IR-UWB Radar-Based Near-Field Head Rotation Movement Sensing Under Fixed Body Motions

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Abstract

In this study, we propose a method to measure a head rotation movement using an impulse radio ultra-wideband (IR-UWB) radar. The method modifies the pulse Doppler processing technique to extract a specific one-dimensional array, which represents the time of arrival (TOA) information of the head motion, from a frame buffer. Head movement sensing can be utilized to differentiate an intended human motion from an unintended head motion. A human interface device can also utilize head movement information.

Keywords: IR-UWB radar, head rotation movement sensing, time-frequency analysis

1. Introduction

Due to its high resolution and less power consumption, impulse radio ultra-wideband (IR-UWB) radar sensor has been applied to various fields [1–3]. For example, GPS sensors are the primary positioning sensor for vehicles [4, 5], but vision and radar sensors are also necessary for positioning [6–9] when GPS is not available due to ionospheric anomalies [10, 11], radio frequency interference [12–14], or indoor environment.

In addition, radar sensors are applicable for user interface by detecting human motions such as hand gestures [15–17], articulator movement [18], and blinking [19, 20]. In these applications, it is important to separate an intended motion from clutter or unintended motion. Particularly, the detection of motion related with face muscles, for example, the movement of articulators and blinking, can be interrupted by a head movement. In this study, we aimed to detect head rotation movements. Through this, eventually, we expect to distinguish other face muscles-related movements from head movement. Additionally, head rotation movement sensing can also be used on its own by human interface devices [21–23].

In the previous study [24], we have measured an intentional eyelid movement with the IR-UWB radar sensor. To analyze an eyelid movement pattern, we composed a frame buffer comprised of multiple radar frames and generated a specific one-dimensional array that represented frequency characteristics by two methods. Both methods worked well for the purpose of analyzing frequency characteristic of small motions such as the eyelid movement.

In this study, we develop a time of arrival (TOA)-based method to produce a one-dimensional array that contains the entire frequency characteristics of a large movement using the IR-UWB radar. After attaining an appropriate one-dimensional array, we performed fast Fourier transform (FFT) on the array to analyze its pattern. The frequency of the maximum peak in the frequency response is related to the number of head rotations. This result shows that the one-dimensional array made by the TOA-based method can be used to grasp frequency characteristics of head rotation movements.

2. Measurements

In this study, we used the Novelda NVA-R661 IR-UWB radar. It emits a pulse radar wave to an object and a reflected pulse radar wave is stored as one frame. We collected approximately 100 frames per second and the experiment was performed for 10 s, collecting 1000 frames in total. Besides, each frame had 256 range cells. Therefore, a frame buffer in this paper is a 256-by-1000 matrix. Finally, we removed stationary clutter from each frame and composed the frame buffer as shown in Fig. 1. Its x-axis, y-axis, and z-axis represent “fast time index” [18], “slow time index” [18], and normalized amplitude, respectively.

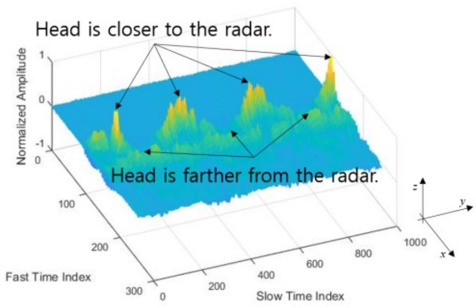
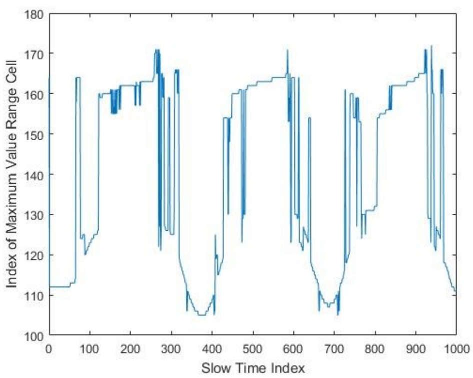


Fig 1. A clutter-removed frame buffer reflecting three sets of head rotation movement.

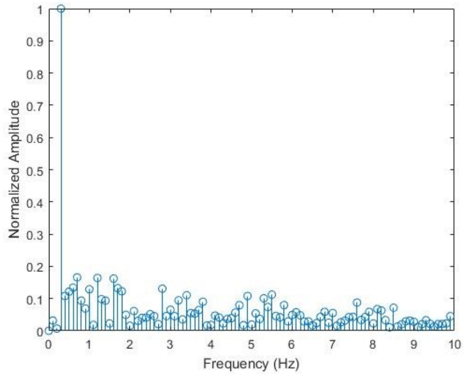
In this paper, we define one set of head rotation movements as a series of head motions tilting forward, rightward, backward, leftward and again forward. In this experiment, a participant performed three sets of head rotation movement under fixed body motions within a 50 cm range from the radar. These head motions can be identified from the patterns of Fig. 1.

3. Head rotation movement detection

We generated one-dimensional array of which each element corresponds to a range cell index that has the maximum value out of whole range cells at each slow time epoch (i.e., frame), as shown in Fig. 2 (a). Figure 2 (a) shows a periodic pattern. Its higher values mean that the head is farther from the radar, and its lower values mean that the head is closer to the radar. Figure 2 (b) shows the frequency response. In the experiment, because the participant performed three sets of head rotation movements over a 10 s period, a peak at 0.3 Hz is the proper outcome, as shown in Fig. 2 (b).



(a)



(b)

Fig 2. (a) Visualization of a one-dimensional array generated using the proposed TOA-based method and (b) its frequency response.

4. Conclusions

In order to detect head rotation movements using an IR-UWB radar, we generated a frame buffer by accumulating multiple frames. Additionally, we produced a specific one-dimensional array that shows the head motion characteristics by the proposed TOA-based method. The array showed a periodic motion pattern and its frequency response had a peak at 0.3 Hz, which is the expected outcome for the three sets of head rotation movements over 10 s. It means that the proposed method used in this study accurately detects the frequency characteristics of the head rotation movements.

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