Evaluation of Handwriting peculiarities Utilizing Laser Speckle Contrast Imaging

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Abstract

Functional handwriting is procees involving various complex interactions among physical, cognitive and sensory systems. Since the muscular motion has a peculiar nature for each person, the handwriting properties, e.g. such as pencil pressure, speed of writing, can be considered to be as a unique marker of the identity. Moreover, impairments of handwriting in many cases are connected to neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD), developmental coordination disorder, autism spectrum disorders (ASD), Parkinson's disease, etc. In this point of view investigations of handwriting kinematics and pressure can be highly important for both criminology and medicine. Commonly, the kinematic and pressure features of handwriting are evaluated using graphics tablet with stylus or electronic pens. The production of such devises is quite expensive. Therefore, a development of new methods of individual handwriting analysis is important and actual goal nowadays. Laser Speckle Contrast Imaging (LSCI) is a powerful method sensitive both to motion and pressure. Since the developed technique requires to use only a simple laser diode and camera for image acquisition, LSCI can be cost effective and practical tool for handwriting analysis. In current Letter we present a robust LSCI-based method for handwriting pressure and kinematics evaluation. The introduced approach has been validated by the Archimedean spiral writing task.

Keywords: laser speckle imaging, handwriting, autism, pressure, speckle patterns, light scattering

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1. Introduction

Handwriting is a functional skill used for communication, self-expression, recording of thoughts, and other. The writing is simultaneously involves both motor and cognitive processes [1]. Most people are typically learn how to write in the childhood, developing individuality and automaticity of handwriting such that motor processes of writing do not interfere the cognitive ones. In the literature, it was shown that handwriting quality is significantly correlated with academic achievement during the school years [2-4], self-esteem [3], psychosocial well-being [5], etc.

Moreover, it was shown that handwriting difficulties can be a sign of neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD) [6], developmental coordination disorder [7], autism spectrum disorders (ASD) [8] etc. Also, investigation of handwriting peculiarities can be helpful for early stage diagnostics of Parkinson's disease [9]. All of these diseases can be associated with a high difficulties in coordinating and performing of skilled motor tasks.

The hand motion features of different persons can be characterized by their muscular structure and cognitive control characteristics. In this way, the handwriting properties such as speed of writing and pencil pressure can be considered to be as a unique marker of identity. In this point of view, the studies of handwriting features determination are highly useful for personal identification [10]. Therefore, identification of meaningful parameters of individual handwriting can be highly important for both criminology and medicine.

Typically, the kinematic and pressure features of handwriting are evaluated using graphics tablet with stylus [11]. However, due to the relatively large thickness of the tablet, handwriting cannot be performed in properly, that can critically affect the accuracy of measurements. Thus, the individual's unique handwriting characteristic can be lost. In order to solve this problem, the different types of electronic pens for evaluation of kinematic and pressure feature have been developed [12]. The production of such devises, including graphics tablets and electronic pens, is quite expensive. Therefore, a development of new method of handwriting analysis is important and extremely actual nowadays.

Laser Speckle Contrast Imaging (LSCI) is a powerful method mostly used for non-invasive real-time mapping/diagnosis of flow [13]. LSCI has been successfully implemented for different biomedical applications such as cerebral blood flow monitoring [14,15], vascular biology [16,17], tumor screening [18], monitoring of weak allergens reaction [19-21], clinical use in skin [22], and other. In addition, LSCI is effectively used in industry for paint drying monitoring and roughness measurement [23,24].

Laser speckle is a random phenomenon which has been statistically described by Goodman [25]. The spatio-temporal coherence properties of light scattered by rough surfaces lead to intensity fluctuations. The image formed at a given point of the observation plane can be described as superposition of amplitude spread functions. Each of these spread functions is arising from a different scattering point on the observed surface. Thus, a highly complex pattern of interference, known as a laser speckle pattern is arised. If any parts of illuminated surface are moving, or if roughness of surface is fluctuated, or if some pressure is applying to the surface, it introduces temporal fluctuations in the single speckle intensity. Captured by CCD or CMOS camera with finite exposure time, these fluctuations manifest blurring of speckle pattern. Such blurring leads to a reduction in speckle contrast, which is calculated using the next equation [25]:

$$K = \frac{\sigma}{<I>}, \quad (1)$$

where K is the speckle contrast, σ is the intensity standard deviation and $<I>$ is the mean intensity.

