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Fiber-optic Activity Monitoring with Machine Learning

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Abstract: Unobtrusive activity monitoring based on fiber-optic Mach-Zehnder interferometer is proposed, employing deep bi-directional long short-term memory network, realizing three activities recognition with accuracy of 99.2% and resolution of 0.5s.

OCIS codes: (280.1415) Biological sensing and sensors; (070.5010) Pattern recognition; (120.3180) Interferometry.

1. Introduction

Activity monitoring is crucial in human health care. One of the most serious problems medical service providers are facing is how to determine whether their patients are in hospital bed, which can help them to locate patients quickly and ensure their safety [1]. As the problem of population aging worsens, activity monitoring could help to ensure the safety of elderly people living alone [2]. Also, activity monitoring can help parents take care of their children when they are in bed without watching beside.

Many existing types of sensors have enabled real-time activity monitoring of patients in bed. Commercial products like watches (e.g. ActiGraph) and headbands (e.g. Zeo Personal Sleep coach) are wearable and non-invasive but may cause discomfort. Pressure sensors installed in mattress have been used in hospital which is not very accurate, and some are uncomfortable for patients to sleep. Other ways like video surveillance cannot detect subtle changes and is expensive [3]. Mattress installed with fiber optical sensors can solve problems caused by wearable products and other sensors. Fiber optical sensors have plenty advantages which include small size, excellent corrosion resistant, anti-electromagnetic interference performance and real-time sensing, hence it can realize real-time accurate signal monitoring.

In this paper, an unobtrusive activity monitoring based on fiber-optic Mach-Zehnder interferometer (MZI) is presented and investigated theoretically and experimentally, where machine learning is used to identify three kinds of activities including absence, presence w/ or w/o movement. The proposed monitoring system is embedded in a mattress. It is non-wearable, cost-effective and has high sensitivity.

2. Fiber Optic Sensing System Setup

The fiber optical sensing system installed in a mattress used to monitor activity signals is based on MZI and the structure of MZI is shown in Fig. 1 containing a DFB laser source, a photodetector (PD), two 1×2 optical couplers (OC) and some fibers. The photodetector collects output lights can be represented as

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}cos\emptyset_{OPD} = I_1 + I_2 + 2\sqrt{I_1 I_2}cos\frac{2\pi}{\lambda}nL \quad (1)$$

$$\frac{\Delta\emptyset_{OPD}}{\emptyset_{OPD}} = \left(1 + \frac{\partial n}{\partial \varepsilon}\frac{1}{n}\right)\varepsilon \quad (2)$$

where I denotes output optical intensity, I_1 and I_2 denotes optical intensity of each arm of MZI, OPD denotes optical path difference, $\emptyset_{OPD}$ denotes phase difference, L_1 and L_2 denotes the length of two arms and L equals to $L_1 - L_2$, ε equals to $\Delta L/L$. Micro strain change on the mattress caused by activity will influence OPD resulting in change in I. Collected signals can be used for further processing and classification with deep neural network.

3. Deep Neural Network (DNN)

A deep bidirectional long short-term memory (Bi-LSTM) network model is developed to recognize 3 kinds of activities: absence, presence w/ or w/o movement. The model of Bi-LSTM is shown in Fig. 2, which is divided into 3 parts: input layer, hidden layers and output layer. The yellow and blue box respectively denotes forward and backward hidden sequences of each hidden layer. The hidden size of each layer is [32,64,128]. The output layer is consisted of a fully connected neural network, followed by softmax-cross-entropy layer. The three-hidden-layer Bi-LSTM DNN is built and run in TensorFlow.

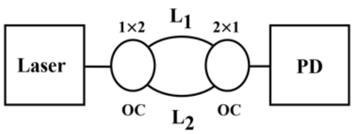

Fig. 1. The structure of MZI.

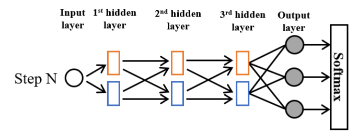

Fig. 2. The model of deep bidirectional LSTM network.

4. Experiments and Results

The sampling rate of experiment data is 1000 Hz. 44081 size data set is divided into three parts with shuffling operation, where 80% are used for training, 10% for validation and the remaining 10% for testing. Fig. 3 shows waveforms with duration of 0.5s, representing three kinds of activities.

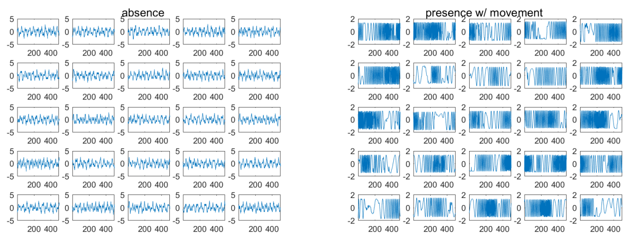

Fig. 3. Waveforms of (a) absence; (b) presence w/ movement; (c) presence w/o movement.

Fig. 4 shows train and validation cost curves illustrating the cross entropy between predicted and actual value, which is individually denoted by yellow and grey. After about 15k iterations, both of them converge below 0.1. Test accuracy is shown in Fig. 5. 1000 tests with batch size of 512 randomly selected from 4408 test set are designed to test the proposed Bi-LSTM DNN model. One can see that the calculated accuracies are higher than 99.2%, hence the model could classify the activities precisely.

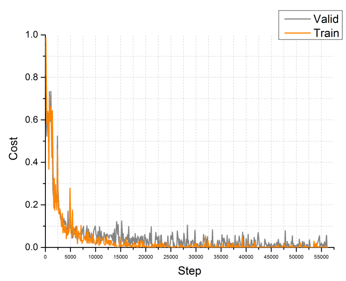

Fig. 4. Train and valid cost of the model.

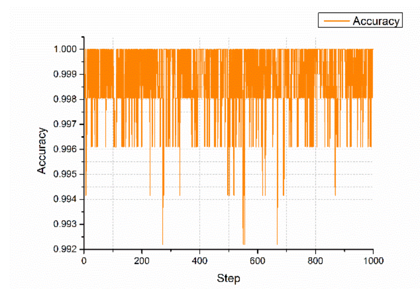

Fig. 5. Test accuracy of the model.

5. Conclusion

In this paper, an accurate non-wearable method using fiber optical MZI installed in the mattress and Bi-LSTM DNN is developed to monitor activities, including absence, presence w/ or w/o movement. Results show the recognition accuracy could reach 99.2% with 0.5s resolution. Using fiber optical sensing system together with machine learning methods could solve the lack of existing methods and can effectively realize activity monitoring. In addition, when the status is continuously identified as presence w/o movement, this period can be combined to be further processed to acquire vital signs, like heart beat and respiration. [4]

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