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REVIEW PAPER

# A review on smartphone skin cancer diagnosis apps in evaluation and benchmarking: coherent taxonomy, open issues and recommendation pathway solution

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## Abstract
This research aims to review the attempts of researchers in response to the new and disruptive technology of skin cancer applications in terms of evaluation and benchmarking, in order to identify the research landscape from the literature into a cohesive taxonomy. An extensive search was conducted for articles dealing with 'skin cancer', 'apps' and 'smartphone' or 'mHealth' in different variations to find all the relevant articles in three main databases, namely, "Web of Science", "Science Direct", and "IEEE explore". These databases are considered wide enough to cover medical and technical literature. The final classification scheme outcome of the dataset contained 110 articles that were classified into four classes: development and design; analytical; evaluative and comparative; and review and survey studies. Afterwards, another filtering process was achieved based on the evaluation criteria error rate within the dataset, time complicity and reliability, which are used in skin cancer applications. The final classification scheme outcome of the dataset contained 89 articles distributed in mapping and crossover with four sections concluded from 110 articles. Development and design studies, analytical studies, evaluative and comparative studies and articles of reviews and surveys comprised of 48.3146%, 22.4719%, 16.8539% (15), and 12.3595% (11) of the reviewed articles, respectively. The basic features of this evolving approach were identified in these aspects. We also determined open issues in terms of evaluation and benchmarking that hamper the utility of this technology. Furthermore, with the exception of the 89 papers reviewed, the new recommendation pathway solution was described in order to improve the measurement process for smartphone-based skin cancer diagnosis applications.

**Keywords** Skin cancer diagnosis, evaluation and benchmarking, smartphone · Mobile health · Real-time apps

## 1 Introduction

Interest in the topic of skin cancer has grown in past years 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 rapidly rising recently. The incidence rate of melanoma has significantly increased. Therefore, melanoma has received considerable awareness from the cancer research field, public health field and medical prevention campaigns. Melanoma is a major and the deadliest type of skin cancer, causing approximately 70% of deaths due to skin cancer worldwide [1]. The main cause of skin cancer injuries that largely affects the epidermal layer of the skin is prolonged sun exposure. Malignant melanoma (MM) is a major type of cancer and requires expensive treatments, and several researchers have conducted various adaptation strategies for soft computing technologies for its diagnosis and early treatment [2]. Nevertheless, two major issues are faced by developers of skin cancer applications. Firstly, is how skin cancer applications can perform multi-criteria evaluation. Secondly, is how novel skin cancer apps are benchmarked

Highlights
• Mapping the research landscape of skin cancer diagnosis apps based evaluation and benchmarking into a coherent taxonomy.
• Highlight the open challenges that hinder the utility of skin cancer diagnosis apps based evaluation and benchmarking.
• Recommendations pathway solution to improve the acceptance of skin cancer diagnosis apps based evaluation and benchmarking

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versus other current apps. This particular area of evaluation and benchmarking are considered a challenge and a gap in existing literature.

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 focuses on the use of mobile technology, that is, smartphones or mobile phones, to detect skin cancer [3]. Many developers have shown increasing attention on creating computer visibility algorithms that run in the smartphone environment because of the transportability and portability of smartphones. Consequently, smartphones have offered good environment for the development of several and diverse new-generation apps that use computer algorithms [4]. The development of smartphone apps for the partition of dermoscopic pictures to check skin cancer will be useful in the diagnosis of melanoma to save time, accuracy and reliability of treatment and cost [5]. The current study aims to increase the reliability of evaluation usability by several researchers. Thus, in future investigations, focusing on conflict among criteria and defining their procedure reflected in the evaluation and benchmarking processes is necessary. A comprehensive review of literature is also needed to identify the limitation of applying the mentioned criteria for studies on skin cancer apps.

Smartphones, which are commonly known as feature phones, refer to mobile phone devices that are smarter than the previous generations of cell phones. These advanced devices have been adopted on several criteria in evaluating software on which they operate as in terms of reliability, time complexity and error rate [6, 7]. This smart feature is due to the close resemblance of smartphones with personal computers. Smartphones exhibit substantial computing power, several connectivity characteristics, advanced operating systems, complete internet access and the capability to setup and run third-party apps. This ability extends the versatility and utility of smartphones given that they offer users new ever-evolving functions. Nevertheless, smart mobile phones are not only scaled-down version of PCs but are also more portable compared with laptops. This scenario presents the concept of context to smart mobile phones in terms of location, ambience and user actions. Accordingly, the progress in smartphones has improved health sciences and awareness on the significance of a healthy lifestyle [8].

The camera feature in smart mobile phones is an innovative development that has been incorporated into a low-priced smart mobile phone-based intelligence system to allow people to obtain images whenever and wherever. Smartphone cameras can help people in isolated communities and poor and developing nations because they can be used to scan, analyse and perform systematic skin check-ups anytime and anywhere [9]. The camera is one of the most important parts and is subject to evaluation criteria based on the images taken. Therefore, captured images are analysed and evaluated based on accuracy, computation time and error rate [8, 10]. An app that runs on a smartphone with a camera can obtain pictures of skin abnormalities. The image of the lesion can be sent from the smartphone to a central server/computer, which uses a colour- and symmetry-based analysis based on artificial intelligence (AI) algorithms to classify the image as benign or malignant. Such a system has been developed to present a perfectly functional feature-rich software app with a clear graphical user interface for analysing skin pictures [11].

This paper aims to elucidate research efforts in using three main criteria to evaluate and benchmark these studies, such as those mentioned above in response to the new and disruptive technology; map the research landscape from the literature into a coherent taxonomy; and discover key features that characterise this emerging line of research.

## 2 Methods

The most significant keyword in the area covered by this article is "apps." However, in our search for apps, we excluded non-m-Health applications, such as those found on personal digital assistants, and non-apps, such as SMS used by conventional mobile phones. In addition, we considered all healthcare-related areas that focus on skin cancer and research in this field but limited our domain to literature in the English language. Three article databases were utilised for the related article search: (1) "Web of Science (WoS)", which provides cross-disciplinary research in various topics, including sciences and social sciences, electrical and electronics approaches and arts; (2) "IEEE Xplore", a scholar database offering consistent articles in computer science and electronic engineering; and (3) "ScienceDirect", a large scientific technique database. This selection covers medical and technical literature and provides a broad show of the efforts of researchers in a broad but pertinent range of disciplines. Research variety involves a literature source search and is grouped into two rounds. In the first round, three screening and filtering iterations were performed. In the first iteration, duplicates were removed. All unrelated articles were then removed through an investigation of titles and abstracts. Finally, an intensive review of whole-text articles was filtered from the second iteration. The three iterations utilised similar criteria of eligibility followed by authors. In the second round, an iteration of screening and filtering based on the criteria was performed and was used in the evaluation and diagnosis of skin cancer aspects for all papers obtained from the first-round iteration. Subsequently, the final included set was related to the evaluation criteria forskin cancer based on smartphone apps. The search was performed through the search engines of "ScienceDirect, IEEE Xplore, and WoS" by entering various keywords into their search boxes. In this search, we utilised a mix of keywords consisted of the terms "skin cancer," "m-Health," "healthcare," "smartphone," and "apps" in several variations combined by the "OR" operator. Figure 1 shows the query text. The advanced search specifications in the indicated databases were utilised to exclude chapters of books, correspondence, letters and short communication. Latest scientific research related to the tremendous trend in smartphone app use in skin cancer evaluation could also be accessed. Each article that met the criteria based on two rounds was included. In the first round, the authors determined an initial target of mapping the scope of research on skin cancer apps into a general and coarse-grained taxonomy of four classes. These classes were derived from a pre-survey of the literature without constraints. Google Scholar was utilised to initially determine the landscape and trends in the literature. After the exclusion of duplicate articles, some articles were removed in both filters and iterations if they did not fulfil a set of inclusion criteria. The exclusion criteria are as follows: (1) the article is non-English; (2) the focus is on particular aspect of smartphone use, such as social networking; and (3) the target is skin cancer diagnosis with m-Health rather than smartphone apps particularly. In the second round, we set a highlight of the most common criteria utilised by researchers in the evaluation for skin cancer process. We highlight three main measurements as in "reliability, time complexity and error rate". The reliability group contains three sub-groups: (1) matrix parameters including TP, FP, TN and FN; (2) relationship parameters consisting of precision, recall, accuracy and specificity; and (3) behaviour parameters comprising G-measure and F-measure. The error rate group consists of the training set and validation set within a dataset in addition to the time complexity. These criteria considering an important measurement for evaluating is currently used in most studies. The final group of articles were analysed and outlined in Word and Excel files. Furthermore, taxonomy was utilised to classify the articles with numerous comments and highlight collection. The proposed taxonomy consists of two phases. The first phase (Fig. 2, left) contains four main classes, namely, development and design, analytical studies, evaluative and comparative studies and reviews and surveys. The second phase (Fig. 2, right) illustrates multiple criteria for evaluating the skin cancer apps.

