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A MODEL BASED FILTERING TECHNIQUE FOR DRIVER’S HEART RATE MONITORING USING SEAT-EMBEDDED VIBRATION SENSORS

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ABSTRACT

In this paper we consider the driver’s heart rate monitoring problem to decide the drowsiness level for safety driving. To detect the heart rate of the driver, we adopt seat-embedded piezoelectric sensors. This sensor measures the body vibration caused by the heartbeat but the signal also contains the large amount of car body vibration according to the road conditions. For this problem, we propose a heart rate detection system based on the ARX model based filtering technique.

Index Terms— Signal processing, biophysical measurement, heart rate, monitoring, safety

1. INTRODUCTION

There are many situations in which a biophysical measurement brings useful information. In recent years, the progress of many types of sensing devices makes it possible to measure biophysical signals away from the laboratories [1](Khandpur, 2004). For example, the advanced safety car concept needs many information of the driver measured by many kinds of sensors [2](Ford, 2011). In these cases, the device may exhibit non-ideal conditions such as wide range of the temperature and/or large vibration of the car body. Driving with drowsiness is one of the main causes of car accidents. In order to prevent drivers from drowsy driving, there is a strong demand for driver monitoring systems[3] (A. Sahayadhas et al. 2012).

To detect the heart rate of the driver, we adopt seat-embedded piezoelectric sensors. This system consists of three parts as shown in Fig. 1; sensing, analysis and feedback. The sensing part measures the driver’s physiological data and environment. The analysis part extracts the heart rate of the driver from the noisy data and determines whether the driver is drowsy or not. When the driver becomes drowsy, the feedback part is activated to awaken the driver. The rest part of this paper, we focus the data sensing and data analyzing. There are many ways to sensing the heart rate related biophysical signals. One of the direct information about the heart rate (heart beat) is obtained by using an electrocardiographic (ECG) sensor attached to the driver’s body. In this case, the ECG may be affected some electrical noises caused by many electric instruments in the modern car and to reduce the noise component, some signal processing techniques are introduced to obtain a heartbeat signal [4](Xu et al., 2012). Another drawback of the ECG based system is to mount some piece of sensor to her or his body.

To avoid this situation, micro-impulse radar (MIR) based system has been proposed [5](Wicki and Schiele, 2004). The system seems to be attractive by its contact-free property but the effect of active sensing to drivers health is not clear.

Considering many factors for designing heart rate detection system, we propose a system based on the body vibration sensing [6](Orlewski et al. 2011). The proposed system does not require any direct-contact sensors to human skin. However, the measured vibration signal contains both small heart beat and large car body vibration according to the road conditions. For this problem, we propose a signal processing system based on the ARX model based filtering technique.

2. CONCEPT OF MEASUREMENT SYSTEM

2.1 Model of measurement system

Before designing the sensing and processing system, we assume the signal transmission model of the measurement system as shown in Fig. 2. The proposed sensing system has two types of sensors; the one is the piezoelectric vibration...
sensors in the seat and the other is the accelerometer attached on the car body. In this setup, the piezoelectric sensors detect the vibration signal from human body caused by the heart beat and from car body according to the road condition. For example, when the car is stopping, the output of the piezoelectric sensor has similar spectral to that of ECG as shown in Fig.3.

In this case, the heart rate cannot be detected from the measured sensor signal.

2.2 Structure of sensing seat

Of course, the measured signal is depend on the assignment of the sensors. We prepared four types sensing seats for evaluation the proposed system (Fig.5).

![Fig.5 Tested seat with different structure](image)

(a) Normal seat + sensors with back
(b) Normal seat + sensors without back
(c) Plate seat +
(d) Thin seat +

Although changing the seat structure, the heart rate cannot be extracted from the sensing data. Some signal processing procedure is needed.

There are other sensors in the proposed system which measures the acceleration of the car body as shown in Fig. 6.

![Fig.6 Assignment of Accelerometer](image)

3. PRINCIPLE OF DATA PROCESSING

3.1 Basic structure of the signal processing

To detect the heart rate through the data from piezoelectric sensors in the seat, we design the structure of the signal processing system considering the signal transmission model of the measurement system. The basic idea is based on the cancelation of the car body vibration component in the measured signal from the piezoelectric sensors.
Completing this procedure, we need the vibration transmission model from car body to seat sensors. There are many algorithms to estimate the vibration transmission characteristics from measured data, we propose an off-line method as shown in Fig.7.

