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Simulation for dynamics of transient ischemic attacks with thermal infrared imaging

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Abstract. Stroke is characterized by the sudden loss of blood circulation to an area of the brain, resulting in a corresponding loss of neurologic function in a patient. According to current methodological recommendations, it is possible to perform surgical and drug treatment to minimize the damage from acute stroke in the first 3-6 hours after the onset of transient ischemic attacks, which is often difficult to identity for emergency physician or clinician. Thermal infrared imaging could serve as a fast non-invasive test to detect asymmetrical pattern in facial temperature of patient as a predictor for vessel occlusion during acute stroke. We develop a software-driven model to simulate for dynamics of facial surface temperature distribution with transient ischemic attacks. The implemented model is designed to develop and debug algorithms for automated analysis of the temperature dysregulation at the processing of patient thermal infrared recording.

1. Introduction

Stroke is characterized by the sudden loss of blood circulation to an area of the brain, resulting in a corresponding loss of neurologic function. For practical purposes, there are two types of stroke after subarachnoid hemorrhage has been excluded. Ischemia accounts for 85% of presentations and primary hemorrhage for 15%. Hemorrhage causes direct neuronal injury and the pressure effect causes adjacent ischemia. Primary ischemia results from thrombotic or embolic occlusion of a cerebral artery. The usual sources of embolism are the left atrium in patients with atrial fibrillation or the left ventricle in patients with myocardial infarction or heart failure [1]. Vessel occlusion arises from atherosclerosis, typically in the internal carotid artery (ICA) or middle cerebral artery (MCA) just above the carotid bifurcation or from small vessel disease deep within the brain. Ischemic stroke causes direct injury from lack of oxygenation and sets up a cascade of neurochemical events that lead to significant damage.

Stroke is a clinical diagnosis, but brain imaging is required to distinguish ischemia from primary intracerebral hemorrhage. The pattern of neurologic signs, including evidence of motor, sensory, or cortical dysfunction and hemianopia, can be used to diagnose certain clinical subtypes and thus to predict disease progression. Other signs also relate to outcome and may help identify the cause. If neurologic abnormalities resolve within 24 hours, symptoms were caused by transient ischemic attacks (TIA) rather than stroke [2]. Patients should be assessed at a hospital immediately after acute stroke. According to current methodological recommendations, it is possible to perform surgical and drug treatment to minimize the damage from acute stroke in the first 3-6 hours after the onset of transient ischemic attacks. Thus, the emerging problem is the lack of methods and tools for non-invasive continuous monitoring of hemodynamic activity of the brain for detection of acute stroke in a patient.

2. Materials and methods

With highly portable infrared cameras thermal imaging during acute stroke triage has become possible. Thermal imaging offers the great advantage of real time two-dimensional surface temperature measurement. With modern technology, a single image may contain several thousands of temperature points, recorded in a fraction of a second. The human body is homeothermic and relatively stable in temperature, but the shell of the body (internal organs, skin, etc) forms part of the regulatory process. Metabolism and flexing of muscles during exercise are the principal sources of heat in body core Thereafter, the heat is transferred from the core towards the outer periphery of the body by blood flow through blood vessels. Blood gains heat from the core of the body and loses heat at the peripheral parts, especially skin. This monitoring process is called thermoregulation. Dynamics of surface temperature distribution is governed by a number of factors, such as blood flow in the surface layer, heat conduction from deeper blood vessels and sweat evaporation [3].