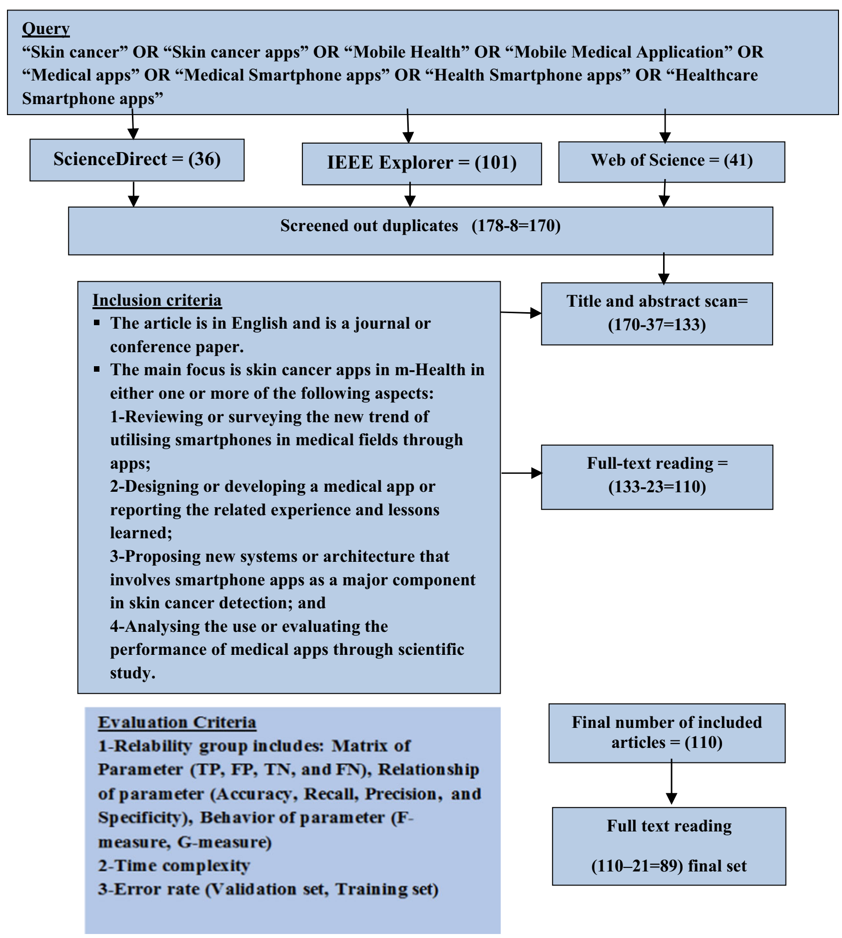



**Fig. 1** Flowchart of study selection, which includes the search query and inclusion criteria

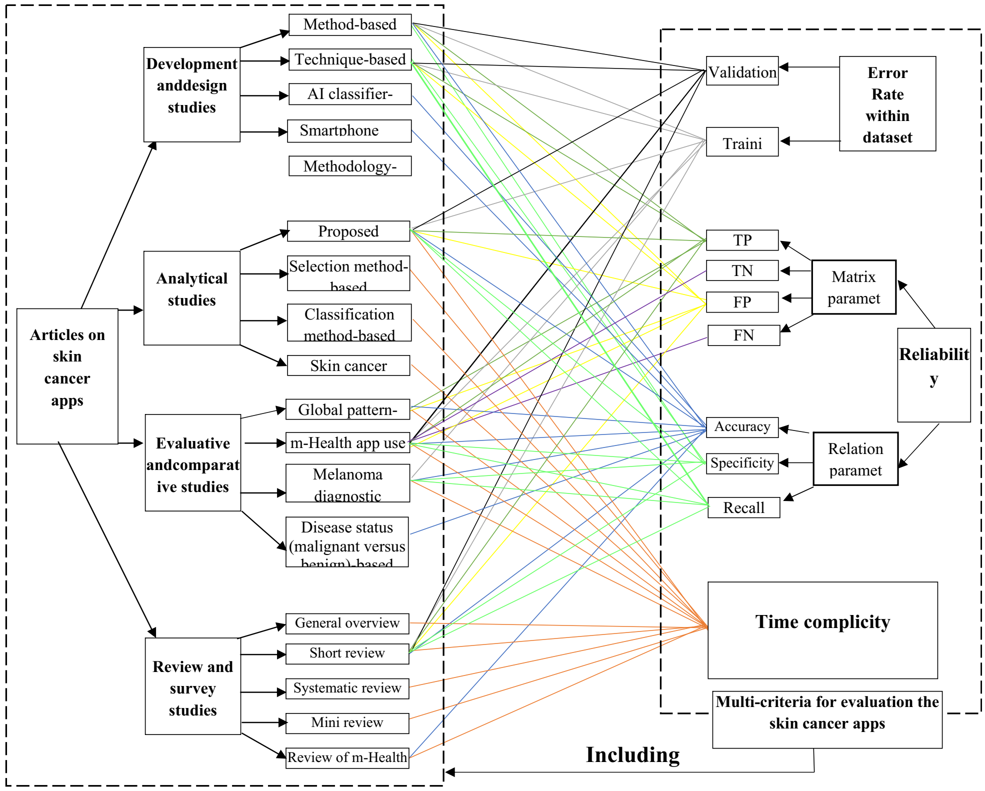



**Fig. 2** Taxonomy of literature on the evaluation criteria forskin cancer apps for smartphones

## 3 Results

The result of initial query search was 178 articles published in 2011–2016: 36 articles from "ScienceDirect", 101 from "IEEE Explore" and 41 from "WoS". Only 8 articles were duplicates across all three libraries. After the scan of the titles and abstracts, 37 further articles were excluded, thereby resulting in 133 articles. The whole-text reading resulted in the exclusion of 23 additional articles Resulting 110 articles for the semi-final included set were read accurately for developing a general map of the research applied on this emerging topic. Out of the 110 articles, 46 (41.81%) focused on the development of various AI algorithms and actual attempts to develop or design medical apps that assist in the prevention and early detection of MM [12]. A total of 28 (25.45%) articles involved analytical studies on the incidence of skin cancer, the classification of malignant cancer or benign cancer and methods for prevention and diagnosis. A total of 22 (20%) articles consisted of studies that range from evaluative or comparative study of apps to the exploration of features designed for skin cancer detection. A total of 14 (12.72%) articles comprised reviews and surveys that referred to actual apps or literature describing medical apps for a specific skin cancer or other diseases or providing a general overview of the technology. Afterward, another filtering process was conducted based on the evaluation criteria of error rate within dataset, time complicity and reliability, which are used in skin cancer apps. The final classification scheme outcome of the dataset contained 89 articles distributed in mapping and crossover with the following four sections from the 110 articles [146]: 43 (48.3146%) development and design studies, 20 (22.4719%) analytical studies, 15 (16.8539%) evaluative and comparative studies, and 11 (12.3595%) reviews and surveys. Figure 2 presents the taxonomy used to review the articles focusing on multiple criteria for evaluation skin cancer apps (right) distributed on the four classes (left), namely, development and design, analytical studies, evaluative and comparative studies and reviews and surveys. The following sections present the classes for statistical analysis.

### 3.1 Development and design studies

Given the growing interest in the topic of skin cancer, most of the articles (46\110) involved the medical society and the performance of descriptive statistics to comprehend this field [12]. On the other hand, in the current study, we performed a new filtering strategy to obtain a decreased number of articles (43\89) based on three main criteria, namely, reliability, time complexity and error rate, to evaluate several studies within the skin cancer field. These articles distributed on the groups describe different directions according to their study with criteria used in the evaluation.

Some of the articles [6, 8, 10, 13–17] described the development and design of various methods and techniques used to detect and diagnose skin cancer based on three criteria, namely, reliability, time consumption and training and validation.

Others [11, 18–22] used only two criteria, namely, reliability, training and validation and testing to evaluate the systems developed in mobile devices and AI algorithms in the diagnoses of skin lesions. Some articles [23–26] also used two criteria, namely, reliability and time complexity, to evaluate techniques designed and developed to be very appropriate for the diagnosis of MM. Others [3, 5, 27, 28] used computation time and training and validation to evaluate mobile-based prototype to analyse skin lesions. One criterion, namely, time complexity, was used to evaluate and develop a novel two-frequency approach for noninvasive MM [29–37], whereas others [38–43] used the same criterion to evaluate m-Health applications to assist clients to inhibit skin cancer development by an immediate alarm. The last group of articles [44–49] adapted reliability criterion to evaluate different methods and devices developed for treating skin cancer.

## 3.2 Analytical studies

The second largest class of articles (28/110) [12] comprised analytical studies that attempted to classify various tumours that infect the skin. However, the second iteration implemented in this study to obtain a narrow new number of articles (20/89) used different criteria to evaluate their study within skin cancer apps.

The first group of articles [50–53] used two criteria, namely, reliability and time complexity, in evaluating the potential to detect skin tumours. Two articles [54, 55] used reliability and error rate to evaluate features, yielding the best classification accuracy for malignant and benign classes in skin. Some [56, 57] used reliability criterion in evaluating the methodology and techniques as useful and efficient in the medical approach to determine the stage of malignancy by determining the quantifier asymmetric index of the MM. Some [58–60] used time complexity criterion in evaluating patients who are exposed to the UV radiation, which often increases the risk of skin cancer. Others [61–63] also used the time complexity criterion in evaluating the devices of microscopy imaging to analysing immune contexture in human skin cancer, which is a significant factor for the diagnosis and treatment of early-phase melanoma. One article [64] used time complexity criterion in evaluating the results for algorithms used in analysis and compare different images. Another article [65] used time complexity criterion in evaluating immunosuppressive agents, which may heighten NMSC risk in children and young adults. Another [66] used time complexity criterion to evaluate family history that with melanoma, especially the carriers of mutations in the CDKN2A gene or MC1R genotype, which are considered a significant element in the diagnosis and assessment of disease hazard during the developmental stages of a malignancy. Another [67] used time complexity criterion to evaluate “Raman spectroscopy in vivo skin cancer diagnosis” according to wave numeral. One [68] used time complexity criterion to evaluate provisions requiring adhere to exposure limits, which is correlated with rising hazard of melanoma/non-melanoma skin cancer. The last article [69] used the error rate criterion to evaluate groups of neoplasms (skin cancer) with enough classification features, which can be considered one category of a tumour that fundamentally varies from Clark Nevus.

## 3.3 Evaluative and comparative studies

Several studies (22/110) [12] describing skin cancer apps attempted to collaborate in the new direction to evaluate and compare these apps and involve mostly professionals from health-care disciplines. Following this study, we used a second filter to narrow down the number of articles (15/89) based on reliability, time complexity and error rate.

Two articles [1, 7] used multiple criteria, which are time complexity, error rate and reliability, to evaluate different mechanisms for the classification of skin cancer according to native and universal strategies for the detection of skin cancer by using different classification methods. Two articles [9, 70] used reliability and time complexity to specifically evaluate the m-Health system using smartphones, which are considered as an innovative and convenient modality for providing medical consultations for people with skin cancer. Two articles [2, 71] used reliability in evaluating 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. Others [72–74] also used the reliability criterion to evaluate different imaging features for skin cancer detection system based on dermoscopy images and filters. Some articles [75–79] used time complexity criterion only to evaluate the techniques and methods for the early detection of risk and prevention of skin cancer and presented a standardised report to clinicians and their patients to offset the perceived time and inconvenience. The last article [80] used the error rate criterion in evaluating the methods to determine the universal pattern which a lesion introduces by modelling in various ways by using different classification methods.

