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A survey on automated melanoma detection

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ABSTRACT

Skin cancer is defined as the rapid growth of skin cells due to DNA damage that cannot be repaired. *Melanoma* is one of the deadliest types of skin cancer, which originates from melanocytes. While other skin cancer types have limited spreading capabilities, the danger of melanoma comes from its ability to spread (metastasize) rapidly. Fortunately, it can be detected by visual inspection of the skin surface, and it is 100% curable if identified in the early stages. However, detection by "subjective visual inspection" creates an important problem, due to investigators' different levels of experiences and education. Dermoscopy (dermatoscopy) has significantly increased the diagnostic accuracy of melanoma since late 90's. In addition, several systems have been proposed in order to assist investigators or to perform an automatic melanoma detection. This survey focuses on the algorithms for automated melanoma detection in dermoscopic images through an extensive analysis of the stages in methodologies proposed in the literature, and by examining related concepts and describing possible future directions through open problems in this domain of research.

1. Introduction

Skin cancer is the most common type among all cancers (Mayoclinic, 2017a; Cancer.Org, 2017a; Bethesda Cancer, 2017). In Europe, the number of new skin cancer cases was 100,339 in 2012, of which 22,199 resulted in death (IARC, 2017). In the USA, the number of new skin cancer cases is more than the total number of all other (e.g., breast, lung, prostate and colon) cancer incidences in each year, and the number of estimated new cases diagnosed in 2017 is 87,110 (Cancer.Org, 2017b; SkinCancer.Org, 2017). In each year, two to three million new non-melanoma and 132,000 new melanoma type skin cancer cases occur, according to World Health Organization (WHO) (WHO, 2017). As seen, "melanoma" cases are analyzed separately in these statistics. There is an important reason for such segregation; melanoma is the most dangerous form of skin cancer, and it is considered the most deadly. Although statistical studies show that only 2% of all skin cancer cases are melanoma, it accounts for 75% of all skin cancer deaths (Melanoma.Org, 2017). A detailed examination of general case-statistics of different countries in the world shows how devastating melanoma is. In Europe, the death rate due to melanoma was reported as one person per 24 min in 2012. Melanoma is considered as the Australia's national cancer, where, after prostate (for men), breast (for women), and bowel cancer, melanoma is the third most common cancer type (Melanoma.Org, 2017). According to statistics cited by SkinCancer.org that in the USA, one person dies of melanoma every 54 min and nearly 9730 people are expected to die of it in 2017 alone (SkinCancer.Org, 2017).

Melanoma starts in pigment cells (melanocytes). As opposed to other skin cancer types, it can spread out (metastasize) over other tissues very rapidly (Medicine Net, 2017). The cancer may metastasize through tissue, lymph system or blood circulation. It can spread only into nearby areas while spreading through tissue; however, it can spread out over other body tissues once it penetrates the lymph system or blood vessels (PDQ Adult Treatment Editorial Board, 2018a). The tissue that melanoma spreads then becomes a cancerous growth, which is difficult to deal with. Fortunately the malignant growth occurs on the skin surface, making detection through a simple visual inspection and a complete cure highly possible, if identified at an early stage. Unfortunately, the stage of a melanoma can only be determined after a suspected lesion (or mole) is excised or biopsied. To determine the stage, four basic features are considered: the tumor thickness (Breslow scale Marghoob et al., 2000), its ulceration, and its spread to lymph nodes or other parts of the body (PDQ Adult Treatment Editorial Board, 2018a). There are five main stages of melanoma, i.e., Stage 0, I (A/B), II (A/B/C), III and IV, and their definitions are summarized in Table 1.

Staging plays an important role in developing an appropriate treatment and determining the prognosis. Several procedures can be applied

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Table 1
Stages of melanoma given by the PDQ Adult Treatment Editorial Board (PDQ Adult Treatment Editorial Board, 2018b) (last update: Jan. 2018) (PDQ Adult Treatment Editorial Board, 2018a).

