# Fiber optic sensor for heart rate detection

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# Fiber optic sensor for heart rate detection

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ABSTRACT

The principle of operation, design aspects, experimentation and performance of an extrinsic fiber optic sensor using fiber optic displacement sensor for the measurement of amplitude and frequency of heart rate signal is presented and investigated. The displacement sensor consists of fiber optic transmitter, fiber optic bundled probe and photodiode detector and an artificial electrocardiogram (ECG) signal is used in the testing. The sensitivity of the sensor is found to be 0.002 mV/μm and thus it is capable of measuring heart rate from 50 bpm to 300 bpm with linearity more than 99%. The simplicity of the design, high degree of sensitivity, dynamic range and the low cost of the fabrication make it suitable for real field applications. Moreover, accuracy and reliability are the excellent pay-offs of this fiber optic sensor.



## 1. Introduction

Monitoring of heart rate is very important to determine the fitness level of the person. The low heart rate or pulse indicates that the person has a low intensity of work out. If a person is not working to their body's potential, there is no way they can burn enough calories to result in weight loss nor can they get up the endurance to build strength. On the other hand, vibration sensors is a very important devices which have many applications and thus a large number of measuring techniques encompassing mechanical, electrical and optical devices have been proposed in the literature [1,2]. For instance, the compact and cheap MEMS-based accelerometers are very popular for vibration measurement but this technique requires the probe to be in contact with the moving object.

Many optical methods have been proposed in the literatures for the small vibration measurement. One of the most popular techniques is based on interferometer where a laser signal beam is directed onto a vibrating target and back-reflected light is recombined with part of the incident light [2]. The performance of this technique is excellent but it is very expensive and also require stringent mechanical alignment. Another approach is to exploit the Doppler effects [3], but this method is not accurate enough for the precise measurement of very small displacement as well as quite expensive.

Recently, plastic optical fibers (POFs) are in a great demand for the transmission and processing of optical signals in optical fiber communication system. They are many potential applications in wavelength division multiplexing (WDM) systems, power splitters and couplers, amplifiers, sensors, scramblers, integrated optical devices, frequency up conversion, etc. [4–6]. In this paper, a rugged, low cost and very efficient fiber optic displacement sensor is proposed and demonstrated for the measurement of amplitude and frequency of heart rate signal. The proposed sensor is based on intensity modulation technique and uses a bundled POF as a probe.

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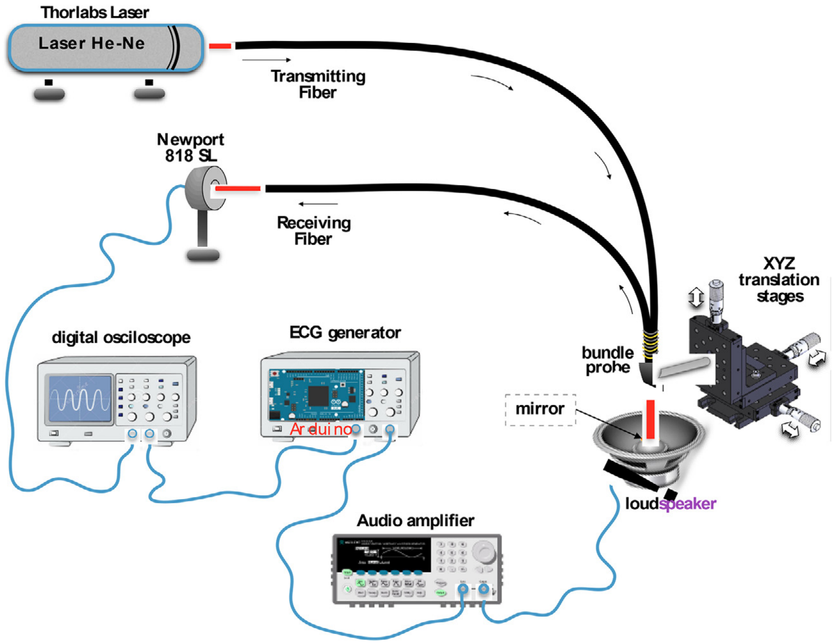