## 3.4 Reviews and surveys

The final and smallest set of articles (14/110) in taxonomy [12] consisted of reviews and surveys of the literature about skin tumours and apps.

The article [81] used three criteria, namely, time complexity, error rate and reliability to evaluate a study involving all the procedures needed for developing an automation diagnostic application for skin cancer detection. The article [82] used reliability and time complexity to evaluate computerisation of skin cancer detection, which can decrease the clinical diagnosis at clinical eye observation. Another [83] also used reliability and time complexity criteria in evaluating the significance of intelligent phone applications for skin cancer detection by patients with skin cancer. Others [84, 85] used time complexity criterion only to evaluate the skin physiology and various surgical and non-surgical management of skin cancers associated with the risk of a cutaneous melanoma and NMSC. Others [86, 87] also used time complexity criterion to evaluate the work on the link between tanning bed use and skin cancer specifically and the biological impacts of UV radiation disclosure, which is related with cutaneous malignancy and indoor tanning. An article [88] also used reliability criterion to evaluate a short review of the experimental results and medical expertise gained in the auto fluorescence diagnosis of benign, dysplastic and malignant skin neoplastic tumours. Another [89] used time complexity criterion to evaluate the most important implementation of techniques and methods for skin cancer classification in the detection of melanoma/non-melanoma skin. Another [90] also used time complexity criterion to evaluate the state-of-the-art m-Health services and apps proposed by various developers. The last article [91] used time complexity criterion to evaluate "meta-analysis of coffee intake level" and hazards for MM by referring to cohort and case studies.

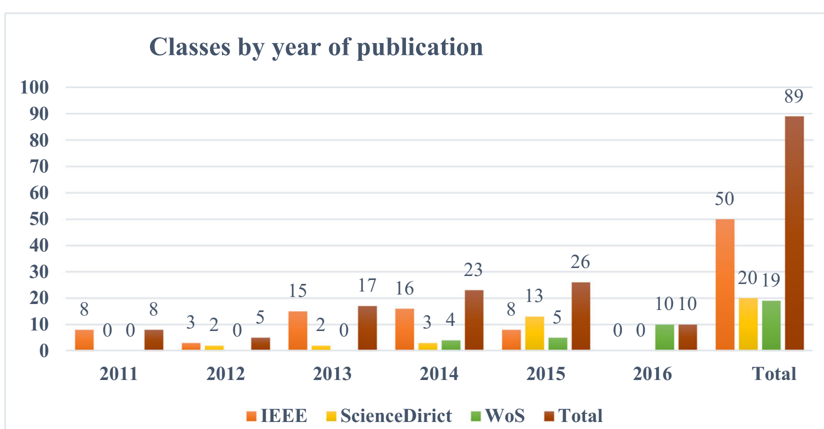
Figure 3 shows the relationship between the number of articles that have been collected from literature and the years of publication of those articles. The chart illustrates a clear contrast to the number of studies presented on the subject of our research. Therefore, consideration must be given on this contrast, notes outstanding to the target objective of this study should be extracted and studies in this field must be expanded. The present research targeted three engines, namely, IEEE, ScienceDirect and WoS, for basic research. These engines are the most reliable sources of research. This study has adopted 89 articles from various sources: 50 from IEEE Xplore, 20 from ScienceDirect and 19 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 classes 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. The 89 articles were adopted from diverse resources in this study. The chart presented varying proportions among these articles, namely, 40 articles under the development and design class, 10 under the review and survey class, 19 under the analysis class and 20 articles under the evaluation and comparison class.

Figure 5 provides a clear picture of the distribution of subclasses 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 subclasses can suggest directions for many future studies in the field of skin cancer apps. In the next section, details about these subsections that represent the direction for many future studies in this field will be discussed.

Figure 6 illustrates the distribution of various evaluation criteria represented by three main groups, namely, reliability group, error rate group and time complexity groups in the taxonomy based on the database searched. This chart displays a ratio of varying criteria used in different studies through subsections of titles in the taxonomy. Accordingly, these studies used the criteria to evaluate their methods and techniques. A total of 40 studies were adapted the reliability groups, 62 for time complicity and 24 studies for error rate.

**Fig. 3** Numerical statistics of related papers in various classes by year of publication



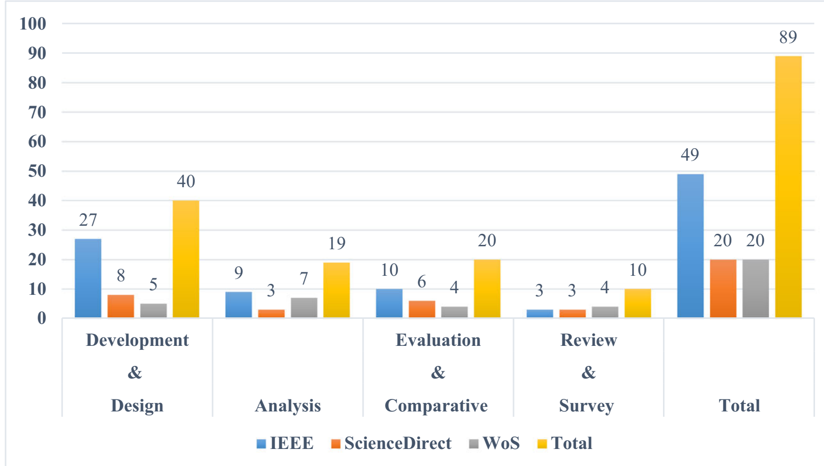



**Fig. 4** Number of included articles by main classes of article and database source

## 4 Discussion

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

A taxonomy developed based on the literature can provide several benefits. A taxonomy of published works poses organisation on a set of publications. A new researcher who is interested in the trend of evaluation and benchmarking the skin cancer apps may be confused by numerous publications using different evaluation criteria with no organisational structure and fail to gain the convenient sense of the actual activities in this field. Various studies treat the topic in different attributes of evaluation criteria. Some investigate a chosen number of current apps, whereas others involve developing the actual apps. Providing taxonomy helps sort different works and activities collected from the literature into a significant, manageable and coherent framework. Taxonomy can also provide researchers with significant visions into a topic in several ways. Firstly, 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 existing apps or sharing the expertise of developing actual apps. Secondly, 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.

The articles reviewed in this study in driven taxonomy shows that by focusing on multiple criteria for evaluating skin cancer apps, distribution on the following four classes is achieved: development and design, analytical studies, evaluative and comparative studies and reviews and surveys. The articles included in this review are discussed in the following subsections to conduct research on skin cancer applications

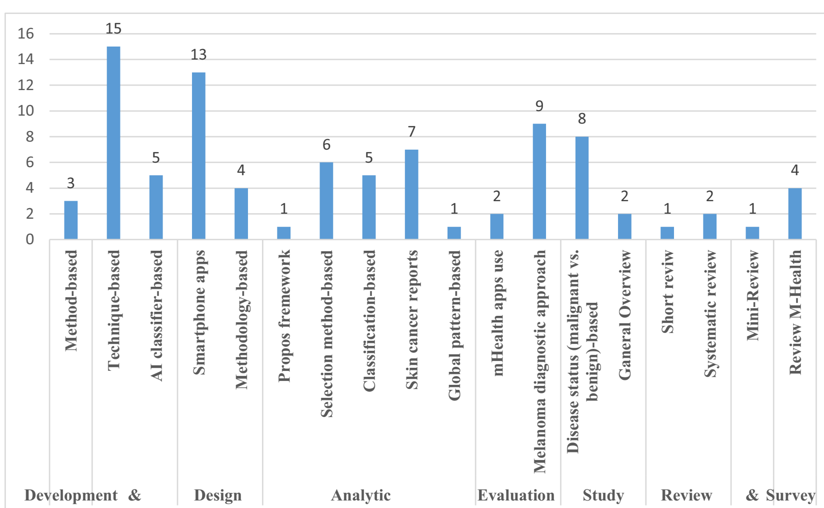



**Fig. 5** Distribution of subclasses in the taxonomy

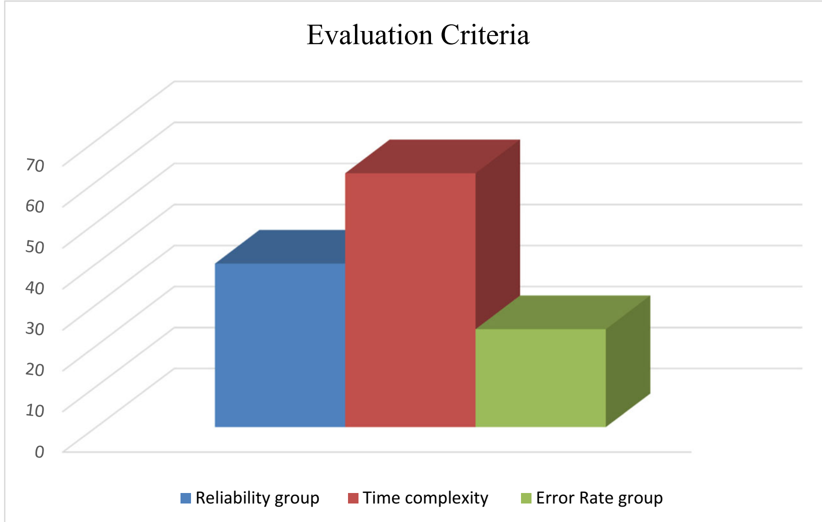



**Fig. 6** Distribution of evaluation criteria in the taxonomy

that diagnose malignant tumours in terms of evaluation aspects, which are the challenges that users of this technology face.

