time-gated intensified ccd camera,
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TIME-GATED INTENSIFIED CCD CAMERA FOR IMAGING OF AN OPTICALLY TURBID MEDIUM – PRELIMINARY EXPERIMENTS

The aim of this paper was to present preliminary experiments of applying intensified ccd camera for measuring temporal and spatial distribution of diffusely reflected photons from highly scattering medium. We illuminated the phantom with picosecond diode laser and observed changing distributions of intensities. We discriminated the photons with respect to their pathlength. The purpose of such study was to develop brain oxygenation imaging system based on time-gated iccd.

INTRODUCTION

For the last years the optical techniques based on near infrared spectroscopy were rapidly developed in medical diagnostics, especially in brain studies [1]. Such techniques are non invasive and potentially could be applied at the bedside. Providing large number of emission and detection points located on the surface of the head allows to image changes of brain oxygenation and/or perfusion leading to positioning of ischemic areas. Several constructions of the optical systems allowing to image changes of brain oxygenation were proposed. Continuous wave [2-6], frequency-domain [7, 8] and time-domain [9-13] systems were reported.

Recently, time-gated imaging with application of intensified CCD was proposed for positioning of absorbing and scattering inclusions [14] as well as fluorescent objects [15] in a turbid medium. Such imaging technique could potentially increase spatial resolution of the optical methods by combination of information on spatial and temporal distribution of photons remitted from an object of interest.

In the present paper we report on a preliminary experiment in which temporal and spatial distribution of photons reemitted from a highly scattering turbid medium, simulating human tissue was imaged. This experiment is a first step in development of a brain oxygenation imaging system based on the time-gated ICCD.

METHODS

In the experiment we observed time-resolved spatial distribution of diffuse reflectance from a highly scattering medium. The medium simulating human tissue consisted of milk and water solution. Near-infrared picosecond diode laser BHL-600 (Becker&Hickl, Germany) at wavelength of 780nm and repetition frequency of 50 MHz was applied. The pulse width was about 100 ps. To

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acquire pictures at different times in respect to the laser pulse we used time-gated intensified CCD camera Picostar HR (Lavision, Germany). The instrument consists of CCD camera and image intensifier. The image intensifier is a vacuum tube which acts as an electronic shutter device with an extremely variable exposure time. The image intensifier can be gated for fractions of a nanosecond. The image intensifier consists of three parts: photocathode, micro channel plate (MCP) and phosphor screen. The object of interest is imaged by objective on the photocathode. Photocathode converts photons into electrons, which are accelerated by an electric field into the MCP. Inside the MCP the electrons are multiplicated by collisions with channel walls. Number of collisions depends on MCP voltage. Finally, the electron cloud from MCP is accelerated by a high voltage to the phosphor screen, which converts electrons back to photons. The fast gating is provided by switching the electric field between the photocathode and the micro channel plate. In our experiment the time-gate was 300 ps. The surface of the phosphor screen is imaged on the CCD camera using optical setup. The CCD is open for a certain collection time in order to collect photons appearing on the phosphor screen and the image is read out at the end of CCD exposure. Such combination of image intensifier and CCD allows to reach very high sensitivity and detection of single photons is possible. Application of high frequency electrical signals between photocathode and MCP allows to provide time-gating in range of fraction of a nanosecond.

