FMCW Radar Driver Head Motion Monitoring Based on Doppler Spectrogram and Range-Doppler Evolution

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***Abstract* — Lack of driver alertness is one of the leading causes of traffic accidents. In this work, a coherent FMCW radar was used to observe the Doppler and range signatures of various head motions. The Doppler and range information was analyzed using range-Doppler evolution, and the Doppler signature was extracted from range-Doppler evolution to create a Doppler spectrogram within LabVIEW. By analyzing the range-Doppler and the Doppler spectrogram in different head and neck motions, Doppler and range characteristics of dorsal flexion of the neck, the motion that indicates low driver alertness, were distinguished from those of other driver head and neck motions. Ultimately, experiments demonstrated the potential of radar-based head motion detection as a driver monitoring solution.**

***Index Terms* — Doppler, FMCW radar, range-Doppler evolution, driver monitoring, head motion**

I. Introduction

Drowsy driving is one of the leading causes of road accidents. Existing technologies preventing drowsy driving such as Driver Alert System by Volkswagen monitor the movement pattern of the vehicle rather than the driver. Other radar-based driver monitoring researches focus on vital signs [1] and facial features recognition [2] to determine the driver's level of alertness. However, it is difficult to separate a driver's breathing or heartbeat patterns from other body motions. Furthermore, monitoring the driver's facial expressions and blinking rate requires a very narrow and precise beamwidth, which can be difficult to focus when the driver is facing away from the radar. In contrast, head motion is less dependent on extraneous movements by the driver because it focuses on the driver's larger external motions. Detecting certain head motions that correlate with low driver alertness can prevent drowsy driving and driving under the influence. For instance, rapid dorsal flexion of the neck signifies low levels of driver alertness and possible loss of consciousness.

Alterations to a continuous-wave signal frequency caused by a moving object, or its Doppler effect, can be analyzed to calculate the velocity of the target object. By continuously changing the signal frequency to generate a linear chirp, the range of the object can be measured as well. The latter form of radar is called the frequency-modulated continuous-wave (FMCW) radar, and it has been used in various biomedical applications such as human target identification [3], heart rate monitoring [4], and fall detection [5].

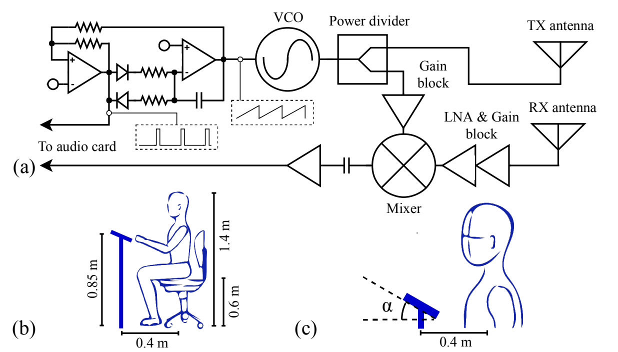

Fig. 1. (a) Block diagram of the FMCW radar. (b), (c) Position of the subject's head relative to the FMCW radar.

In this research, an FMCW radar is used to observe various head and neck motions that can be analyzed to determine a driver's state of alertness. Experiments will be performed to observe the changes in range and Doppler caused by various neck and head movements such as dorsal flexion, dorsal hyperextension, lateral bending, and rotation. Frames of Doppler spectrogram and range-Doppler evolution illustrating different head motions will be observed for characteristics that distinguish each motion. The results will validate the potential of FMCW radar to monitor a driver's head motion.

II. Theory of Radar-Based Head Motion Detection

A coherent FMCW radar is capable of simultaneously tracking the range and Doppler signature of a moving target. The coherent FMCW radar used in this study had a center frequency of 5.8 GHz and a chirp repetition rate of 353 chirps per second. The data was collected at the sampling frequency of 192000 samples per second (S/s). Fig. 1 (a) shows the simplified block diagram of the radar.

