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# Non-invasive micro-opto-electro-mechanical system adaptation to radial blood flow pulse and velocity analysis

**K. Malinauskas*, V. Ostaševičius**, R. Daukševičius***, V. Jūrėnas******
**Kaunas University of Technology, Studentų 65, 51369 Kaunas, Lithuania, E-mail: karolis.malinauskas@ktu.lt*
***Kaunas University of Technology, Studentų 65, 51369 Kaunas, Lithuania, E-mail: vytautas.ostasevicius@ktu.lt*
****Kaunas University of Technology, Studentų 65, 51369 Kaunas, Lithuania, E-mail: rolanas.dauksevicius@ktu.lt*
*****Kaunas University of Technology, Kęstučio 27, 44312 Kaunas, Lithuania, E-mail: vytautas.jurenas@ktu.lt*

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## 1. Introduction

Chinese pulse diagnosis in traditional Chinese medicine (TCM) has been practiced for more than 2000 years. Chinese medicine practitioners use fingertips to feel the wrist-pulses of patients in order to determine their health conditions. Depending on the hand and sensing wrist-pulse practitioner can establish the condition of different organs of the patient Fig. 1.

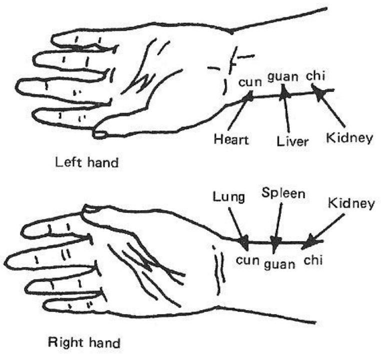



Fig. 1 Different hand represents different human organ

The wrist-pulse has been noticed to be the most fundamental signal of life, containing essential information of person health. Pathologic changes of a person's condition are reflected in the wrist-pulse pictures. Clinical studies prove that patients with hypertension, hypercholesterolemia, cardiovascular disease, and diabetes, exhibit premature loss of arterial elasticity and endothelial function, which eventually resulted in decreased flexibility of vasculature, and heightened stress to the circulatory system. The wrist-pulse shape, amplitude, and rhythm are also altered in correspondence with the hemodynamic characteristics of blood flow [1, 2].

The growing recognition of the importance of developing effective preventive medical system to contemporary healthcare has placed Chinese pulse diagnosis an important position [3]. However, wrist-pulse analysis is a matter of technical skill and subjective experience. The accuracy of each experiment depends upon the individual's practice and quality of sensitive awareness. Different Chinese practitioners might not always give identical wrist-pulse waveform pattern recognition for the same patient. The classifications of wrist-pulse waveform patterns identified and named by different Chinese physicians in their medical literatures are not always the same. In history, Chinese physicians clearly appreciated the significance of the wrist-pulses and association of changes in the wrist-pulses with diseases, but they did not progress beyond the stage of manual palpations, thereby remaining largely uninfluenced by quantitative measurements. Quantified description of Chinese pulse diagnosis would pave a way in its modernizing advancements [4].

This paper aims to use micro-opto-electro-mechanical systems (MOEMS) for adaptation of computerized wrist-pulse signal diagnosis. Section 2 represents some theoretical basis of pulse waveforms. Section 3 performs extensive experiments to validate the proposed method. Continuing, in section 4 one of the possible prototypes of the final biocompatible wrist-pulse sensor is presented. Finally, the paper is concluded in the last section.

