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(Review Article)

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Non-invasive blood pressure measurement from the finger using an optical system based on dynamic light scattering

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Abstract

This paper review presents the results of a Novel method for non-invasive blood pressure measurement from the finger using an optical system based on dynamic light scattering developed by Elfi-Tech's innovative technology group [1].

A small-scaled, optical, mobile device that measures BP at the finger using dynamic light scattering was developed. The device is positioned at the base of the index finger and contains a ring with an inflatable cuff with two miniaturized dynamic light scattering (mDLS) sensors situated away from, but close to the cuff. The cuff is inflated to above systolic pressure, and changes in blood flow (hemodynamics) are measured during deflation of the cuff.

Blood Pressure measurement is carried out using specially designed algorithms based on hemodynamic indexes and waveform analysis which capture systolic and diastolic points in real-time.

Keywords: Photoplethysmography; Dynamic Light Scattering; Mean Absolute Error; Hemodynamics; Diastolic; Systolic; Inflatable Cuff

1. Introduction

Blood pressure is an important parameter that is used by medical practitioners for monitoring the health performance of a wide variety of patients, such as acutely ill patients in critical care units, and patients with chronic hypertension. There are various methods for monitoring blood pressure ranging from direct invasive methods using an arterial line, to indirect non-invasive methods that rely on inflatable cuffs [2].

Utilizing an inflatable cuff enables application of pressures above the systolic pressure, and then slow deflation of the cuff so that first the systolic and then the diastolic pressure points are reached. There are a number of manual and automated methods to detect these points.

One of the manual methods for detecting the systolic and diastolic pressure points, usually conducted by a trained medial practitioner, and considered relatively accurate, is based on the use of a stethoscope positioned close to the upper arm cuff, to identify the initiation and termination of the Korotkoff sounds.

Automated methods mainly rely on cuffs that can detect oscillations in the blood vessel as a result of the pressure wave. The mean arterial pressure relates to the maximum of these oscillations and the systolic blood pressure (SBP), and diastolic blood pressure (DBP) are extracted using different empirically derived algorithms. Methods that rely on oscillometric techniques are usually cumbersome and often very uncomfortable for the patient.

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In the past few decades, many researchers have sourced for an alternative method that would enable measurement of blood pressure using a small device at the body's extremities such as the finger.

2. Technical rationale

Regular monitoring of blood pressure (BP) is important for the treatment of hypertension. This enables the patient to keep track of their blood pressures and seek medical attention immediately deviations are observed.

Most of the current instruments used for blood pressure measurement are cumbersome and difficult to move about. Also, self-usage appears almost impractical, especially for the older population.

There are optical solutions, such as PPG-based technologies, that were developed for improving convenience. However, these provide derived measurements that are often inaccurate, especially for diastolic values.

This aim of this review is to identify emerging technologies capable of providing convenient methods for self-measurement of blood pressure using more accurate methods.

Such technology will enable patients to monitor their blood pressures in real-time with more accurate results.

The research by Elfi-Tech's innovative technology group on the use of dynamic light scattering (DLS) technique to measure blood pressure from the finger [1] is the focus of this review.

