近紅外光硬體設備介紹
fNIRS — Instrumentation

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本週課程內容

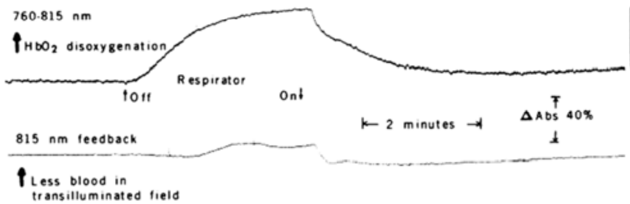
- Design of fNIRS Instrumentation
  - Continuous wave NIRS,
  - Phase-modulated NIRS
  - Time-resolved NIRS,
- **Application of Near Infrared Spectroscopy in Biomedicine.** Thomas Jue, Kazumi Masuda. Springer, 2013.
  - Principles and instrumentation (chap 1)

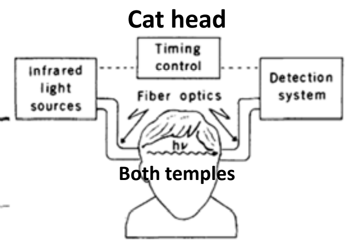
fNIRS硬體設計
Instrumentation Design

SCIENCE, Vol. 198, 1977

Noninvasive, Infrared Monitoring of Cerebral and Myocardial Oxygen Sufficiency and Circulatory Parameters

FRANS F. JÖBSIS *Department of Physiology, Duke University, Durham, North Carolina 27710*





Abstract. *The relatively good transparency of biological materials in the near infrared region of the spectrum permits sufficient photon transmission through organs in situ for the monitoring of cellular events. Observations by infrared transillumina-*

Brain Oxygenation

- Tissue oxygenation by analyzing
  - Transmitted light intensity
  - Reflected light intensity

Cat cranium: 5~6 cm width
Human adults cranium: 13~15 cm width

- Reflection techniques are most commonly nowadays.

Change in absorption

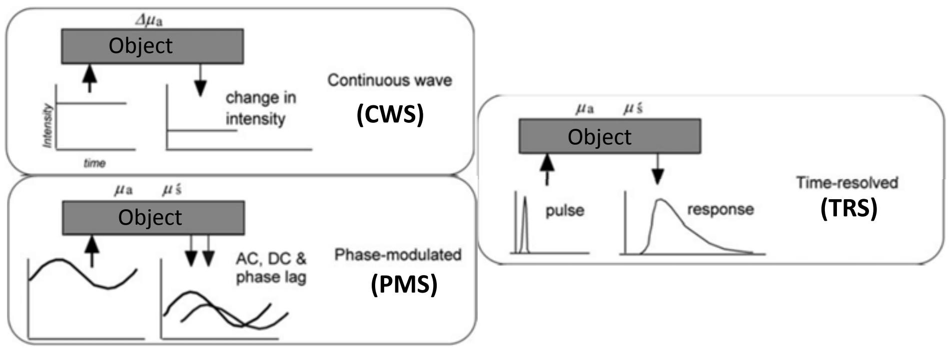
- Assuming that changes in light absorption are meainly due to changes in blood oxygenation or volume.
- $\Delta\mu_a(\lambda) = \varepsilon_{HbO}(\lambda)\Delta c_{HbO} + \varepsilon_{HbR}(\lambda)\Delta c_{HbR}$

μ_a : the absorption coefficient
$\varepsilon_{HbO}(\lambda)$: molar absorption coefficients of HbO at wavelength λ
$\varepsilon_{HbR}(\lambda)$: molar absorption coefficients of HbR at wavelength λ

Change in absorption

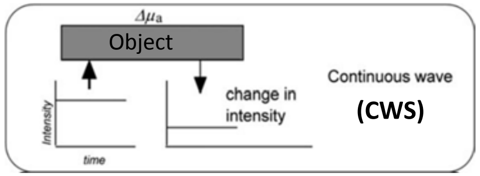
- Two wavelenths are usually chosen to be around the isosbestic point (805 nm) of HbO and HbR
  - 770/830, 760/840, and 690/900 nm
- Larger difference between two wavelenths
  - Larger changes in intensity
  - Optical path length may not be identical !