## 2. Radial pulse characteristics

A beating heart generates pressure and flow waves which propagate throughout the arterial system. The shapes of wrist-pulse waveforms are altered by their continuous interaction with the non-uniform arterial system. The pressure waves expand the arterial walls as traveling, and the expansions are recognized as wrist-pulses. Each discontinuity reflects the incident waves in the mechanical and geometrical properties of the arterial tree, e.g. at bifurcations and stenosis. The palpable wrist-pulses can thus be studied in terms of one forward traveling wave component, the collective waves running from heart to periphery and containing information of the heart itself; and one backward traveling wave component, the collective waves containing information of the reflection sites, i.e. kidney, stomach, spleen, liver, lungs, etc. Moreover, the reflected pressure waves tend to increase the load to the heart and play a major role in determining the wrist-pulse waveform patterns [5-7]. Hence, wrist-pulse waveforms can be expressed in terms of its forward and backward running components with a phase shift in time as illustrated in Fig. 2.

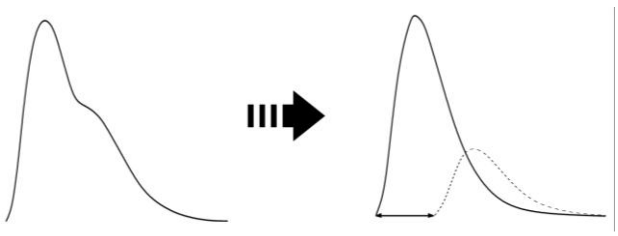


Fig. 2 Forward wave is higher in amplitude, and backward wave is lower in amplitude, with a phase shift

A normal wrist-pulse waveform has a smooth, fairly sharp upstroke, a momentarily sustained peak, a quick down stroke and decay. The reflected wave also has similar shape to the initial wave but smaller in amplitude.

Young healthy people usually have pulse patterns as shown in Fig. 3. Following Traditional Chinese Medicine terminology the graphs clearly show the presence of dicrotic notch and dicrotic wave and the pulses can be identified as taut, slippery or moderate.

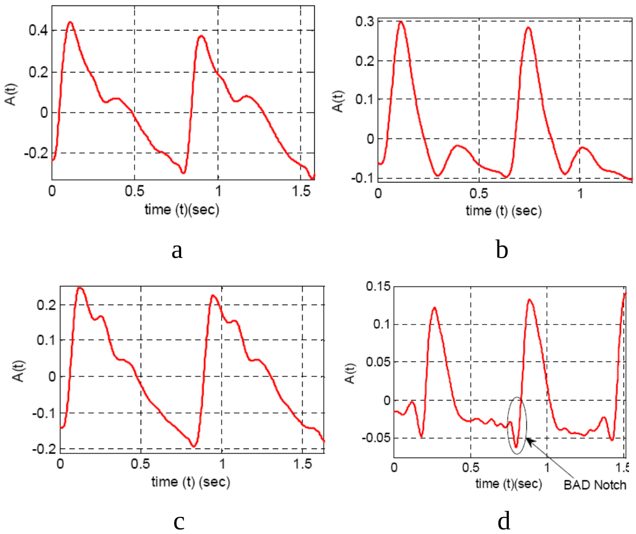


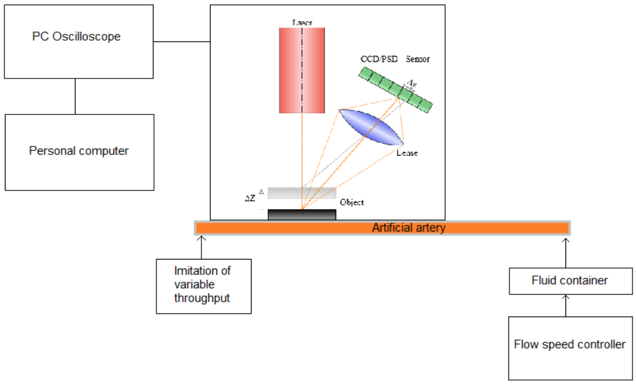

Fig. 3 Radial pulse patterns: a) taut pulse pattern; b) slippery pulse pattern; c) moderate pulse pattern; d) abnormal pulse pattern with BAD Notch

The abnormal pulse pattern shows formation of a unique "V" shaped notch identified as BAD Notch [8] (Fig. 3, d). The BAD Notch can reflect the state of various problems with health (i.e. problems with: gallbladder, kidneys, stomach, lungs, heart, high level of cholesterol and more).