3. Technical approach

3.1. Physical principles

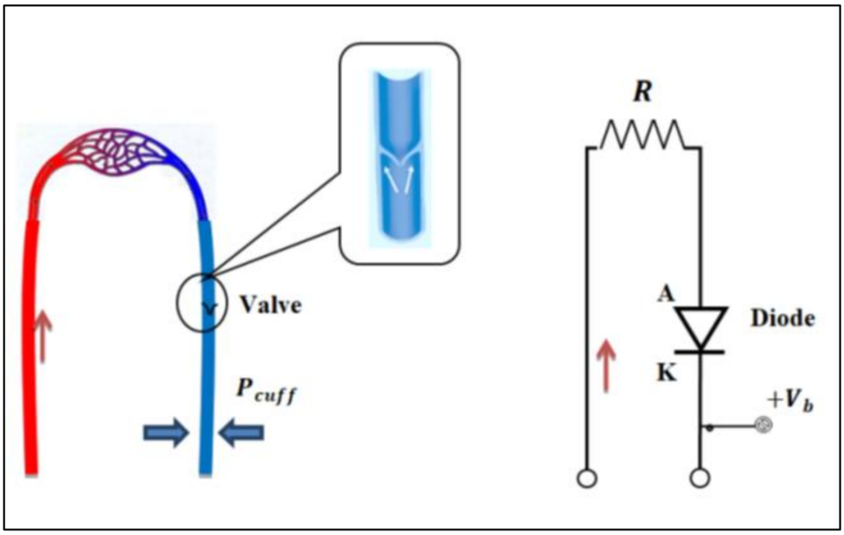

Figure 1 Electrical Impedance analogy of the finger [1]

Photoplethysmography (PPG) is a technique for estimating skin blood flow using infrared light [3]. It is an optical method that is generally associated with the fluctuations of the local blood volume and can be divided into two components; the direct current (DC) component which represents the static flow in the blood vessels and tissues, and the alternating current (AC) component which represents the pulsed blood flow in the artery as a result of the contraction and relaxation of the heart.

PPG signals used for detecting blood pressure values are typically extracted from the fingertip or from the second phalanx. By recording the changes in blood flow (hemodynamics) during pressure decrease it is possible to detect the systolic pressure point, and to derive the diastolic pressure point.

One disadvantage of using this method is the need to place the PPG sensor directly on the skin where deflation of the occluder may lead to motion artifacts. Another key disadvantage is that the method yields significantly lower estimates when poor PPG signals are acquired from places that are not at the fingertip.

The vascular hemodynamics can be expressed in terms of electrical impedance as shown if fig. 1. This analogy was used to build a model of blood circulation in the limb, under the condition of externally applied pressure.

The peripheral vascular system consists of arteries which supply oxygenated blood to the organs, and veins which carry deoxygenated blood back to the heart. Many veins contain one-way valves which open when blood is ejected toward the heart, and close once the surrounding muscles contract or gravity pulls the blood away from the heart. This ensures a constant flow of deoxygenated blood towards the heart, especially in large, deep veins [1].

In smaller veins, such as the human digits, certain valves termed microscopic venous valves (MVVs) exist [4]. These valves open only when pressure on the arteries exceeds the pressure on the veins. In a similar way, the diode in the electric circuit will open only if the voltage at the anode is greater than the voltage at the cathode, i.e., negative blocking voltage.

By applying external pressure using a cuff, the outflow of blood from the veins is restricted. The veins begin to swell and the pressure in the veins rises. This is analogous to an increase in blocking voltage in the electrical impedance circuit. Static condition is achieved when the external pressure reaches the person's venous pressure.

When the external pressure exceeds systolic pressure, no blood flow is detected. When the external pressure is between systole and diastole values, blood flow is detected periodically. When external pressure is below diastole values, blood flow is measured continuously.

Under these conditions the AC component of the pulse wave is transformed non-linearly, just as the electrical signal when passed through a semiconductor detector as shown in fig. 2.