## 4.1 Open issues of evaluation and benchmarking

Recently, a field of evaluation criteria and benchmarking skin cancer apps has been significantly rising, although it still confronts problems and issues in several significant aspects. For instance, such issues are evaluation criteria, criteria trade-off, benchmarking process and criterion importance. The major issues in the evaluation criteria and benchmarking skin cancer apps are explained in details in the next sub-sections. The Fig. 7 below illustrates the main issues of evaluation and benchmarking skin cancer applications:

### 4.1.1 Issues for evaluation criteria

In terms of evaluation metric, the evaluation criteria for the applications of skin cancer received several criticisms. Numerous criticisms have been made on the evaluation criteria, error rates within dataset metrics of images, training and validation and reliability group of evaluation criterion. A problematic figure exists on the variation of error rate values in dataset criticism that results from the variation in the size of the datasets used in various skin cancer experiments. Therefore, the lack in standard dataset leads to important problems whilst error rate values in many experiments are considered. Moreover, dataset collection by many researches is dependent on their individual studies, resulting in unnecessary consumption of effort and time [18, 29, 30, 32, 39]. For the reason that the reliability group criticisms are dependent on the matrix of parameters parts, namely, TP, FP, TN and FN [29, 45], some pixels are lost when cropping the background from the skin cancer images using Adobe Photoshop when manually labelling the actual class and comparing with the predicted class to computing one of the matrices of parameters are needed. At this point, the process will affect the outcomes from all reliability groups (matrix, relationship and behaviour) of parameters, which are considered debatable. Although these metrics in the literature are broadly criticised, these studies still used them to evaluate the applications of skin cancer and other domains of image processing. Furthermore, all studies mentioned above used reliability, time complexity rate or error rate criterion without reference to a specific level to be compared with other criteria [23, 28, 29].

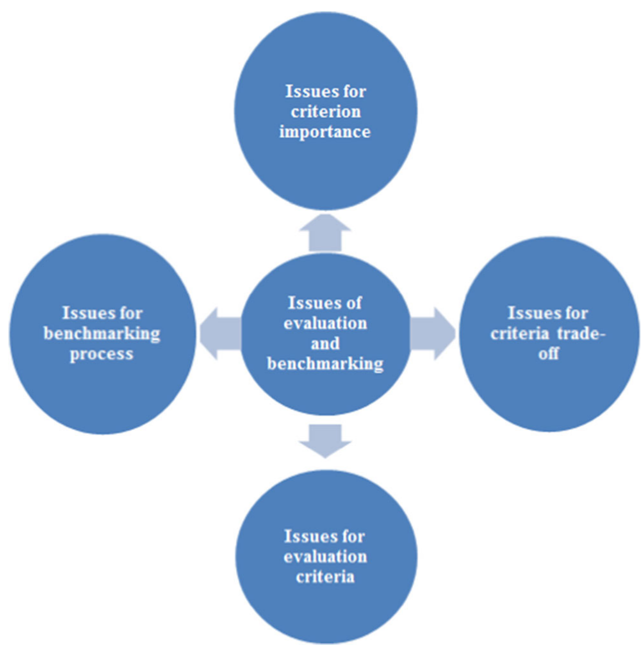



**Fig. 7** The main issues of evaluation and benchmarking skin cancer applications

#### 4.1.2 Issues for criteria trade-off

This situation of trade-off occurs when one reliability or aspect of something is losing and results in gaining another reliability or aspect and vice versa. Based on our literature review, several aspects of trade-off used by researchers among different criteria were conducted. Typically, confusion for decision makers can be caused by trade-off situation amongst criteria. In the current study, the varying ratios collected among the various criteria demonstrated the effect of the conflict on different criteria used by researchers. Consequently, the conflict amongst evaluation criteria for skin cancer constitutes stark challenges in our intention to create a skin cancer segmentation/classification approach. Mainly, such challenge comes from conflicting terms, particularly, the conflict amongst the criteria and amongst the data. Therefore, the realisation of the advantages and disadvantages of particular choices is crucial in making decisions. The "term trade-off" is quite used in an evolutionary context, in which the selection process acts as the "decision-maker" [28, 32, 71, 82].

Conflicting criteria or trade-off problem amongst reliability, time complexity of skin cancer applications and error rate within the dataset in the evaluation and benchmarking of skin cancer applications based smartphone are clearly reported in the mentioned studies. To evaluate the skin cancer applications, we used such criteria that consider the main necessities [14, 24, 73]. The reliability must be in a high rate and time complexity for conducting the output image must be low while maintaining low error rate that results from the training datasets. Conflicting data generated is observed due to the section matrix of parameters on TP, FP, TN and FN, which shows the rise in TP and TN when parameters FP and FN are reduced [13, 27, 81]. This phenomenon indicates a clear conflict among the probability criteria. Such parameters considerably affect the rest of the criteria values within the reliability group. Thus, evaluation and benchmarking process must consider such requirements. Each reviewed study reported that evaluation and benchmarking of all criterions are independent of the general framework. For that reason, the approach of skin cancer classification must be performed to standardise basic and advanced requirements, and a clear methodology must be implemented during research for testing, evaluation and benchmarking. A new and flexible method for evaluation must be used to handle all conflicting criteria and data problems. However, to our knowledge, solutions in this aspect have not yet been suggested on these particular issues.

#### 4.1.3 Issues for benchmarking process

Benchmarking in skin cancer applications based smartphone are restrained to reliable skin cancer. This process is primarily dependent on a comparison of the new generation with others under the conditions and criteria to be considered after the development process for any system. Thus, the major challenges in developing applications of skin cancer are that developers focus on either increasing reliability with low error rate or decreasing time complexity only. The results of the skin cancer applications are frequently affected by this approach, and high reliability and low rate of time complexity or error cannot be attained simultaneously. Consequently, this trade-off is reflected in the benchmarking processes. Studies often suffer from conflicts among different criteria during benchmarking; resulting in main challenges because the measure of others criteria creates a set of numbers that represents various criteria. Furthermore, the trade-off among the criteria causes another problem with which developers cannot compare new applications amongst other applications. Thus, cases that affect the processes of benchmarking conducted amongst various criteria results need to be eliminated [2, 19, 24, 29, 46].

#### 4.1.4 Issues for criterion importance

Articles on smartphone skin cancer applications demonstrate several objectives throughout the planning stages. Such objectives are reflected within the systems in the design, evaluation and benchmarking. The significant of criteria is the key objective in this study through evaluation and benchmarking despite the conflict among them. Thus, the conflicts amongst the criteria constitute main challenges during evaluation. An appropriate procedure needs to be developed for such objectives while increasing the significance of a particular evaluation criterion and reducing others. Two main aspects must be taken into consideration. Firstly, the behaviour of skin cancer applications must be understanding and achieved, giving particular signi0066icance to the design. Other aspect includes evaluating the approach considering the trade-off. Nevertheless, the opinions of the evaluator may be conflicting with the objectives of the designers, which can affect the final evaluation of the needed approach. Technically, the applications of skin cancer through evaluation and benchmarking process includes simultaneous consideration of multiple attributes, namely, reliability, time complexity rate and error rate within dataset, and assigns the proper weight for all features to benchmarking the approaches of skin cancer [16, 35, 81, 84].

After comparing the scores of all approaches, the approaches with the "highest balancing rate" must receive the highest priority level, whereas those with the "least balancing rate" must be given the lowest priority levels. Evaluation and benchmarking processes are challenging tasks and are difficult due to all approaches for skin cancer exhibit multiple attributes that need to be considered. For instance, time complexity rate and error rate within the dataset have been proven to be very important in skin cancer filed because they offer an objective complement to the skin cancer decision and optimise inter-rater consistency. Thus, for all of these attributes, each decision maker provides different weights. On one hand, the developers who aim to give a score for a skin cancer approach might attribute more weight to the feature rather than to other features that gain less interest than these attributes. By contrast, developers who aim to use benchmarking software to solve such problems will probably target various attributes as the most significant attribute. Therefore, the processes of evaluation and benchmarking for skin cancer approaches suffer from multi-complex attribute problems, such that all approaches are considered as an available alternative for the decision makers [52, 57, 60, 73].

## 4.2 Recommended pathways and solutions for future direction

With the exception of the 89 papers reviewed earlier, the new recommendation pathway solution of this research will be described in this section. The supporting reviews are presented as follows.

The processes of evaluation and benchmarking on skin cancer applications involve simultaneous consideration for multi criteria ("reliability, time complexity rate, and error rate within dataset") to evaluate and score skin detection applications. So that, adapting candid and structured techniques to decisions using multiple attributes may increasing the quality of decision making and methods set, known under the collective heading multi criteria decision analysis (MCDA), are usable in these situations. Consequently, useful methods that deal with MCDM issues are presented as the recommended pathways and solutions which collectively help the decision makers to organise any problem to be solved and apply analyses, assessments and ranking [92].

### 4.2.1 Definition and significance of MCDM

[91] define MCDM as "an extension of decision theory that covers any decision with multiple objectives. A methodology for assessing alternatives on individual, often conflicting criteria, and combining them into one overall appraisal…". Moreover, [93] define MCDM as "an umbrella term to describe a collection of formal approaches, which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter."

MCDM is considered as a significant technique for decision-making and is a part of operations research, which deals with decision problems regarding decision criteria [94, 95]. It is involved with structuring and planning and can solve decision problems using various attributes [95]. The use of MCDM is widely rising recently because of its ability to promote the decision quality by making the process decision more efficient, reasonable, clear and explicit than by traditional process [96]. The main goals of MCDM are the following: (A) assist data miners select the appropriate alternative and (B) assign rank to the alternatives in decreasing order of efficiency, (C) classify the applicable alternatives among a group of available alternatives [92, 97, 98]. According to that, the proper alternative(s) will be ranked. In any rank in MCDM, the definition of the fundamental terms is needed, containing the decision matrix and its attribute [99]. An evaluation matrix includes *n* attribute and *m* alternatives, which need to be identified. The intersection of attribute and alternative is defined as z_ij. So that, we have a matrix (z_ij) _ (*m***n*) explained as following:

$$DM = \begin{array}{c} \\ Y_1 \\ Y_2 \\ \vdots \\ Y_m \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_2 & \dots & X_n \end{array} \\ \begin{bmatrix} z_{11} & z_{12} & \dots & z_{1n} \\ z_{21} & z_{22} & \dots & z_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ z_{m1} & z_{m2} & \dots & z_{mn} \end{bmatrix} \end{array}, \quad (1)$$

where $Y_1$, $Y_2$, …. , $Y_m$ are suitable alternatives, which decision-makers need to rank, that is, skin cancer applications. $X_1$, X, …, $X_n$ are the attributes/criteria against which the performance of all alternativesare evaluated, that is, "reliability, time complexity rate, and error rate within dataset". Then, $z_{ij}$ is the rating of alternative $Y_i$ with respect to criterion $X_j$, and $W_j$ is the weight of criterion $X_j$.

