beneficial to students because they gain the opportunity to participate in real-world projects, instead of only being onlookers.[53]

4.2. Challenges

Skin cancer is a serious disease. Therefore, many developers and researchers have attempted to find quick and easy solutions through the creation of applications to help doctors and patients diagnose the disease early. However, the surveyed works indicated that researchers are concerned about the many challenges associated with skin cancer apps and their effectiveness in health care. The challenges reported for skin cancer apps are discussed below along with the citations of the relevant references to which the reader can refer for the original suggestion on and the further discussion of the challenges. The challenges are categorized into a few groups according to their nature to aid discussion, as shown in Fig. 7.

4.2.1. *Challenges related to biological effects*

Biological effects can impede the diagnosis of skin tumors. The early detection of melanoma is considered one of the greatest challenges faced in dermatological practice[8]; the misclassification of melanoma and non-melanoma *in situ* suggests a considerable overlap between the two categories of melanoma.[16] However, the standard biopsy could cause the dissemination of the cancer cells; thus, this procedure is not advisable in many cases, which includes some cutaneous neoplasties.[19] The detection of early-stage tumors with a $\lambda/10$ characteristic surface size can represent a significant challenge for raw images compared with others.[37] However, the most important risk factor for melanoma is the unprotected exposure to UV radiation,[40] and NSAID use was confirmed to be not associated with NMSC risk. Consequently, the dose–response relationship with a long duration of NSAID use is insignificant.[59] Several studies focussed on the association among tanning bed use and skin cancer, the biological effects of UV radiation exposure, and UV burden, which is considered a major reason for skin cancer.[63,65,88,100]

4.2.2. *Challenges related to smartphone apps*

The use of smartphone apps for medical purposes can have unwanted effects, many of which have been highlighted in the literature. However, challenges related to the apps exist. Reference 28 referred to creating a mobile melanoma detection application that was developed for the Android system only and is an Android Developer Tool as opposed to a development tool for the Apple system, whereas Ref. 45 provided an app that can be employed only on the iPhone 4 device, although many different systems are used in various devices that are currently available in the market. Smartphone images that are captured under loosely controlled conditions for melanoma detection and image processing are often subject to computation and memory constraints.[46] Therefore, the researchers had to learn how to use APIs to