NIRS Techniques



Continuous-Wave NIRS

- The simplest NIRS technique.
- Only measure the changes in optical density.
- $\Delta OD = ln\left(\frac{I_{rd}}{I_d}\right) = \Delta\mu_a\langle L\rangle$



Assuming that the scattering coefficient does not change during measurement.

Continuous-Wave NIRS

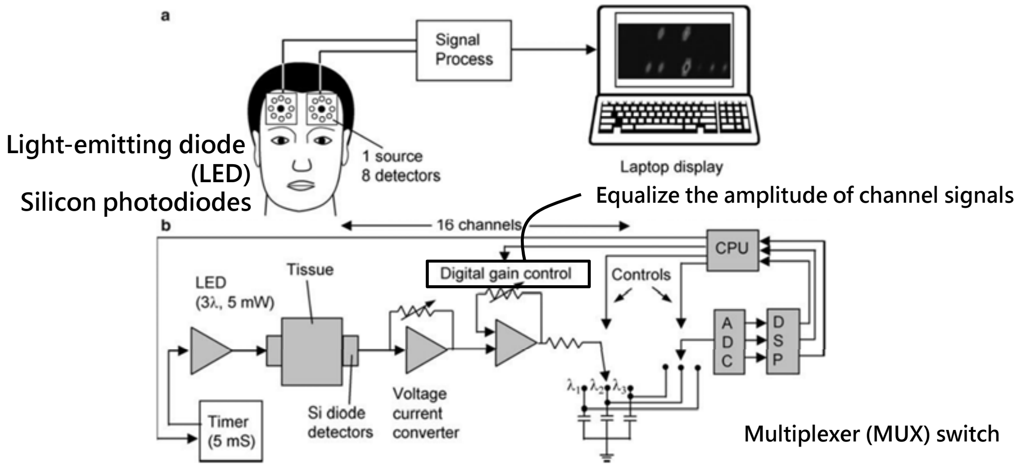
- $\Delta c_{HbO} = \frac{1}{k}\left(\varepsilon_{HbR}(\lambda_2)\Delta\mu_a(\lambda_1) - \varepsilon_{HbR}(\lambda_1)\Delta\mu_a(\lambda_2)\right)$,
- $\Delta c_{HbR} = \frac{-1}{k}\left(\varepsilon_{HbO}(\lambda_2)\Delta\mu_a(\lambda_1) - \varepsilon_{HbO}(\lambda_1)\Delta\mu_a(\lambda_2)\right)$,
- $k = \varepsilon_{HbO}(\lambda_1)\varepsilon_{HbR}(\lambda_2) - \varepsilon_{HbR}(\lambda_1)\varepsilon_{HbO}(\lambda_2)$

- Δc_{HbO} and Δc_{HbR} can be continuously monitored.

Continuous-Wave NIRS

- Advantages
  - Highly sensitive
  - High sampling rate
  - Economical
  - Can be miniaturize

Continuous-Wave NIRS



Chance, B.; Nioka, S.; Zhao, Z., "A wearable brain imager," *Engineering in Medicine and Biology Magazine, IEEE*, vol.26, no.4, pp.30,37, July-Aug. 2007

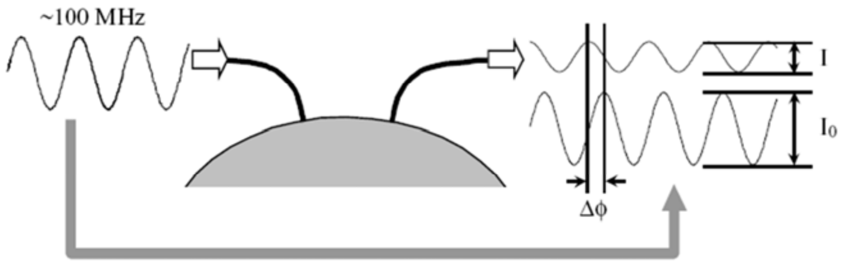
NIRSport, NIRx tech.

