# 3D Remote Diagnosis and Monitoring in Virtual Wards *

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**Abstract.** This study presents a novel 3D medical examination method to monitor patients remotely. The NHS England recently proposed "virtual wards' due to the backlog of patients care after the pandemic, the aim of this is that patients can receive the same care by remaining at home as they would expect by being in a physical hospital. However, the currently proposed technologies (usually webcams and tablets) lack the ability to perform remote 3D medical analysis; this means that valuable diagnostic information may be lost. To address this gap, we propose to create a test dummy by using an Intel (D405) depth camera to capture this important depth information. This could be used to better analyse tumours, skin diseases and lesions, blunt force trauma, deformations, bone fractures and breaks. The health expert would then be able to remotely see 3D images of the patients on a 3D screen (Nubia Pad 3D) and remotely touch the patient by using an in-house built wearable untethered multimodal fine grained haptic glove. To our knowledge, this is the first proposed and tested technology to examine and diagnose patients in 3D exploring the virtual ward concept. We believe that this approach will enhance, and therefore improve, remote diagnostic capability, and that this will reduce the qualitative gap between in-person and remote patient analysis.

**Keywords:** remote medical diagnostic · hand wearable · patients monitoring

## 1 Introduction

NHS England proposed virtual wards to address the backlog in the health care system to provide a quality remote care system for its patients. The NHS wishes to provide care to patients "in-situ" where they live, whether that is in a care setting or at home. The target is to provide 40–50 virtual wards per 100,000 people and scale up the capacity before next winter [1], [2]. The virtual ward idea has been implemented in many regions including the North West region [3]. The NHS has stated that before any implementation of new virtual wards

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thet the provider should ensure that both clinicians and patients are involved in co-design from the start of development [1].

Within the NHS England model, the vast majority of care is face-to-face. While this is an ideal, face-to-face care requires significant resources. Virtual wards at home or remote monitoring are alternatives to inpatient care or admission. DOCOBOAPP has been used as an application in virtual wards in NHS Northwest England [4]. This application designed to run on an Android or iOS tablet or smartphone and transforms it into a secure patient access device. It also provides self-help home monitoring for patients with long-term conditions, enabling patients to record their daily symptoms, vital signs, lifestyle impacts and quality of life status. The current 2D technology used in NHS virtual wards superficially addresses remote monitoring of the patient, however, the medium is such that it may be difficult for a medical practitioner to remotely interpret important patient information that would be obvious in a face to face meeting. For example, to ascertain if there is anything unusual about skin texture on a flat screen is quite difficult. A 3D view, which they can touch would make medical investigation far easier.

In our study, we propose how medical experts can remotely examine 3D images of the patient's body. Current technology in proposed virtual wards the patients can record parameters such as daily symptoms, vital signs, and quality of life status. Moreover, the medical experts can make a video call via a tablet to see the patients if needed. However, if the medical experts would like to do anything more complex, for example, measure the changing volume of a skin lesion over time, then existing virtual ward technology fails; the patient would have to book an in person appointment. DOCOBOAPP does not address any type of 3D medical examination remotely. We propose a novel 3D medical examination method to monitor patients remotely to add another dimension to the proposed virtual wards in NHS England. In our approach, Intel (D405) depth cameras are used in order to create a point cloud for 3D medical diagnosis. This could be represented by using XR headset, 3D monitors, or by stereoscopic 3D simulation on a conventional display.

Very often during a medical examination in person, a medical expert relies not only on visual inspection of the area of interest but also relies on being able to touch and feel. They heavily rely on the combination of two types of senses. They are kinesthetic feedback and cutaneous feedback. There have been many studies on kinesthetic feedback medical related tele-operated studies to the date. However, cutaneous feedback is mostly restricted or limited in such studies. We argued that fine-grained information is needed in medical examinations operated remotely to investigate the details of images of the patients and can convey via cutaneous feedback. The majority of well-known haptic devices used in telerobotics and telemedicine, such Phantom and Omega, offer single point contact interaction [5]. They do not have tactile matrix actuators. Even if haptic devices have mini vibration motors as their haptic feedback, they may be regarded as cutaneous feedback but not as a tactile matrix actuator or tactile display if they are not grouped together. Therefore, we add another dimension to the 3D remote monitoring system by integrating our recently in-house developed multimodal, fine-grained visual-haptic system for remote sensing.

