# Fiber-optic MZI activity monitoring based on RLS algorithm

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## ABSTRACT

*A non-invasive activity monitoring using Mach-Zehnder interferometer* (MZI) *is presented and recursive least square (RLS) algorithm is performed to classify presence and absence activity states with accuracy higher than 98.5% within 1 second.*

**Keywords:** *Activity monitoring, MZI, RLS algorithm*

## 1. INTRODUCTION

Activity monitoring can ensure a prompt alarm of some abnormal conditions such as falls from beds by those monitored people, especially elderly people and infants. In hospitals, it is necessary to restrict some patients in bed, while activity monitoring can help to detect their activities [1].

Recursive least square (RLS) is an adaptive filter algorithm improved from the gradient method and has a faster convergence speed. It was adopted to eliminate noise from non-stationary signals in previous studies [2].

In this paper, fiber-optic activity monitoring using Mach-Zehnder interferometer (MZI) based on RLS algorithm is proposed. The non-intrusive monitoring setup with optical fibers embedded in a bed mattress has high sensitivity as well as fast response. The algorithm can successfully classify the activities into presence and absence states within 1 second.

## 2. FIBER-OPTIC MONITORING SETUP

The setup includes an activity monitoring system based on MZI embedded in a mattress. Fig. 1 depicts the main structure of monitoring system, which consists of a DFB laser source, MZI and a photodetector (PD). MZI is consisted of two 1*2 optical couplers and two optical interference paths. The output light intensity $I_{out}$ can be computed from [3]

$$I_{out} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\Delta\varphi) \qquad (1)$$

$$\Delta\varphi = \frac{2\pi}{\lambda} n\Delta L \qquad (2)$$

where $I_1$ and $I_2$ respectively represent the input intensity of two optical paths in MZI, Δφ represents phase difference caused by optical path difference ΔL. The output light intensity collected by PD is the raw signal which is to be further conducted by digital signal processing and state classification algorithm. When someone lies on the mattress, micro strain induced by human's cardiac and breath activity changes the fiber length and effective index. Consequently, the phase difference varies with the human state.

## 3. STATE CLASSIFICATION ALGORITHM

State classification algorithm consists of three stages: signal pre-processing, feature extraction, and decision stage. In the first stage, the raw signal is processed by wavelet filter aiming to remove unwanted noise and abnormal values. In the next stage, RLS is employed to estimate auto-regressive parameters of the input non-stationary signals x(n), whose model is shown in Fig. 2. Signals preprocessed by wavelet transform is the input signal x(n). φ(n) is constructed as:

$$\varphi(n) = [x(n), x(n-1), ..., x(n-Order+1)] \qquad (3)$$

where Order is empirically determined in 450 which is relevant with sampling rate. Error signal e(n) is defined as:

$$e(n) = x(n) - \varphi^T(n)a(n-1) \qquad (4)$$

Auto-regressive parameter a(n) can be calculated recursively from [4]:

$$a(n) = a(n-1) + K(n)e(n) \qquad (5)$$

$$K(n) = \frac{P(n-1)\varphi(n)}{\lambda + \varphi^T(n)P(n-1)\varphi(n)} \qquad (6)$$

$$P(n) = \frac{1}{\lambda}[P(n-1) - K(n)\varphi^T(n)P(n-1)] \qquad (7)$$

where forgetting factor λ is empirically determined in 0.985.