NIRSport System Specifications

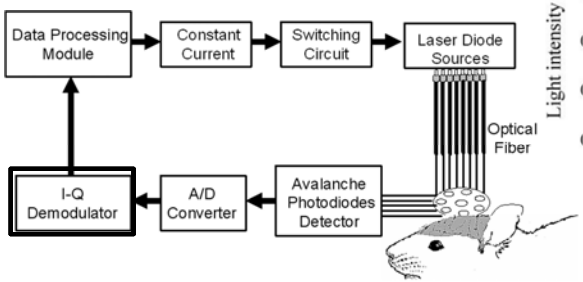
- Dimensions: 105 mm x 170 mm x 40 mm (3.9" x 6.7" x 1.6")
- Weight: 350 g
- Power Consumption: 3 W
- No. of Detector Channels: 8
- Sensitivity: < 1 pW
- Dynamic Range: 60 dBopt
- Sensor Type: Si Photodiode, active sensor
- No. of Illumination Sources: 8(Time-Multiplexed)
- Wavelengths: 760 nm, 850 nm
- Sampling rate: 62.5 Hz
- Emitter Type: LED
- Host Connection: USB 2.0 data + USB 2.0 power

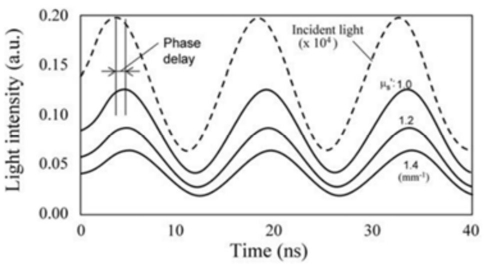
Phase-Modulated NIRS

- Also called frequency domain measurements.
- Light source is at ~MHz frequencies
  - Amplitude difference (attenuation), time delay (propagation time)



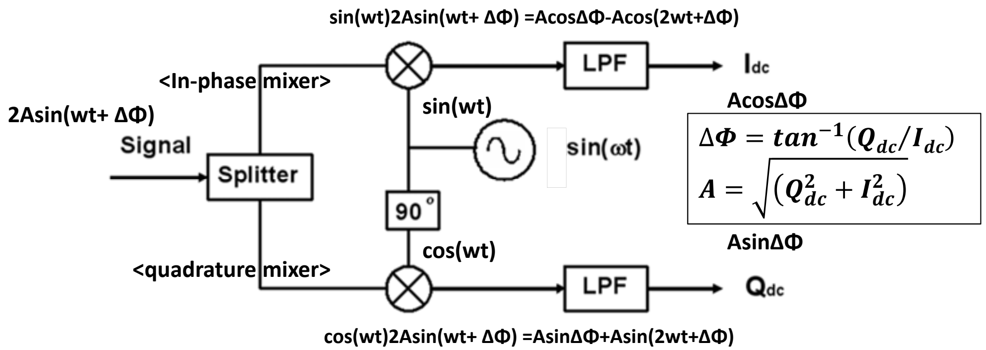
Phase-Modulated NIRS





Phase-Modulated NIRS

- I-Q demodulator



$$\Delta\Phi = tan^{-1}(Q_{dc}/I_{dc})$$

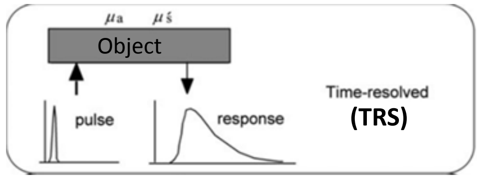
$$A = \sqrt{(Q_{dc}^2 + I_{dc}^2)}$$

ISS Oxiplex (ISS Inc.)

	ISS OxiplexTS	Other Tissue Oximeters
Method of Operation	Uses modulated light beam probing the tissue and frequency-domain technique	Use continuous-wave light beam probing the tissue
Scattering Coefficient	Measured	Assumed
Absorption Coefficient	Measured	Measures changes
Deoxygenated Hemoglobin	Measured	Measures changes
Oxygenated Hemoglobin	Measured	Measures changes
Total Hemoglobin	Measured	Measures changes
Tissue Hemoglobin Oxygen Saturation (SO2)	Measured	Measures changes

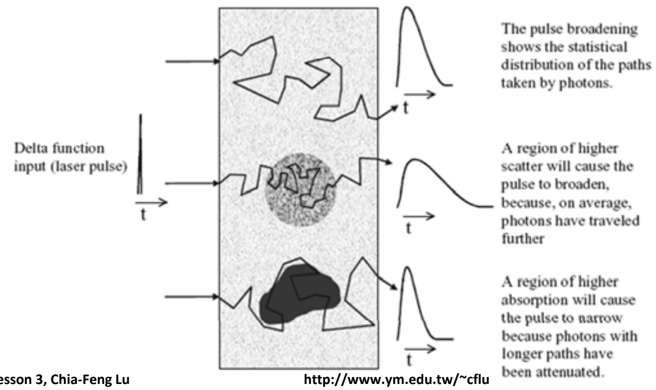
Time-Resolved NIRS

- Measure the temporal changes in the reflected light intensity after irradiation of a picosecond (10^{-12}) pulse.
- Obtain a distribution of the total path length
- Resolve μ_a and μ'_s