The speckle contrast imaging can be used (utilizing statistical analyzing of blurring degree) for evaluation of motion of scattering centers localized within an object of interest, and, therefore, for assessment of local pressure applied to the object. The higher speed of scattering centers displacements within the object, as well as an external pressure, applied to the surface of the object, produce the higher blurring degree. Therefore, changes of local pressure on the surface of observed object produces corresponding changes in speckle patterns and, respectively, in the speckle contrast.

LSCI is a simple method utilizing coherent laser source (particularly, laser diode) for object illumination and CCD or CMOS camera for raw speckle images acquisition. In fact, it was shown that even web camera and smartphone camera can be used for LSCI [26,27]. In current paper, we introduce a simple and robust LSCI-based method for handwriting evaluation as an alternative to the available approaches.

2. Experimental setup

The experiemnatl setup, presented in Figure 1, has been used for evaluation of handwriting kinetics and pen's pressure.

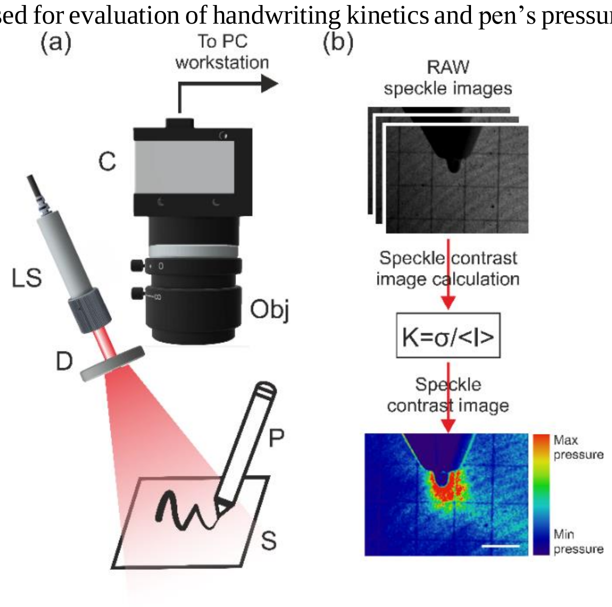

Figure 1. LSCI system scheme and principles of operation. (a) Schematic presentation of LSCI scheme: C – CCD camera, LS – light source, D – diffuser, Obj – objective, P – pen, S – sample of paper; (b) Principle of speckle contrast images calculation: CCD camera captured stack of raw speckle images. Further, speckle contrast images calculated using eq. (1) by a custom-developed algorithm in offline regime. Scale bar is equal 5 mm.

13 mW laser diode (RLD650-13-3, Roithner Lasertechnik GmbH, Austria) emitting light at 655 nm, which was further expanded by a Thorlabs Engineered Diffuser (ED1-C20, Thorlabs, USA), illuminats the list of paper (see Fig.1). Further, a CMOS camera (DCC3240M, 1280 × 1024, pixel size of 6.7 μm, Thorlabs, USA) used in combination with a 12 mm F1.4 objective (Kenko Tokina Co., Ltd, Japan) has been used for the acquisition of gray-scale raw speckle images. The obtained images were processed by a custom-developed algorithm in the offline regime using a Fiji/ImageJ (image processing package) and MATLAB r2018b software environment.

For acquisition of speckle contrast images two methods are typically applied. The first one, and the most commonly used method is the spatial analysis utilizing a sliding window over the raw speckle image [28]. The sliding windows with size 5×5 and 7×7 pixels are usually used for spatial processing of each raw image in captured image sequence using equation 1. Further, obtained speckle contrast images averaged for noise signal reduction. However, using of the sliding window lead to loss of spatial resolution in the final speckle contrast image. To avoid reduction in spatial resolution, an alternative method of temporal analysis has been introduced [29]. To perform temporal processing speckle contrast values should be calculated using equation 1 for each pixel of raw speckle images sequence. Thus, temporal processing allows to preserve the initial resolution of the final speckle contrast image. In this way, in the current work, the temporal processing has been choosen as optimal.

3. Results and discussion

To demonstrate the posibility of evaluation of handwriting pressure changes the following experiments have been performed. The laser diode illuminates the sheet of paper. The volunteer periodically pressed the paper by the tip of pen similar as in the handwriting during 10 seconds. CCD camera captured this process with 1 msec exposure time. Further, the sequence of time dependent speckle contrast images has been calculated. For calculation of each speckle contrast image 10 raw speckle frames has been used. The obtained speckle contrast images were converted into the 8-bit images in the way that lower speckle contrast values, and, respectively, higher pressure, corresponds to the higher image intensity values. Further, these 8-bit images were colored in false color palette for the better clarity. The blue color corresponds to absence of pressure and red color corresponds to maximal pressure.