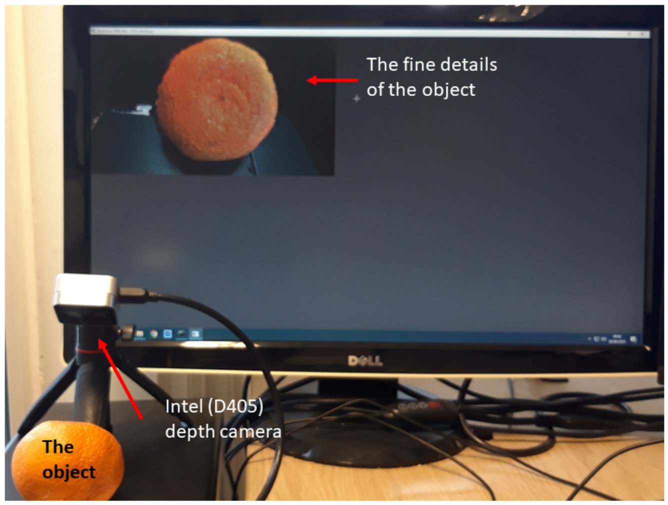


**Fig. 1.** Intel (D405) to record 3D fine grained details on the screen.

Therefore, in our 3D remote medical diagnostic system combines 2 important qualities:

1. mapping 3D graphically, using 3D depth camera and/or 3D display technology, and
2. mapping 3D haptically, by further developing our untethered multimodal fine grained haptic glove.

The structure of the rest of the paper is as follows. Methodology is divided into two parts. The first part on 3D remote medical diagnostic system in 3D graphically, using 3D depth camera and/or 3D display technology and the second part on 3D remote medical diagnostic system in 3D haptically, by further developing our untethered multimodal fine grained haptic glove. The results section follows the same order. The last part of the paper is discussion and conclusion.

## 2 Methodology

### 2.1 3D remote medical diagnostic system in graphically, using 3D depth camera and/or 3D display technology

In this experiment as shown in Fig. 3, Intel (D405) depth camera is used to extract 3D graphics as a detailed pointcloud. We experimented with a number of different cameras; for example, the Revo Mini camera, the Sipeed MaixSense A010 ToF camera, the Oak-D Lite, Intel RealSesne D435. These did not have the resolution or the correct focal length for near object analysis. However, the Intel RealSense D405 provided accurate close up images of surfaces. In this test, to simulate skin, we used an orange. The RealSense Python SDK was used, along with Open3D, to sample the surface texture. Node.js was also used, but this doesn't seem to be supported in the latest version of the SDK at the time of writing. Viewing transformations such rotating or zooming of the 3D surface allowed realtime different views of the surface. The RealSense SDK saved the surface information as a rosbag file. In order for efficient transmission these files are converted into Polygon File Format (PLY) format and can be transmitted directly or can be further converted into GL Transmission Format (glTF) file format. Once in glTF they are served to the remote medical practitioner using a WebXR framework. This could be via Three.js, PlayCanvas or via Babylon.js. Once in this format the files can be viewed on a XR headset or be viewed on a 3D display such as the Nubia Pad 3D or on a Looking Glass display. These images can then be used by medical experts remotely to understand the nature or the condition of the patient with far more detail. This point cloud information could be further utilised for medical diagnosis, for example measuring and recording volume of specific lumps, warts, lesions or cuts, with a high degree of accuracy.

### 2.2 3D remote medical diagnostic system in haptically using untethered multimodal fine grained haptic glove

We developed an untethered multimodal fine grained haptic glove which which consists of five 4x4 miniaturized fingertip actuators, to convey cutaneous feedback in our previous studies [6],[7], and [8] as shown in Fig. 4.1. This wearable is described as modular, lightweight, Bluetooth, and WiFi-enabled. Here the software is developed to demonstrate rapid tactile actuation of edges of 3D images, the idea is to use in medical examination or investigation for medical experts to convey tactile information remotely. The medical experts can wear it if they would like to experience something unusual on the skin of the patients; as an example. This allows the medical experts to feel the contours in cutaneous feedback like lesions, blunt force trauma, deformations. An Arduino IDE was used to develop the firmware that controls the vibration motors, and solenoids. A VR environment was developed using Unity 2019.