Time-Resolved NIRS

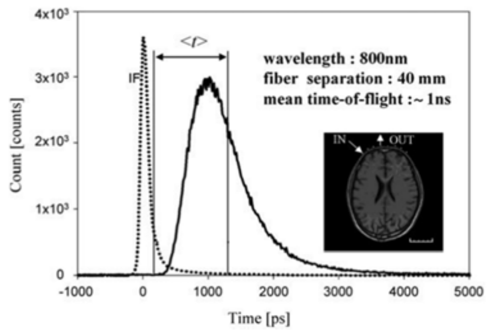
- Temporal point spread function (TPSF)



Hillman's PhD thesis, 2002

Time-Resolved NIRS

- Integrating the temporal profiles
  - Intensity of light
- Modified Beer-Lambert law
  - Absorbance changes
- The center of gravity of the temporal profile
  - Mean optical path length
- Diffusion equation
  - μ_a and μ'_s



Time-Resolved NIRS

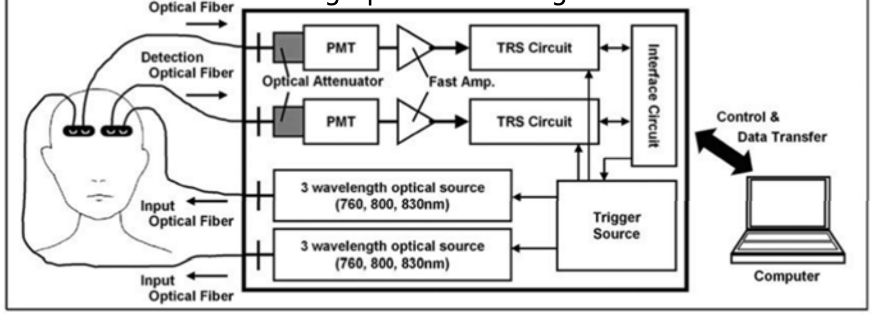
- The reflectance at position ρ and time t
- $R(\rho,t) = (4\pi Dc)^{-3/2} z_0 t^{-5/2} \exp(-\mu_a ct)\, exp\left(\frac{\rho^2+z_0^2}{4Dct}\right)$

  D : diffusion coefficient, $D = 1/[3(\mu_a + \mu'_s)]$
  c : the speed of light in the tissue
  z_0: $\mathbf{1}/\mu'_s$
- Using simple mean least-squares fitting algorithms to determine from μ_a and μ'_s experimental data.

Time-Resolved NIRS

- TRS-20 system

Photomultiplier tube (PMT)
Single photon-counting mode → TPSF



Picosecond light pulser (PLP)

Time-Resolved NIRS

- The integrated intensity of a TPSF

  → a CWS measurement.
- The magnitude of the Fourier transform of a TPSF at the required frequency

  → frequency domain components
- A TPSF represents the tissue's impulse response function (IRF) which is the optimal measurement to characterize a system.

Time-Resolved NIRS

- Disadvantages
  – Very high costs for the PLP
  – Low sampling rate (repeat photon counting)
  – Large Instrument size
  – Need intensively initial calibration

TR systems

TRS-20

MONSTIR

University of London

Technique Comparison

Parameters	CWS	PMS	TRS
$[HbO_2]$, [Hb], [tHb]	Changes	**Absolute value**	**Absolute value**
SO_2	No	**Yes**	**Yes**
Absorption coefficient	No	**Yes**	**Yes**
Scattering coefficient	No	**Yes**	**Yes**
Time-resolved profile	No	No	**Yes**
Mean path length	No	**Yes**	**Yes**
Sampling rate (Hz)	$\leq$**100**	$\leq$10	$\leq$1
Portability	**Wearable**/portable	Portable	Portable
Instrument cost	**Low**/moderate	Moderate	High
Initial stabilization	**Not required**	**Not required**	Required
Light source	LED/laser diode	Laser diode	Laser diode
Detector	Silicon photodiode	Avalanche photodiode	Photomultiplier tube

THE END

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