It is clearly seen from Fig.2 (a) that pressing of paper sheet by the pen tip leads to appearance of area with increased intensity around the tip corresponding to decreased speckle contrast values and, thus, to the presence of pressure. Therefore, analysis of time dependent speckle contrast values provide an information about relative changes of local pressure induced by pen during handwriting.

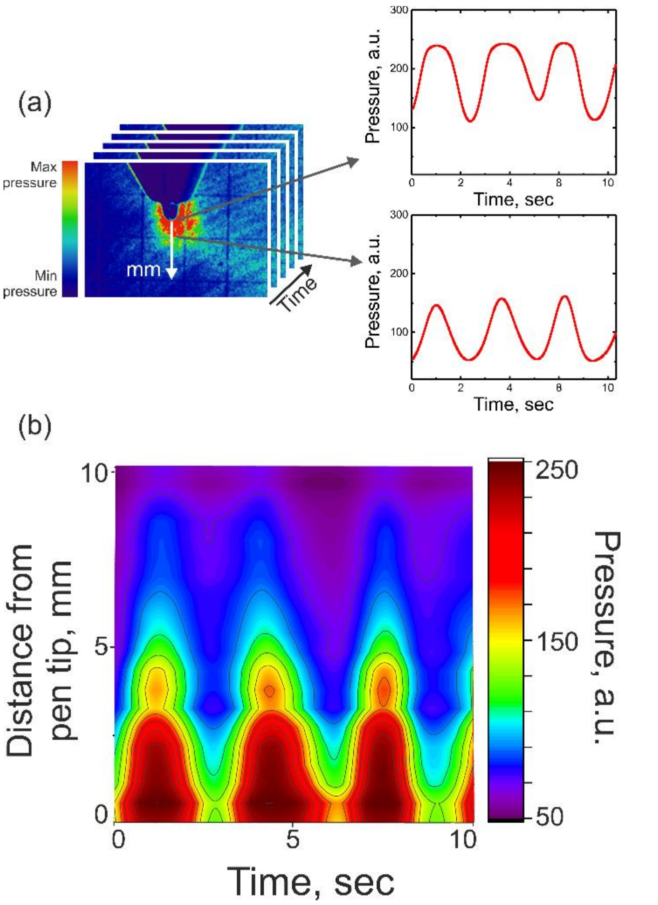

Figure 2. Example of time dependent pressure changes analysis for experiment with periodical pressing of paper by the pen tip. (a) Speckle contrast image and time dependent pressure changes profiles for points located at the distances 1 mm and 3 mm from the pen tip. (b) Surface corresponding to the time dependent pressure changes for the points located at the distances 0 mm to 10 mm from the pen tip.

To obtain such an information, intensity values along the 10 mm length vector (represented as white arrow at Fig.2 (a)) directed from the end of pen tip to the bottom of frame were calculated for each obtained speckle contrast image. Fig.2 (a) shows time dependent profiles for described experiment at the points located at the distances 1 mm and 3 mm from the pen tip. Fig.2 (b) shows surface plot corresponding to the time dependent pressure profiles along the 10 mm length vector directed from the end of pen tip to the bottom of frame. It is clearly seen that local pressure induced by pen decreased from the pen tip to the bottom of frame. It should be pointed out, that vector for pressure evaluation has been chosen only in the area corresponding to the paper sheet not the pen tip itself. Since movement of pen influences the speckle contrast only in the localized area corresponded to the pen's tip, the pressure evaluation was not interrupted by movement of the pen. Arguably, the proposed analysis of the observed speckle patterns can be used as a tool for diagnosis of particular mental diseases and/or for determination of relative pressure variations during handwriting evaluation of an individual.

