1. MULTISPECTRAL IMAGING

FOR NON-CONTACT COGNITIVE LOAD ESTIMATION

OUR GOAL

Develop a system that can measure brain function without being in direct contact with the user

CONTRIBUTION

- A quantifiable metric for cognitive load
  - The current standard is the NASA Task Load Index survey
- Brain imaging in an active or fast-paced environment such as crew training
  - Extends to many other applications such as in-surgery tumor detection or burn victim diagnosis

Factor		Response Line	
Mental Demand	Low	|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|	High
Physical Demand	Low	|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|	High
Temporal Demand	Low	|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|	High
Performance	Good	|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|	Poor
Effort	Low	|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|	High

EXISTING TECHNOLOGY

1. Bulky
2. Not versatile for different head sizes
3. Requires physical contact
4. High price

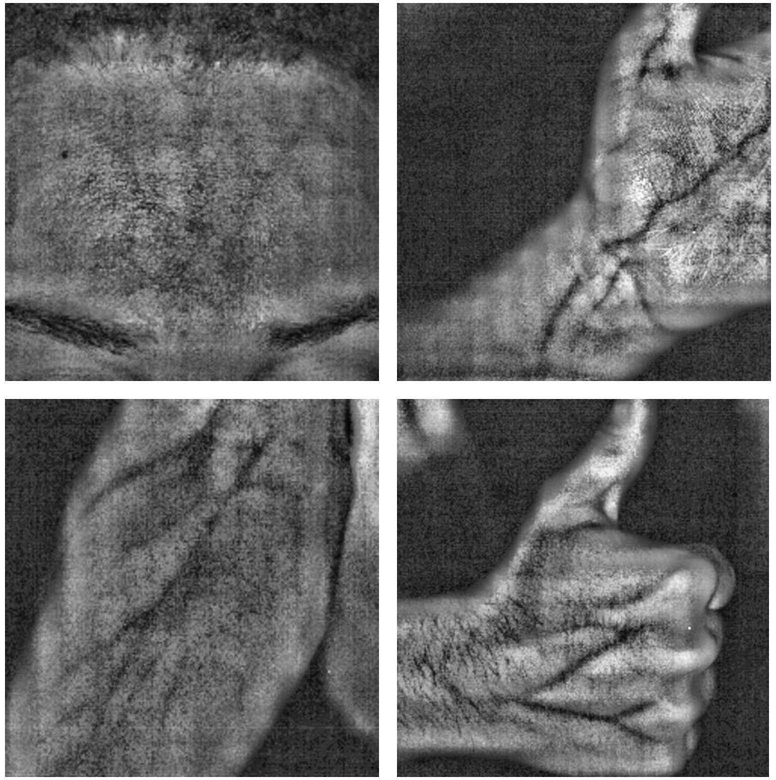
An EEG headset

An fNIRS headset

THE EXISTING WORK

REWRITING THE PIPELINE

- Rewrote the codebase to be in Python instead of MATLAB
- Optimizations
  - Parallelization
  - Memoising
  - Batch processing
- Resulted in a speedup of $\sim 10^4$
- Implemented image processing techniques to incorporate differences in wavelength intensity



MY CUSTOM MODEL

```python
class MulticlassMultispectralResNet50(nn.Module):
    def __init__(self, in_channels=8, classify=True, out_classes=2):
        super(MulticlassMultispectralResNet50, self).__init__()
        self.in_channels = in_channels
        self._norm_layer = nn.BatchNorm2d
        self.inplanes = 64
        self.dilation = 1

        self.groups = 1
        self.base_width = 64
        self.conv1 = nn.Conv2d(in_channels=in_channels, out_channels=64, kernel_size=7, stride=2, padding=3, bias
        self.bn1 = self._norm_layer(64)
        self.relu = nn.ReLU(inplace=True)
        self.maxpool = nn.MaxPool2d(kernel_size=3, stride=2, padding=1)
```