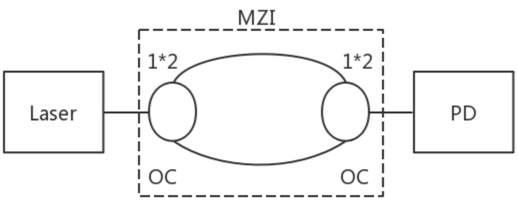


Fig. 1 Structure of the monitoring system

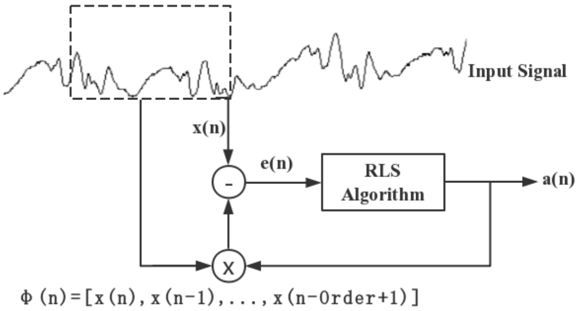


Fig.2 RLS model

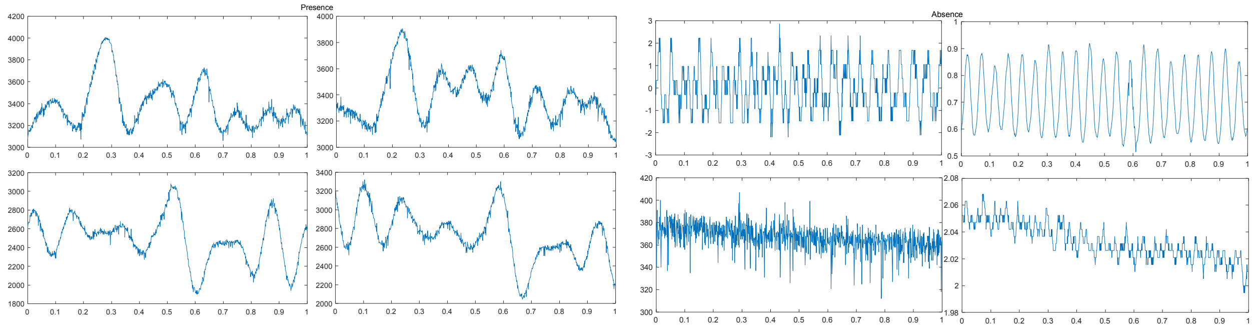


Fig. 3 Signals (a) presence state and (b) absence state

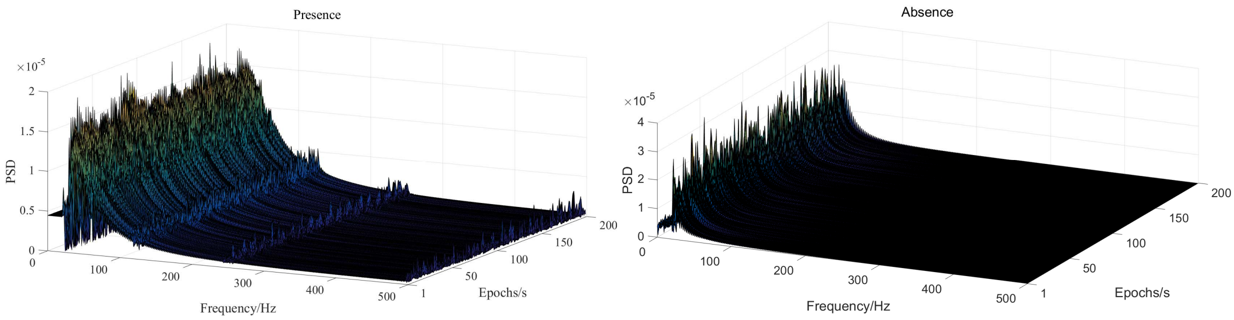


Fig. 4 PSD computed by RLS parameters of (a) presence and (b) absence signals

After auto-regressive processes, power spectral density (PSD) can be evaluated by auto-regressive parameters, from which, three typical frequency bands are selected for the following stage, which is 110-150 Hz, 220-270 Hz, 450-500 Hz respectively.

In the decision stage, the variances of PSD values in these three selected frequency bands denoted with variance_i (i=1, 2, 3) are calculated respectively and the activity state can be recognized if it satisfies the following rule:

$$\begin{cases} \text{judge\_i} = 1, \text{ if variance\_i} > \text{threshold\_i}; (i = 1,2,3) \\ \text{state is presence, if } \sum_{i=1}^{3} \text{judge\_i} \geq 2; \\ \text{state is absence, otherwise.} \end{cases}$$

where judge_i = 1 means the state is preliminary judged as presence and judge_i = 0 means the state is preliminary judged as absence; threshold_i is empirically set as 4, 0.4, 0.1 respectively. The state is finally judged as presence when as least two preliminary states are judged as 1.

## 4. EXPERIMENTS AND RESULTS

The sampling frequency is 1000 Hz. Several one-second signals at presence state and absence state are given in Fig. 3. The x-axis represents time (s), the y-axis is expressed in arbitrary units. PSD is calculated within a second.

Fig. 4 shows the PSD of presence and absence signals with duration of 200 seconds respectively. The x-axis represents epochs (s), the y-axis represents frequency (Hz), the z-axis represents PSD. It shows that the PSD has more fluctuations on the presence state in the selected frequency bands compared with the absence state.

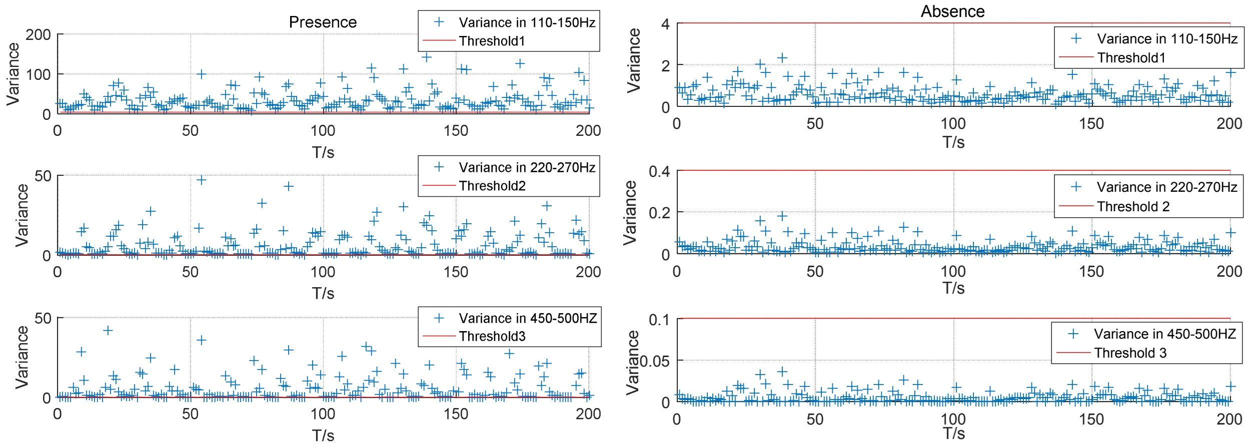


Fig. 5 Variance of PSD values of (a) presence and (b) absence signals in three selected frequency bands

Fig. 5 illustrates the variance of PSD values and thresholds in three selected frequency bands respectively. The x-axis represents time (s), the y-axis represents variance. Total 1500 seconds of signals were tested and the algorithm correctly recognized 98.5 percent of activity states.

## 5. CONCLUSION

In conclusion, a fiber-optic MZI sensing system performing RLS algorithm is developed for activity monitoring, which can recognize the presence and absence state. The accuracy is higher than 98.5% and the resolution is 1 second.

## ACKNOWLEDGMENTS

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