The radar would be most effective in areas of the vehicle directly in front of the driver, such as the steering wheel or the dashboard. In this study, the radar was placed 0.85 m above the floor, and the subject was sitting on a chair 0.6 m above the floor to simulate the seat of a car. The radar was placed 0.4 m in front of the subject (Fig. 1(b), (c)). Preliminary experiments performed to find the

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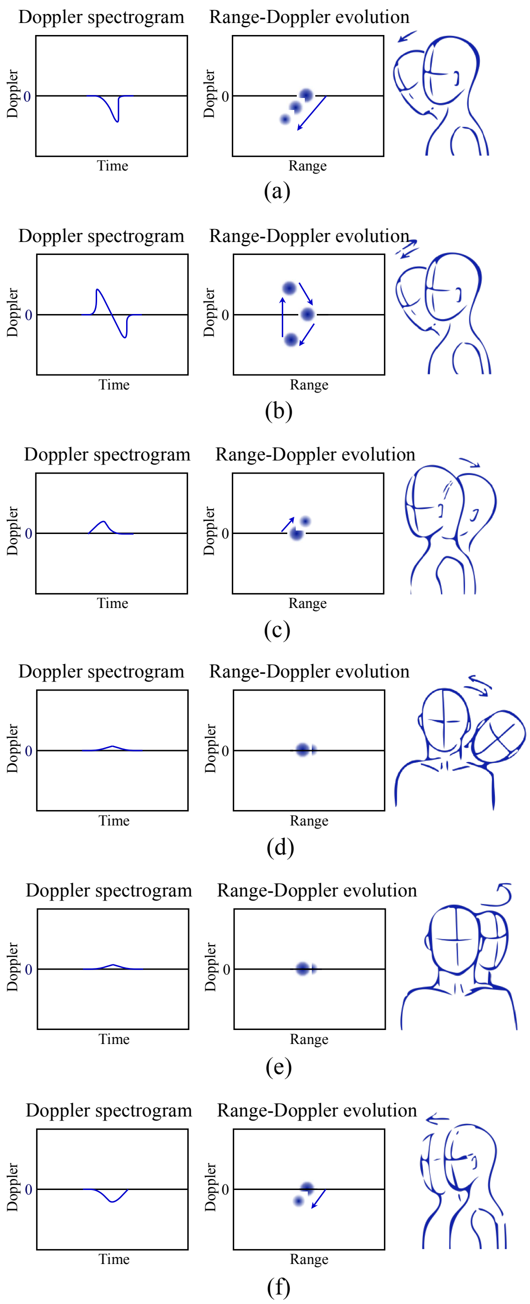

Fig. 2. (a)-(f) Different neck and head motions and their theorized Doppler and range-Doppler evolution.

optimal angle of inclination α of the radar will be detailed in section II. In this section, six different head and neck motions used by drivers and their corresponding Doppler spectrogram and range-Doppler evolution are analyzed.

Figure 2(a) illustrates the dorsal flexion of the subject's neck, where the subject's head tilts forward at an angle. This motion involves the movement of the head toward the radar and is characterized by negative Doppler signature and decreasing range. However, if the subject lifts the head back up after the initial dorsal flexion, the

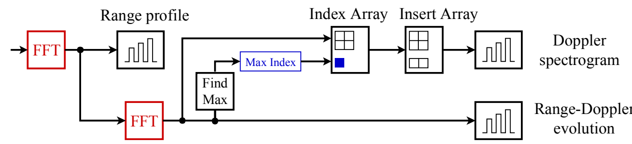

Fig. 3. Flowchart of LabVIEW Programming used to extract Doppler spectrogram from range-Doppler evolution.

Doppler signature and range will increase before returning to zero (Fig. 2(b)). Since sudden, quick dorsal flexion of the neck usually indicates low levels of driver alertness, it is important to distinguish dorsal flexion from other head and neck motions. Placing the radar at an angle can help differentiate between the Doppler signature of neck flexion and other forward body motion.

Figure 2(c) illustrates the dorsal hyperextension of the subject's neck, where the subject's head tilts backward at an angle. This motion involves head movement away from the radar and is characterized by positive Doppler signature and increasing range. It is important to differentiate dorsal hyperextension from dorsal flexion because they both involve head movements towards and away from the radar.

Figure 2(d) illustrates the lateral bending of the subject's neck, where the subject's head tilts sideways without rotation around its axis. Fig. 2(e) illustrates the rotation of the subject's neck, where a subject's head rotates around its axis. Both lateral bending and rotation of the neck involve relatively little movement of the head towards or away from the radar and should not result in significant changes in range or Doppler.