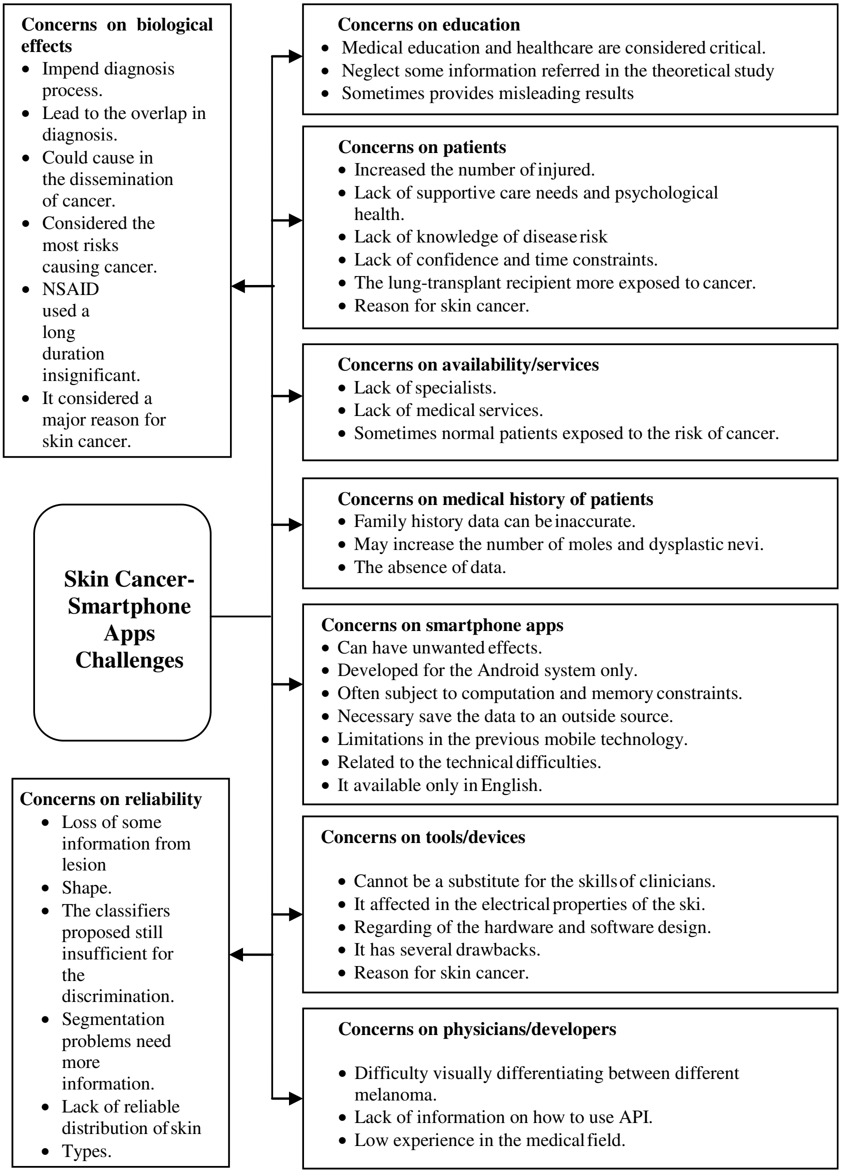

Fig. 7. Challenges categories for smartphone applications based on skin cancer.

gather the necessary information and save such data to an outside source.[53] Reference 55 identified some limitations in the previous mobile technology, in which the quality of the synchronization of audio with video transmission in a moving environment has an impact on the quality of communication, which could be improved by a variable transmission rate and good frequency utilization.[55] The limitation of

Ref. 86 relates to technical difficulties where a number of images were not transmitted instantaneously, which prevented mobile phones from capturing dermatoscopy images, despite the fact that another study that used the same technique was able to improve diagnostic accuracy.[86] However, the study referred to 39 apps that are available only for Apple users for melanoma detection. Another limitation of the study is that the apps were only available in English; therefore, the researchers may have failed to identify apps that were published in other languages.[110]

4.2.3. *Challenges related to patients*

The increase in patients with melanoma constitutes a major challenge in many countries. Statistics have shown that a large number of individuals within a given population have been diagnosed with melanoma, especially the white population, and this trend continues to rise.[41] Moreover, Ref. 57 raised awareness among healthcare professionals about the need for vigilance to identify the supportive care needs and the psychological health of patients with NMSC. However, a significant proportion of patients with NMSC have unmet supportive care needs and have experienced heightened distress levels.[57] Reference 61 validated that albinos make poor use of free and available antiretroviral therapy services because they fear being easily identified and considered a stigma by the community. However, this study has a limitation due to the possible existence of a selection bias because the participation of some of the patients was voluntary. Furthermore, clinical diagnoses are not always confirmed histologically because some patients live outside of the targeted healthcare area.[68] The lack of confidence and time constraints are issues that arise during a patient visit for skin cancer examination. These issues lead to some barriers and a practice gap.[82] However, the weaknesses of this study include a relatively small cohort of patients with a history of non-Hodgkin lymphoma (NHL). These patients are subject to the high recurrence rates of BCC and SCC, even after using Mohs micrographic surgery to remove one skin cancer layer and examining this layer under a microscope immediately.[95] Finally, limited studies corroborated that skin cancers frequently occur in lung-transplant recipients. Therefore, the risk of subsequent skin cancer is increased substantially in patients who develop skin cancer after their transplantation.[103]

4.2.4. *Challenges related to tools/devices*

Various tools and devices have been proposed for helping physicians diagnose various dermatology lesions. Computer accuracy has improved but cannot be a substitute for the skills of clinicians or histopathology.[6,7,70] In one automated method, the resonant frequency in the sensors is significantly affected by the electrical properties of the skin during the diagnosis of the disease.[15] Major concerns exist in relation to the design of the hardware and software of a system to reduce the platform overhead with minimal user intervention and minimal cost.[50] "Due to the subjectivity of human interpretation in dermoscopy images for detection of melanoma, there has been a growing interest in the development of automated systems to help clinical diagnosis."[51] CAD systems for pigmented skin lesions have demonstrated good performance diagnostically, but such systems cannot be used yet to provide the best diagnostic results or replace the skills of clinicians or histopathology to prevent the high recurrence rates of BCC and SCC, even after Mohs micrographic surgery.[95] Laser-induced breakdown spectroscopy (LIBS) can be used as a surgical tool to distinguish melanoma lesions. However, this tool has several drawbacks, such as problems with the beam and detector position and space limitations, which must be overcome before LIBS becomes suitable for practical use in the clinical setting.[99]