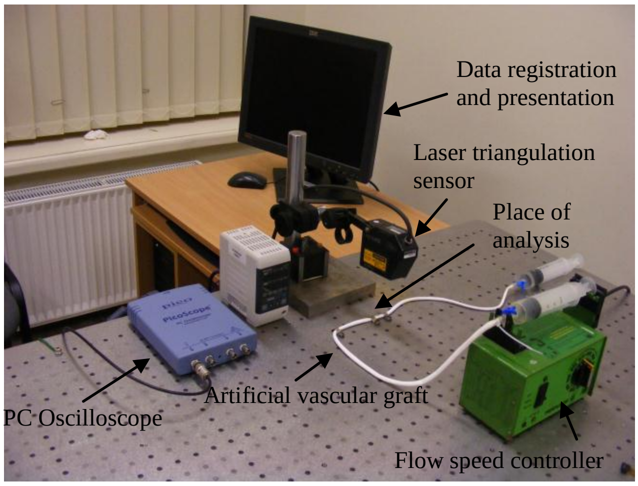
## 3. Experimental analysis

### 3.1. Experiments with artificial vascular graft

Proposed computerized MOEMS pulse signal diagnosis can be divided into three stages: data collection, feature extraction and pattern classification. In the first stage of our work, the pulse signals are collected using micro-fabricated micro-objects attached to either artificial vascular graft with the diameter of 2.4 mm or human wrist directly. Displacements of the object under investigation are registered by laser triangulation high-speed, high-accuracy CCD displacement sensor KEYENCE LK-G Series. At the second stage using PC Oscilloscope the analog signal of pulse wave forms is obtained for further examination. Pattern classification stage is still under evaluation processes. Principle scheme and experimental model of the first experiment carried out is presented in Figs.4, a, b. In order to study the characteristic of each pulse waveforms quantitatively, first of all having the experimental model two different pressures to the system were applied, namely, 120 mmHg (15998 Pa, N/m^2) and higher 140 mmHg (18665 Pa, N/m^2). From the numbers it can be seen that the first one imitates normal systolic pressure of healthy person and the second one is with hypertension possibility. Secondly, it is worth mentioning that artificial vascular graft used in the experimental model is made of expanded polytetrafluoroethylene (ePTFE, Young's modulus, $E = 600$ MPa) consisting of a carbon and fluorine based synthetic polymer that is biologically inert and non-biodegradable in the body.