Figure 2(f) illustrates forward body motion by the subject, where the subject's head and upper body move forward without bending down at an angle. This movement should result in negative Doppler and decreasing range, although changes in Doppler should not be as pronounced as that of dorsal flexion.

III. Specifications and Experimental Setup

A. Experimental Setup

Preliminary experiments were performed to determine the angle α at which the transmitter and receiver should be placed to maximize detection of dorsal flexion and to better differentiate its Doppler history and range-Doppler evolution from those of other motions. After experimenting with angles 15°, 30°, 45°, and 60°, the results showed that the transmitter and receivers best detect Doppler signatures of dorsal flexion at an angle of 30° from the horizontal. In this experiment, the FMCW radar was positioned with the angle of inclination of 30°.

B. Extracting Doppler from Range-Doppler Evolution

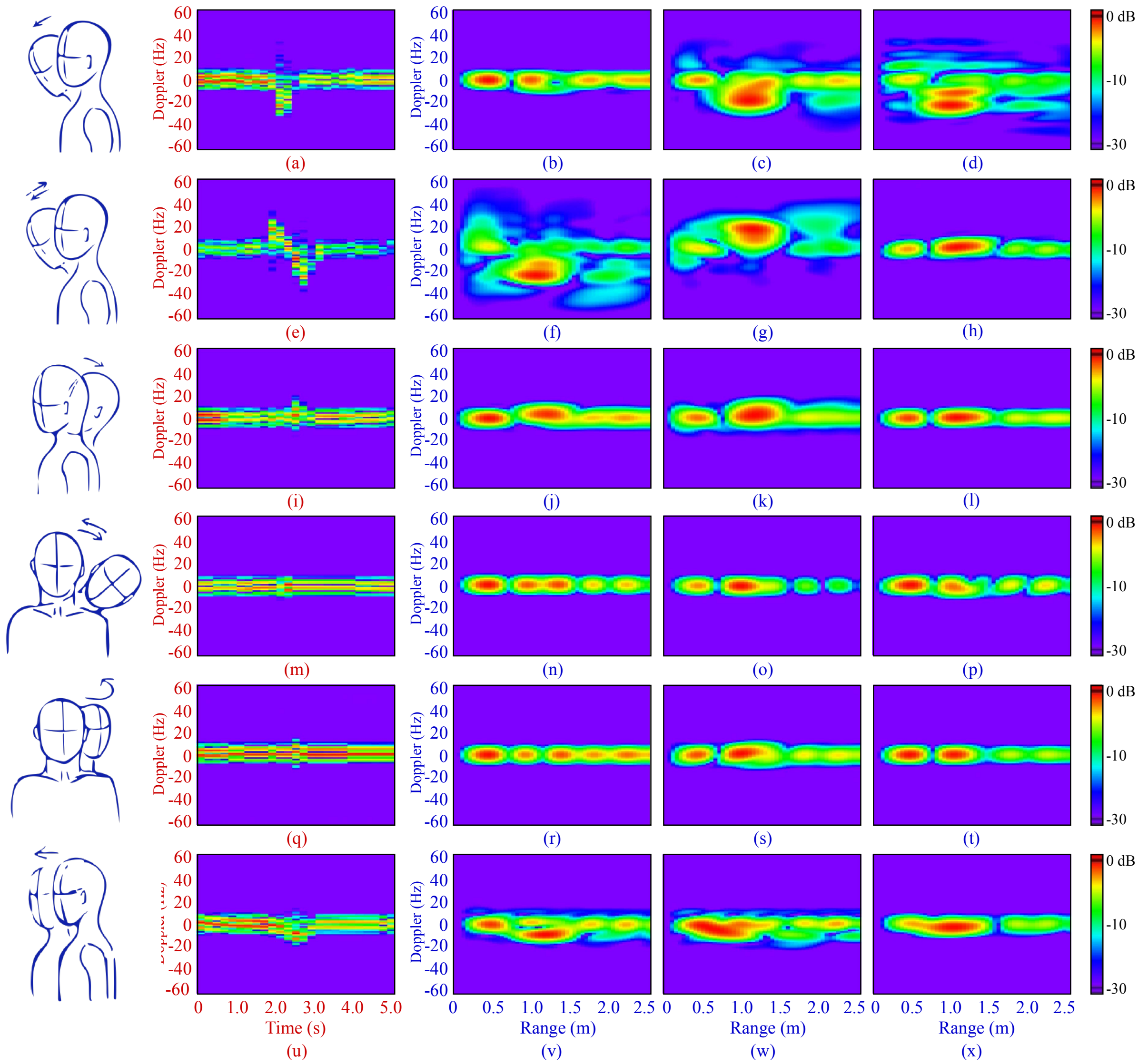

Fig. 4. Experimental Doppler spectrogram and range-Doppler evolution frames of different neck and head motions.

Figure 3 shows the FMCW signal flow chart. Range profile of the subject was calculated by performing a Fast Fourier Transform (FFT) along the fast time of the radar output. Range-Doppler evolution was created by isolating each window of the range profile and performing another FFT along the slow time. In this work, Doppler history was extracted from range-Doppler evolution to display the change in Doppler over time.

To extract the Doppler history from existing range-Doppler data, the range-Doppler evolution was indexed to display the Doppler signature of a specific range. This "range of focus" was designated as the range at which the maximum Doppler signature was observed. As the subject moved towards and away from the radar, the range at which their Doppler signature was observed became the range of focus. Furthermore, to prevent stationary clutter from interfering with identifying the appropriate range of focus, slow Doppler signature (-10 Hz to +10 Hz) were disregarded when a Doppler component with normalized intensity above -9.5 dB appeared in the range under observance. The user could limit the range at which the program can search for the maximum Doppler signature by setting the minimum and maximum range of focus. Because this experiment required observing targets relatively close to the radar, the minimum range of focus of 0 m and the maximum range of focus of 2 m were used.

IV. RESULTS

Frames of Doppler spectrogram and range-Doppler evolution in Fig. 4(a)-(d) correspond to the dorsal flexion of the subject's neck. The Doppler spectrogram displayed negative Doppler as the subject's head moved toward the radar. When the subject didn't raise their head again, the