4.2.5. *Challenges related to reliability*

A key challenge in terms of reliability is that image segmentation approaches can misclassify pixels as small white spots, which may lead to the neglect of the irregularity in the lesion shape, even though such irregularities are considered by dermatologists to include valuable information for performing manual segmentation.[2,17,31] The overall performance of the proposed classifiers remains insufficient for the accurate discrimination of the combination of colors and textures that may lead to a more optimal classification performance compared with a separate color and texture features analysis.[42] Segmentation problems need more information in one spectral band compared with color images that have three spectral bands of color.[44] Moreover, the absence of a reliable distribution of different skin types in different populations and adjustment for skin color are also desired by dermatologists.[60]

4.2.6. *Challenges related to education*

Medical education and health care are considered major and pertinent issues when talking about reliable mobile phone infrastructure, which could provide the ideal framework for m-Health initiatives.[54] A theoretical study pointed out that subsurface blood flow causes an overall reduction in the performance of the frequency-modulated thermal wave imaging technique, which could be a limiting factor for the diagnosis of small volume lesions. Therefore, researchers should not neglect this aspect during the theoretical study of subsurface blood flow, which often causes an overall reduction in the performance of the detection of the disease.[58] Observational studies can sometimes produce misleading results regarding the connection between tanning bed use and melanoma and thus present erroneous results.[106]

4.2.7. *Challenges related to physicians/developers*

Many physicians and developers interested in health care have highlighted the problems in diagnosing various forms of skin tumor. Physicians have difficulty visually differentiating between melanoma and Clark nevus lesions, which are benign.[26] However, the challenges faced by developers depend on the platform they use when implementing the use of an API because they have to learn how to use APIs to gather the necessary information and save such data to an outside source.[53] Reference 79 proposed a CAD system that can be effectively used to diagnose skin cancer accurately. This tool is substantially useful for rural areas, because experts in this medical field may not be available.[79]

4.2.8. *Challenges related to availability/services*

Health-care services face some challenges because of the lack of specialists working in the field of melanoma detection. Therefore, the use of free and available antiretroviral therapy services for albinos is poor.[61] The lack of medical services for the diagnosis of skin cancer in remote areas in poor and developing countries presents a great challenge in terms of the availability and efficacy of health-care services.[83] Dermatology patients presenting for regular care are often exposed to the risk of skin cancer.[101]

4.2.9. *Challenges related to medical history of patients*

Knowing the medical history of a person and their family is crucial in the diagnosis of tumors in some patients with skin cancer. The absence of a family history for the evaluation of skin cancer cannot be replaced by objective methods. Moreover, some self-reports of family history data can be inaccurate,[73] but the number of moles and a typical or dysplastic nevi may increase because of the personal or family history of melanoma and exposure to UV radiation. The risk of skin cancer can increase[90] in the absence of data. Assumed historical trends in melanoma can be a reasonable proxy for future cases of melanoma and NMSC.[91] However, the weaknesses of this study include a relatively small cohort of patients with a history of NHL who are subject to high recurrence rates of BCC and SCC, even after Mohs micrographic surgery.[95]

5. Recommendations

We briefly provide some recommendations from the literature that aim to mitigate the challenges faced by developers, physicians, designers, and patients and simplify ways to achieve accurate diagnosis and prevent the occurrence of various skin cancers, as shown in Fig. 8.

5.1. *Recommendations to developers*

Many of the recommendations must be followed by developers because the development of different systems and devices helps patients and physicians alike. They can introduce further improvements using a segmentation process based on classification methods, such as the well-known support vector machine, which can be merged with the proposed segmentation approach through a majority voting system.[2] The refinement of current approaches and the development of new techniques