**Fig. 1.** Experimental setup of fiber optic sensor for heart rate detection.

## 2. Experimental setup

The schematic experimental setup for the proposed heart rate sensor is shown in Fig. 1. It consists of a fiber optic transmitter, a fiber-optic probe, loudspeaker, audio amplifier and a silicon detector. The fiber optic probe is constructed from a bundle POF of length 2 m, which consists of one transmitting and one receiving fiber. The transmitting fiber has a single core with a diameter of 1.0 mm while the receiving fiber has 16 cores with diameter of 0.25 mm. All the fibers have a numerical aperture of 0.5. The fiber-optic probe is chosen since it provides many advantages such as small size, light weight, geometrical versatility, EMI immunity and ease of multiplexing and de-multiplexing especially for intensity modulation based extrinsic sensor application. The bending losses in the fiber-optic probe are minimized by putting both fibers in close contact, thus forming an equal radius of curvature [7].

In the experiment, a reflective mirror surface is pasted on a load speaker and the probe is held in position perpendicularly to the reflective surface. The static displacement of the fiber optic probe is achieved by mounting it on a piezoelectric displacement meter, which is rigidly attached to a vibration free table. Red light from He-Ne laser at peak wavelength of 633 nm is launched into the transmitting fiber and the reflected signal from receiving fiber is routed to the silicon detector and measured by moving the probe away from the zero point. The zero point is the point where the reflective surface and the probe are in close contact. The signal from the detector is converted to voltage and is measured by a digital voltmeter. At first, without ECG signal, the output voltage from the detector was recorded by varying the probe distance in a range from 0 to 6 mm in a step of 12 $\mu$m. Based on the displacement response, the probe is placed in a way such that the detector output corresponds to the center of the linear region of the characteristic curve at zero vibration condition. Then, an artificial electrocardiogram (ECG) signal is generated by ECG generator to simulate the heart rate at different frequencies ranging from 50 to 300 bmp. The signal is amplified by the audio amplifier and send to the loudspeaker to vibrate the mirror. The output voltage from the silicon detector is measured by an oscilloscope for different frequencies of heart rate ranging from 50 to 300 bmp and different heart rate amplitudes. The heart rate amplitude is changed by varying the driving voltage of the audio amplifier.

## 3. Results and discussions

At first, we investigate the optimum location to place a vibrating mirror in the proposed fiber-optic displacement sensor (FODS) setup to measure the amplitude and frequency of the ECG signal. Fig. 2 shows the sensor response with the displacement of the POF probe from the reflecting mirror attached to the speaker. As shown in the figure, the displacement curve exhibits the maximum peak of output voltage with a steep front slope and back slope which follows an almost inverse square law relationship. The signal intensity is minima (near to zero) at zero distance because the light cone does not reach the receiving fiber. When the displacement is increased, the size of the reflected cone of light at the plane of fibers increases and starts overlapping with the core of the receiving fiber leading to a small output. Further increase in the displacement leads to large overlapping which results in increase in output. The output after reaching the maximum starts decreasing for larger