Doppler signature returned to zero. The range-Doppler evolution frames displayed negative Doppler and decreasing range as the subject's head moved toward the radar, and the Doppler signature faded when the subject didn't raise their head again.

However, when the subject raised their head to an upright position again after dorsal flexion, the Doppler signature became positive before returning to zero (Fig. 4(e)-(h)). Likewise, the range-Doppler evolution frames showed that both the Doppler and range increased again after the initial decline. Since dorsal flexion of the neck while driving is more problematic if the subject does not raise their head again, analyzing the Doppler spectrogram and range-Doppler evolution over time can determine the severity of the subject's lack of alertness.

Frames of Doppler spectrogram and range-Doppler evolution imaging in Fig. 4(i)-(l) correspond to the dorsal hyper-extension of the subject's neck. The Doppler spectrogram and range-Doppler evolution displayed findings consistent with predictions detailed in Section II.

Frames of Doppler spectrogram and range-Doppler evolution in Fig. 4(m)-(p) and Fig. 4(q)-(t) correspond to the lateral bending and lateral rotation of the subject's neck, respectively. Since left and right bending and rotation result in identical Doppler spectrogram and range-Doppler evolution, only the right bending and right lateral rotation were tested. The Doppler spectrogram and range-Doppler evolution displayed findings that were consistent with predictions detailed in Section II.

Frames of Doppler spectrogram and range-Doppler evolution imaging in Fig. 4(u)-(x) correspond to the general forward body motion. Although forward body motion also causes negative Doppler and increasing range, the change in Doppler signature was more gradual than that of dorsal flexion. Furthermore, the change in range and Doppler in forward body motion were not as pronounced as those in dorsal flexion.

V. Conclusion

This work demonstrates the potential of an FMCW radar to monitor driver's head motions with real-time Doppler spectrogram and range-Doppler evolution. Signals measured from various head motions show that dorsal flexion of the head displays a unique signature that can be distinguished from that of other head motions used in driving. With the help of image-processing software, the radar-based head-motion monitoring technology can be implemented by itself or integrated with other sensing methods to serve as a reliable alternative.

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