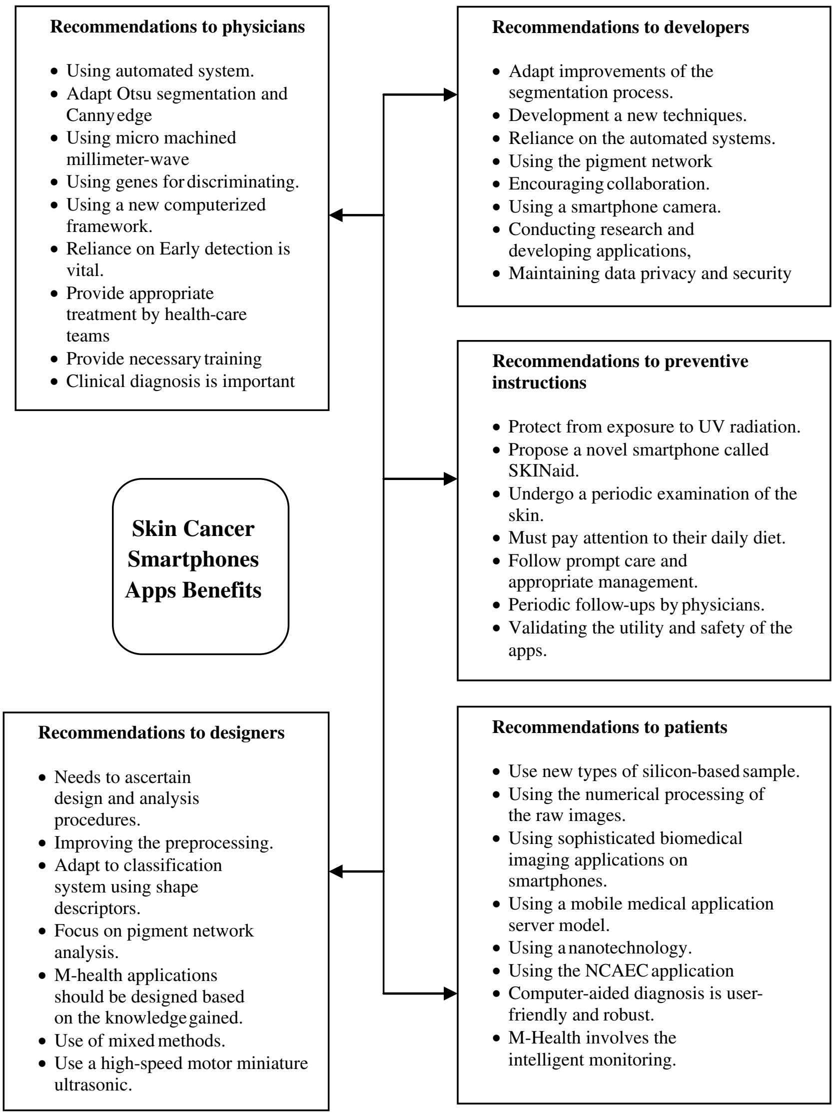

Fig. 8. Recommendations categories for smartphone applications based on skin cancer.

help in improving the ability to diagnose skin cancer and in achieving a significant reduction in the melanoma mortality rate.[6]

Classification methods play a significant role in building and developing reliable automated systems for the diagnosis of skin lesions.[10] For example, the development of the curvelet and using other methods can increase the accuracy of classification results.[32] Furthermore, the accuracy of classification could be improved by extracting novel features using the pigment network.[39,40,46] Therefore, encouraging nationwide collaboration is necessary for the full development of the C-SMART platform, which enables the optimal sharing of medical databases and medical applications among authorized medical staff or patients and their family members.[50] Developing a version of a skin cancer detection application using a smartphone camera, allowing doctors to test this application on real patients and input, and determining whether they agree with the automatic analysis are important.[52] Moreover, conducting research and developing applications that aim to bring the technology to underserved populations is beneficial to students who can participate in the real-world projects.[53] Reference 68 conducted an awareness-raising campaign specifically for golfers and golf course workers who are a key target population in the prevention of skin cancer. One key factor in the success of the campaign was the fact that such campaign was carried out at the site of risky behavior. Another factor was the development of a multi-component intervention model that included innovative techniques and a motivational strategy.[68] Moreover, the development and testing of pigmented skin lesion classification systems through the creation of a benchmark data set are of utmost importance.[70] Maintaining data privacy and security is, hence, a major issue in information management for patients and health professionals.[84]