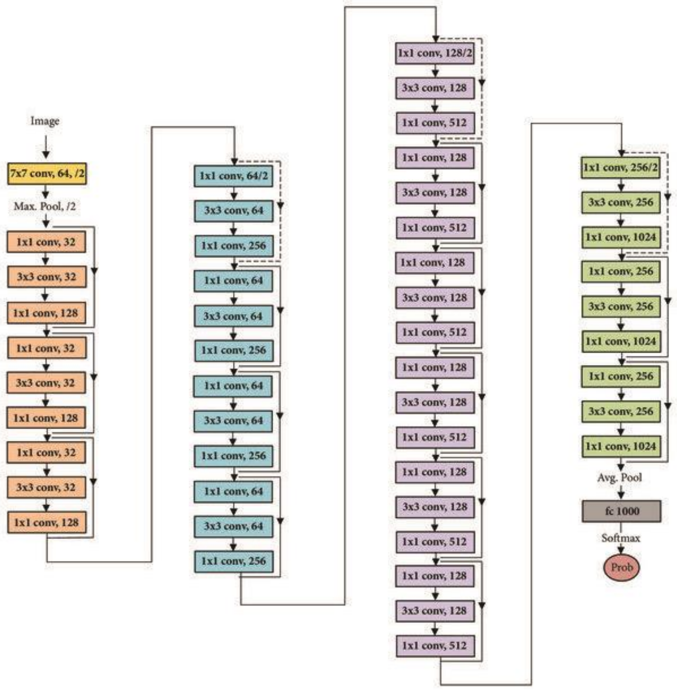
PyTorch doesn't have an implementation, so I wrote my own

```python
class MultichannelBrightnessJitter(torch.nn.Module):
    """Randomly change the brightness, contrast, saturation and hue of an image.
    If the image is torch Tensor, it is expected
    to have [..., 1 or 3, H, W] shape, where ... means an arbitrary number of leading dimensions.
    If img is PIL Image, mode "1", "I", "F" and modes with transparency (alpha channel) are not supported.

    Args:
        brightness (float or tuple of float (min, max)): How much to jitter brightness.
            brightness_factor is chosen uniformly from [max(0, 1 - brightness), 1 + brightness]
            or the given [min, max]. Should be non negative numbers.
    """

    def __init__(
        self,
```

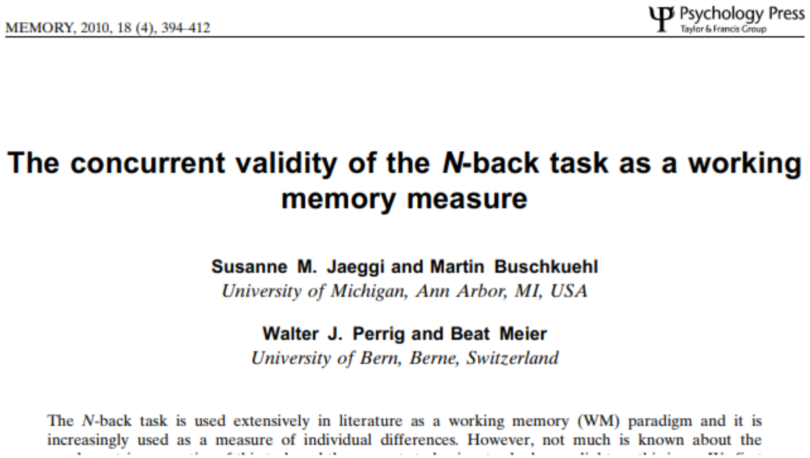
And a custom data processing pipeline



ResNet-50: 50 layer, 25 million parameter model

DATA COLLECTION METHODOLOGY

- Independent Variable:
  - The relative task difficulty (n-back length)
- Dependent Variable:
  - The blood flow in the prefrontal cortex
- Control:
  - Sequence randomization
  - Focal position