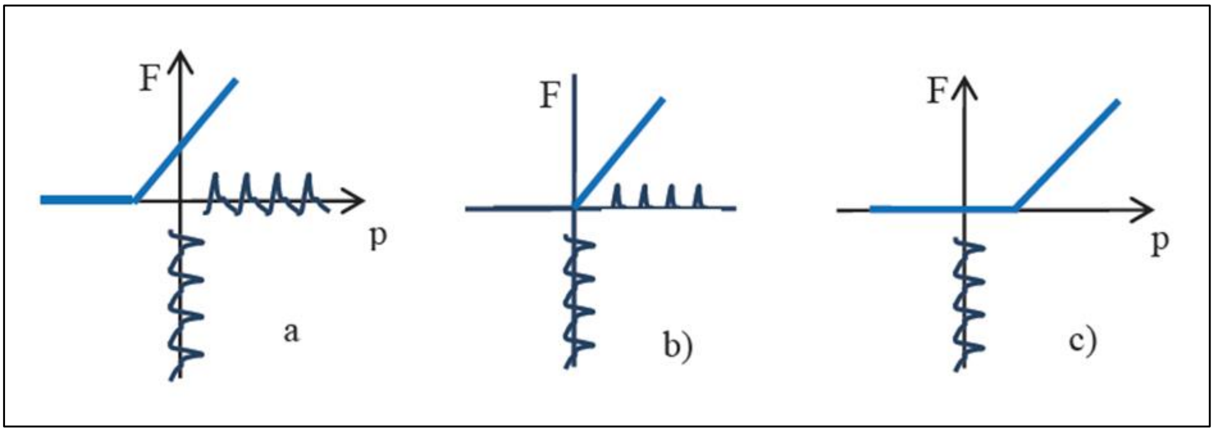

Figure 2 The pulse wave transformed by the transfer function F(P) of the venous valves in three different regions: a) Ppulse < Pdiast, b) Pdiast < Pcuff < Psist, and c) Pcuff > Psist. [1]

From this model, it is observed that changes in the pulse wave form can be used as an indicator of the diastolic point transition. Therefore, by varying the pressure in the cuff and continuously measuring the blood flow it is possible to detect the diastolic pressure.

As the pressure in the cuff increases, the blood volume reduces. Once this pressure exceeds the diastolic value, the time during which the valve is open will start to decrease. In terms of the electrical analogy, the conduction angle of the diode will start to decrease.

At pressures higher than the systolic value, the blood flow will stop completely (conduction angle becomes zero), and the value of the systolic blood pressure can then be derived.

As the pressure begins to decrease, the non-pulsating blood flow component appears, but there is a clipping of the signal's shape. Once the entire signal is observed, the diastolic point is reached.

3.2. Measurement system

The measurement system is based on a miniaturized dynamic light scattering (mDLS) sensor, a technology developed by Elfi-Tech Ltd. which enables the measurement of capillary blood flow. The system measures the fluctuations of the light field scattered by moving erythrocytes, analogous to the laser Doppler Flowmetry (LDF) method [5].

The probe unit shown in fig. 3 is located at the finger root. It consists of the mDLS sensor and a pressurizing assembly, which is made up of a clear plastic ring with an inflatable cuff. Two DLS sensors are placed on the outside of the ring on the palmar side. The plastic material enables projection and detection of light from the skin. The probe is connected to a control and monitoring unit [1].

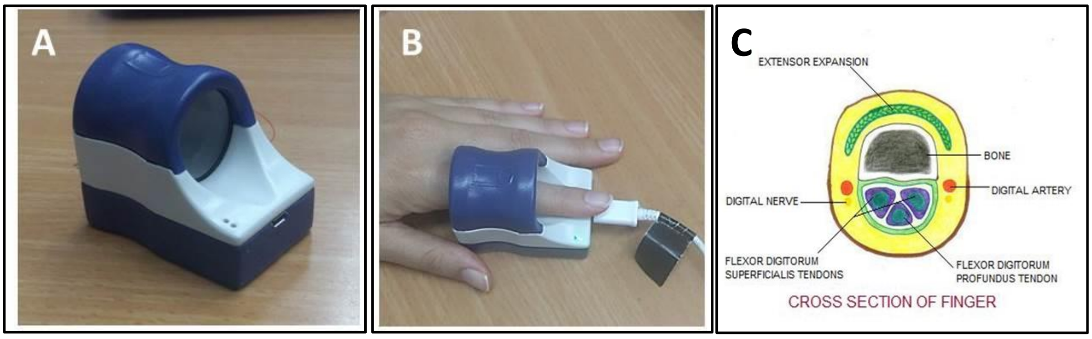

Figure 3 The blood pressure measuring system [1]

The apparatus is made up of a clear ring frame which holds the inflatable cuff (A). The DLS sensors are placed on the outside of the plastic ring, the occluder is located on the finger root (B) while the DLS sensors are located at the finger root (C).