For instance, let us assume that *DM* is the decision matrix utilised to score and ranking the alternatives *Yi*, where according to $X_j$ Table 1 is an example of multiple attribute problem expressed in a previous article [100].

The data in the flowchart cannot be easily evaluated due to the huge numbers of *X2* and *X3* (Figs. 7 and 8).

The process of "decision-making" can be improved by comprising stakeholders and decision makers and offer the process with structure and support. Using a candid approach, we could enhance the "decision-making" quality and a set of techniques of the structure of methods to decisions regarding multiple criteria could enhance. These techniques provide limpidity on which criteria are relevant, the significance attached to each and how to involve this information in a framework for evaluating the existing alternatives. By doing so, researchers can assist in increasing the transparency, consistency and validity of the decision. The MCDM can possibly contribute to fair, transparent and rational priority-setting processes.

**Table 1** Example of multiple attribute problem

| Xj<br>Yi | X1 | X2 | X3 | X4 | X5 | X6 |
|---|---|---|---|---|---|---|
| Y1 | 2 | 1500 | 20,000 | 5.5 | 5 | 9 |
| Y2 | 2.5 | 2700 | 18,000 | 6.5 | 3 | 5 |
| Y3 | 1.8 | 2000 | 21,000 | 4.5 | 7 | 7 |
| Y4 | 2.2 | 1800 | 20,000 | 5 | 5 | 5 |

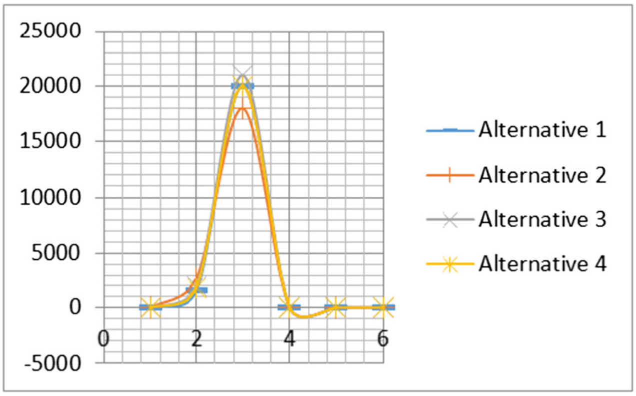



**Fig. 8** Graphical representation of the example in Table 1

**Applications of MCDM** MCDM has become commonly used in several fields for different apps by ranking and finding the suitable solutions to choose the appropriate alternative, including energy management [101], energy planning [102], transportation [103], geographical information systems [104, 105], resource and budgeting allocation [106] and healthcare domain [107].

**MCDM in healthcare domain** The using of MCDM in healthcare has become widely used recently and is a popular methodology to assist decision making in healthcare [107–115]. With the different MCDM techniques, healthcare decision makers can improve their decision making by systematically gaining the suitable solutions [116]. The significance of healthcare decision making cannot be confirmed enough, as several of these decisions are difficult, involving uncertainties and the elicitation of values and preferences of stakeholders [109]. MCDM doesn't mimic or replace medical judgments but is relatively utilised to specify, gather and structure the required information by reviewers to enhance the "decision-making" process [108]. No crucial solutions are available for enhancing the processes of decision making in healthcare; however, techniques like MCDM will be a step further [109]. Therefore, nowadays, MCDM is considered the new direction and has been conducted in various healthcare domains in the previous studies.

**MCDM methods** Various MCDM theories are discovered. Figure 9 illustrates the most popular and famous MCDM methods that utilise different concepts [117]:

The advantages and limitations for these MCDM methods are presented in Fig. 10 according to previous studies [118, 119, 120–140, 115].

Based on our analysis, none of the discussed methods has been used to evaluating and benchmarking real-time skin cancer applications in a healthcare environment. The approach of non-adoption of a requirement-driven is considered The challenge of these methods, as well as makes them unsuitable for measure and scoring dependent on "decision-making" [117].

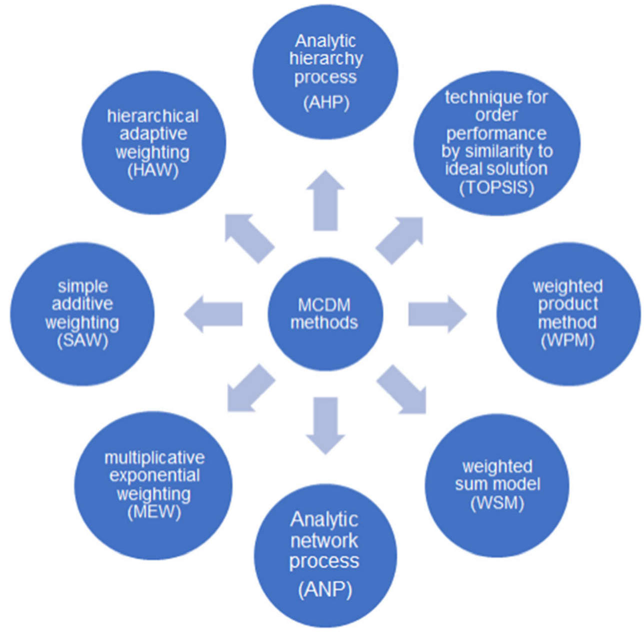



**Fig. 9** Most popular and famous MCDM methods

Nevertheless, the method that is functionally associated with discrete alternative problems is TOPSIS and considers the most practical ways to settle problems of real-world. Its greatest advantage is its ability to immediately locate the proper alternative. So that, it is appropriate for many alternatives and attributes cases [141]. The shortage of assigning for weight elicitation and the checking of judgment consistency is considered a major limitation of TOPSIS method. [137]. AHP method offers a procedure to gain the relative importance of different attributes with consideration to the objective which is the significant requirement of TOPSIS method. AHP is utilised to assign weights for objectives dependent on the preferences of stakeholders [141]. Nevertheless, as it is significantly restricted by the human capacity for processing information, $7 \pm 2$ is regarded as the comparison ceiling [138]. According to that, TOPSIS mitigates the requirement of paired comparisons, and the capacity limitation may not significantly control the processes [142].

On these days, to prevent shortcomings in a single method, the newest trend is to integrate two or more methods DM methods [143–145]. The integration of AHP-TOPSIS have become a popular accepted integrated MCDM method based on these purposes: the using of weights and objective data to gain relative distances, the ability to providing full rank results, the smoothing of trade-offs by dealing with nonlinear relationships, the ease at which it can be implemented by a programmable procedure and the convenience to be combined with stochastic analysis [141, 145].Many integrated approaches of AHP-TOPSIS are involved in alternatives measuring and rank cases on previous studies [141, 146, 147].

Finally, to evaluate and benchmark skin cancer applications, we recommend the integrating of AHP method to assign

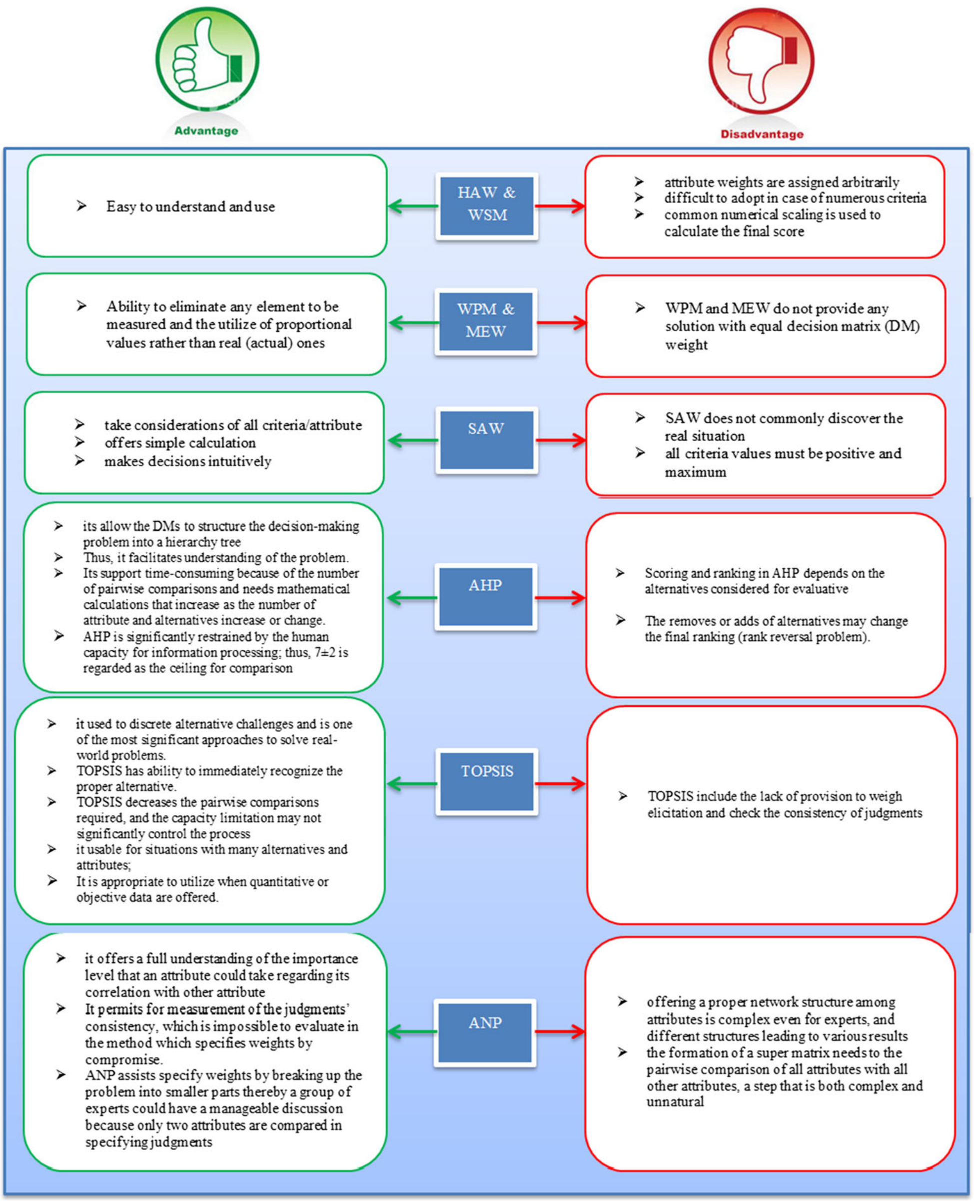



**Fig. 10** the advantages and limitations for MCDM methods

and distributed each weight for evaluation attributes/criteria "reliability, time complexity rate, and error rate within dataset" according to the judgment of experts, and TOPSIS method is also required to offer a comprehensive ranking of skin cancer applications.

