University of Kent

Optical Coherance Tomography

Akinetic swept laser apparatus and method for fast sweeping of the same

Professor Adrian Podoleanu is the inventor of this technology.
Reference: 051
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Summary: The invention discloses a method and apparatus for producing a narrow line laser emission that can be tuned at frequency rates exceeding 100 kHz. The laser apparatus is capable of fast scanning speeds close to multiples of the cavity resonance frequency. The laser cavity can be either a ring or a line resonator. This comprises dispersive means and a nonlinear medium, whose parameter when modulated induces mode-locking, referred from now on as a mode-locking mechanism block, an optical amplifier used as a gain medium and a splitter that ensures that a certain percentage of the laser emission from the gain medium is tapped outside the cavity. The driving method is accomplished with an electronic mechanism that includes a controller drive sweeping generator and a voltage controlled oscillator that injects a tunable radio frequency signal into the nonlinear mode-locking mechanism block. In particular, a semiconductor amplifier can accomplish both functions of amplification and mode-locking, by driving it with RF signals. Two resonant mechanisms are employed to modulate in frequency the mode-locking mechanism block (usually the optical gain in a semiconductor amplifier) and to achieve high frequency tuning rates. The configuration is compatible with working at sweeping rates close to multiples of the cavity resonance frequency as well as with buffering for increased tuning speeds.

Background: The method mostly accepted today for optical coherence tomography (OCT) is based on sweeping the frequency of a narrow band laser, usually termed as a swept source. Several principles of sweeping the laser emission have been developed. The most common principle employed is that of a spectral filter in a closed loop, where the tunable laser apparatus uses a Fabry-Perot filter, as disclosed in Patent Document 1 (US 2003/6538748 B1), a polygon filter, as disclosed in Patent Document 2 (US 2009/7489713 B2), or a micro electrical mechanical scanning (MEMS) filter, as disclosed in Patent Document 3 (US 2012/8275008 B2). Commercial vendors exist, such as Axsun and Santec, companies using MEMS filters. Such filters limit the tuning to several hundreds of kHz. In Non-Patent Document 1 (R. H. Huber et al, "Fourier domain mode-locking (FDML): A new laser operating regime and applications for optical coherence tomography", Optics Express 14(8), 3225-3237 (2006)), a large tuning frequency has been reported using Fabry-Perot filters and principles of Fourier domain mode-locking (FDML) that allowed sweeping rates exceeding several MHz. However, the reliability of Fabry-Perot and the complexity of buffering limit the applicability of such principles. The filters mentioned above are based on mechanical movement of parts which limits their reliability. Therefore, there is an interest in akinetic laser sources that achieve tuning with no mechanical movement of parts. On the other hand, in modern applications of OCT there is an increasing demand in three dimensional imaging at high speed, with increased axial range.

Technology: In the present invention, the RF tuning is practised over many such bands. More specifically, two resonant modulation effects are applied. A first modulation that induces mode-locking is imposed by driving the optical gain medium at a high radio frequency value. A second modulation is applied, inspired from the practice of Fourier domain mode-locking applied to Fabry-Perot lasers, where sweeping is performed at a rate close to the inverse roundtrip of the wave in the cavity. In opposition to the prior art where the sweeping has to be performed at the exact inverse of the roundtrip, the method disclosed here essentially uses a detuning of the excitation from the inverse of the roundtrip.

Apparatus and method for processing the signal in master slave interferometry and apparatus and method for master slave optical coherence tomography with any number of sampled depths

Professor Adrian Podoleanu is the inventor of this technology.
Reference: 059
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Summary: The invention related to an apparatus and method for master slave interferometry, referred to as Complex Master Slave (CMS). The method and apparatus can be used to provide complex-valued measurements of a signal reflected from an axial position inside an object or of signals reflected from points at several axial positions inside an object.

Background: Spectrometer based (Sp) and Swept source (SS) based interferometry and Sp-OCT and SS-OCT are technologies based on analysing the spectrum of the interference signal produced between optical signal from an object under investigation and a local optical reference signal. OCT can produce in real time a cross section image of the object, i.e. a two dimensional (2D) image in the space (lateral coordinate, axial coordinate). The two configurations for Sp-OCT and SS-OCT are described in the article "Optical coherence tomography", by A. Podoleanu, published in Journal of Microscopy, 2012 doi: 10.1111/j.1365-2818.2012.03619.x.