4. Results and discussions

4.1. Model predictions

In order to test the model, signals acquired with Dynamic Light Scattering (DLS) and Photoplethysmography (PPG) were simulated while decreasing the external pressure. The results are presented below.

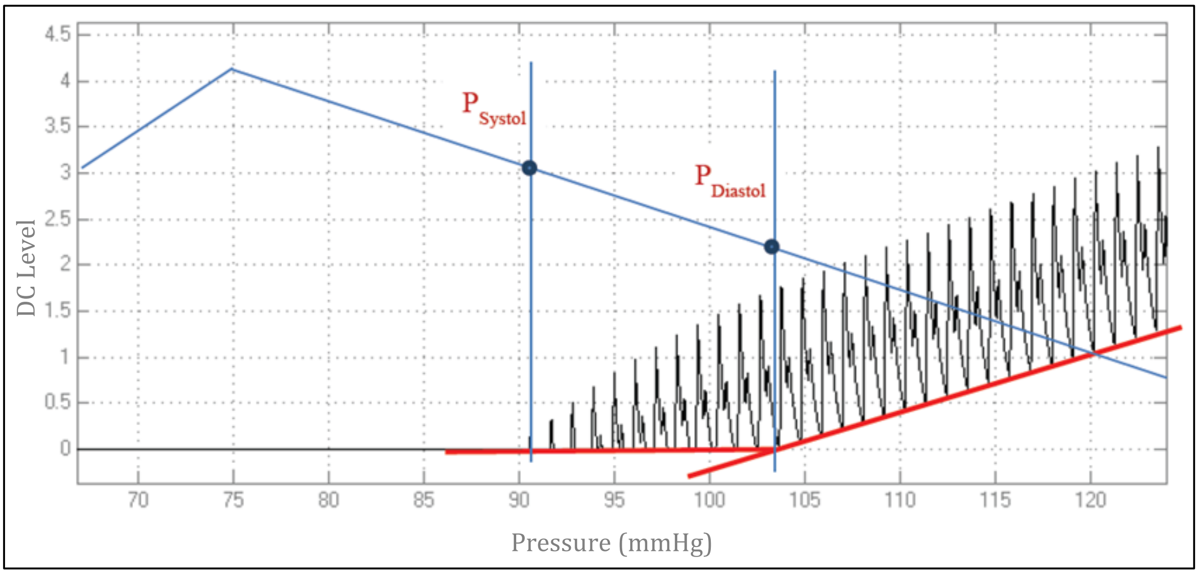

Figure 4 Simulated DLS signal during a decrease in external pressure [1]

As can be observed in fig. 4, the model accurately predicted the response of blood flow to pressure changes. When the blood pressure is below the systolic value, the DLS signal is clipped. When the pressure is below the diastolic value, the entire signal appears and there is an increase in DC levels.