## 5 Conclusion

This research aims to review the attempts of researchers in response to new and disruptive technology of skin cancer applications in term of evaluation and benchmarking in order to identify the research landscape from the literature into a cohesive taxonomy. This paper presents a taxonomy to review the articles focusing on multiple criteria for evaluation and benchmarking skin cancer apps involving "reliability, time complexity rate, and error rate within dataset" (right part of taxonomy) distributed on the four classes (left part of taxonomy), namely, development and design, analytical studies, evaluative and comparative studies and reviews and surveys. Furthermore, this paper illustrated statistical numbers about many aspects, including: (1) the relationship between the number of articles collected from the literature and the years of publication of those articles, (2) the number of included articles of the four broad classes of our taxonomy by the number of articles and database searched, (3) the distribution of subclasses within the taxonomy based on the database searched and (4) the distribution of various evaluation criteria groups in the taxonomy based on the database searched. Moreover, the findings of this paper emphasised four main open issues of the evaluation criteria, and benchmarking skin cancer applications are explained, namely, issues for evaluation criteria, issues for criteria trade-off, issues for benchmarking process and issues for criterion importance. Moreover, the MCDM in the framework of the evaluation and benchmarking for real-time skin cancer were discussed. Various decision-making techniques presented diverse configurations and situations. Consequently, beneficial methods that deal with MCDM issues are presented as the recommended pathways and solutions which collectively help the decision makers to organise any problem to be solved and apply analyses, assessments and ranking. The new recommendation pathway solution in evaluating and benchmarking skin cancer applications is a combination of the AHP method and is recommended to assign and distributed weights for evaluation attributes/criteria "reliability, time complexity rate, and error rate within dataset" according to the judgment of experts. The TOPSIS method is also required to offer a comprehensive ranking of skin cancer applications.

## Compliance with ethical standards

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

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

## References


1. Barata C, et al. Two systems for the detection of melanomas in dermoscopy images using texture and color features. IEEE Syst J. 2014;8(3):965–79.
2. Malyuskin O, and Fusco V. Resonance microwave reflectometry for early stage skin cancer identification. In *2015 9th European Conference on Antennas and Propagation (EuCAP)*. 2015.
3. Mendi E, et al. Automatic mobile segmentation of dermoscopy images using density based and fuzzy c-means clustering. in 2014 IEEE International Symposium on Medical Measurements and Applications (MeMeA) 2014.
4. Alsalem MA, et al. A review of the automated detection and classification of acute leukaemia: coherent taxonomy, datasets, validation and performance measurements, motivation, open challenges and recommendations. Comput Methods Prog Biomed. 2018;158:93–112.
5. Rosado L and Ferreira M. *A prototype for a mobile-based system of skin lesion analysis using supervised classification*. 2013. IEEE.
6. Do TT, et al. Early melanoma diagnosis with mobile imaging. 2014. IEEE.
7. Mahmoud MKA, Al-Jumaily A, and Takruri M. The automatic identification of melanoma by wavelet and curvelet analysis: study based on neural network classification. IEEE.
8. Abuzaghleh O, Barkana BD, and Faezipour M. Automated skin lesion analysis based on color and shape geometry feature set for melanoma early detection and prevention. IEEE.
9. Abuzaghleh O, Faezipour M, and Barkana BD. *A comparison of feature sets for an automated skin lesion analysis system for melanoma early detection and prevention*. in 2015 Long Island systems, Applications and Technology 2015.
10. Wadhawan T, et al. SkinScan©: a portable library for melanoma detection on handheld devices. IEEE.
11. Mhaske HR and Phalke DA. *Melanoma skin cancer detection and classification based on supervised and unsupervised learning*. 2013. IEEE.
12. Yas QM, et al. A systematic review on smartphone skin Cancer apps: coherent taxonomy, motivations, open challenges and recommendations, and new research direction. Journal of Circuits, Systems and Computers. 2018;27(05):1830003.
13. Masood A, Al-Jumaily A, and Anam K. *Self-supervised learning model for skin cancer diagnosis*. 2015. IEEE.
14. Dumitrache I, Sultana AE, and Dogaru R. Automatic detection of skin melanoma from images using natural computing approaches. IEEE.
15. Abuzaghleh O., Barkana BD, and Faezipour M. SKINcure: a real time image analysis system to aid in the malignant melanoma prevention and early detection. IEEE.
16. Sabouri P, et al. A cascade classifier for diagnosis of melanoma in clinical images. IEEE.
17. Hu R, Queen CM, and Zouridakis G. *Detection of Buruli ulcer disease: Preliminary results with dermoscopic images on smart handheld devices*. 2013. IEEE.
18. Fosu KPO and Jouny I. *Mobile melanoma detection application for Android smart phones*. 2015. IEEE.
19. Ballerini L, et al. Non-melanoma skin lesion classification using colour image data in a hierarchical K-NN classifier. IEEE.
20. Duarte MF, et al. Melanoma classification from Hidden Markov tree features. 2012. IEEE.
21. Ruela M, et al. On the role of shape in the detection of melanomas. 2015. IEEE.
22. Haider S, et al. Enhanced classification of malignant melanoma lesions via the integration of physiological features from dermatological photographs. IEEE.
23. Taeb A, Gigoyan S, Safavi-Naeini S. Millimetre-wave waveguide reflectometers for early detection of skin cancer. IET Microwaves, Antennas & Propagation. 2013;7(14):1182–6.
24. Töpfer F, Dudorov S, Oberhammer J. Millimeter-wave near-field probe designed for high-resolution skin cancer diagnosis. IEEE Transactions on Microwave Theory and Techniques. 2015;63(6): 2050–9.
25. Varshney U. Mobile health: four emerging themes of research. Decis Support Syst. 2014;66:20–35.
26. Wang Y, et al. Toward in vivo biopsy of melanoma based on photoacoustic and ultrasound dual imaging with an integrated detector. Biomedical optics express. 2016;7(2):279–86.
27. Hartinger AE, Guardo R and Gagnon H. *EIT system and reconstruction algorithm adapted for skin cancer imaging*. In *2012 11th International Conference on Information Science,* Signal processing and their applications (ISSPA). 2012.
28. Littman-Quinn R, et al. *mHealth applications for telemedicine and public health intervention in Botswana*. 2011. IEEE.
29. Tittmann BR, et al. Fine mapping of tissue properties on excised samples of melanoma and skin without the need for histological staining. IEEE Trans Ultrason Ferroelectr Freq Control. 2013;60 (2):320–31.
30. Caratelli D, et al. Accurate time-domain modeling of reconfigurable antenna sensors for non-invasive melanoma skin Cancer detection. IEEE Sensors J. 2012;12(3):635–43.

