Development of Vital Signs Detection System with Velocity Sensors

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Abstract. In this paper we develop a non-intrusive method for detecting vital signs in a passenger vehicle. Various types of sensors can detect vital signs, including body temperature, carbon dioxide, and body vibrations. Velocity sensors that are convenient and accurate at acquiring data are adopted in this research. Studies have shown that the human body generates vertical vibrations at a low frequency, mainly caused by an involuntary vibration phenomenon, called "ballistocardiac vibration". This vibration can be detected with sensors at a low frequency range. If people hide in a vehicle, vital vibrations are transmitted to the body of the vehicle, making it resonate at the same frequency range. These vibration signals offer an effective method for detecting people concealed in a vehicle. To increase the system's accuracy, signal processing is essential for extracting a specific vital-frequency band, by calculating the signals of a person in a vehicle from several velocity sensors.

1. Introduction

This study provides an experimental procedure and an algorithm for detecting the vital signs of a person in a vehicle. The detection of vital signs can be usefully applied in many areas. For example, a system that recognizes the passenger's presence can prevent the injury of the left behind children due to hyperthermia [1]. In addition, bio-signs are very useful signals to monitor the health of a patient [2]. For example, when the body vibration amplitude increases in a specific frequency range, a doctor can make a preliminary diagnosis easily. Another potential application of vital sign detection is to identify stowaways hiding in vehicles [3].The human body continuously generates involuntary ballistocardiac vibrations in the range of 4 to 8Hz [4]. When a person is concealed in a vehicle, the low-frequency waves are transmitted to the vehicle chassis, where velocity sensors with high sensitivity can detect low-frequency vital signs. However, the system must be accurate under various disturbance conditions. Thus, this study compiles the vibration signals, and uses the proposed signal processing to test the feasibility of the method.

2. System and data processing

2.1. System

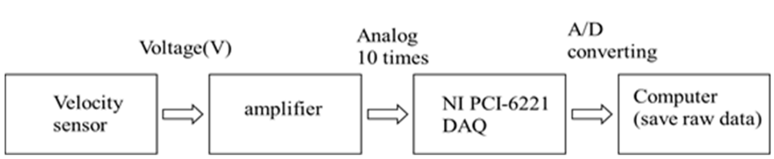

Figure 1. Measuring system.

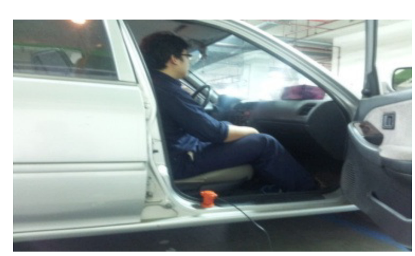

Figure 2. One of the sensor locations.

The measuring system was based on four passive velocity sensors. When the velocity sensors were placed on the doorframe of vehicle body vertically, the vibrations could be transformed to voltage

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signals. To enhance the signal intensity, an amplifier was used to boost signals up to ten times. An NI PCI-6221 DAQ was used to acquire the amplifying data and convert the data from analog to digital signals. Finally, the raw digital data was saved in an industrial computer. Figure 1 shows a flowchart diagram of the system and Figure 2 shows one of the sensor locations.

2.2. Data processing

Signal processing was the most valuable procedure in extracting a valid vital-frequency band, as shown in Figure 3. To enhance the ballistocardiac effect, raw data gathered from the measuring system was processed using a band-pass filter at a frequency range between 2 and 10Hz. Filtered data from each channel was then manipulated using the root-mean-square (RMS) method with one-second intervals. Calculating the total of the RMS values from each of the four channels produced 32 vital index values from each 32-second measuring procedure. The following equation defines H as a level of vital sign. Δt means the sampling time which is taken as 0.001 second. T means the calculating interval which is 1 second in this study. *c1(k), c2(k), c3(k)*, and *c4(k)* are continuous signals of each of the four channels.

$$H=\left(\frac{\Delta t}{T}\sum_{k=1}^{\frac{\tau}{\Delta t}}\left(c1(k)\right)^2\right)^{\frac{1}{2}}+\left(\frac{\Delta t}{T}\sum_{k=1}^{\frac{\tau}{\Delta t}}\left(c2(k)\right)^2\right)^{\frac{1}{2}}+\left(\frac{\Delta t}{T}\sum_{k=1}^{\frac{\tau}{\Delta t}}\left(c3(k)\right)^2\right)^{\frac{1}{2}}+\left(\frac{\Delta t}{T}\sum_{k=1}^{\frac{\tau}{\Delta t}}\left(c4(k)\right)^2\right)^{\frac{1}{2}} \quad (1)$$

When the procedure was done ten times with a person present and ten times with no person present, the final, processed H value provided a significant threshold for judging whether or not a vital sign is present in the vehicle.