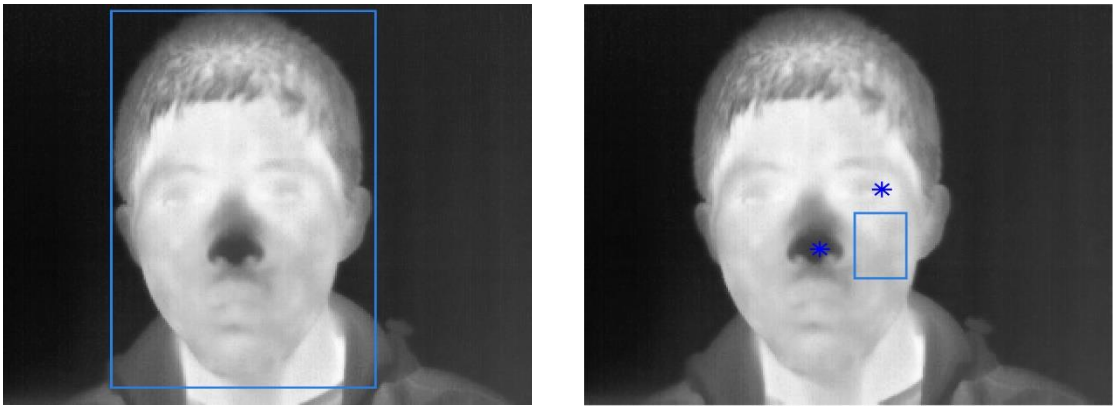
Infrared thermography (IRT) is a remote, non-contact technique in which thermal patterns on the surface of the test objects are monitored. Subsurface defects cause abnormal thermal patterns, which indicate the presence of those defects. Similarly in medical applications, due to clinical illness abnormal thermal patterns on the skin surfaces are analyzed. Moreover, such temperature dysregulation occur earlier than other clinical signs, which creates important prerequisites for the possibility of early detection [4]. The IRT has been successfully used in diagnosis of breast cancer, diabetes neuropathy and peripheral vascular disorders. It has also been used to detect problems associated with gynecology, kidney transplantation, dermatology, heart, neonatal physiology and fever screening.

Thermal infrared imaging could serve as a fast non-invasive test to detect asymmetrical pattern in facial temperature of patient as a predictor for vessel occlusion during acute stroke [5]. Monitoring of facial surface temperature with thermal recordings in a patient is used to analyze the hemodynamic brain activity. The clinical pilot study led by Aulmann was to evaluate the pattern of superficial facial skin temperature in patients with acute proximal arterial occlusion of the anterior circulation compared to non-ischemic controls [6]. In 46 patients suffering from acute occlusion in the anterior circulation (ICA: 17, M1-MCA: 13, M2-MCA: 16) infrared thermal imaging of the face was performed before endovascular treatment. Asymmetric temperature patterns were evaluated visually. Quantitative temperature values were obtained from regions of interest (ROIs) placed symmetrically on the left and right half of on the facial thermal image. Presence and side of vessel occlusion was correlated with temperature measurements. Regional facial asymmetric temperature was readily visible at 0.5°C. Temperature differences ranged from 0.5 to 1.5° C in stroke patients, and <0.5°C in controls.

The aim of our research is developing methods for processing and automated analysis of thermal infared images in order to create technology for non-contact monitoring of hemodynamic activity during acute stroke. We develop a software-driven to simulate for dynamics of facial surface temperature distribution with transient ischemic attacks. The implemented model provides sequential processing at each frame of input video recordings using the following operations:

- face detection on initial frame;
- face tracking on sequent frames;
- face boundary tracing and spatial orientation detection on each frame;
- feature keypoints extraction from ROIs on each frame;
- extension for pattern of temperature dysregulation on each frame from random timestamp.

Thermal infrared recordings were recorded with an FLIR ONE Pro mobile camera (Gen 3). Combining a visible higher-resolution imaging thermal sensor able to measure temperatures up to 400°C and detect multiple temperatures of ROIs at once and stream to smartwatch for remote viewing. Both cameras were connected via USB Type-C to the Android smartphone to capture recordings. Further RGB video processing were performed with Matlab R2017a (MathWorks Inc, Natick, USA) with a frame rate of 20 Hz and a resolution of 160×240 pixels. Data processing was done offline after the recording sessions.



a) b)

Figure 1. Main steps of thermal image processing: a) face area detection b) facial keypoints identification and ROI selection.