5.2. *Recommendations to physicians*

Physicians are considered a critical component in the treatment and diagnosis of various diseases, particularly dermatological lesions. Inexperienced dermatologists often use an automated system that helps them make highly accurate diagnosis.[8] Otsu segmentation and Canny edge detection are considered the best approaches to support physicians in the diagnosis and detection of melanoma.[17] Reference 21 presented a micro-machined millimeter-wave near-field probe that combines high resolution and high sensitivity, which are important for the diagnosis of small, early stage skin tumors. The micro-machined tapered-tip probe has a two-dimensional scanning resolution as small as $1/6\,\mu$m of the medium-normalized wavelength.[21] Moreover, tests support the generalization ability of classifiers using the genes presented for discriminating malignant from benign samples,[25,27] and clinicians depend on the new computerized framework to automatically extract and measure the five features from skin lesions and accurately classify them as benign or malignant.[34] Early detection is vital, especially concerning melanoma, because surgical excision is the only life-saving method for patients with skin cancer.[41] Health-care teams provide appropriate treatment, which can make a difference in the lives of patients during the treatment of skin malignancy by recognizing patient needs and related cancer concerns.[57,92] Training facial surgeons and dermatologists to offer HIV treatment services, especially to albinos, is necessary.[61] Clinical diagnosis is important at high sensitivity to reduce unnecessary biopsies, which can be readily used for the diagnosis of other types of cancer.[96] The skills of dermatologists must also be improved with continued attention given to value-driven dermatologic care, which can motivate through improved patient outcomes and financial sustainability.[101]

5.3. *Recommendations to designers/developers*

Designers provide various necessary solutions that help physicians and users overcome technical problems encountered using various medical devices. A good designer needs to ascertain which design features and analysis procedures are likely to lead to a good model.[7] Improving the pre-processing and processing parts of the automatic removal of the black frame using reaction-diffusion cellular neural networks and cellular automata makes hair wire removal efficient for signature extraction using natural computing and for the location of useful genes to eliminate artifacts.[24] The classification system using shape descriptors is fairly robust to a change in the segmentation method. Enriching these shape descriptors with the best set of texture and color features is thus interesting and can be applied to larger databases.[31] Accordingly, designers should focus on pigment network analysis to extract new efficient features and test the system with a different large data set.[35] Moreover, m-Health applications should be designed based on the knowledge gained, which allows the model to fill the gap between the intention to use an m-Health application and the actual usage of m-Health applications in the medical domain.[49] However, the optimal design for any project depends on the use of mixed methods to provide the most complete and useful information during the planning stage and to manage the time, money, and expertise needed for the project.[64] The design of a high-speed miniature ultrasonic motor that can be used in handheld mode that is integrated with a photoacoustic and ultrasound imaging system modality would hence be useful to visualize the multiple features of melanoma.[109]

5.4. *Recommendations to patients*

Many patients with different kinds of skin cancer need considerable advice and recommendations that can direct them to follow safe and healthy practices in their daily lives. Advanced algorithm classifications are applied together with intensive tests on THz images of skin cancer.[11] The potential uses of the systems in biomedical approaches aim toward cancer therapy *in vivo*.[14] New types of silicon-based sample can be used, which can be tailor-made to mimic the dielectric properties of the tissue of different water contents and remain stable over the long term.[32] The accuracy of tissue discrimination can be substantially enhanced using the numerical processing of the raw images based on correlation algorithms that facilitate a transition from the proposed technique to clinical practice.[37] Using sophisticated biomedical imaging applications on smartphones has advantages, such as portability and low cost; therefore, these applications can have a significant impact on health-care delivery as assistive devices in underserved and remote areas.[45,56] The methodology and techniques presented in Ref. 47 are useful and efficient in the domain of classification and feature selection for various diseases. This research is devoted to applying this methodology to the analysis of microarray gene expression data to find the most important descriptive genes for investigating the disease. This approach is a part of a very intense domain — bioinformatics.[47] However, the mobile medical application server model, which is for intelligent terminals under the 3G network environment, provides customers with a quick and convenient medical treatment and health information consulting service by analyzing the characteristics of the existing mobile network and the current development of mobile medical treatment. This model works perfectly with a system and achieves interoperability with the hospital management system.[55] Computing phase information is presented to transform raw thermograms into phasegrams; the merit of this imaging method is the clear differentiation of different melanoma stages[58] while using nanotechnology, which provides an exceptional opportunity on the molecular scale through a specific interaction with cancer cells and the inhibition of their function with several formulations used in medical practice, which have become the standard for care.[71] Using the NCAEC application for secondary aesthetic improvement in complex facial defects is a concise and proven method.[72] Multimedia text messages are more flexible compared with an SMS program design, which allows participant input into new program features.[76] CAD is user-friendly and robust for images acquired in any condition and can facilitate the automatic diagnosis of skin cancer.[79] m-Health, which involves the intelligent monitoring of patients, can lead to improved health outcomes and lowered health-care costs[85]; thus, the widespread use of cellular phones and the expansion of wireless networks lead to meaningful integration and innovative telemedicine.[86]