In Fig.7, \( y(n) \) denotes the measured data from piezoelectric sensors which is assumed the sum of heart beat signal \( y_c(n) \) and vehicle vibration signal \( y_o(n) \). By using the seat characteristic model \( \hat{G}(s) \) which is the estimate of the signal transfer function \( G(s) \) from body vibration to seat sensor, we can cancel the signal by

\[
\hat{y}_c(n) = \hat{G}(s)u(n) - y(n) \tag{4}
\]

Where, \( u(n) \) is the measured car body acceleration from the sensors as shown in Fig. 6.

In order to estimate the transfer function, we describe the seat characteristic by ARX model as shown in Fig.8.

\[
A(q)y(k) = B(q)u(k - n_p) + \epsilon(k) \tag{1}
\]

\[
A(q) = 1 + a_1q^{-1} + a_2q^{-2} + \ldots + a_nq^{-n} \tag{2}
\]

\[
B(q) = 1 + b_1q^{-1} + b_2q^{-2} + \ldots + b_nq^{-n_p-1} \tag{3}
\]

are assigned.

Where, \( y(k), u(k), \epsilon(k) \) denote model output, model input and measurement noise, respectively. The model orders \( n_a, n_b \), and \( n_k \) correspond the number of poles, zeros and the time delay of the transfer function of \( G(s) \).

To determine the orders and parameters of the ARX model, we adopt System Identification Toolbox in MATLAB as the signal processing algorithm.

Using the above algorithm, there is an important problem to resolve. The problem is the availability of the vehicle vibration signal at the seat sensor position.

In general, the seat sensors can measure only the sum of the heart beat signal and car body vibration. Moreover, the seat sensor signal is affected by the breath movement of the human body. However, in this application, we can eliminate these effects by using the signal filtering.

### 3.2 Pre and post filtering of the signals

As mentioned in the previous section, the exact value of the reference signal for the adaptive filter cannot be obtained. However, the bandwidth of the vehicle vibration, heart beat and breath movement signal are very different.

The vehicle vibration has the most power in higher frequency than the heart beat signal. The heart beat signal has the bandwidths from 1 to 1.5 Hz. The breath movement has the maximum power around 0.2Hz.

According to these characteristic of the signals, pre-filtering of the measured signal are performed by using band-pass and band-stop filters. Fig. 9 shows the typical result of the pre-filtering.

The band-pass filter which has the band widths 1 to 3Hz eliminates the vehicle vibration and the breath movement and the band-stop filter which has the band widths 1.35-1.45Hz eliminates the heart beat signal from the measured signal through the piezoelectric sensors.

Using the pre-filtered signal, the adaptive filter is trained, and the estimate of the biophysical signal is obtained.

\[
\hat{y}_c(n) = y(n) - \hat{y}_i(n) \tag{4}
\]
However, the above signal contains the breath movement signal, the post-filtering with the band widths 1 to 3Hz is applied.

4. EVALUATION OF THE PROPOSED ALGORITHM

In order to evaluate the performance of the total system, extensive experiments have been performed combining the seat structure and different load conditions. From the results, we can see that the normal seat + sensors with back plate have the best performance for various load conditions. In this case, the model structure obtained by System Identification Toolbox in Matlab is $n_u = 14$, $n_y = 20$ and $n_k = 1$. Fig. 10(a)-(j) show the detection results for different data periods in long data (circles indicate the successful detection). The blank periods are non-steady state data. Figure 10 shows the typical acceleration and vibration data measured by sensors.

![Acceleration signal](image1)
![Vibration signal](image2)

Fig. 10 (a) Acceleration signal (b) Vibration signal

![Reconstructed ECG signal](image3)

Fig 11 Typical detection result of heart rate (Compare with true value of ECG )

By processing the sensor signals with proposed algorithm, we can confirm that the heart rate (and the periodic signal corresponds to ECG) are successfully detected as shown in Fig.11.

5. CONCLUSIONS

In this paper, we propose a heart rate detection system based on the measured vibration signals. The key technique for eliminating large disturbance is the model based filter which describes the characteristic of the signal transmission. The extensive results for various conditions show the effectiveness and the feasibility of model based signal processing.

6. REFERENCES