Preliminary evaluation of Time-of-flight (ToF) imaging system for monitoring DIBH radiotherapy

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Abstract. The study focusses on evaluation of a Time-of-flight (ToF) camera for monitoring breath-hold (BH) level during voluntary deep inspiration breath-hold radiotherapy (vDIBH-RT). A commercial Argos 3D P330 ToF camera (Bluetechnix, Austria) was used to provide the distance of the patient imaged based on the light reflected from the illuminated surface. A volunteer was recruited in this study to preliminary evaluate the performance of the ToF camera for optical surface imaging. The vDIBH-RT was simulated by instructing the patient to perform DIBH for 15 seconds during ToF imaging. A small region was selected on the image of the patient’s chest surface, mid-way between the nipples. 200 consecutive ToF images of the selected area were captured during the DIBH. Imaging was repeated during free breathing (FB). These were performed for two times (representing fractions) to evaluate the inter-fraction variability. MATLAB (MathWork, Natick, MA) was used to calculate the average distance and standard deviation (SD) across each set of images acquired during a DIBH representing the BH level and BH stability, respectively. The inter-fraction variability defined as the difference between fraction-1 and fraction-2 was 4.5 mm ± 0.86. The BH stability for both sessions were within 1 mm. The distance measured during free breathing shows traces similar to the respiratory pattern obtained when using spirometry system. In conclusion, the ToF camera has potential in monitoring BH during DIBH-RT for breast cancer.

1. Introduction
Breast cancer radiotherapy carries a low but significant risk of cardiac morbidity due to radiation dose received by the heart during the treatment delivery. The risk is specific to left breast cancer patients as the target volume is immediate to the heart [1]. Deep inspiration breath-hold radiotherapy technique (DIBH-RT) was introduced to reduce cardiac dose during left breast cancer treatment. The technique could reduce cardiac dose by over 50% [2]. However, poor reproducibility and stability of the breath-hold (BH) during each treatment fraction could results in geographic miss.

A number of methods are currently being used to monitor the reproducibility and stability of the BH. The common methods used include; Active Breathing Control (ABC) and Real-time Position Monitoring (RPM) system. The ABC system requires the patients’ nose to be pegged and mouth connected to the device, which cannot be withstand by some patients [3]. The use of RPM was found to increase patient skin dose due to the infrared marker-block placed on the patients during the treatment delivery [4]. Most recently, commercial surface imaging systems such as AlignRT (VsionRT,
London, UK) and Catalyst (C-RAD, Uppsala, Sweden) were introduced to overcome the limitations associated with the other techniques [5]. However, these commercial systems are costly and their working principle, “triangulation” is only accurate at shorter working distance compared to ToF systems [6].

This study focuses on ToF camera based on complementary metal–oxide–semiconductor (CMOS) image sensor technology. The preliminary characterisation of the camera has been performed in an earlier study [7]. The characterisation study shows that the camera could detect target displacement with accuracy better than 1 mm using phantom measurement and CBCT as reference. Therefore, this study aims to evaluate the feasibility of the camera in monitoring the stability and reproducibility of the BH during vDIBH-RT for left breast cancer patient.

2. Materials and Methods

2.1 The ToF imaging camera

The commercial Argos 3D P330 ToF camera (Bluetechnix, Austria) consists of high-power laser diode illuminator and CMOS-based ToF sensor. The illuminator transmits modulated infrared light to a target which is reflected to the sensor. Each pixel in the sensor measures the correlation function between the incidence and reflected signals from which the phase shift is calculated. The phase shift is subsequently used to calculate the target-sensor distance that is displayed in a 2D image. The ToF camera was mounted on the ceiling directly above the treatment couch and angled 49º downward, focussing at the isocentre to allow distance measurement in AP dimension of the patient. The sensor-to-isocentre distance was approximately 890 mm. The ToF camera setup and properties are shown in Figure 1a and 1b, respectively.