a

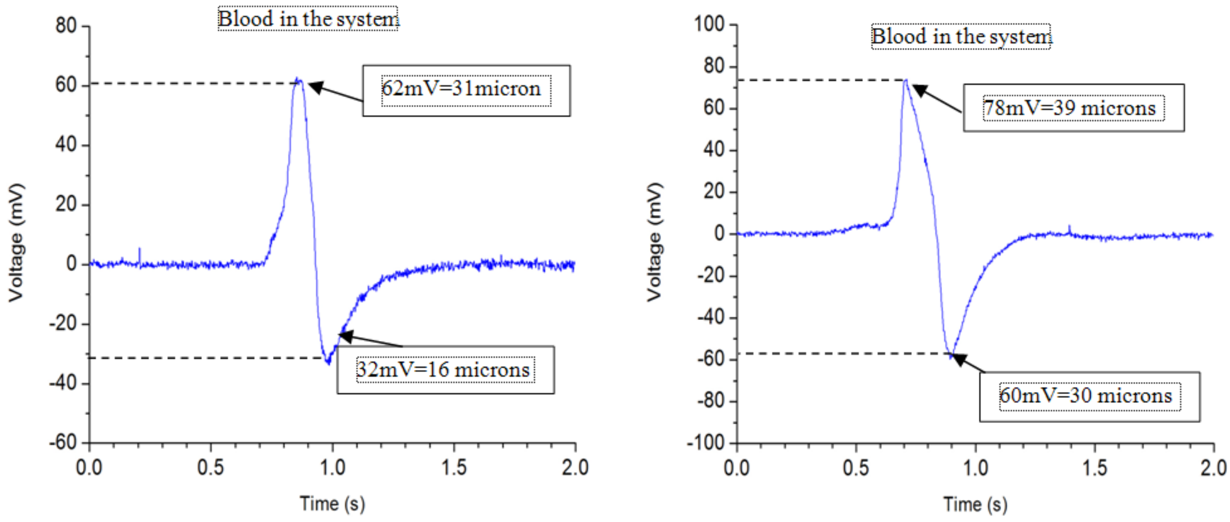



b

Fig. 4 a) principle scheme of the artificial blood flow system in radial artery; b) experimental model of the artificial blood flow system

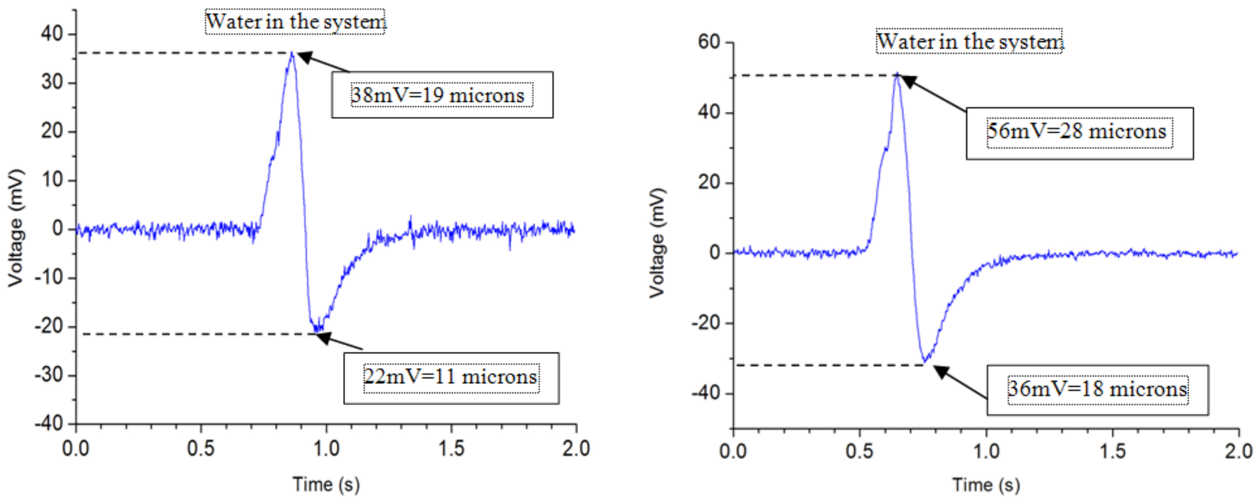
It must be clear that the results obtained with vascular graft and real radial artery is different because of different modulus of elasticity.

Further two different viscosity fluids ($8.90 \times 10^{-4}$ Pa s and $3.2 \times 10^{-3}$ Pa s) were introduced to the artificial blood flow system and the displacements of points under investigation were registered. It was noticed that the more viscous fluid we have the bigger displacement of the point under investigation is obtained. Figs. 5, a, b, and Figs. 6, a, b represent the registered data. Figs. 5, a, b represents the case of analysis when solution having similar technical specifications as real blood was used. Figs. 6, a, b represents the case of analysis when simple water solution was used just under different pressure inputs. As the system registers potential differences in millivolts the conversion rate to displacement is approximately: 1 micrometer equals to 2 mV.




