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RESEARCH PAPER

Quantitative Monitoring Wound Healing Status Through Three-dimensional Imaging on Mobile Platforms

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Wound measurement;
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3D imaging;
2D planimetry;
Ruler method

Abstract There are approximately 6.5 million patients in the U.S. suffering from chronic wounds and approximately 140,000 patients hospitalized every year with new wounds. With a long healing process, this demands the need for a non-contact, low cost, and remote monitoring solution that can assist clinicians in diagnosing and treating a patient's wound. This will reduce the burden of countless office visits, especially for those who are elderly and incapacitated. We present a mobile platform based wound 3D imaging app. The app is the only integrated measurement solution encompassing wound area and volume through low cost yet accurate 3D imaging. Extensive experiments show the app has 1.14% and 4.41% relative errors for wound area and volume measurement respectively, far exceeding currently employed clinic methods. In addition, non-invasive volume measurement methods currently use expensive industrial 3D (>$20K) cameras, but our solution provides cheap and accurate results.
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Introduction

There are approximately 6.5 million patients in the U.S. suffering from chronic wounds (e.g. diabetic foot ulcers, and pressure ulcers) and approximately 140,000 patients are hospitalized every year with new wounds.[4] Currently, over 23 million people or 7.8% of the U. S. population have been diagnosed with diabetes. Among them, 5 million people suffer from chronic ulcers.[4] A study from the Centers for Disease Control and Prevention (CDC) concluded that between 1995 and 2010, the prevalence of diagnosed diabetes increased by 50% or more in 42 states, and by 100% or more in 18 states.[1] With soaring diabetes and obesity rates, chronic ulcers will affect more and more people's lives. Currently, an excess of $25 billion is spent annually on the treatment of wounds, and the burden is growing rapidly due to increasing health care costs, an aging population, and certainly the sharp rise in the incidence of diabetes and obesity.[1,8] Due to poor care worldwide, diabetes have caused complications in foot ulcers leading to an amputation of a lower limb every 30 s and only a 20% survival rate after 5 years—a higher mortality rate than colon, breast or prostate cancer.[5] Evidence suggests that 80% of amputations are actually preventable through access of good quality and routine care,[5] for example, comprehensive and accurate wound documentation, early infection diagnosis, and personalized treatment.

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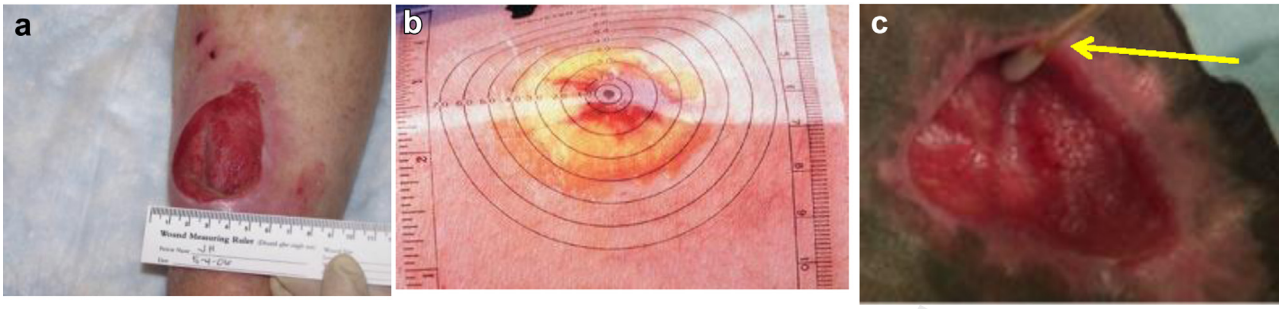

Figure 1 Several typical current wound measurement methods: a) ruler, b) tracing, and c) Q-tip swab (yellow arrow pointed). Q10

Reliable Wound Area/Volume Growth Tracking and Under Skin Infection Detection are Right at the Center of Good Quality Care

A wound's geometric shape and appearance contains a wealth of information about its cause, severity, length of time, change of status, and prognosis for healing. Regular wound size and appearance checkups help doctors assess progress in wound healing and validate the effectiveness of interventions. Studies have shown that documenting the reduction of wound area/volume due to the development of granulated/epithelial tissues is a vital part of wound healing and treatment assessment process.[10] As an example, Flanagan discovered that percentage reduction in true wound surface area is the best way of predicting healing rates, and said that 40% reduction in wound surface area over the first two to three weeks of treatment is predictive of healing in 12–24 weeks.[9]

What are Current Methods on Wound Assessment and What are Their Problems? Q3

Currently, clinical assessments on wound tissues are all done through visual inspection only, and wound size measurements (width, length and depth) are commonly done through either a disposable ruler[3,7] (Fig. 1a courtesy of Reference 2), transparent tape based edge tracing (Fig. 1b courtesy of Reference 13), liquid filling, or even a dipstick swab (Fig. 1c courtesy of co-author's institute). Since it is very subjective to select reference points to measure the wound's dimension, the measured results are often non-repeatable and crude with up to 44% error in area measurement reported.[3,7] The contact based methods are invasive, painful, and difficult for patients,[16] in addition, these methods are prone to contagion. On the other hand, newer non-invasive methods such as 2D digital planimetry[16] and 3D stereophotogrammetry[11] have been experimented or evaluated to achieve the goals of quantifying wound tissue growth through 2D and 3D imaging respectively. However, each has its own drawbacks. 2D digital planimetry was reported to have up to 10% area measurement errors,[3] and produced volume measurement errors of up to 52% when relying on Q-tip for wound depth estimation.[18] 3D stereophotogrammetry is the most accurate measurement method reported[18,22]. However, pointed out by the co-author's institute, system's bulk size and high costs (~tens of thousands) make it impractical for home based care or even hospital settings.[11] Q4

We present a new measurement solution or app on mobile platforms to directly tackles the aforementioned challenges facing current chronic wound care. The app uses computer vision algorithms for quantitative measurement in 3D digital space. Since iDr utilizes a client-server framework to allow mobile app based simple wound video uploading, easy patient data access and analysis, it is designed to significantly reduce the inconvenience and high cost barriers for chronic wound care.

Research Materials and Methods

The mobile app or iDr is designed to help clinicians to objectively and conveniently monitor chronic wound healing process through 3D imaging. Through the app, clinicians can track the wound growth trend through the history data recorded in the past. The wound growth history data includes wound area and wound volume.

3D Imaging for Wound Volume and Area

The smartphone camera is an optical imaging system. Objects in any 3D world are imaged on the sensor's image plane. While it is not possible to recover the actual 3D

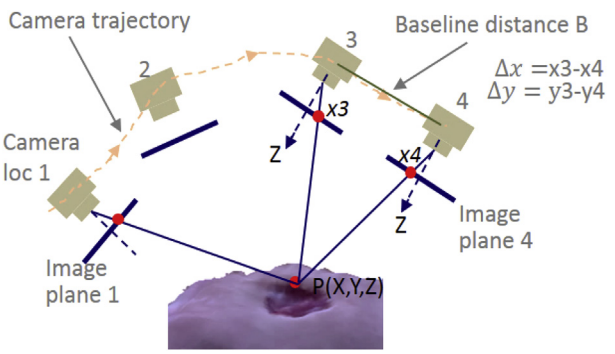

Figure 2 3D SFM when single camera is used for imaging.

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