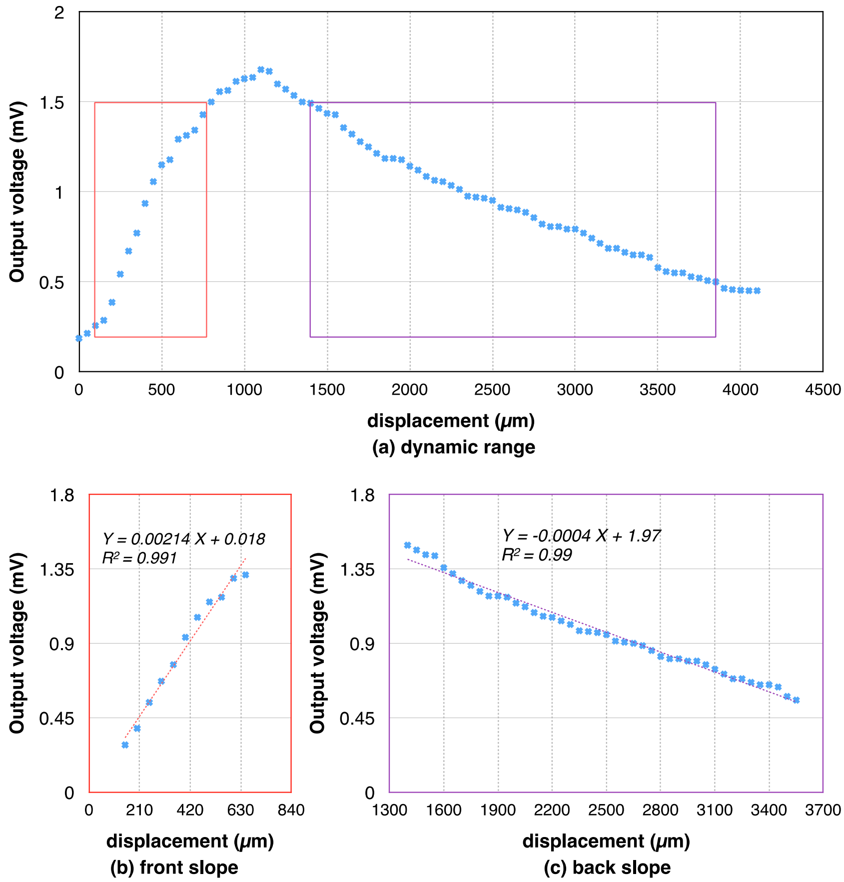



**Fig. 2.** Variation of the output voltage with the axial displacement of the loudspeaker from bundled probe (a) dynamic range (b) front slope and (c) back slope.

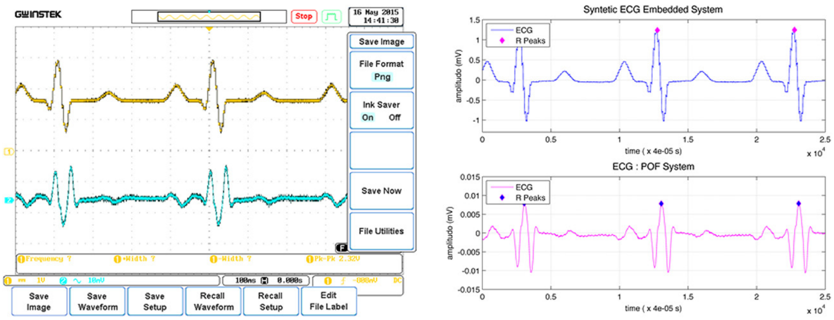
**Table 1**
Performance of the FODS.

| Parameter of performance | Front slope | Back slope |
|---|---|---|
| Sensitivity (mV/μm) | 0.002 | 0.0004 |
| Range (μm) | 150–650 | 1400–3450 |
| Linearity (%) | >99 | >99 |

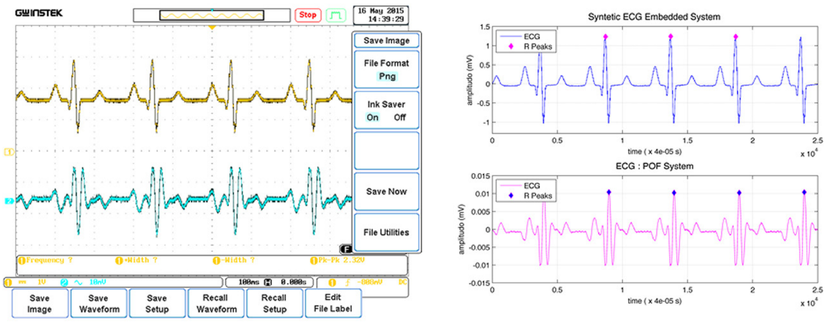
displacements due to large increase in the size of the light cone and the power density decreases with increase in the size of the light cone. The sensitivity of the sensor on either side can be obtained from the slope of the curve. Thus a sensitivity of 0.002 mV/μm can be achieved within a range from 150 to 650 μm for the front slope and a sensitivity of 0.0004 mV/μm can be obtained over a range from 1400 to 3450 μm for the back slope. The performance of the FODS is summarized in Table 1.