Stage	Definition
Stage 0	Abnormal melanocytes can be found in the outer layer of the skin (epidermis). These cells may turn into cancer. This stage is also called as "melanoma in situ".
Stage I	Cancer has formed. Considers the thickness and ulceration. This stage is divided into Stage IA and Stage IB. **Stage IA:** Tumor is not greater than 1 mm thick and has no ulceration. Formation of a break on the skin. **Stage IB:** Either, tumor has ulceration but not greater than 1 mm thick or; its thickness is in between 1 mm and 2 mm but has no ulceration.
Stage II	Considers the thickness and ulceration. This stage is divided into Stage IIA, Stage IIB and Stage IIC. **Stage IIA:** Either, tumor has ulceration and greater than 1 mm thick but not greater than 2 mm thick or; its thickness is in between 2 mm and 4 mm but it has no ulceration. **Stage IIB:** Either, tumor has ulceration and greater than 2 mm thick but not greater than 4 mm thick or; its thickness is more than 4 mm but it has no ulceration. **Stage IIC:** Tumor has more than 4 mm thickness and it has ulceration.
Stage III	Considers metastasis. Tumor can have any thickness with or without ulceration. It may be spread to one or more lymph nodes or cancer cells are at least 2 cm away from the primary tumor and may be in between primary tumor and a nearby lymph node in a lymph vessel or there may be smaller tumors around primary tumor on/under the skin in a 2 cm radius.
Stage IV	Cancer may have spread into other parts of the body; lung, brain, liver etc., which can be far away from the primary tumor.

at "staging" such as, further physical examination; lymph node mapping (i.e., a substance is injected near melanoma that can be tracked through lymph ducts and according to the result, a biopsy or a removal operation for lymph nodes can be done); CT scan; PET scan (i.e., patient is injected a radioactive glucose, and tumor cells consumes more glucose than the normal ones and therefore, they show up brighter in the scan); MRI with gadolinium (i.e., tumor cells shows up brighter with gadolinium in magnetic resonance images); and lastly, blood chemistry tests (i.e., Lactate Dehydrogenase (LDH) levels can be checked in the blood sample, and high levels of LDH may indicate melanoma in the body) (PDQ Adult Treatment Editorial Board, 2018a). All these procedure results are finally combined with the biopsy of the suspected lesion, resulting in the stage information. For a melanoma case in Stage III or Stage IV, the removal of the lesion itself is insufficient for treatment. As mentioned before, it is much harder to deal with it at these stages, and it may require treatments such as chemotherapy (Airley, 2009), radiation therapy (Washington and Leaver, 2016), immunotherapy (Naing and Hajjar, 2017), and targeted therapy (Yan et al., 2011; Siegel et al., 2018). Therefore, it is crucial for a patient to get a suspected lesion or mole evaluated for early stage detection.

The way for early detection of melanoma starts with awareness raising in the community. At the moment, there are various facilities and events that can evaluate skin surface lesions and moles. For instance in Turkey, there are 19 visual inspection clinics for melanoma (EuroMelanoma.Org, 2017). There are also several programs available online for making appointments in different clinics around the world. In addition, information is available from the World Wide Web (Kanser.Gov.Tr, 2017; Kanser Vakfi, 2017; Mayoclinic, 2017b). Furthermore, there is also a widely accepted guideline to increase awareness of lesions and moles, the "ABCD(E)'s of Melanoma" (WebMd, 2017; Bad.Org, 2017). This basic guideline explains the **A**symmetry, the **B**order irregularity, the number of different **C**olors, and the **D**iameter features of a lesion or a mole. The "E" here stands for "**E**volution" referring to signs that if the lesion or the mole is growing rapidly. In current studies, the "E" is not considered in the automatic detection concept for melanoma. A person who suspects a lesion or a mole after utilizing the aforementioned guideline should visit a dermatologist or a specialist physician for visual inspection. Following this, the investigator may give advice if an excision is needed. If it is the case, this is a relatively easy and short operation to remove or to completely cure the suspected lesion or mole.

As stated briefly above, melanoma is a very dangerous form of skin cancer, and it can be identified visually by investigators. There is indeed a strong need for automated detection algorithms because of the concept of the "subjectivity" problem. This problem originates from the different experiences and education levels of visual melanoma investigators. An average successful visual inspection accuracy is around 65% (Lee, 2001). This reported relatively low accuracy rate is mostly due to the lack of experience of visual investigators, but also it is related to the patient, who may be in a regular clinic, where an ordinary registrar evaluates the lesion or the mole, rather than a specialized facility.

Dermoscopy has widely been utilized in order to increase the melanoma inspection accuracy. In 1663, dermoscopy originated with Kolhaus (Katsambas et al., 2015), who investigated small vessels with a microscope. Later in 1878, the immersion oil, which is placed between the lesion (or the mole) and the lens, was introduced to his method in order to be able to see the textures of lesions or moles (Senel, 2011). Then, a light source is included in the system which leads to a specialized microscope for skin surface lesions (or moles) that is called as the *dermascope* (*dermatoscope*). Basically, this is a device consisting of a built-in light source and a lens (magnifying glass) to examine the skin surface at from 60x to 100x magnification levels. Visual investigator places the device on the skin surface, with a special gel in-between the lens and the skin, and takes a clear magnified picture of the lesion or the mole.

In 2001, a company called 3Gen manufactured a polarized version of the dermatoscope: DermLite (2017a), and since then, the usage