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Scanning laser device for visualization of joint inflammation

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Abstract

This paper describes the design and functioning of a hand scanning system that has been designed for fast, inexpensive and operator independent visualization of inflammation in the hands and wrists of Rheumatoid Arthritis patients by measuring hemodynamic changes associated with inflammation. This is done by measuring the hemodynamic response (blood pooling) in the hands and wrists to an applied stimulus (venous occlusion by a pressure cuff on the lower arm). By comparing the hemodynamic response on a joint with the response on a reference position, it is then possible to visualize the inflammation for the individual joints. Measurements with this system show that the required illumination stability during a measurement can be achieved. The system has recently received CE marking. Currently clinical trials using this hand scanning system are being carried out.

Rheumatiod Arthritis, joint inflammation, laser scanning

1. Introduction

Rheumatoid Arthritis (RA) is an inflammatory joint disease, which, if left untreated, can result in irreversible joint damage and disability. Patient outcome can be significantly improved with a treatment based on novel medication (biologicals) in combination with "tight-control" which requires frequent patient monitoring. Implementation of "tight-control" can be difficult in clinical practice due to work-load and work-flow issues.

Recently a new patented method for visualisation of joint inflammation (Optical Spectral Transmission imaging, or OST imaging) caused by RA was introduced [1, 2]. Based on this method a novel hand scanning system has been designed. This hand scanning system supports the rheumatologist in objectively assessing the RA disease activity in a fast, non-invasive, inexpensive and operator independent way.

2. Measurement method

2.1. Venous occlusion

Before the start of a measurement with the hand scanning system, the patient places his or her hands on a glass plate. The system contains two pressure cuffs which are positioned around the lower arms of a patient. The measurement starts with the recording of the transmission without pressurizing the pressure cuffs for ten seconds, providing reference gray scale values. After ten seconds, the pressure cuffs are pressurized to about 8.0 kPa (60 mmHg) above ambient pressure, which causes a venous occlusion and results in blood pooling in the hands. This occlusion is applied for sixty seconds, after which the cuffs are depressurised and the blood pooling diminishes. Thirty seconds after the cuffs have been depressurized, the measurement stops.

Inflammation of tissue causes vascular changes including vasodilation (widening), increased extravasation (leakage) and angiogenesis (generation) of blood vessels. These vascular changes also ensure that the amount and speed of blood pooling during a measurement will be different for healthy and inflamed joints.

2.2. Optical recording

With the OST imaging method, the blood distribution in the hand, during and after the occlusion, is monitored by tracking the light transmission through the hand. During a measurement the patient hands are illuminated from the bottom with near-monochromatic light sources at two different wavelengths (650 nm and 808 nm). At the top, a camera system records the light that is transmitted through the hands with a frame rate of 4 Hz (2 frames per second for each illumination wavelength). This results in a 3D data cube (figure 1), containing the transmitted light for each position on the hand in time (transmission curves).

By comparing the transmission curve at a position on a joint with a curve at a nearby position not on a joint (and thus free of inflammation) using a model, an estimation of the blood pooling behaviour of the joint can be given. This in turn is an indication of the amount of inflammation of that specific joint.

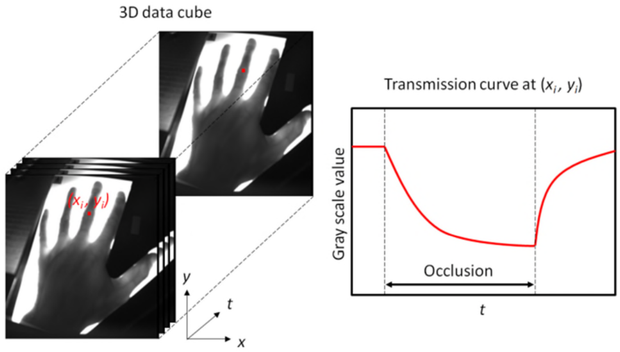

Figure 1. 3D data cube and transmission curve.

3. System design

3.1. Ergonomic design

In the design of the hand scanning system, the patient comfort level was strongly taken into account. During use, the patient is seated in front of the system and inserts his or her hands through a cylindrical opening that holds the pressure cuff and places his or her hands on a glass hand rest. When the operator has verified correct hand placement and the patient is in a comfortable position, a measurement is started. The patient needs to keep their hands stationary and remain in this position for about two minutes, under supervision of an operator. After this period, the measurement can be stored and evaluated or post processed by a rheumatologist at any time. This work-flow ensures flexibility and time efficiency for the patient and rheumatologist (as the rheumatologist does not need to be present during a measurement).

