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Research on the Vital Monitoring of the Driver Using a Millimeter-wave Radar Sensor

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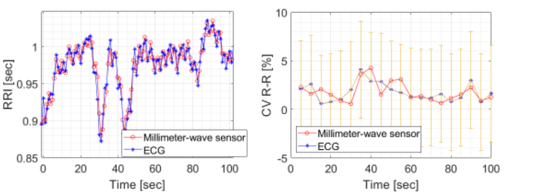
In recent years, in-cabin sensing devices for drivers to support safety-driving has high demand according to the development of advanced driver assistance systems (ADAS) and autonomous driving (AD) technology. The vital sensing technology using millimeter-wave sensors can contribute to supporting safe driving. Using millimeter-wave sensors, low-cost and high robust sensing systems of human vital can be achieved. Although driver monitoring systems using camera devices are well studied, the driver monitoring systems have issues with the accuracy of vital sensing and robustness against the brightness in the environment. On the other hand, a millimeter-wave sensor is constructed based on millimeter-wave radar technologies. It can accurately measure the distance and angle between sensors and drivers and doppler velocities caused by the driver's heartbeat, respiration, and body motion. Moreover, it is possible to eliminate the influences of the clothes because radio waves of millimeter-wave frequency bands can penetrate thin dielectric materials.

Millimeter-wave sensors can detect the small vibration using the analysis of the micro-Doppler phenomenon. Therefore, millimeter-wave sensors can measure drivers' heart rate and R-R interval (RRI). To obtain a good ADAS and AD system, the surveillance of the status of the driver's physical and psychological health are necessary. In the market of millimeter-wave vital sensors, mainly the 60 GHz frequency band sensor will be utilized, which has excellent resolution.

This paper reports the current status regarding the development of Kyocera's millimeter-wave vital sensing for driver monitoring systems. The Kyocera's millimeter-wave sensor is configured based on the basic millimeter-wave radar technologies consisting of the chirp configuration, two-dimensional fast Fourier transform (2D-FFT), and the constant false alarm rate processing (CFAR) and the estimation of direction of arrival waves (DOA). Our original audio processing methods configured central processing to measure heart rate and RRI. The overview of the proposed 60GHz millimeter-wave sensor is denoted in the proceeding.

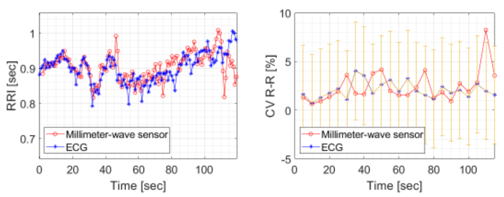
We executed the experiments using a driving simulator owned by Shibaura Institute of Technology to confirm the performance of the manufactured millimeter-wave sensor for the driver monitoring systems. The manufactured millimeter-wave sensor was installed on the sun-visor in the cabin of the driving simulator. The distance between the sensor and the examinee's chest was 0.6 m. We employed the Polar H10 chest band and the smartwatch as the gold standard to confirm the accuracy of the millimeter-wave sensor. The measurement of RRI was executed under the condition of 1) ideal quiet status when the examinee was sitting on the office chair and 2) driving with a speed of 90km / h, simulating a highway using the driving simulator. In this experiment, we obtained the RRI and CVRR. CVRR is calculated as the ratio of the mean and variance of RRI. We calculated the CVRR for the calculation period was set to 5, 10, and 20 seconds. We confirmed the accuracy of the RRI and CVRR data of the millimeter-wave sensor compared with the ECG data.

Figures 1 (a) and (b) show the measured data of RRI and CVRR when the examinee was sitting on the office chair. With regard to RRI, the millimeter-wave sensor data is almost consistent with ECG. Concerning CVRR, the trends of both sensors are corresponding. Figures 2 (a) and (b) show the RRI and CVRR when the examinee drove the driving simulator. The RRI data of both sensors are consistent except for the high-frequency variability, which corresponds to the high-frequency component (HF) of the heart rate variability (HRV). The differences between both sensors of the high-frequency component are due to the body motion caused by the diving action. Although the mean value of both sensors of CVRR is corresponding, the tendency of fluctuation. These differences due to the body motion will be improved by more advanced denoising techniques of the generated heart sound waveforms.



(a) R-R interval (b) CVRR

Figure 1 Experimental results of (a) the RRI and (b) CVRR when the exmainee was sitting on the office chair.



(a) R-R interval (b) CVRR

Figure 2 Experimental results of (a) the RRI and (b) CVRR when the examinee was driving in driving simulator (speed = 90 km/h).