31. Töpfer F, Emtestam L, and Oberhammer J. Dermatological verification of micromachined millimeter-wave skin-cancer probe. In *2014 IEEE MTT-S International Microwave Symposium (IMS2014)*. 2014.
32. Körner A, et al. Supportive care needs and distress in patients with non-melanoma skin cancer: nothing to worry about? Eur J Oncol Nurs. 2016;20:150–5.
33. Heckman C, et al. Development of an internet intervention to address behaviors associated with skin cancer risk among young adults. Internet Interventions. 2015;2(3):340–50.
34. Glodde N, et al. Differential role of cannabinoids in the pathogenesis of skin cancer. Life Sci. 2015;138:35–40.
35. Paradisi A, et al. Markedly reduced incidence of melanoma and nonmelanoma skin cancer in a nonconcurrent cohort of 10,040 patients with vitiligo. J Am Acad Dermatol. 2014;71(6):1110–6.
36. Liu J, et al. Both HDAC5 and HDAC6 are required for the proliferation and metastasis of melanoma cells. J Transl Med. 2016;14 (1):7–7.
37. Rashtak S, et al. Incidence and risk factors for skin cancer following lung transplantation. J Am Acad Dermatol. 2015;72(1):92–8.
38. Abuzaghleh O, Faezipour M and Barkana BD. Skinaid: a virtual reality system to aid in the skin cancer prevention and pain treatment. in 2013 IEEE Long Island Systems, Applications and Technology Conference (LISAT) 2013.
39. Blumrosen G, et al. C-SMART: efficient seamless cellular phone based patient monitoring system. in 2011 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks. 2011.
40. Nezerwa M, et al. *Universal design with mobile app development: Bridging the Gap for the forgotten populations*. In *2015 Long Island Systems, Applications and* Technology 2015.
41. Chen X, et al. A study on the model of mobile medical application in 3G network. in 2011 International Conference on Consumer Electronics, Communications and Networks (CECNet). 2011.
42. Godoy SE, et al. Dynamic infrared imaging for skin cancer screening. Infrared Phys Technol. 2015;70:147–52.
43. Bourouis A, et al. M-health: skin disease analysis system using Smartphone's camera. Procedia Computer Science. 2013;19: 1116–20.
44. Ali AR, Couceiro MS, and Hassenian AE. Melanoma detection using fuzzy C-means clustering coupled with mathematical morphology. In *2014 14th International Conference on Hybrid Intelligent Systems*. 2014.
45. Raikar A, Sangani SP, and Hanabaratti KD. Diagnosis of melanomas by check-list method. in 2013 Fourth International Conference on Computing, Communications and Networking Technologies (ICCCNT) 2013.
46. Caratelli D, et al. Locally conformal FDTD modeling of MEMS-based antenna sensors for melanoma detection. In *2011 IEEE International Symposium on Medical Measurements and Applications*. 2011.
47. Youl PH, et al. Can skin cancer prevention and early detection be improved via mobile phone text messaging? A randomised, attention control trial. Prev Med. 2015;71:50–6.
48. Jain S, jagtap V, Pise N. Computer aided melanoma skin Cancer detection using image processing. Procedia Computer Science. 2015;48:735–40.
49. J Chaube, U., V. Kumar Vyas, and H. Girishkumar Bhatt, Design and synthesis of potent N-Phenylpyrimidine derivatives for the treatment of skin Cancer Vol. 6. 2016.
50. Truong BCQ, et al. *High correlation of double Debye model parameters in skin cancer detection*. In *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology* Society 2014.
51. Liu Z, et al. Cancer-promoting effect of capsaicin on DMBA/TPA-induced skin tumorigenesis by modulating inflammation, Erk and p38 in mice. Food Chem Toxicol. 2015;81:1–8.
52. Doran CM, et al. Benefit cost analysis of three skin cancer public education mass-media campaigns implemented in new South Wales, Australia. PLoS One. 2016;11(1):e0147665-e0147665.
53. Moon Y, et al. Differentiation of cutaneous melanoma from surrounding skin using laser-induced breakdown spectroscopy. In *2016 Conference on Lasers and Electro-Optics (CLEO)*. 2016.
54. Møllersen K, Hardeberg JY, and Godtliebsen F. Divergence-based colour features for melanoma detection. in 2015 Colour and Visual Computing Symposium (CVCS) 2015.
55. Mete M and Sirakov NM. Optimal set of features for accurate skin cancer diagnosis. In *2014 IEEE International Conference on Image Processing (ICIP)*. 2014.
56. Sankaran S and Sethumadhavan G. Quantifications of asymmetries on the spectral bands of MALIGNANT melanoma using six sigma threshold as preprocessor. in Third international conference on computational intelligence and information technology (CIIT 2013). 2013.
57. Paja W and Wrzesień M. Melanoma important features selection using random forest approach. In *2013 6th International Conference on Human System Interactions (HSI)*. 2013.
58. Tran B, et al. Association between ultraviolet radiation, skin sun sensitivity and risk of pancreatic cancer. Cancer Epidemiol. 2013;37(6):886–92.
59. Wang F, et al. The distribution of biologically effective UV spectral irradiances received on a manikin face that cause erythema and skin cancer. J Photochem Photobiol B Biol. 2014;140:205–14.
60. Karimkhani C, et al. The surgeon general should say that indoor ultraviolet radiation tanning causes skin Cancer. Am J Prev Med. 2015;49(3):437–40.
61. Töpfer F, Dudorov S, and Oberhammer J. *2-Dimensional near-field millimeter-wave scanning with micromachined probe for skin cancer diagnosis*. In *2013 IEEE 26th International Conference on Micro Electro Mechanical Systems (MEMS)*. 2013.
62. Hillert R, et al. Large molecular systems landscape uncovers T cell trapping in human skin cancer. Sci Rep. 2016;6:19012–2.
63. Khunsap S, et al. Anticancer properties of phospholipase A2 from Daboia siamensis venom on human skin melanoma cells. Journal of Venomous Animals and Toxins including Tropical Diseases. 2016;22(1):7.
64. Sokołowski A and Pardela T. Fourier transforms in melanoma image classification. In *2013 6th International Conference on Human System Interactions (HSI)*. 2013.
65. Khosravi H, Schmidt B, Huang JT. Characteristics and outcomes of nonmelanoma skin cancer (NMSC) in children and young adults. J Am Acad Dermatol. 2015;73(5):785–90.
66. Helgadottir H, et al. CDKN2a mutation-negative melanoma families have increased risk exclusively for skin cancers but not for other malignancies. Int J Cancer. 2015;137(9):2220–6.
67. Zhao J, et al., Wavenumber selection based analysis in Raman spectroscopy improves skin cancer diagnostic specificity. Vol 141. 2016.
68. Ferrucci L, et al., *Indoor tanning in businesses and homes and risk of melanoma and nonmelanoma skin cancer in 2 US case-control studies*. Vol. 71. 2014.
69. Dawei N. *Classification of melanoma and Clark nevus skin lesions based on medical image processing techniques*. In *2011 3rd International Conference on Computer Research and* Development 2011.
70. Lamel SA, et al. Application of mobile teledermatology for skin cancer screening. J Am Acad Dermatol. 2012;67(4):576–81.
71. Töpfer F, Dudorov S, and Oberhammer J. Micromachined 100GHz near-field measurement probe for high-resolution

microwave skin-cancer diagnosis. In *2012 IEEE/MTT-S International Microwave Symposium Digest*. 2012.
72. Singh D, Gautam D, and Ahmed M *Detection techniques for melanoma diagnosis: A performance evaluation* in *2014 International Conference on Signal Propagation and Computer Technology (ICSPCT* 2014*)*. 2014.
73. Valavanis I, et al. *Inference of a robust diagnostic signature in the case of Melanoma: Gene selection by information gain and Gene Ontology tree exploration*. In *13th IEEE International Conference on BioInformatics and* Bioengineering 2013.
74. Alfed N, et al. Pigment network-based skin cancer detection. in 2015 37th annual international conference of the IEEE engineering in medicine and biology society (EMBC). 2015.
75. Bhowmik A, et al. Suitability of frequency modulated thermal wave imaging for skin cancer detection—a theoretical prediction. J Therm Biol. 2015;51:65–82.
76. Wysong A, et al. Non-melanoma skin cancer and NSAID use in women with a history of skin cancer in the Women's Health Initiative. Prev Med. 2014;69:8–12.
77. Del Boz J, et al. Skin Cancer prevention and detection campaign at golf courses on Spain's Costa del sol. Actas Dermo-Sifiliográficas (English Edition). 2015;106(1):51–60.
78. Barrett PD, Barrett HE. An audit into use of minimum dataset reporting of skin cancers in the north of England Cancer network. Pathogenesis. 2015;2(1):5–8.
79. Yang A, et al. Increased skin tumor incidence and keratinocyte hyper-proliferation in a mouse model of down syndrome. PLoS One. 2016;11(1):e0146570.
80. Sáez A, Serrano C, Acha B. Model-based classification methods of global patterns in Dermoscopic images. IEEE Trans Med Imaging. 2014;33(5):1137–47.
81. Masood A and Al-Jumaily A, *Computer Aided Diagnostic Support System for Skin Cancer: A Review of Techniques and Algorithms*. Vol. 2013. 2013. 323268.
82. Azadeh Noori H, Al-Jumaily A, and Sulaiman R. Review on automatic early skin cancer detection. In *2011 International Conference on Computer Science and Service System (CSSS)*. 2011.
83. Borisova EG, Angelova LP, Pavlova EP. Endogenous and exogenous fluorescence skin Cancer diagnostics for clinical applications. IEEE Journal of Selected Topics in Quantum Electronics. 2014;20(2):211–22.
84. Haque T, et al. Topical therapies for skin cancer and actinic keratosis. Eur J Pharm Sci. 2015;77:279–89.
85. Chummun S, McLean NR. The management of malignant skin cancers. Surgery (Oxford). 2017;35(9):519–24.
86. Friedman B, English JC, Ferris LK. Indoor tanning, skin Cancer and the young female patient: a review of the literature. J Pediatr Adolesc Gynecol. 2015;28(4):275–83.
87. Colantonio S, Bracken MB, Beecker J. The association of indoor tanning and melanoma in adults: systematic review and meta-analysis. J Am Acad Dermatol. 2014;70(5):847–857.e18.
88. Kassianos AP, et al. Smartphone applications for melanoma detection by community, patient and generalist clinician users: a review. Br J Dermatol. 2015;172(6):1507–18.
89. Korotkov K, Garcia R. Computerized analysis of pigmented skin lesions: a review. Artif Intell Med. 2012;56(2):69–90.
90. Silva BMC, et al. Mobile-health: a review of current state in 2015. J Biomed Inform. 2015;56:265–72.
91. Liu J, et al. Higher caffeinated coffee intake is associated with reduced malignant melanoma risk: a meta-analysis study. PLoS One. 2016;11(1):e0147056-e0147056.
92. Jadhav A and Sonar R, "Analytic hierarchy process (AHP), weighted scoring method (WSM), and hybrid knowledge based system (HKBS) for software selection: a comparative study," in Emerging trends in engineering and technology (ICETET), 2009 2nd international conference on, 2009, pp. 991–997.
93. Belton V and Stewart T, Multiple criteria decision analysis: an integrated approach. Springer Science & Business Media, 2002.
94. Malczewski J, GIS and multicriteria decision analysis. John Wiley & Sons, 1999.
95. Petrovic-Lazarevic S and Abraham A, "Hybrid fuzzy-linear programming approach for multi criteria decision making problems," arXivPrepr.Cs/0405019, 2004.
96. Zionts S. MCDM—if not a roman numeral, then what? Interfaces (Providence). 1979;9(4):94–101.
97. Zaidan AA, Karim HA, Ahmad NN, Zaidan BB, Kiah MLM. Robust pornography classification solving the image size variation problem based on multi-agent learning. J. Circuits, Syst. Comput. 2015;24(2):1550023.
98. Zaidan AA, Zaidan BB, Hussain M, Haiqi A, Kiah MLM, Abdulnabi M. Multi-criteria analysis for OS-EMR software selection problem: a comparative study. Decis Support Syst. 2015;78: 15–27.
99. Whaiduzzaman M, Gani A, Anuar NB, Shiraz M, Haque MN, Haque IT. Cloud service selection using multicriteria decision analysis. Sci World J. 2014;2014
100. Huang JJ, Multiple attribute decision making: methods and applications. Chapman and Hall/CRC, 2011.
101. Wang J-J, Jing Y-Y, Zhang C-F, Zhao J-H. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sust Energ Rev. 2009;13(9):2263–78.
102. Haralambopoulos DA, Polatidis H. Renewable energy projects: structuring a multi-criteria group decision-making framework. Renew Energy. 2003;28(6):961–73.
103. Qu L, Chen Y. A hybrid MCDM method for route selection of multimodal transportation network. Adv Neural Networks-ISNN. 2008:374–383, 2008.
104. Gbanie SP, Tengbe PB, Momoh JS, Medo J, Kabba VTS. Modelling landfill location using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): case study Bo, southern Sierra Leone. Appl Geogr. 2013;36:3–12.
105. Ligmann-Zielinska A, Jankowski P. Impact of proximity-adjusted preferences on rank-order stability in geographical multicriteria decision analysis. J GeogrSyst. 2012;14(2):167–87.
106. Phillips LD, e Costa CAB. Transparent prioritisation, budgeting and resource allocation with multi-criteria decision analysis and decision conferencing. Ann Oper Res. 2007;154(1):51–68.
107. Diaby V, Campbell K, Goeree R. Multi-criteria decision analysis (MCDA) in health care: a bibliometric analysis. Oper Res Heal Care. 2013;2(1):20–4.
108. Thokala P, et al. Multiple criteria decision analysis for health care decision making—an introduction: report 1 of the ISPOR MCDA emerging good practices task force. Value Heal. 2016;19(1):1–13.
109. Adunlin G, Diaby V, Xiao H. Application of multicriteria decision analysis in health care: a systematic review and bibliometric analysis. Health Expect. 2015;18(6):1894–905.
110. Marsh K, Dolan P, Kempster J, Lugon M. Prioritizing investments in public health: a multi-criteria decision analysis. J Public Health (Bangkok). 2012;35(3):460–6.
111. Ho W. Integrated analytic hierarchy process and its applications–a literature review. Eur J Oper Res. 2008;186(1):211–28.
112. Liberatore MJ, Nydick RL. The analytic hierarchy process in medical and health care decision making: a literature review. Eur J Oper Res. Aug. 2008;189(1):194–207.
113. Guindo LA, et al. From efficacy to equity: literature review of decision criteria for resource allocation and healthcare decisionmaking. Cost Eff Resour Alloc. 2012;10(1):9.
114. Marsh K, Lanitis T, Neasham D, Orfanos P, Caro J. Assessing the value of healthcare interventions using multi-criteria decision