Fine-grained haptic hand wearable has an open-backhand and open-palm thimble design similar to "weart" TouchDIVER [9] for easy hand tracking. But unlike the TouchDIVER, which has only three fingertip modules, this prototype

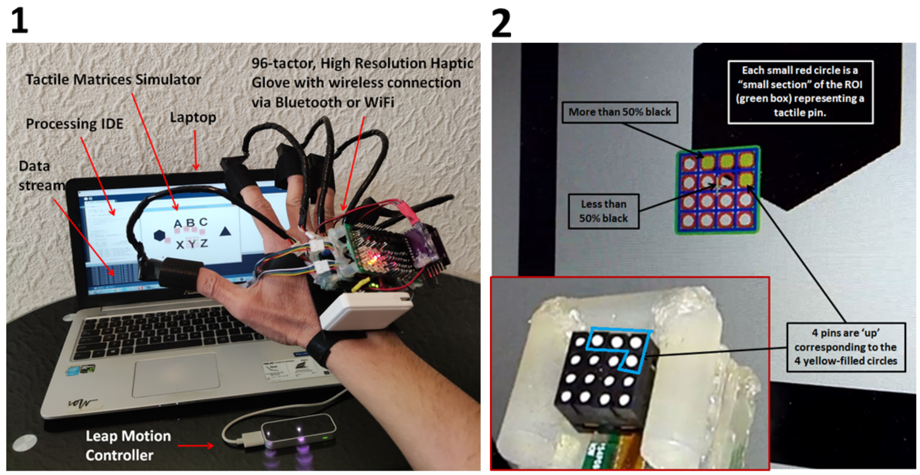


**Fig. 2.** A figure caption is always placed below the illustration. Please note that short captions are centered, while long ones are justified by the macro package automatically.

has five fingertip modules. The prototype has an open-palm design similar to the Dexmo Haptic Force-feedback Gloves [10]. The fine-grained prototype has 80 tactile feedback actuators. Moreover, the prototype can produce not only "up" or "down" tactile feedback from the P20 Braille cells but also different tapping or vibration patterns at different frequencies with varying duty cycles. This would be useful for the medical experts to understand different texture, edges, and other sort of information of the patient.

A single fingertip tactile matrix, as shown in Fig. 4.2 was initially developed. A different commercially available Metec P20 Braille cell that uses piezo-based actuators was used for the fine-grained haptic hand wearable. The Metec P20 Braille cell [12] has a distinct and noticeable pushing force at the fingertip during the activation of the tactile pins. It has a compact and lightweight module containing a back panel with shift register chips that can interface easily with a microcontroller. The hardware section provides more details on the specifications of the P20 Braille cell.

## 3 Results

### 3.1 Results of 3D remote medical diagnostic system in graphically

The results of a 3D remote medical diagnostic system graphically, using 3D depth camera and/or 3D display technology are shown below. The object of this experiment is an orange. The part is over-ripen in the orange. The idea is to see fine details of over-ripen orange via Intel (D405) depth camera and a 3D screen (Nubia Pad 3D) as shown in Fig. 3. In Fig. 3A shows the ripe orange and Fig. 3B and Fig. 3C shows fine details of over-ripen orange. Similarly, we propose a novel

3D medical examination method to monitor patients remotely when the medical experts would like to examine fine details of tumours, skin diseases and lesions, blunt force trauma, deformations, bone fractures and breaks of the patients.