5.5. *Recommendations on preventive instructions*

One of the most important aspects in maintaining human health is the prevention of widespread diseases around the world, which can be achieved by following instructions and recommendations. Unprotected exposure to UV radiation and consuming certain foods are considered the most important risk factors for skin cancer. Reference 38 proposed a novel smartphone-based virtual reality system named SKINaid to help in skin cancer prevention and pain treatment. The study used image processing techniques that focussed on identifying/classifying the food items in the prevention stage[38]; the potential chemoprevention effects of NSAIDs should be considered for subjects with a prior history of NMSC.[59] Avoiding UV radiation is also necessary, given its potential to reduce the incidence of skin cancer, particularly in the fair-skinned population.[60,65] Therefore, health-care providers must educate parents on the risks of indoor tanning and encourage parental contribution to discussions on tanning bed avoidance.[63,106] Patients must undergo a periodic examination of the skin, and various clinical and environmental factors must be assessed as part of the follow-up in transplant recipients.[67] Skin cancer patients must also pay attention to their daily diet and sun exposure and exercise the close surveillance of these factors.[81,82,87,100] For prompt care and appropriate management, frequent follow-ups are necessary to decrease the chance of recurrence and the possibility of subsequent metastasis in NMSC patients.[95] The preventive aspect is covered in Ref. 103, which advocates educating the infected persons about UV protection and the importance of self-examination of the skin and periodic follow-ups by physicians to aid the early detection of skin cancers, especially among patients with a lung transplant.[103] Patients with malignant skin cancers should also be managed in a multi-disciplinary setting, which has a plastic and reconstructive surgeon, a dermatologist, an oncologist, and a histopathologist with particular expertise in dermatopathology.[104] Validating the utility and safety of the apps used by clinicians are important in providing information to educate their patients and their potential usefulness for melanoma detection.[110]

6. A New Research Direction

With the exception of the 110 papers reviewed earlier, the new direction of this research will be described in this section. The supporting reviews are presented as follows.

The health-care system primarily uses the Internet to facilitate the remote exchange of digital medical images and information among hospitals and clinics, as well as to provide e-health services to patients.[111–119] Medical information systems offer vital information, including complex data sets, such as medical annotations, clinical examinations, diagnoses, doctor's findings and opinions, and prescriptions with scanned images related to the clinical examinations of patients.[120] Digital medical images, e.g., ultrasound, computed tomography (CT), electrocardiography (ECG), magnetic resonance imaging (MRI), X-ray, and skin cancer images, are fundamental to the diagnosis and treatment of various diseases. Therefore, ensuring security in the storage, transmission, processing, and analysis of medical images without violating the code of ethics for health information professionals is vital,[121] given that the risks of protecting medical information increase, particularly over the Internet.[122–127] This condition imposes three mandatory characteristics: confidentiality, reliability, and availability. Another key requirement is that a medical image should not undergo any degradation that will affect diagnosis based on the image. In general, medical images must remain intact, without any visible alteration from their original form, to fulfill this requirement. To achieve the aforementioned objectives, health authorities and information security experts direct considerable attention toward the use of information concealed either by digital watermarking or steganography in medical images as a technique to enhance data security, image fidelity, authenticity, and content verification in e-health environments, where images are stored, retrieved, and transmitted electronically.[128] A key objective of information concealment either by watermarking or by steganography is to embed data into different multimedia files, including image, audio, video, and text formats.[129–1]

[2] The embedded information can include data regarding hospitals, patient records, and diagnostic information, among others.

The watermarking or steganography of medical images requires more care than that of other image types. Unlike in natural image watermarking or steganography, distortion is unacceptable in medical images because even a slight change may mislead forensic pathologists. That is, when additional information is embedded into medical images, such information should not affect image quality.[163,164] Accordingly, appropriate techniques should be established to achieve a trade-off between payload and imperceptibility,[127,165–167] thereby allowing clinical diagnosis to be performed properly on watermarked or stenographic medical images.[168] Several important constraints should be satisfied in dealing with the watermarking or steganography of medical images. When information is embedded into the host image, distortion is generated. Such distortion is highly undesirable in medical applications, in which even a small distortion in an image, such as an MRI or X-ray image, may affect the diagnosis of a physician. Accordingly, information should not only be extracted from the image, but the original image should also be restored completely. Reversible watermarking or steganography satisfies the aforementioned requirement. This technique can restore the exact state of the original image. An effective means to embed information into a medical image is to define a region of interest (ROI), which contains important information and should be stored without any distortion.[169] Therefore, medical images typically comprise an ROI and a region of non-interest (RONI). The ROI sections of an image include significant information for diagnosis and thus should remain intact during the embedding process. The remaining sections of an image are called RONI. Concealed information may be embedded into such sections.[170,171]