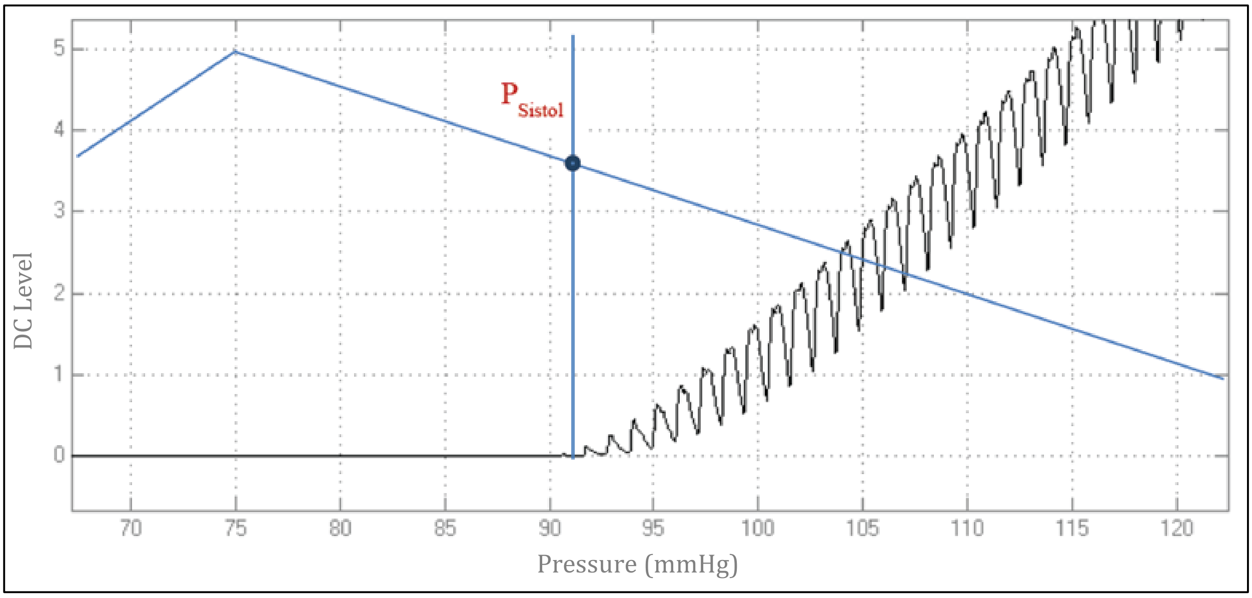

Figure 5 Simulated PPG signal during a decrease in external pressure [1]

From fig. 5, when the blood pressure is below the systolic value, the PPG signal returns, and the DC level begins to increase. No diastolic point can be observed in this signal. The PPG signal has only one characteristic point which corresponds to the systolic pressure.

When compared with the PPG signal, it is obvious that the DLS signal contains additional information from which the diastolic pressure point is extracted.

4.2. Assessment of error

The Mean Absolute Error (MAE) is an arithmetic average of the absolute errors between paired observations expressing the same phenomenon and is commonly used to compare alternative techniques of measurement.

Mathematically, the MAE is expressed as:

$$MAE = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n}$$

Where y_i and x_i are measured values using alternative techniques and n is the number of measurements taken.

4.3. Device accuracy

Blood pressure from 69 patients visiting a hypertension outpatient clinic, and a control group of 15 healthy subjects were measured [1].

The subjects were measured while sitting in an upright position after a few minutes rest. Their hands were placed on the table at the level of the heart. First, their BP were measured with Elfi-Tech's device. Then, an automatic commercially available device (Omron) was used on the same arm to provide a reference measurement.

BP readings obtained with the DLS-based device were compared with measurements recorded at the arm location with an Omron instrument used in the clinic as shown in fig. 6.

The Mean Absolute Error (MAE) for systolic and diastolic blood pressures obtained were 7.8 mmHg and 9 mmHg, respectively at all ranges of BP measured.