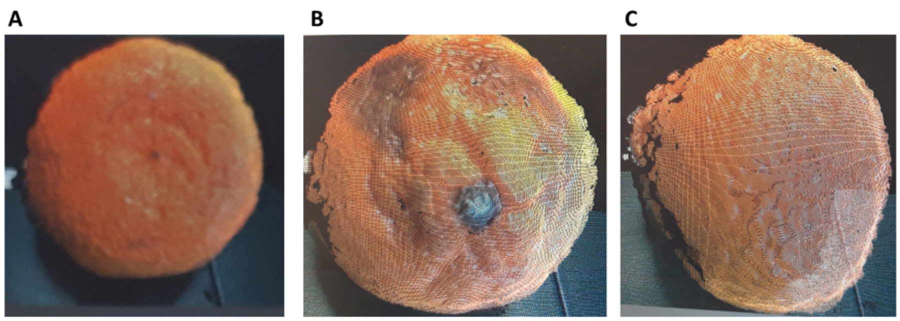


**Fig. 3.** Intel (D405) to record 3D fine grained details on the screen.

### 3.2 Results of 3D remote medical diagnostic system in haptically

The results of a 3D remote medical diagnostic system haptically using untethered multimodal fine grained haptic glove are shown in Fig. 4. The prototype has edge detection capabilities in addition to surface scanning. Fig. 4a to Fig. 4e shows the edge detection procedure utilising the Canny edge and Hough transform. The Canny edge detection algorithm is used to produce the output as white edges on a black backdrop, as shown in Fig. 4b, from the given RGB image of a cup, as shown in Fig. 4a. Because the prototype interprets a black colour pixel as a "up" signal for the actuator, it is necessary to flip this Canny edge result. The Canny edge result is now displayed as black lines with a white background as shown in Fig. 4c by simply utilising the picture filter function "filter(INVERT)" without any spaces. The Hough transform for lines function in the OpenCV library can be used to create the image with thick lines as shown in Fig. 4d. As shown in Fig. 4e, the enhanced Canny edge image on a white background is subsequently fed as background in the tactile matrix simulator [11]. The idea is that medical experts would be able to feel the details of the 3D images of the patients via wearable untethered multimodal fine grained glove. This experience would be similar when they examine patients in person appointments.

## 4 Discussion and conclusion

This paper aims to bring another step forward to explore possible applications in “virtual wards’ ’ at home ideas from the NHS. Within the NHS England model, virtual wards for older people operate in a similar way to hospital at home, with

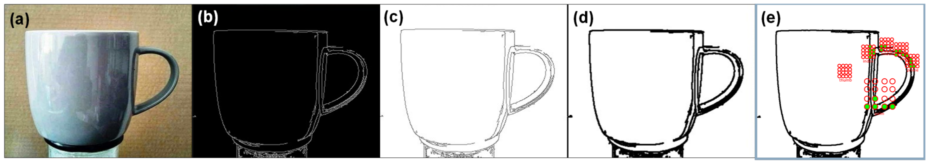


**Fig. 4.** a) given RGB image of a cup, b)white edges on a black backdrop of the cup, c)The Canny edge result is now displayed as black lines with a white background of the cup, d) the image of the cup with thick lines, and e)the enhanced Canny edge image on a white background is subsequently fed as background in the tactile matrix simulator.

the majority of care being face-to-face. However, hospital at home or remote monitoring is proposed as alternatives to inpatient care or admission. Remote monitoring in using technologies and wearables are proposed to monitor patients day-to-day activities in virtual wards at home. The proposed technologies and wearable would not be able to monitor depth images of the patients. For example, the medical expertise from the hospital would like to see an image of the wound. The current technologies are limited to a video call and there are not sufficient details enough to examine. Therefore, we experimented using an Intel (D405) depth camera in order to capture important depth information and a 3D screen (Nubia Pad 3D) and felt 3D fine grained information to investigate depth images of patients. This study would give us an overview as point cloud information for medical diagnosis. The results from 3D remote medical diagnostic system in graphically, using 3D depth camera and/or 3D display technology and 3D remote medical diagnostic system in haptically using untethered multimodal fine grained haptic glove.

As an example, If the medical experts would like to study the progress of a patient's wound, this system is ideal for them as it can be stored as point cloud information for medical diagnosis. Moreover, the experts would be able to examine the nature of the examination, they would be able to scale up wounds. Moreover, the untethered multimodal fine grained haptic glove 3D remote medical diagnostic system is haptically. Therefore, this proposed 3D remote diagnosis and monitoring in virtual wards would add another dimension to NHS England virtual wards.

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