For the ECG measurement, at first, the POF probe is placed in the center of the linear region when the speaker is set at zero vibration condition. As the driving voltage is given, the vibration is detected by the sensor. It is observed that the proposed sensor is capable of measuring heart rate within a frequency range of 50–300 bpm. Fig. 3(a) and (b) compare the measured pulse signal with the input pulse signal to the speaker at two different frequencies of vibration; 50 and 300 bpm, respectively. In the experiment, the input signal is detected after the audio amplifier while the measured pulse signal is obtained at the silicon detector. It measures the output signal that comes out from the receiving fiber and detected by a silicon detector. As shown in the figure, both waveforms have the same frequency of 50 bpm and 300 bpm with the measured output signal shows a higher noise. The simplicity of the design, high degree of sensitivity, dynamic range and the low cost of the fabrication make it suitable for real field applications.

Fig. 4 plots relation between the measured frequency and the input frequency from the generator. It is shown that the relation has a linear function with slope of 1.00. This indicates that the proposed sensor can accurately measure the frequency of heart rate. Fig. 5 compares the amplitude at the output sensor with the input amplitude. It is shown in the figure that the variation of heart rate amplitude of the output sensor has a linear function relation with the input amplitude of heart rate. For amplitude detection, the sensor have a maximum error around 1.8% and the resolution is obtained at 1.05 mV.




(a) at 50 bpm.




(b) at 300 bpm

**Fig. 3.** Comparison heart rate signal from generator and sensor output at different frequencies (a) 50 bpm and (b) 300 bpm.

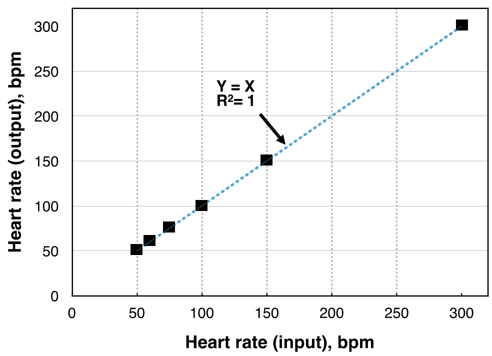



**Fig. 4.** Output heart rate versus input hear rate signal from 50 to 300 bpm.

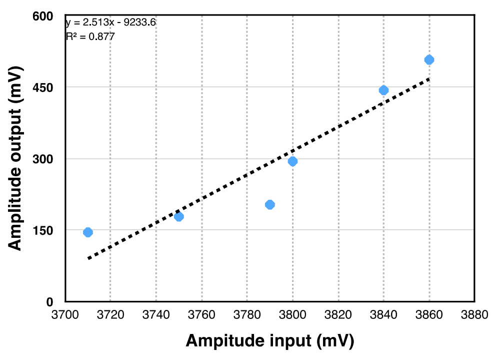



**Fig. 5.** Output of heart rate amplitude versus input of heart rate amplitude.

## 4. Conclusions

An extrinsic FODS has been successfully used to measure the amplitude and frequency of heart rate signal. The sensor used consists of fiber optic transmitter, fiber optic bundled probe and photodiode detector and an artificial ECG signal is used in the testing. It use an POF probe the gather a reflection signal from the mirror surface mounted on the loudspeaker which is modulated by ECG signal from the audio generator. The sensor is capable of measuring heart rate within a frequency range of 50–300 bpm with almost 100% linearity. The sensor could be applied to monitor heart rate of human body and other biomedical applications.

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