a b

Fig. 5 a) impulse pressure is 120 mmHg; b) impulse pressure is 140 mmHg




a b

Fig. 6 a) impulse pressure is 120 mmHg; b) impulse pressure is 140 mmHg

3.2. Blood flow velocity analysis

Blood flow velocity is a measurement of the rate at which blood moves through a particular vessel. A number of factors can influence the rate of blood flow, making this measurement an important part of clinical diagnosis in some circumstances, as changes in velocity can indicate the presence of particular medical issues. Using suggested equipment, it is possible to actually see the blood flow velocity in an area of concern. If a patient has a low blood velocity, it can mean that he or she will suffer loss of blood flow in some areas of the body, as the blood will be moving too slowly to get where it needs to go. The decreased rate of flow can also lead to deoxygenation, as less blood will be reaching certain areas, and therefore those areas will be starved of oxygen. Stroke patients often experience a radical decline in blood flow velocity, which leads to cell death in the brain as cells are deprived of the oxygen they need. Principle scheme of proposed techniques working principle is presented in Fig. 7.

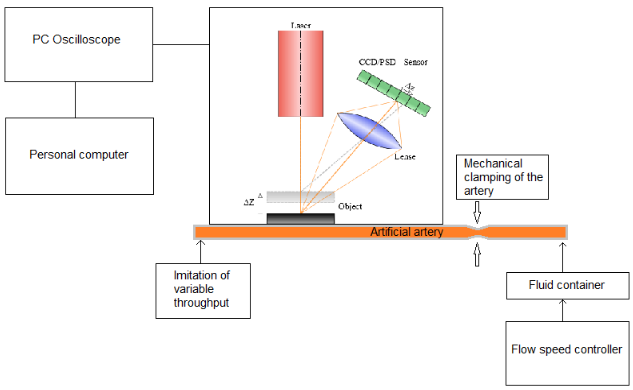



Fig. 7 Principle scheme for the blood flow speed analysis

The rate of flow was chosen to be 600 ml/h. Analyzing the results obtained it can be understood that blood velocity also can be measured using suggested techniques. The clamping point was situated 25 cm from the measurement point. Fig. 8 represents ideal case when clean artificial graft and perfect artificial blood was used in the experiment.

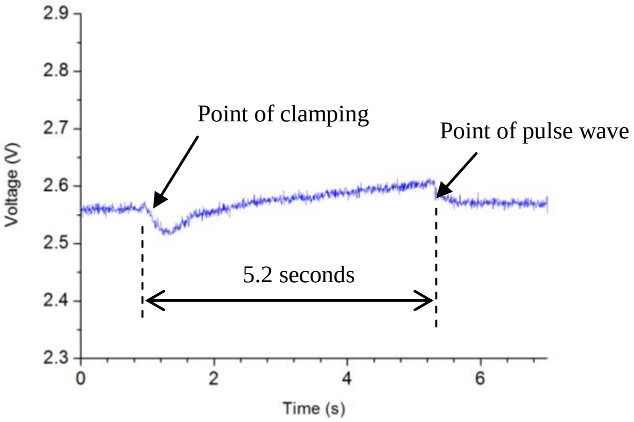



Fig. 8 Registering blood velocity

3.3. Experiments with patient

Numerous experiments were done with 28 year old male. It is obvious that the obtained results needs filtering from possible noise in order to assign them to one of the possible Traditional Chinese Medicine pulse patterns. Nevertheless the analysis shows extremely desirable results (Fig. 9).