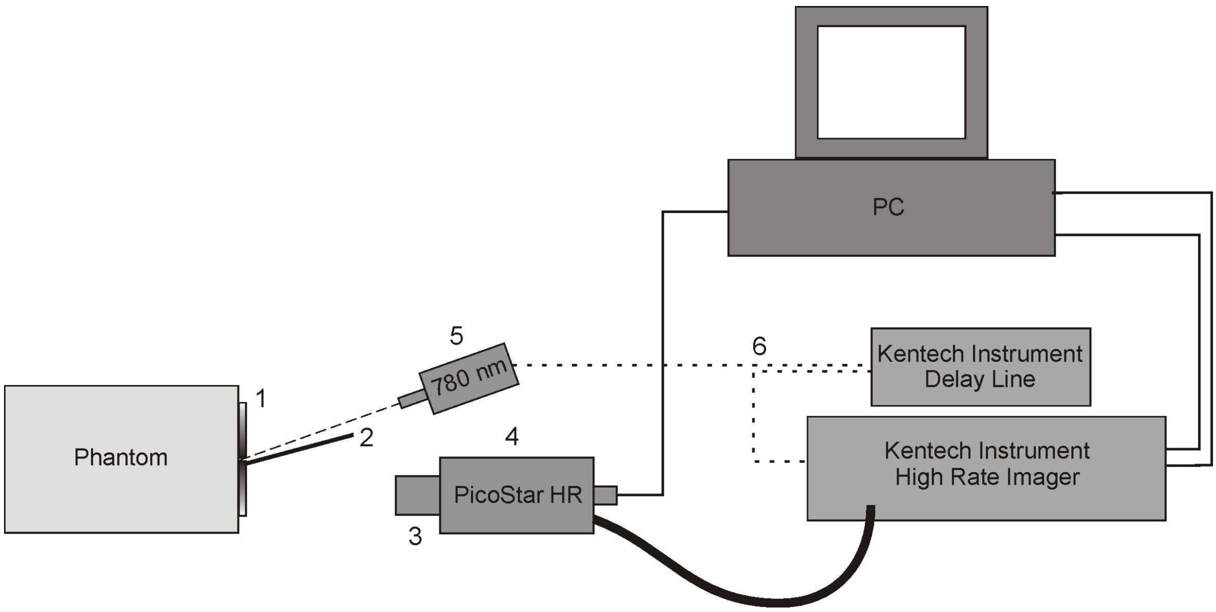

Fig. 1. Setup for measuring time-resolved spatial distribution of diffuse reflectance (1. amplitude filter, 2. black screen, 3. Nikon standard 50mm objective, 4. ICCD camera, 5. Becker&Hickl near -infrared picosecond diode laser, 6. trigger line).

In our experiment diode laser pulses penetrated the phantom which was solution of water and milk (7:1) placed in a glass aquarium. A train of light pulses illuminated the phantom and the camera grabbed the image collected on the phosphor screen. CCD data collection time was 640 ms. The data from the camera was acquired with the use of a PC class computer (Pentium IV, 3.30 GHz) and DaVis software v.7.0 provided by the ICCD manufacturer (LaVision. Germany). The 12bit images of 640×480 pixel resolution were recorded. The time between the laser pulse and opening of the camera was changed using delay line (Kentech Instruments, UK). The change of delay time was controlled with a RS232 communication line and took about 350ms. Such procedure

allows to distinguish photons arriving on the surface of the phantom at different times in respect to the laser pulse. On the surface of the phantom an amplitude filter was fixed in order to compensate for the distance dependence of intensity of reemitted light. The transmittance of the filter increased with the radius. Laser light illuminated the surface of the phantom through a hole in the center of the filter. The black screen was located approximately 1cm apart from the light source (as shown in fig.1.) in order to avoid damage of the camera which could result from direct acquisition of high intensity light reflected in the spot of illumination by the ICCD.
During experiment we measured also response of our setup and we determined the time position of the laser pulses t_0. The delay times between the successive images was designated against t_0.

RESULTS

We measured spatial distribution of diffusely reflected light after passage through the highly scattering phantom. Time-resolved experiment allowed us to distinguish photons with respect to their pathlength. In Fig. 2 images of spatial distributions of photons were presented for different delay times *t* against laser pulse (from 50 ps to 550 ps with steps of 100 ps). The area of 3 cm by 6 cm was imaged. Analyzing short time delays, increase of intensity together with increase of spatial distribution area of the diffusely reflected light can be observed. For long time delays increase of the area can be also observed, but the intensity decreases.

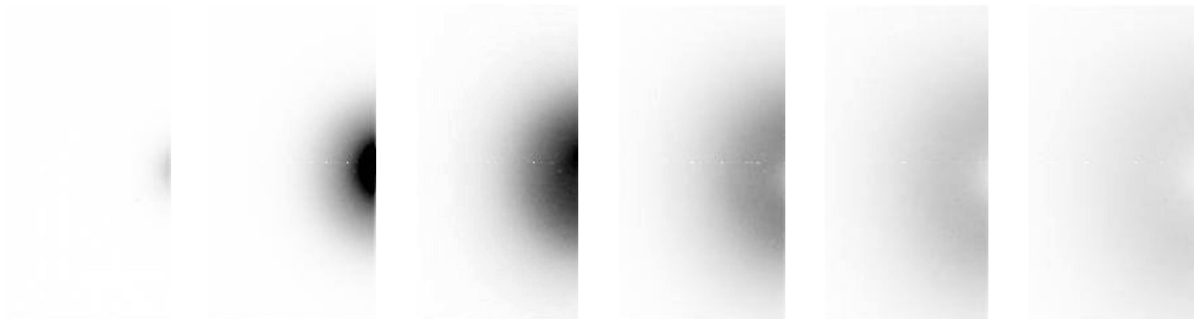

Fig. 2. Time-gated images from ICCD obtained for a turbid medium in reflectance geometry for various delay time t

DISCUSSION

The presented experiment showed that the observation of spatially and temporally-resolved diffuse reflectance from a highly scattering turbid medium is feasible. According to diffusion theory, late photons propagate in average with longer pathlength, thereby they appear on the surface of the phantom at larger distance from the source. At large distance from the source, the number of reemitted photons decreases which makes observation difficult. These effects can be observed in successive images in Fig. 2. It can be expected that non homogeneities included in the medium can be detected and positioned by analyzing temporal and spatial distributions of diffusely reflected photons. Such studies will be carried in order to verify methodology allowing to construct a time-resolved brain imager based on the ICCD.

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