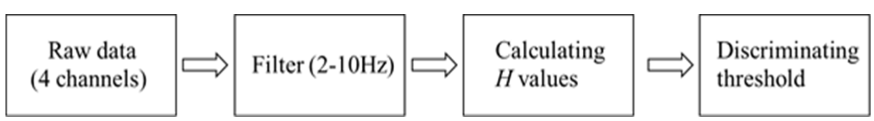

Figure 3. Data processing.

3. Results and experiment

In order to validate the performance of the system, experiments were carried out in a passenger vehicle (Civic, manufactured by HONDA) in three steps. First, the data were gathered from non-presence and presence states to demonstrate the variations of time and frequency domains in a basement parking lot. Second, according to the recorded data, an algorithm was proposed to estimate the threshold for determining whether or not people were present in the vehicle. Finally, to show the feasibility of the system in a realistic environment, the system was also tested with wind and ground noise to prove its robustness.

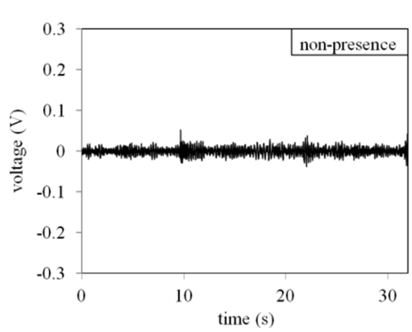

Figure 4. Non-presence state in the time domain.

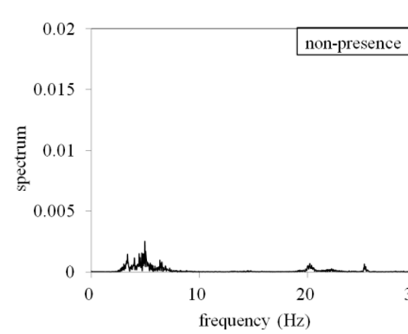

Figure 5. Non-presence statein frequency domain.

3.1. Measurement

The voltage of velocity sensors in a time domain was weak when no person was in the passenger vehicle, in an ideal environment, as shown in Figure 4. In addition, Figure 5 shows no pronounced peaks in the Fast Fourier Transform (FFT) analysis from 4Hz to 8Hz. These results were compared to the results for the experiment measuring the presence condition. In contrast, when a person is concealed in the trunk space (as shown in Figure 6), the time-domain signals were strong (as illustrated in Figure 7). Figure 8 also shows that the magnitude of FFT is high and the peak is sharp at 4-8Hz. The peak values of the presence state are approximately six times higher than those of the non-presence state.

Figure 6. A person hidingin the trunk space.

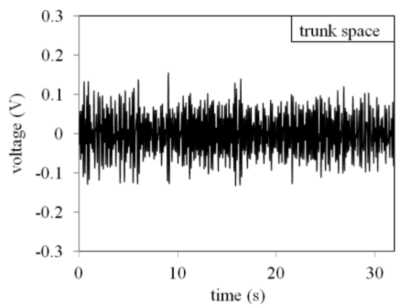

Figure 7. Presence state in time domain (trunk space).

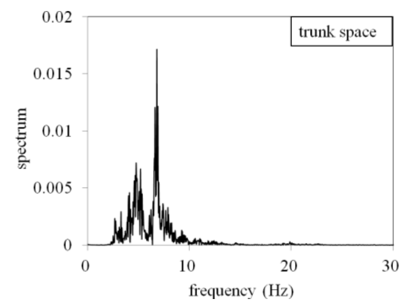

Figure 8. Presence state in frequency domain (trunk space).