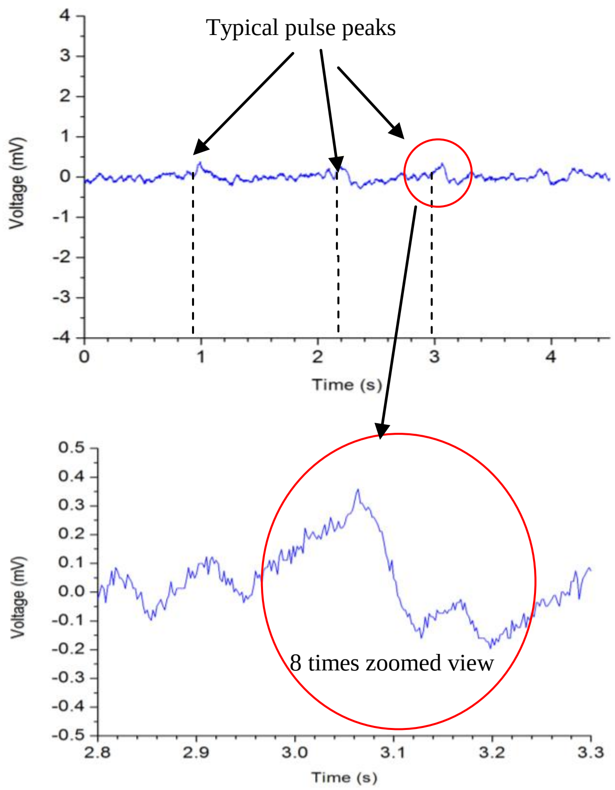
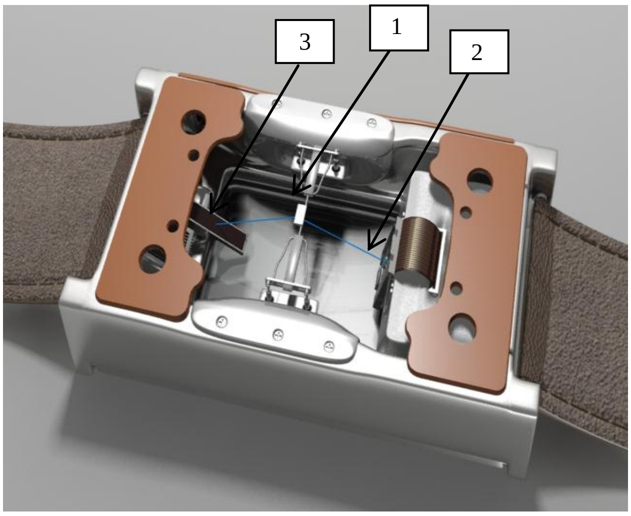


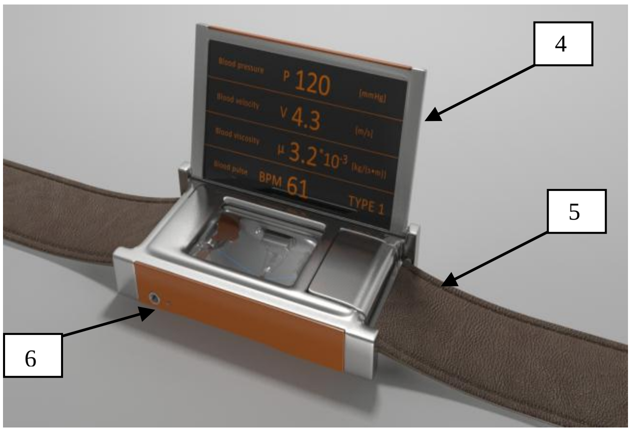

Fig. 9 Experimental results of blood pulse with patient

**4. Prototypes of biocompatible wrist-pulse sensor**

The prototype of one of the possible wrist-pulse sensor was created using simulation and 3D modeling program. Basic parts of the sensor are: *1* – sensitive micro-object (mirror, cantilever), *2* – laser, *3* – CCD sensor, *4* – adjustable wrist lever chain, *5* – case with informative screen, *6* – computer connection channel (Fig. 10).




a




b

c

Fig. 10 a, b, c Prototype of the MOEMS sensor

**5. Conclusions**

In order to perform computerized Chinese pulse diagnosis, the following new MOEMS sensor has been introduced in this paper to extract characteristics of Chinese pulses. Experimental results show that implementing such system various critical parameters of human health can be measured, i.e. blood velocity, blood viscosity, pulse rate, etc. Moreover, after filtering the obtained signal radial pulse types of patients can be registered and distinguished. Interviewing ambulance doctors it became obvious that such remote and reasonable price device would save many patients lives. Possible prototype of the MOEMS sensor was executed using 3D modeling programs. For further analysis the production of modeled MOEMS senor follows. Problems of present noise in the signal will be solved. Mathematical model of presented sensor will be executed by powerful modeling programs.