analysis: a review of the literature. PharmacoEconomics. 2014;32 (4):345–65.
115. Kalid N, et al. Based on real time remote health monitoring systems: a new approach for prioritization ‘large scales data’ patients with chronic heart diseases using body sensors and communication technology. J Med Syst. Apr. 2018;42(4):69.
116. Mühlbacher AC, Kaczynski A. Making good decisions in healthcare with multi-criteria decision analysis: the use, current research and future development of MCDA. Appl Health Econ Health Policy. 2016;14(1):29–40.
117. Zaidan AA, Zaidan BB, Al-Haiqi A, Kiah MLM, Hussain M, Abdulnabi M. Evaluation and selection of open-source EMR software packages based on integrated AHP and TOPSIS. J Biomed Inform. 2015;53:390–404.
118. Oliveira M, Fontes DBMM, and Pereira T, “Multicriteria decision making: a case study in the automobile industry,” in International symposium on operational research and applications (ISORAP2013), 2013.
119. M. Aruldoss, “A Survey On multi criteria decision making methods and its applications,” Am. J Inf Syst, vol. 1, no. 1, pp. 31–43, 2013.
120. Mansooreh M and Pet-Edwards J, “Technical briefing: making multiple-objective decisions,” Inst. Electr. Ve electron. Eng. Inc., IEEE Comput. Soc. press. USA, 1997.
121. Triantaphyllou E, “Multi-criteria decision making methods,” in Multi-criteria decision making methods: A comparative study, Springer, 2000, pp. 5–21.
122. Triantaphyllou E, Shu B, Sanchez SN, Ray T. Multi-criteria decision making: an operations research approach. Encycl. Electr. Electron.Eng. 1998;15(1998):175–86.
123. Yoon KP and Hwang CL, Multiple attribute decision making: an introduction, vol. 104. Sage publications, 1995.
124. Abdullateef BN, Elias NF, Mohamed H, Zaidan AA, Zaidan BB. An evaluation and selection problems of OSS-LMS packages. Spring. 2016;5(1):248.
125. Jumaah FM, Zaidan AA, Zaidan BB, Bahbibi R, Qahtan MY, Sali A. Technique for order performance by similarity to ideal solution for solving complex situations in multi-criteria optimization of the tracking channels of GPS baseband telecommunication receivers. Telecommun Syst. 2017:1–19.
126. Kiah MLM, Haiqi A, Zaidan BB, Zaidan AA. Open source EMR software: profiling, insights and hands-on analysis. Comput Methods Prog Biomed. 2014;117(2):360–82.
127. Qader MA, Zaidan BB, Zaidan AA, Ali SK, Kamaluddin MA, Radzi WB. A methodology for football players selection problem based on multi-measurements criteria analysis. Meas J Int Meas Confed. 2017;111:38–50.
128. Yas QM, Zadain AA, Zaidan BB, Lakulu MB, Rahmatullah B. Towards on develop a framework for the evaluation and benchmarking of skin detectors based on artificial intelligent models using multi-criteria decision-making techniques. Int. J. Pattern Recognit. Artif.Intell. 2017;31(3):1759002.
129. Salman OH, Zaidan AA, Zaidan BB. Naserkalid, and M. Hashim, “novel methodology for triage and prioritizing using ‘big data’ patients with chronic heart diseases through telemedicine environmental,”. Int J Inf Technol DecisMak. 2017;16(5):1211–45.
130. Yas QM, Zaidan AA, Zaidan BB, Rahmatullah B, and Karim HA, “Comprehensive insights into evaluation and benchmarking of real-time skin detectors: review, open issues & challenges, and recommended solutions,” Measurement, 2017.
131. Zaidan BB, Zaidan AA, Abdul Karim H, Ahmad NN. A new approach based on multi-dimensional evaluation and benchmarking for data hiding techniques. Int J Inf Technol Decis Mak. 2017:1–42.
132. Zaidan BB, Zaidan AA, Karim HA, Ahmad NN. A new digital watermarking evaluation and benchmarking methodology using an external group of evaluators and multi-criteria analysis based on ‘large-scale data. Softw PractExp. 2017;47(10):1365–92.
133. Zaidan BB, Zaidan AA. Software and hardware FPGA-based digital watermarking and steganography approaches: toward new methodology for evaluation and benchmarking using multi-criteria decision-making techniques. J. Circuits, Syst. Comput. 2017;26(7):1750116.
134. Zaidan BB, Zaidan AA. Comparative study on the evaluation and benchmarking information hiding approaches based multi-measurement analysis using TOPSIS method with different normalisation, separation and context techniques. Measurement. 2018;117:277–94.
135. Kalid N, Zaidan AA, Zaidan BB, Salman OH, Hashim M, Muzammil H. Based real time remote health monitoring systems: a review on patients prioritization and related‘ big data’ using body sensors information and communication technology. J Med Syst. 2018;42(2):30.
136. Jumaah FM, Zadain AA, Zaidan BB, Hamzah AK, and Bahbibi R, “Decision-making solution based multi-measurement design parameter for optimization of GPS receiver tracking channels in static and dynamic real-time positioning multipath environment, ” Measurement, 2018.
137. Shih HS, Shyur HJ, Lee ES. An extension of TOPSIS for group decision making. Math.Comput.Model. 2007;45(7–8):801–13.
138. Saaty TL, Ozdemir MS. Why the magic number seven plus or minus two. Math. Comput.Model. 2003;38(3–4):233–44.
139. Lesmes D, Castillo M, and Zarama R, “Application of the Analytic Network Process (ANP) to establish weights in order to re-accredit a program of a university,” in Proc. of The 10th International Symposium on The Analytic Hierarchy Process, 2009, vol. 29.
140. Saaty TL, “The analytic hierarchy process, New York: McGrew Hill,” Int. Transl. To Russ. Port. Chinese, Revis. Ed. Paperb. (1996, 2000), Pittsburgh RWS Publ., 1980.
141. Nilsson H. E.-M.Nordström, and K. Öhman, “decision support for participatory forest planning using AHP and TOPSIS,”. Forests. 2016;7(5):100.
142. Kandakoglu A, Celik M, Akgun I. A multi-methodological approach for shipping registry selection in maritime transportation industry. MathComputModel. 2009;49(3):586–97.
143. Barrios MAO, De Felice F, Negrete KP, Romero BA, Arenas AY, Petrillo A. An AHP-Topsis integrated model for selecting the most appropriate tomography equipment. Int J Inf Technol Decis Mak. 2016;15(4):861–85.
144. Çalışkan H. Selection of boron based tribological hard coatings using multi-criteria decision making methods. Mater Des. 2013;50:742–9.
145. Ortíz MA, Cómbita JP, la Hoz Á l AD, De Felice F, Petrillo A. An integrated approach of AHP-DEMATEL methods applied for the selection of allied hospitals in outpatient service. Int J Med Eng Inform. 2016;8(2):87–107.
146. Beikkhakhian Y, Javanmardi M, Karbasian M, Khayambashi B. The application of ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods. Expert Syst Appl. 2015;42(15):6224–36.
147. Taylan O, Kaya D, Demirbas A. An integrated multi attribute decision model for energy efficiency processes in petrochemical industry applying fuzzy set theory. Energy Convers Manag. 2016;117:501–12.
148. Keeney RL and Raiffa H, Decisions with multiple objectives: preferences and value trade-offs. Cambridge university press, 1993.