MEMORY, 2010, 18 (4), 394-412

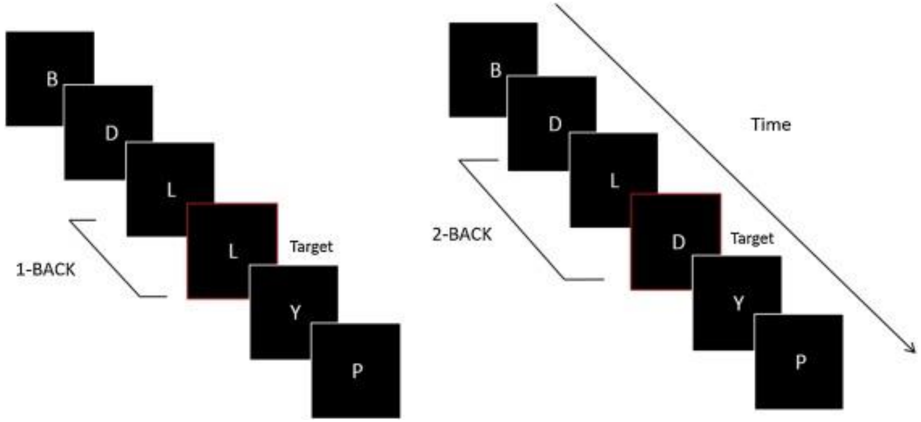
Psychology Press
Taylor & Francis Group

The concurrent validity of the *N*-back task as a working memory measure

Susanne M. Jaeggi and Martin Buschkuehl
University of Michigan, Ann Arbor, MI, USA

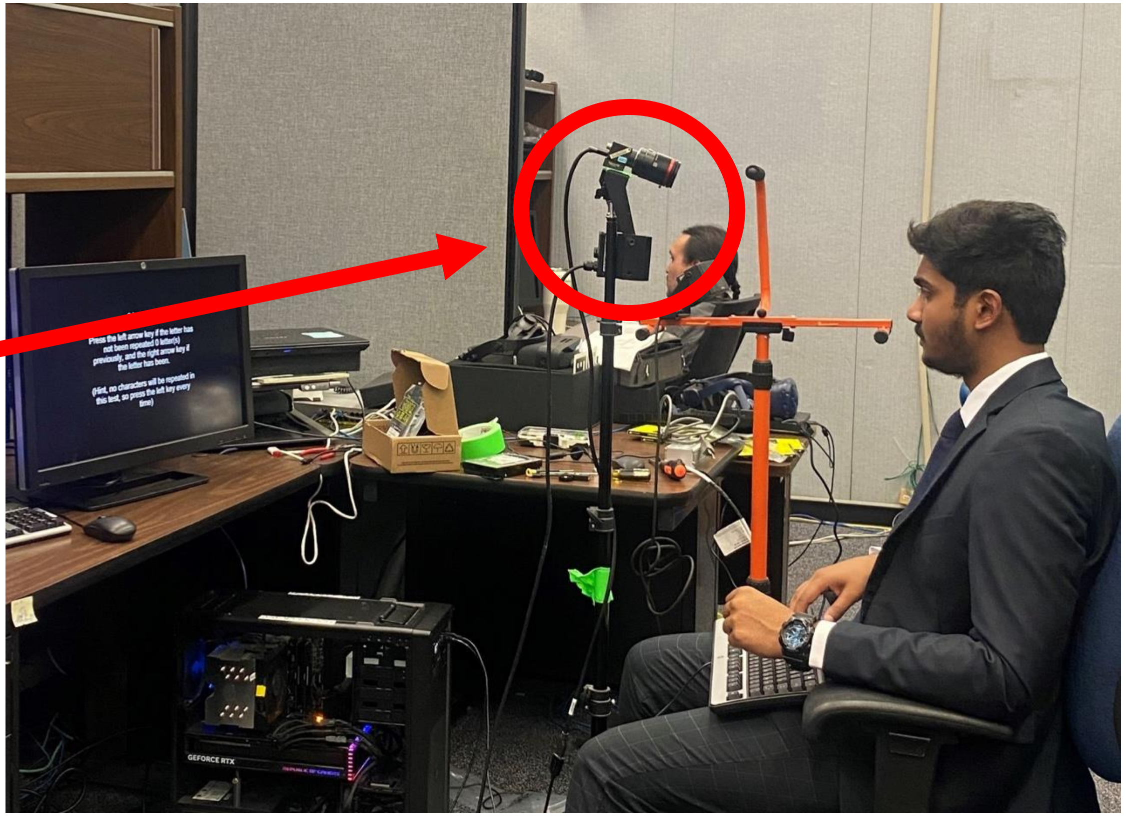
Walter J. Perrig and Beat Meier
University of Bern, Berne, Switzerland

The *N*-back task is used extensively in literature as a working memory (WM) paradigm and it is increasingly used as a measure of individual differences. However, not much is known about the