Technology: The invention provides embodiments and methods, that can be used to provide complex-valued measurements of a signal reflected from an axial position inside an object or of signals reflected from points at several axial positions inside an object. We therefore refer to the novel method disclosed here as Complex Master Slave (CMS). Embodiments are disclosed where axial complex-valued profiles are created with no need for data resampling. In the signal processing, procedures are employed that avoid performing a Fourier transform of the spectrum. A method is disclosed that can be used to measure reflectance and phase profiles in depth, that can be subsequently used for medical analysis, flow and polarization characterisation or in sensing applications. Embodiments of apparatuses and methods are disclosed where the number of depths simultaneously sampled is independent on the number of measurements initially performed on a model object, by creating a function that can generate any reference signals for the CMS method as desired by the user. Embodiments and methods are disclosed that can generate reference signals from a minimal number of experimentally collected channelled spectra at the interferometer output, or none. The embodiments and methods disclosed allow producing any number of en-face optical coherence tomography (OCT) images from as many depths as desired and axial complex-valued A-scan profiles with any density of depths. Embodiments and methods disclosed allow elimination of random phase cumulated from the moment spectra were acquired from the model object, until measurements are done on the object under study. Embodiments and methods are disclosed where the depth dependent dispersion introduced by the object is eliminated.

Camera adapters for portable imaging systems

Professor Adrian Podoleanu is the inventor of this technology.
Reference: 002-AGHP
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Summary: The present technology concerns adapters that enable commercially available digital cameras to perform both Confocal imaging as well as Optical Coherences Tomography imaging to be utilised, for instance, in vision testing or art conservation.

Background: A variety of instruments which produce depth resolved information and imaging of the eye, tissue or industrial objects are known. They involve Confocal Microscopy (CM) and Optical Coherence Tomography (OCT) principles. A general problem with all these configurations is their large volume and high cost. This restricts their use to a few medical practices and research centers. Therefore, a need exists for more compact high depth resolution measurement and imaging systems, portable and of much lower cost to allow the CM and OCT technology to be used in various applications such as topography, art conservation and vision testing.

Technology: The present technology concerns specific adapters which can make use of the devices in any commercially available digital camera to accomplish different functions, such as a fundus camera, as a microscope or as an *en-face* OCT to produce constant depth OCT images or as a Fourier domain (channelled spectrum) OCT to produce a reflectivity profile in the depth of an object or cross section OCT images, or depth resolved volumes. This invention allows for addition of confocal detection and provides simultaneous measurements or imaging in at least two channels, confocal and OCT, where the confocal channel provides an *en-face* image simultaneous with the acquisition of OCT cross sections, to guide the acquisition as well as to be used subsequently in the visualisation of OCT images. Different technical solutions are available for the assembly of one or two digital cameras, which together with such adapters, lead to modular and portable high resolution imaging systems, which can accomplish various functions with a minimum of extra components while adapting the elements in the digital camera. Of particular importance is the fact that the cost of such adapters is comparable with that of commercial digital cameras. The present technology can also be applied to colour cameras and their associated optical sources to deliver simultaneous signals using their colour sensor parts to provide spectroscopic information, phase shifting interferometry in one step, depth range extension, polarisation, angular measurements and spectroscopic Fourier domain (channelled spectrum) OCT in as many spectral bands simultaneously as the number of colour parts of the photodetector sensor in the digital camera. In conjunction with simultaneous acquisition of a confocal image, at least four channels can simultaneously be provided using the three colour parts of conventional color cameras to deliver three OCT images in addition to the confocal image. This technology is applicable to measurements and imaging of specimens which are sufficiently transparent for visible or infrared light (e.g. eye, skin heart, vessels, dental tissue, dental prostheses, paintings, powders and other scattering semi-transparent objects), as well as for profilometry of any object which reflects visible or infrared light. The dual imaging aspect of the invention is especially useful for moving objects.

Spectral domain interferometry & spectral domain optical coherence tomography systems

Professor Adrian Podoleanu is the inventor of this technology.
Reference: 039-AP
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Summary: The present technology concerns a device for real time depth measurements in sensing in Spectral Domain Interferometry as well as a device for *en-face* and cross section image production in Optical Coherence Tomography.

Background: Spectral Domain (SD)-interferometry and SD-Optical Coherence Tomography (OCT) are technologies based on analysing the spectrum of the interference signal produced between signal from an object under investigation and a local reference signal. OCT can produce, in real time, a cross section image of an object (e.g. a two-dimensional image with a lateral and axial coordinate).