3.2. Reproducibility analysis

According to the proposed algorithm, ten tests were conducted to measure the non-presence and presence states in the basement parking lot, as shown in Figure 9. Blue lines and red lines represent the detection of non-presence and presence states, respectively. Figure 9 shows that the H values are more stable in the non-presence state, and the H values are always lower than 0.05. In contrast, when a person was present in the vehicle, the H values were more unstable, fluctuating between 0.07 and 0.33. Thus, the threshold was reached between 0.05 and 0.1.

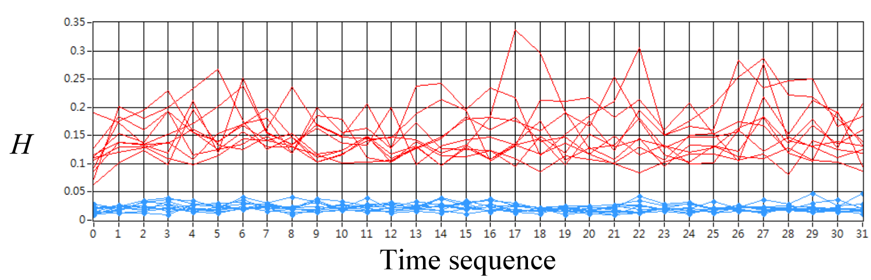

Figure 9. Line chart of index H for twenty tests.

3.3. Robustness test

In order to test the robustness of the system, experiments were conducted in the various interferences environment. The experiment was conducted ten times under both presence and non-presence conditions. Figure 10 shows that the majority of red lines (presence state) are higher than 0.1 and the majority of blue lines (non-presence state) are lower than 0.1 when the maximum wind velocity reached 2.5m/s.

To include the ground-noise effect, an idling vehicle was parked near the test vehicle equipped with the sensors. The tests were carried out according to the same procedure as those of the windy environment. Figure 11 shows the test results under conditions of both wind and ground noise. Similar results were obtained in the ground noise test as in the windy environment test.

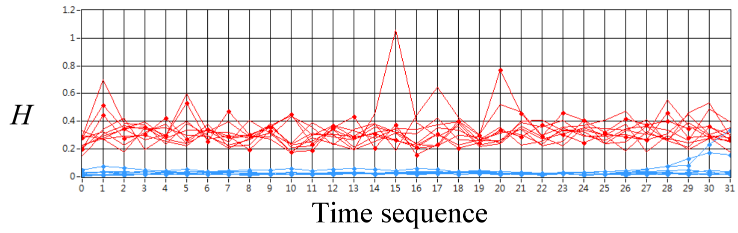

Figure 10. Test in the windy environment.

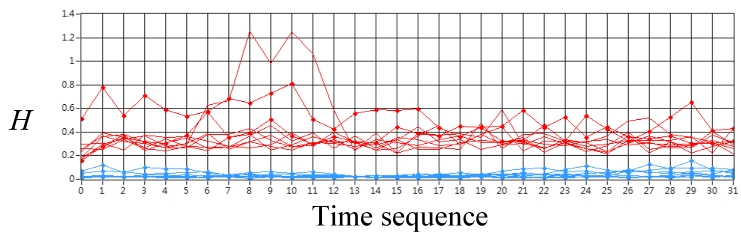

Figure 11. Test including wind and ground noise effect.

4. Discussion

According to the results shown in Figures 4 to 8, the intensity of vital signs was clearly distinguished in the time and frequency domains. Thus, the proposed method was able to determine the threshold in an ideal environment. When the gap of threshold value was between 0.05 and 0.1, the discriminative rate was almost 100%.

Figure 10 and Figure 11 show the robustness of the system under various disturbance conditions. If the threshold reached 0.1, the discriminative rate could reach over 90%. To increase the discriminative rate, using only certain parts of the indexes for judging is a valid method. For example, by removing the two highest H values in each test from Figure 10 and Figure 11, the remaining 30 H values can provide almost 100% valid results for discriminating whether or not vital signs exist in a vehicle under various conditions.

5. Conclusion

In this study, a novel method was proposed to detect ballistocardiac vibrations by obtaining the specified frequency band of vital vibrations with velocity sensors. An algorithm was additionally proposed to obtain better discrimination rates. The experimental results confirmed that the system is effective for detecting vital signs, in both ideal and non-ideal environments. The system was only verified for a passenger vehicle. Further tests are in progress to verify the application of the system to other types of vehicles, such as trucks and container vehicles.

References

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