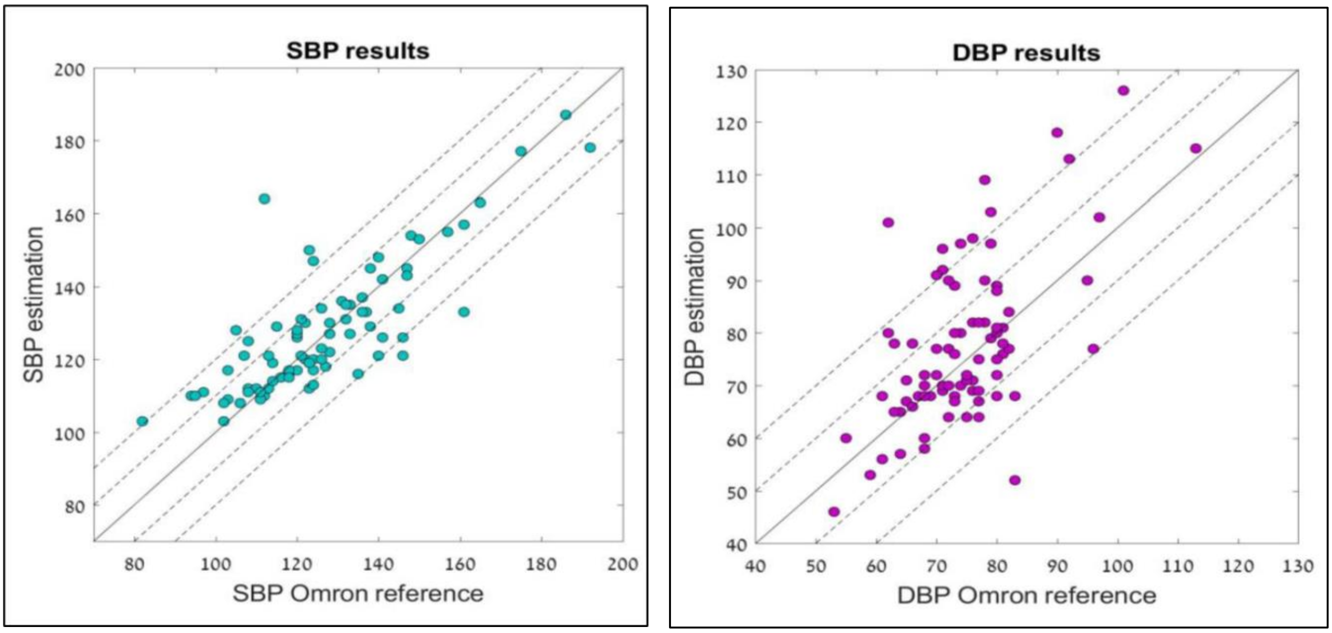

Figure 6 DLS-based BP measurements vs. Omron reference [1]

The systolic results mostly have an absolute error (AE) less than 10 mmHg for all reference values, showing greater accuracy than the diastolic results.

Multiple measurements were also carried out for healthy subjects over a period of days to demonstrate the robustness of the measurement system and its ability to track alternating BP values in the same subject with high accuracy.