The system has been designed to facilitate patients varying in length from P05 (adult population South East Europe) to P95 (adult population the Netherlands, 30 to 60 years) [3, 4, 5].

3.2. Optical design

The hand scanning system uses laser light to illuminate the bottom of the patient hands. The illumination light is projected using a laser scanner, consisting of three high precision rotating mirrors, four high power laser diodes and beam delivery optics. Figure 2 gives an overview of the optical path of the laser scanning system.

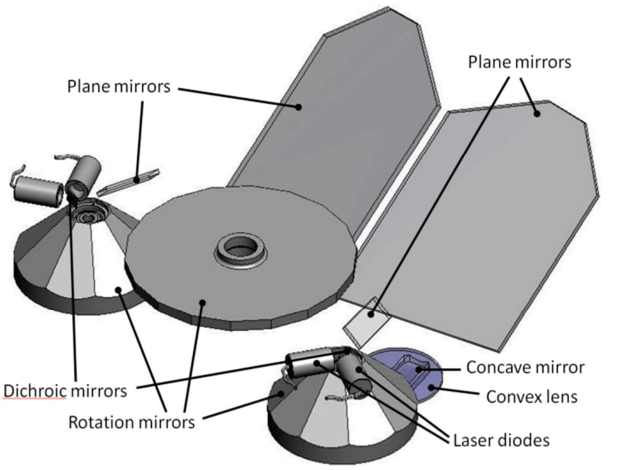

Figure 2. Schematic overview of the optical path of the laser scanning system

The transmitted light is recorded using two CMOS cameras, one for each hand. The two cameras record transmission images of the hands with a frame rate of 4 Hz and an exposure time of 250 ms. By accurately synchronising the motion of the rotation mirrors up to several microseconds with the switching of the lasers, a fixed illumination pattern can be projected underneath the patients hands, which will be identical for each recorded camera frame. This pattern ensures that the laser light is only projected underneath the hand and fingers and not at a glass plate position that is not covered (as this will cause a strong disturbance signal).

In the hand scanning system the synchronisation was realized by using a Field Programmable Gated Array (FPGA), connected to the encoders of the rotation mirrors and to the driving electronics of the high power laser diodes. In this way small angular velocity variations can be compensated for.

The rotation mirrors have been custom designed for the hand scan system. They have an optimized reflectance for the two illumination wavelengths and are produced using diamond fly cutting production techniques.

4. Signal stability

The gray scale variations due to the blood pooling are relatively small compared to the background signal (about 10 % change). This means that the variations in illumination level within the laser scanner need to be as small as possible. To evaluate these variations, signal stability measurements were performed. During these measurements, a ten millimetre thick white polyoxymethylene plate was placed on top of the glass plate. This plate functions as a dummy hand. Underneath the plate, a hand illumination pattern is projected similar as present during a normal patient measurement.

As the transmission of the plastic plate is constant over time, any variations that can be monitored with the camera system are caused by variations in the laser scanner illumination intensity, by external optical disturbances or noise associated with the camera. The variations are considered small enough if the Full Width Half Maximum (FWHM) value of a pixel gray scale value distribution around its average value $\hat{G}$ is smaller than 5.0 % (assuming a Gaussian distribution). For a Gaussian distribution the following equation holds: FWHM $\approx 2.3548 \cdot \sigma_G$, where σ_G is the standard deviation of the gray scale value. Therefore, this requirement translates to $\sigma_G \leq 2.1 \times 10^{-2}\,\hat{G}$.

Table 1 shows the recorded values of σ_G and $\hat{G}$ for 5 different pixels (left hand region on the glass plate) during such a measurement for both 650 nm and 808 nm. This shows that for both illumination wavelengths the variations are well below the specified maximum value. The values in the right two columns are comparable. This shows that the system and measurement noise is sufficiently low.

Table 1. Recorded σ_G and $\hat{G}$ values for the left hand during a signal stability measurement of the hand scanning system.

Pixel number	Illumination wavelength [nm]	σ_G	$2.1 \times 10^{-2}\,\hat{G}$
1	650	0.30	0.61
2	650	0.27	0.42
3	650	0.20	0.30
4	650	0.18	0.25
5	650	0.37	0.50
1	808	0.19	0.96
2	808	0.16	0.65
3	808	0.12	0.30
4	808	0.13	0.27
5	808	0.19	0.82

5. Outlook

Currently clinical trials using this hand scanning system are being carried out, in which hand scan measurements are compared to ultrasound and MRI data. The hand scanning system has recently received CE marking enabling further development of the system towards clinical practice.

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