Our critical review of information concealment presents watermarking and stenographic approaches for medical images. However, these approaches focus on X-ray, ECG signals, CT scan, MRI (shoulder), CT (abdomen), MRI (knee), broadcast printing, fingerprinting, scanning electron microscopy, and radar images.[127,168–178] This condition results in the incomplete coverage of the watermarking area for medical images. To date, no particular study on any type of skin cancer images, either taken from a hospital setting or based on Smartphone apps, is available.

To perform such study, the segmentation of the ROI from skin cancer images is vital as the first step in medical image analysis (MIA) because the error resulting from segmentation is transferred to later MIA steps. This task is considered difficult due to the complexity of the involved anatomical features. The ROI may not be separated from its surroundings because of gray-level inconsistency and the absence of sharp edges along its border.[179] This condition generates distortion in the image after watermarking. Therefore, an appropriate segmentation method is necessary. The most suitable segmentation method that can be used is the application of skin detectors, given that skin pixels comprise the background of skin cancer images. However, the segmentation of a colored skin image remains the most difficult image processing task in many applications, such as in pornographic image filtering,[180–184] face detection,[185] human motion analysis,[186] and watermarking and steganography.[188–190] Moreover, skin detectors are difficult to apply in skin cancer cases[187] because skin color and skin-like color objects, such as hair, presented in a captured image become uncontrolled and pose problems for skin detectors.[191] Consequently, skin detection may involve errors, and false detection occurs due to the failure to identify non-skin objects with skin-like color pixels.[192] Another challenge originates from the fact that the appearance of skin color in an image depends primarily on lighting conditions to provide the geometry of illumination and color at the time an image is captured.[193] Maintaining color consistency is yet another problem and a major challenge in skin detection.[194] Color should be presented invariantly or at least in a manner that is insensitive to changes in lighting conditions. That is, the choice of color space significantly affects the performance of any skin detector and its sensitivity to changes in lighting conditions.[195] Therefore, appropriate techniques for solving skin detection problems are necessary, given that the ROI, which contains sensitive information, should be avoided when embedding a watermark to maintain image quality. Image segmentation should be performed properly to obtain the determinant characteristics of a disease or a subsequent lesion.

7. Limitations

The most pertinent limitation of this survey is the number and identity of the source databases, although the selected sources are a good and broad representative collection. Moreover, the fast progress in this field hardly allows for any timeliness in a survey. Furthermore, the fact that a snapshot of the research activity on this vital trend of skin cancer apps does not necessarily reveal the reality of app use or impact reflects the response of the research community to the trend, which is the main objective of this study.

8. Conclusions

The provision of adequate health care for patients with skin cancer has become a global concern. Skin cancer is the most dangerous type of cancer and is widespread among people because of the late diagnosis of the disease and the excessive exposure to UV radiation by fair-skinned individuals. Research on the trend of using a smartphone app to detect skin cancer is already active. Therefore, insights into this emerging field are needed. This article aimed to contribute such insights through surveying and taxonomizing the literature. Specific patterns were identified from the studies on skin cancer apps, and these works were roughly classified into four distinct research categories: development and design, analytical studies, evaluative and comparative studies, and reviews and surveys. Research studies on the attempts to develop skin cancer app development and broad framework proposals also exist.

Some domains have received more attention compared with others from researchers (e.g., public health), and some functions have been of great or less interest (e.g., health reference materials). These domains and functions reflect the type of articles on the topic of skin cancer apps, but give a clear indication about the gaps in this field in terms of development and evaluation. Researchers have described the challenges they have faced, and many have made recommendations in resolving the existing and anticipated challenges, the list of which opens up many opportunities for further research in this field. Other researchers have proposed that some studies should initially focus on the functional aspects of the technology (the usefulness of medical apps) and leave the non-functional requirements (e.g., preventive strategies) at a later stage. Additionally, the new direction of this research has been explained. Currently, no fastidious study presents watermarking and stenographic approaches for any type of skin cancer images based on Smartphone apps.

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