Evaluation of reconstruction algorithm efficiency by using image quality parameters

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Introduction

Optical mammography has gained a growing interest as a complementary or alternative diagnostic tool to traditional X-ray mammography for the capability of infrared (IR) radiation to distinguish between different tissues depending on their optical properties. Among the different proposed methods for studying the emerging light from the investigated sample, time-resolved techniques have already been largely adopted. They consist of irradiating the sample with an ultrashort laser pulse and analysing the temporal behaviour of the transmitted signal in order to reconstruct the image of the target. It's now well known that imaging procedures play a fundamental role in the performances of optical imaging systems. In fact, through an appropriate use of such procedures, it is possible to improve the image quality in a significant way. To this aim, many reconstruction algorithms have been proposed by different researchers, but a systematic investigation on the algorithm's efficiency, based on fundamental image parameters: spatial resolution, contrast and signal-to-noise ratio (SNR), could still be useful. For this reason, we investigated some of the most common reconstruction algorithms used in time-resolved laser transillumination imaging, using a well-controlled solution as the scattering sample with optical properties similar to those of biological tissue. A black mask was inserted in order to experimentally measure all the image quality parameters.

Theoretical background

Reconstruction algorithms

The images of biological tissues obtained using near infrared radiation dramatically depends on the amount of scattered light. Time-resolved techniques are among the most obvious candidates for facing this problem. An ultrashort laser pulse (few ps or hundreds of fs) is delivered on the sample and the transmitted photons are sent to an ultra fast detector able to give their temporal dependence. The early coming photons undergo few scattering events and then give the best contribution to image reconstruction. For this reason, particular attention to the first coming photons is usually paid in time-resolved image reconstruction even though a compromise could be made in considering very short integration times due to the rarity of these little scattered photons. Hence, to enhance the imaging performances of time-resolved laser transillumination systems many approaches have been proposed;[1] for example, the use of mean time-of-flight, modulus and phase of the Fourier transform, optical properties and so on. Using some of these physical quantities, we developed a software program package that starts from temporal profiles, which are given by a streak camera (see Figure 1) for each position of bidimensional scanning of samples to be imaged and, subsequently, elaborates each temporal pro-

Near Infrared Spectroscopy: Proceedings of the 9th International Conference

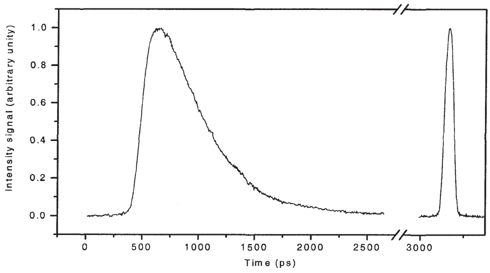

Figure 1. Typical dispersion curve. The narrow pulse on the right hand side represents the response of the experimental set-up without phantom.

file using different algorithms: i.e. integration around maximum of intensity with different integration times, integration with different temporal gate starting from an intial time that can be freely chosen by the user, mean time-of-flight calculations, rising and falling time evaluations, analytical fitting procedure for determing optical coefficients to be used for imaging and for temporal extrapolation to initial times. By using this program, one of the above-mentioned elaboration algorithms can be selected and a matrix value ready for TRANSFORM Software 2D (Fortner Research LLC, 1996) is obtained. All the images can be represented using the same linear grey scale (256 different tones) to facilitate the comparison. It is useful to note that in the same program it is possible to reduce acquisition time using computer-simulated streak camera background signal curves. In fact, when time-resolved data are acquired by a streak camera, some time has to be devoted to background signal acquisition. Usually, to avoid wasting too much time, the background acquisition is not done for every point in the sample scanning, but only from time to time. If something changes in the experimental conditions, this procedure in acquiring data can worsen the quality of the image that can be obtained. Hence, the background subtraction by software could help to reduce the acquisition time and to control the background subtraction procedure better (further work is still in progress). In this paper, due to the kind of measurements to be analysed, we concentrated our attention on using different integration times, i) starting from an initial one on the rising part of the temporal dispersion curve and ii) around the maximum of the above mentioned curve in which the best signal-to-noise ratio is obtained.

Image quality parameters

It is well known that the intrinsic quality of an image is strictly related to the concepts of spatial resolution, noise and contrast. Many of these concepts come from X-ray radiography and so they are strictly only suitable for linear and shift-invariant image systems. They are not completely suitable for time-resolved laser transillumination systems, which are surely not linear or shift-invariant, due to the diffused nature of transmitted light. In any case, these parameters are the only ones allowing a quantitative approach to image quality problems. As stated previously, an important parameter to evaluate the image quality is the spatial resolution that gives the minimum dimension for an object that can be detected when it is inserted into a diffusing media. Different experimental methods are available in order to measure it: the point spread, the linear spread and the edge response function (ERF).[2] As far as time-resolved laser transillumination image systems are concerned, the ERF seems to be the most suitable. With this method the spatial resolution Δx is given by the FWHM of LSF obtained as the derivative of the ERF, which is fitted with a Gaussian curve. Contrast can be defined as the ratio between the difference in signal between the background of the image (T1) and the structure (T2) one is looking for, and the background itself; C = (T1–T2)/T1. A commonly used parameter to characterise the signal level relative to the noise level is the signal-to-noise ratio (SNR). For laser transillumination image systems the SNR has been defined as the ratio of the average normalised transmittance to the standard deviation of the average normalised transmittance: $SNR = T_m / \sigma(T_m)$. The above-mentioned program is able to evaluate all these image quality parameters for each kind of algorithm. For the Δx evaluation, a numerical integration for Gaussian function has been used differently from usual procedures, employing analytical approximation by inverse polynomials. The numerical integration is particularly useful because it gives much more precision and reduces the calculation time