Quantitative analysis for thermal asymmetric patterns requires accurate and robust image processing algorithm with face detection and defining region of interest (ROI) at facial surface. Mekyska proposed a simple face detection algorithm for thermal infrared images with bimodal intensity distribution [7]. Following the proposed algorithm, thermal frame is converted to grayscale format, binarized and segmented by Otsu algorithm. In the next step extreme points for profile curves, extracted from vertical and horizontal projections histogram of binarizied image, are detected to find the coordinates of the rectangle, which contain human face. The main limitation of this method is that it cannot detect the face when a person stands in different poses and at different distances from infrared sensors. To solve this problem, we propose modified face detection algorithm, which additionally performs a search for local extrema from smoothed profile curves, corresponding to the adjacent area between head and shoulders. This approach can significantly improve realibility for face detection algorithm and noise resistance with thermal sensor.

The modified face detection algorithm was applied to the initial frame from input thermal video. In a real-time approach we realize proposed a face tracker using as Kanade-Lucas-Tomasi algorithm with low computational complexity [8]. For facial boundaries detection we implement Moore-Neighbor tracing algorithm modified by Jacob's stopping criteria [9]. The geometric position of the face was determined with estimation of detected boundary lines by an ellipsoid shape and calculation for the angle of axes rotation. After determining for face area position, the periorbital regions were located using a 95% threshold of the pixel intensity, as they are the warmest area of the face due to the high vascularization (figure 1). In the case when periorbital region could not be detected, the frame in question was discarded. The nose region is found at much lower temperatures, especially for girls and women. In addition, this region may have different time characteristics than the rest of the face. For example cold nose can heat after coming into a warm room slower than the rest of the face [10]. We used this feature and developed a simple algorithm for nose region detection, which is used the analysis of surface temperature distribution along the vertical axis of the orientation ellipse. The selection of feature keypoints allows to definitely determine the position ROIs on thermal frame.

After ROIs detection, we added temperature asymmetric pattern on the right half of the face on each frame of input record, starting with some random timestamp (figure 2). The performance of implemented model has been evaluated with using NVIE thermal image database [11]. The test results with 5 random recordings show, that developed simulation model works effectively and does not give any artifacts in the conditions of human movement and changes of image background.

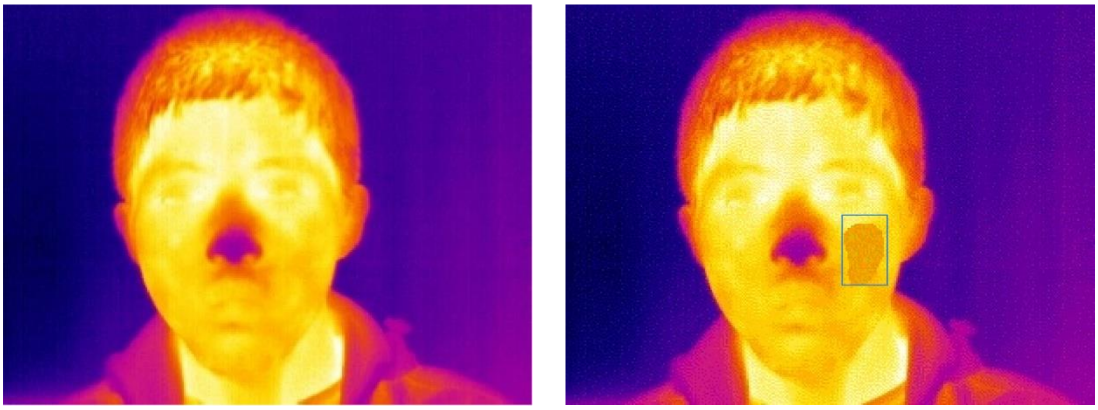


Figure 2. Input and output RGB frame from processed thermal infrared recording.

3. Conclusion

With highly portable mobile infrared cameras thermal imaging during acute stroke triage has become possible. Thermal imaging could serve as a fast point-of-care test to detect asymmetrical pattern in facial temperature as a predictor of proximal vessel occlusion in stroke. The implemented model is designed to simulate for dynamics of facial surface temperature distribution with transient ischemic attacks during acute stroke and can be used to develop algorithms for automated analysis of the temperature dysregulation at the processing of patient thermal infrared recordings.

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