Technology: The present technology concerns an apparatus which can process, in real-time, depth measurements in sensing in SD-interferometry. For imaging purposes, the technology also concerns an apparatus able to deliver *en-face* and cross section images from a volume of data collected using SD-OCT. This technology involves neither data linearisation nor software cuts of the volume of data collected (costly and time consuming procedures), in order to maximize the output signal. It relates to a new concept of master-slave interferometry where parameters of a master interferometer dictate the result in a slave interferometer and the master interferometer can be the same measuring interferometer used in two stages. The parameters of the master interferometer are at least optical path difference (OPD) or the speed of variation of the OPD in the master interferometer. This novel imaging system produces coherent gated data from selected axial positions which can be from positive as well as negative OPDs, in parallel, thus allowing generation of *en-face* (C-scan) OCT images simultaneously from several paths, free from mirror terms, alongside production of A-scans and B-scan images using a plurality of reflectivity values measured in parallel from different depths within A-scans.

Spectral low coherence interferometry

Professor Adrian Podoleanu is the inventor of this technology.
Reference: 042-AP
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Summary: The present invention concerns a spectral interferometry apparatus which can be used to monitor or measure an unknown length by following a characteristic of an indicating signal.

Background: Low coherence interferometry provides absolute distance measurements and is well suited for measuring absolute or relative distances based on signal returned by rough reflecting surfaces. Spectral low coherence interferometry is based on the measurement of periodicity of the channelled spectrum of the optical signal coming from a two beam interferometer. The largest the optical path difference (OPD) of the interferometer, the denser the spectral modulation of the channelled spectrum. Channelled spectrums allow for the OPD information to be translated into the periodicity of their peaks and troughs and hence, no mechanical means are needed to scan the object of interest in depth when performing optical coherence tomography of tissue (e.g. human organs). In that regard, an in-depth non-invasive imaging for human tissues can be achieved.

Technology: This technology concerns a spectral interferometry apparatus that can be used to monitor or measure an unknown length by following a characteristic of an indicating signal. The measurement is performed by adjusting an optical path difference (OPD) in an interferometer part of an interferometer configuration until sound or light or both are obtained with the desired strength and pitch. Embodiments are presented where the unknown length is the eye length. Spectral interrogation of the interferometer optical output is achieved by reading the signal of an analogue photodetector array in a spectrometer or by tuning a swept source and processing the signal of a photodetector. Sound of different pitches is produced either directly in this process, or by using a nonlinear amplifier, or a mixer. For enhanced signal, the array may be driven by a nonlinear clock or the swept source may be driven by a distorted driving signal. This technology allows measurements of lengths using a minimum of devices which can be conveniently assembled in a small size, low weight, and low cost instrument that can be operated independent of a computational power simply by following a meter indication, a needle, a digital indication, a light or sound signal. This invention can be particularly applied in ophthalmology, regarding measurements of the eye length.

Wavefront sensors

Professor Adrian Podoleanu is the inventor of this technology.
Reference: 035-AP
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Summary: The present technology concerns wavefront sensors of high resolution, able to acquire depth resolved aberration information from essentially transparent objects or tissue using principles of low coherence interferometry and perform coherence gated wavefront sensing.

Background: Different methods of wavefront sensing are known, psycho-physical, involving the human subject and objectives, such as refractive, laser ray tracing (LRT), Shack-Hartmann (SH) wavefront sensors (WFS), and pyramid (P) wavefront sensors. So far, all these methods provide 2D aberration information, whereas there is need for 3D information and enhanced performance with respect to wavefront sensing.

Technology: The present technology concerns wavefront sensors of high resolution, able to acquire depth resolved (3D) aberration information from essentially transparent objects or tissue using principles of low coherence interferometry (LCI) and perform coherence gated wavefront sensing (CG-WFS). The wavefront aberrations are collected using spectral domain LCI (SD-LCI) or time domain LCI (TD-LCI). When using SD-LCI, chromatic abberations can also be evaluated. This invention allows for a wavefront corrector to compensate for the aberration information provided by CG-WFS, in a combined imaging system that can use one or more channels from the class of i) optical coherence tomography (OCT), ii) scanning laser ophthalmology (SLO), iii) microscopy such as confocal or phase microscopy, iv) multiphoton microscopy, such as harmonic generation and multiphoton absorption. For some implementations, the invention also allows for simultaneous and dynamic aberration measurements/correction with the imaging processes. The present sensors can operate under large stray reflections in the optics and thus, lead to simplification of adaptive optics assisted imaging instruments and to the improvement of their performance. In particular, but not exclusively, this technology relates to the imaging of the retina *in vivo*, in which case enhanced quality OCT and SLO images are generated.