Experimental techniques and methods

The experimental set up was mainly composed by a Ti:Sa laser working in a femtosecond regime at 800 nm with a repetition rate of 76 MHz pumped by an argon laser. The detector was a streak camera with a temporal resolution of a few picoseconds in synchroscan mode. For further details see Reference 3. In the present work, we report on an investigated sample consisting of a 2% solution of commercial Intralipid, 10% with distilled water with a reduced scattering coefficient equal to 1.92 cm^{-1} and optical absorption coefficient equal to . 010 cm^{-1}. For the detrmination of these values see Reference 3. The solution was set in an optical glass cuvette (50 × 143 × 96.5 mm) that was oriented so that the illuminated surface was perpendicular to the beam. A stepping motor system, performing the *x–y* translational movements (with 1 mm steps) and a GPIB interface, is able to drive the whole system by computer, sending light to the sample and collecting properly designed optical fibre bundles.

The spatial resolution has been evaluated by ERF measurements carried out by imaging the edge of a black mask (thickness: 1 mm) placed in the middle of scattering cell. The cell dimensions were sufficient to avoid appreciable boundary effects. Then, also the contrast and the SNR were evaluated as previously described.

Results and discussion

In this section we will compare the results obtained for spatial resolution, contrast and SNR using the two above-mentioned algorithms. In Figure 2 the spatial resolution, which is evaluated using different integration times, starting from different initial points in the rising part of the temporal dispersion curve (see Figure 1), is reported. A similar trend is also obtained for the other algorithm. The values of spatial resolution, normalised with respect to the sample thickness are around 0.1–0,.3 has been obtained for both the algorithms even though the former seems to be better. As far as contrast is concerned (see Fig-

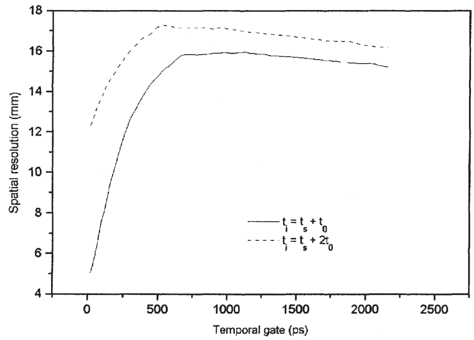

Figure 2. Spatial resolution v. different integration times (t_s = starting time, t_0 = time of flight.

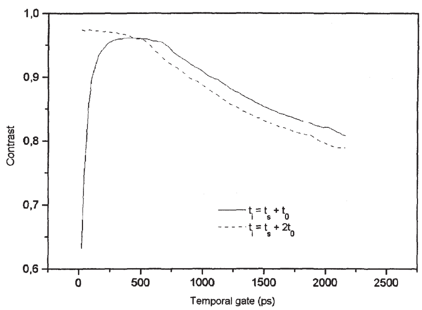

Figure 3. Contrast v. different integration times (t_s = starting time, t_0 = time of flight

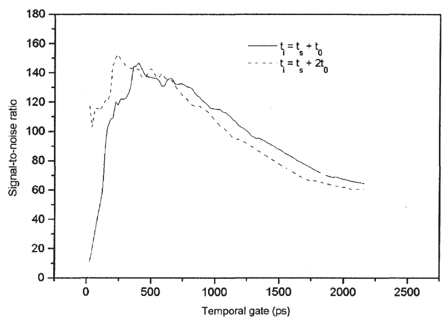

Figure 3. Contrast v. different integration times (t_s = starting time, t_0 = time of flight

ure 3), the best results are obtained for short integration times, as is obvious, but the results concerning SNR (see Figure 4) indicated that a good compromise in choosing integration time has to be done if the best spatial resolution with a good contrast and SNR is to be obtained. Our results are comparable with those already reported in literature[1] and also for the second algorithm (the one working around the maximum) which is the simplest and fastest. Therefore, it deserves more attention as it also shows different behaviour of integration on the right side and the left side of the maximum. The difference in the rising and falling edge of the temporal dispersion curve has already been observed when similar data are used for determing optical properties of thick scattering samples.

Conclusions

An overall analysis of main image quality parameters seems to be a good procedure to evaluate, in an objective way, the efficiency of different recostruction algorithms. In addition, the present set of measurements, together with many other similar ones, has allowed us to completely test our time-resolved laser transillumination imaging system and the different software procedures, which, until now have been developed in our laboratory.

Acknowledgements

Thanks are due to Istituto Nazionale per la Fisica della Materia and to European Community for financial support.

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