2.2 Patient characteristics and setup

A patient-volunteer aged 64 for radiotherapy treatment of breast cancer who signed the written consent was involved in this prospective study. An experienced radiation therapist assessed the ability of the patient to perform stable BH for up to 15 sec. This duration was selected instead of the standard 20 sec duration commonly used for DIBH-RT as the patient did not undergo any BH training. During the rehearsal session, we observed that the patient could only hold her breath, comfortably, for approximately 15 secs. The patient was not treated using DIBH-RT. We only simulated the technique after the patient completed her day treatment while she was still in the treatment position. DIBH was rehearsed with the patient before the commencement of the ToF image acquisition. The breath-hold and ToF acquisition were performed with gantry head at 5° to simulate the anterior field. Elekta Synergy (Agility) linear accelerator (Elekta Medical Systems, Crawley, UK) at Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia (USM) was used in this study.

2.3 ToF Image acquisition

The ToF camera was operated from the linac control room while observing the patient on CCTV images. A square region of interest (ROI) was selected on the chest surface of the patient located on the sternum at the level midway between the nipples. The size of the ROI selected was 10 × 10. The illustration of the patient setup and selection of the ROI was shown using a sample of the depth image in Figure 1c. The BH instruction was given to the patient by the radiation therapist from the linac control room via intercom. During each image acquisition, 200 consecutive frames were captured at a frame rate of 20 fps using 2000 µs integration time and 30 MHz modulation frequency. The data were obtained during the first and second day of the patient treatment, simulating two treatment fractions.

The data were analysed using MATLAB (MathWorks, Natick, MA). For each image in a set of the 200 consecutive images captured per acquisition, the distance values recorded for each pixel in an image were averaged so that each image is represented by a single distance value, d. The d in each set
of images captured per acquisition were plotted against the acquisition time to illustrate the breath-hold level (BHL) and BH stability (Figure 2). The BHL and stability of the BH were then calculated as average and SD of the d, respectively.

Figure 1. (a) The ToF camera setup (b) The ToF camera (c) sample of the distance image and ROI selection shown as square box

3. Results and Discussion
We have evaluated the feasibility of ToF based imaging system for BH monitoring during vDIBH-RT for left breast cancer. Figure 2 illustrates the results of the BHL and BH stability during fraction-1 and fraction-2. The respiratory trace obtained during FB was also included in the figure for comparison.

Figure 2. Result of the distance measurement for BH (a) and FB (b) during two treatment fractions

The values shown in Figure 2 were the average ± SD of the ROI acquired during DIBH. The average value is the sensor-to-chest surface distance representing the BHL. The BHL during fraction-2 (871.6 mm ± 0.5) was greater compared to fraction-1 (867.1 mm ± 0.7) indicating shallower BH in the
later. Higher BHL value represents shallow BH. This is because with shallow breath-hold, the chest surface occupies the lower position and thus, longer sensor-to-chest surface distance or BHL. The difference between the fraction-1 and fraction-2 BHL (4.5 mm ± 0.86) represents the inter-fraction variability. The difference is perhaps because the patient did not observe at least one week of BH practice before the commencement of the treatment as done in standard practice. Nevertheless, the inter-fraction variability is within the 5 mm tolerance level for breast treatment adopted in our centre.

The stability of the BH as indicated by the SD of the d captured during single BH was better during fraction-2 (0.5 mm) compared to fraction-1 (0.7 mm). This could be because most patients are very nervous during the first fraction as they are not sure of what they will experience during the treatment. However, in both fractions, the stability values were less than 1 mm. This agrees with a recent study which reported average stability of 0.9 mm [8]. This shows evidence of good chest surface stability during DIBH. The breathing motion during FB results in continuous rise and fall of the chest surface and thus, sensor-to-chest surface distance resulting in similar respiratory traces obtained when using spirometry system.

The data presented here is for only one patient over two fractions. Also, we did not involve a reference standard to evaluate the accuracy of the ToF camera.

4. Conclusion
The preliminary investigation shows that ToF imaging has the potential for monitoring stability and reproducibility of breath-hold during DIBH-RT for left breast cancer. The result indicates that the camera could detect chest surface displacement and measure the stability of the breath-hold, similar to the commercial surface imaging systems. This work is currently being carried out on a larger number of patients with the use of CBCT as a reference standard

5. References
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