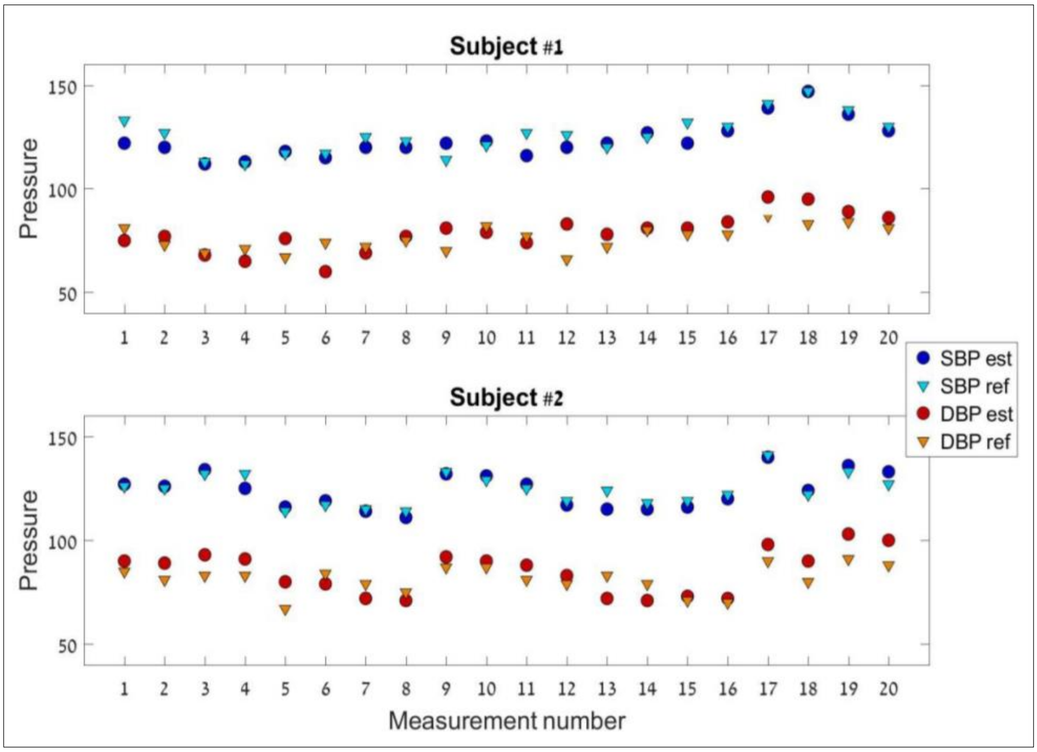

Figure 7 Robustness of DLS-based measuring device [1]

In fig. 7, the result of BP measurements for two subjects with varying BP points over a period of time as is evident from the reference results (cyan and orange triangles) is presented.

It can be observed that the measuring device was able to track the BP with high accuracy (blue and red circles).

5. Conclusion

The measurement of blood pressure in the clinical setting is one of the most important vital signs for assessing the cardiovascular status of patients. Self-measurement of BP is a useful index for monitoring treatment of hypertension, and the development of a simple-to-use apparatus would be an important contribution for health care.

A physical model that explains the relation between arterial pressure values and the hemodynamic response measured from the finger root following changes in externally applied pressure is proposed and, using this model, a small scaled, optical, mobile device that accurately measures BP at the finger using dynamic light scattering has been developed.

The accuracy of the DLS-based apparatus compares well with the more cumbersome Omron device in clinical use and provides data based on more direct measurements of the actual hemodynamic changes caused by blood pressure fluctuations, and not on derived measurements.

In fact, the intrinsic accuracy of the new device provides BP measurements of medical grade, and therefore can be applied to acute care settings as well as for ambulatory measurements. The compactness of the device and the absence of wires and tubing contribute to its ease of use in the hospital arena. In addition, its simple operation and the accuracy will contribute to the ambulatory care of patients with hypertension and other cardiovascular disorders.

Using this apparatus, BP from 69 patients visiting a hypertension outpatient clinic, and a control group of 15 healthy subjects were measured. BP readings were compared with measurements recorded at the arm location with an Omron device used in the clinic. The mean absolute error (MAE) for systolic and diastolic blood pressures were 7.8 mmHg and 9 mmHg, respectively at all ranges of BP measured.

In conclusion, using Elfi-Tech's innovative technology, it is possible to measure BP accurately at the finger location using a compact, convenient mDLS-based device with high accuracy.

References

[1] Adi Schejter Bar-Noam, Alexander Kaminsky, Albert Bravo, Louis Shenkman, Naomi Nacasch, Ilya Fine, Novel method for non-invasive blood pressure measurement from the finger using an optical system based on dynamic light scattering, Proc. SPIE 11075, Novel Biophotonics Techniques and Applications V, 110750P (22 July 2019); doi: 10.1117/12.2525685.

[2] A.S. Meidert and B. Saugel, Techniques for non-invasive monitoring of arterial blood pressure, Frontiers in Medicine, 2018.

[3] M. Elgendi, On the analysis of fingertip photoplethysmogram signals, Current cardiology reviews, 2012.

[4] A. Caggiati, M. Phillips, A. Lametschwandtner, C. Allegra, Valves in small veins and venules, European Journal of Vascular and Endovascular Surgery, 2006.

[5] I. Fine, A. Kaminsky, B. Kuznik, L. Shenkman, A non-invasive method for the assessment of hemostasis in vivo by using dynamic light scattering, Laser Physics, 2012.