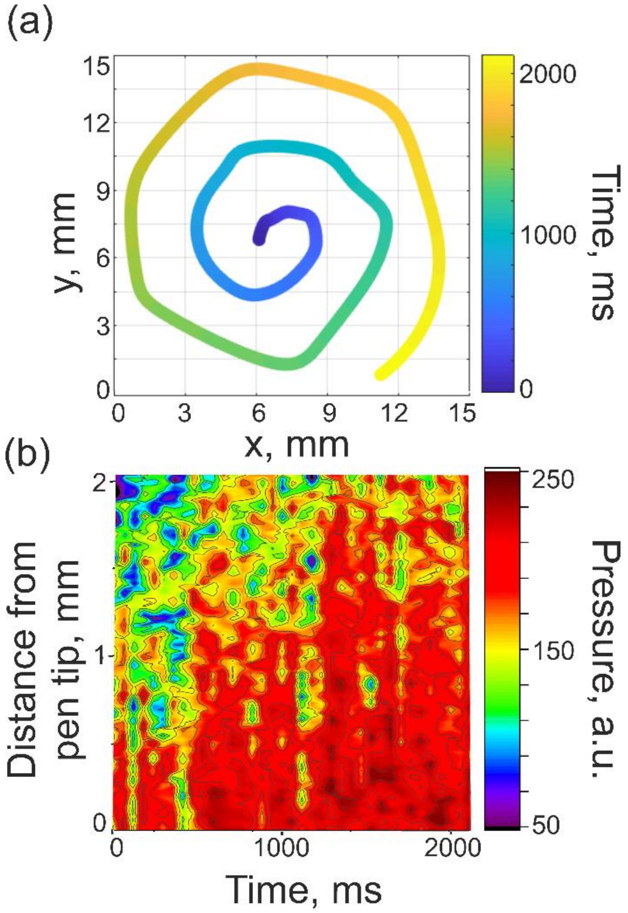

Figure 3. Example of handwriting kinematics and pressure analysis during the Archimedean spiral writing task. (a) Color-coded time dependent trajectory of the Archimedean spiral writing task (b) Surface corresponding to the time dependent pressure changes for the points located at the distances 0 mm to 2 mm from the pen tip.

In addition, the following experiment has been performed to demonstrate the posibility of evaluation of both handwriting kinematics and pressure changes. In a similar way the laser diode illuminates the list of paper. The volunteer drew the Archimedean spiral using the pen. The Archimedean spiral is one of the most popular handwriting exercises used for evaluation of the motor performance in various movement disorders [30, 31]. As far as all writing data are captured by camera, the trajectory of pen's tip can also be easily monitored utilizing motion tracking algorithm [32]. Moreover, it is also possible to assess the speed of handwriting performance. Fig.3(a) shows trajectory of the pen's tip during performing of handwriting task. The trajectory has been tracked using MTrackJ plugin for ImageJ software. The trajectory line has been color coded in the way that changing of color corresponds to time value from beginning of the handwriting task. It is clearly seen that inner spiral turn takes more time than outer to be performed. Thus, the speed of writing is different for the various parts of performed figure.

For estimation of the pressure pattern during the Archimedean spiral exercise the same method described above has been applied. The surface plot corresponding to the time dependent pressure profiles has been plotted for the 2 mm length vector directed from the pen tip to the bottom of the frame (see Fig.3 (b)). As well as in the previous experiment, vector has been plotted only in the area corresponding to the paper sheet not the pen tip itself. So, all data were collected from the static area where the speckle contrast was influenced only by the changes in pressure but not by the motion of pen. It is clearly seen that local pressure caused by the pen's tip is changing during the writing task.

The analysis of kinematic and pressure patterns obtained by the proposed LSCI method can allow to distinguish handwriting performed by different persons or allow to diagnose the early stage of neurodevelopmental disorders.

Thus, we introduce the concept of evaluation of individual handwriting with LSCI approach. To became a practical tool for a routine day-to-day use, the proposed method requires further development. Particularly, the calibration of speckle contrast values on the real pressure caused by pen on paper surface should be performed. It should be also pointed out, that the proposed approach can be used in a back-reflected mode, when the illumination and detection of scattered light is performed from the underside of the transparent glass table, whereas the paper sheet is placed on the surface.

4. Conclusion

We present simple and robust experiemntal method for evaluation of handwriting pressure and kinematics by using LSCI. Since the experimental implementation of introduced technique requiers to use only a simple laser diode and standard camera for image acquisition, the method can be cost effective, affordable and practical tool for express assessment of handwriting features. The proposed technique has been verified by the Archimedean spiral writing task. Thus, the LSCI has been, to the best to our knowledge, used for for the first time for examination of handwriting features. The proposed technique still requires further development to become a practical tool for routine day-to-day handwriting assesment. We also believe that LSCI-based handwriting evaluation has a great potential and will find an application in diagnosis of neurodevelopmental disorders.

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