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Fiber-based wearable sensors for bio-medical monitoring

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In a recent study, Prof. Rui Min and collaborators published their paper in the journal of *Opto-Electronic Science* that is entitled "Smart photonic wristband for pulse wave monitoring". The paper introduces novel realization of a sensor that uses a polymer optical multi-mode fiber to sense pulse wave bio-signal from a wrist by analyzing the specklegram measured at the output of the fiber. Applying machine learning techniques over the pulse wave signal allowed medical diagnostics and recognizing different gestures with accuracy rate of 95%.

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The field of wearable sensors for cardio-vascular sensing is becoming more and more popular given the need to constantly monitor vital bio-signs in applications such as elderly care, sport, security/rescue forces etc. One common direction is to develop flexible electronics[1] and strain sensors[2]. Another direction is to use optical sensors and more specifically optical fiber sensors[3,4].

The usage of fiber based sensing architectures as high precision and high sensitivity sensing platform is becoming more and more common in large variety of fields starting from structural health applications and reaching all the way to bio-medical monitoring. One important application is usage of fiber sensors for continuous vital signs monitoring. Connecting such a fiber sensor as part of a wristband is especially relevant since the wrist is a passage place for large blood arteries, passing close to the skin surface and allowing to sense blood pulsation in high precision.

Speckle patterns are self-mixing interference patterns generated when coherent light (from a laser) is reflected from rough surfaces (e.g. as biological tissues). Those patterns are very sensitive to movements and changes in the reflecting surface since such movements modify the photonic spatial phase distribution and thus change the interference condition leading to change in the speckle pattern. Usage of a specklegram[5] generated at the output of a multimode fiber was demonstrated before for bio-medical sensing while involving machine learning tools. Artificial intelligence algorithms were shown to enhance the sensing sensitivity and specificity that could be obtained using such fibers for bio-sensing[6,7]. Sensing of vital bio-signs using analysis of a specklegram could be done in free space[8], however then the main challenge is to perform the bio-monitoring while the subject is in motion. When performing the sensing via free space sensor results in relatively high sensitivity to motion artifacts.

Fiber based wearable solutions solve this challenge and allow motion agnostic sensing capabilities. However, the fiber-based sensors cope with the challenge of properly integrating them into the wearable fabric or on top of the measured subject that is being monitored[9]. The reason for that is that glass fibers are not sufficiently flexible to bending. Prof. Rui Min and collaborators, came up with an innovative solution involving developing a polymer based multi-mode fiber sensor being highly flexible and endured such that it does not pose inconvenience on the wearer that is being monitored while the fiber sensor is

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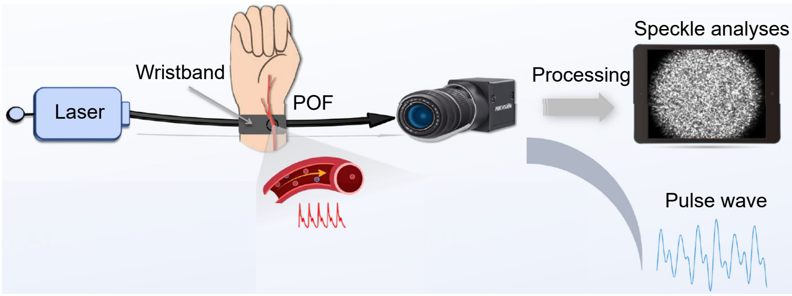

Fig. 1 | Pulse wave sensing configuration for a polymer optical fiber (POF) integrated into a wristband (Figure reproduced from ref.[10]).

integrated in a sports wristband as a smart photonic wristband[10].

Prof. Rui Min and collaborators analyse speckle image extracted from the multimode optical fiber and optimize their sensor design by embedding polymer fibers with different core diameters and by applying various image-processing algorithms. Those algorithms also involve artificial intelligence to process the speckle patterns being extracted from the fiber, to relate the changes in the speckle pattern with blood pulse wave that is being monitored. This is enabling pulse palpation measurements comparable to those obtained by well-trained practitioners of traditional Chinese medicine (see Fig. 1 for the experimental architecture)[10].

As a result of the precise sensing and the algorithmic optimization, the obtained measurement error did not exceed 3.7%. In addition, by training a convolutional neural network (CNN) that processes the extracted pulsation signal, the authors were capable of recognizing different gestures with accuracy rate of 95%.

The future challenge is to be able to use the demonstrated real-time acquisition of human pulse signals in daily life for cardiovascular disease monitoring and diagnosis as well as for home monitoring, paving the way for medical Internet of Things (IOT)-enabled smart systems.

As a summary, the main advantage of the approach presented in ref.[10] is the simplicity at which the sensor can be integrated into a wristband and its measurement sensitivity being totally agnostic to motion artifacts (lack of sensitivity to motion) making the device suitable for not only medically related applications but also for wealth care markets such as elderly care as well as for sport community members. The future will involve advancements in the field of wearable sensors to be incorporated into fabric and clothing to have accessibility to additional measurement positions along the body of the wearer as e.g. the chest, in order to extract not only cardio related signals but also respiration signals to cope with larger variety of cardio-pulmonary diseases diagnosis capabilities.

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