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K. Malinauskas, V. Ostaševičius, R. Daukševičius, V. Jūrėnas

NEINVAZINĖS
MIKRO-OPTO-ELEKTRO-MECHANINĖS SISTEMOS TAIKYMAS RADIALINĖS ARTERIJOS PULSO IR KRAUJO GREIČIO ANALIZEI

R e z i u m ė

Radialinės arterijos pulso analizė yra vienas iš svarbiausių sveikatos diagnostikos metodų Kinų medicinoje. Kraujo bangavimo tipai radialinėse arterijose yra labai svarbūs ir informatyvūs žmogaus sveikatos analizei. Turint pakankamai žinių ir praktikos iš kraujo bangavimo (pulso) įmanoma nustatyti, kokias sveikatos problemas turi pacientas (t.y. galimos problemos: su tulžimi, inkstais, skrandžiu, plaučiais, širdimi, cholesterolio lygiu kraujyje ir daugiau). Tačiau kiekvienas medikas gali padaryti klaidų įvertindamas žmogaus sveikatą. Šiame straipsnyje pateiktas kompiuterizuotas mikro-opto-elekto-mechaninės sistemos taikymas radialinei arterijos pulsacijai ir kraujo greičiui analizuoti. Signalo nuskaitymui naudojamas lazerinis trianguliacinis poslinkių matuoklis, fiksuojantis dominnačius radialinės arterijos poslinkius. Kompiuterio pagalba signalas yra filtruojamas. Galimas mikro sensoriaus prototipas yra pateiktas 4 skyriuje. Eksperimentiniai rezultatai rodo, jog siūloma technologija yra labai tiksli ir  tinkama nustatinėjant radialinės pulsacijos tipus ir kraujo greitį. Taip pat galėtų būti plačiai naudojama greitosios pagalbos medicinoje dėl santykinai mažų gamybos kaštų ir gabaritų.

K. Malinauskas, V. Ostaševičius, R. Daukševičius, V. Jūrėnas

NON-INVASIE
MICRO-OPTO-ELECTRO-MECHANICAL SYSTEM ADAPTATION TO RADIAL BLOOD FLOW PULSE AND VELOCITY ANALYSIS

S u m m a r y

Radial pulse examination is one of the most important diagnostic methods in traditional Chinese medicine. It has been used in establishing diseases and in guiding medicine selection for thousands of years. Blood flow fluctuation types present in radial artery contains rich and critical information which can reflect the state of various problems with health. Having precisely mastered the art of blood flow pulse practitioners can exactly determine what kind of health problems (i.e. problems with: gallbladder, kidneys, stomach, lungs, heart, high level of cholesterol and more) the patient has. Being non-invasive diagnostic technique this type of examination depends on the practitioner's subjective analysis and may be unreliable and inconsistent. In this paper, we present novel computerized non-invasive micro-opto-electro-mechanical radial pulse signal analysis techniques strongly correlating with the valuable knowledge of traditional Chinese medicine. First, the fluctuations of blood flow are registered by laser triangulation displacement sensor. Then, using computer based techniques the signal is filtered from possible noise. Possible prototype model of final object is presented. Experiment results show that the proposed system works accurately and could be especially effective and helpful in ambulance medicine because of its portability and manufacturing price.

**Keywords:** Micro-opto-electro-mechanical system, blood flow pulse, radial pulse types, non-invasive biocompatible optical micro sensor.

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