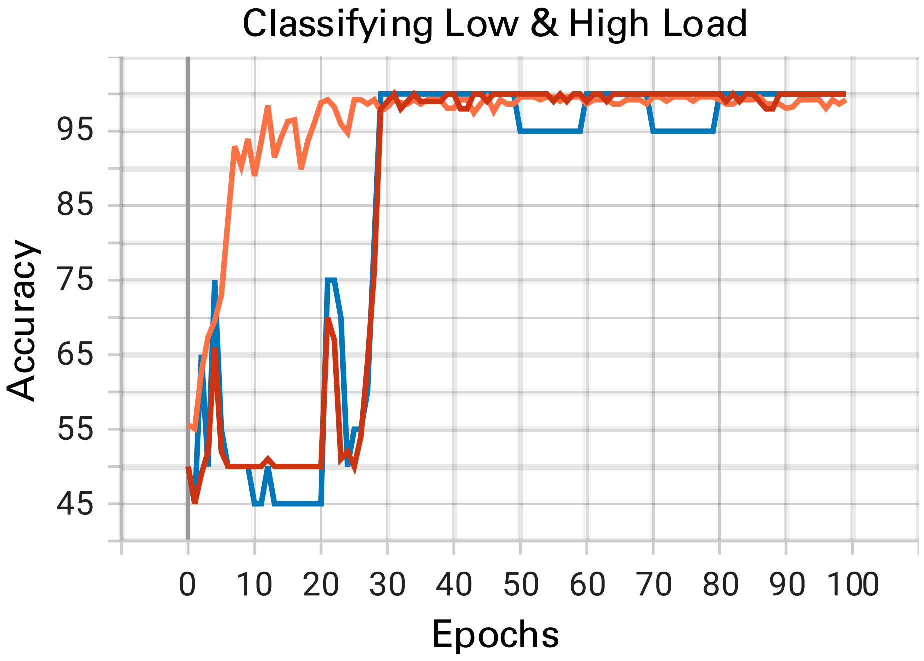
DATA COLLECTION SETUP

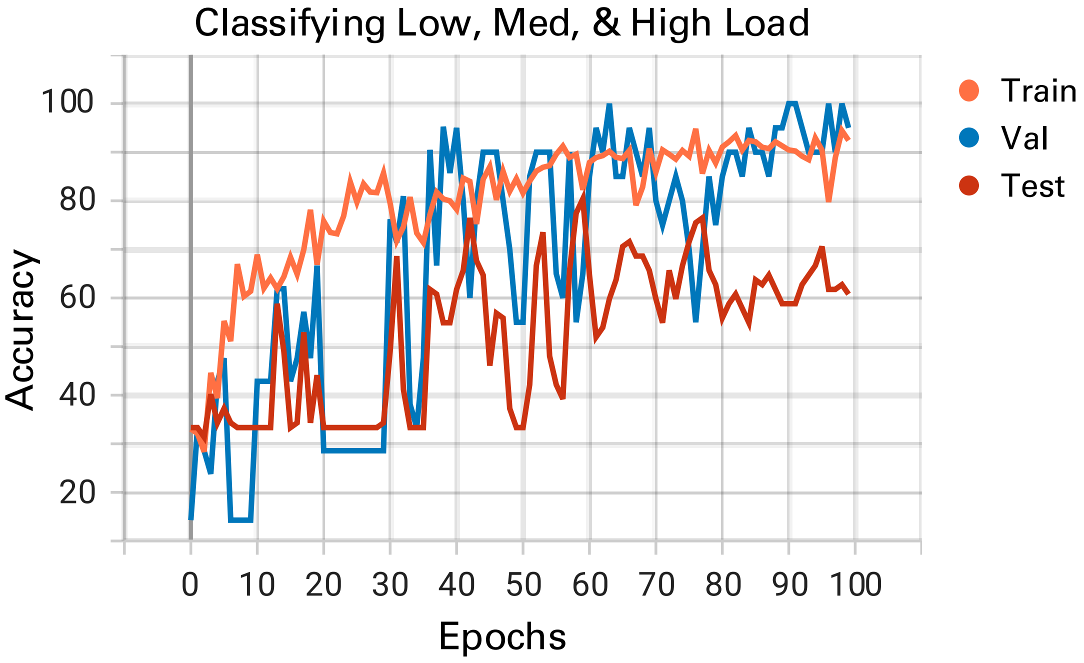
Collected data from ~40 interns while under low, medium, and high cognitive load



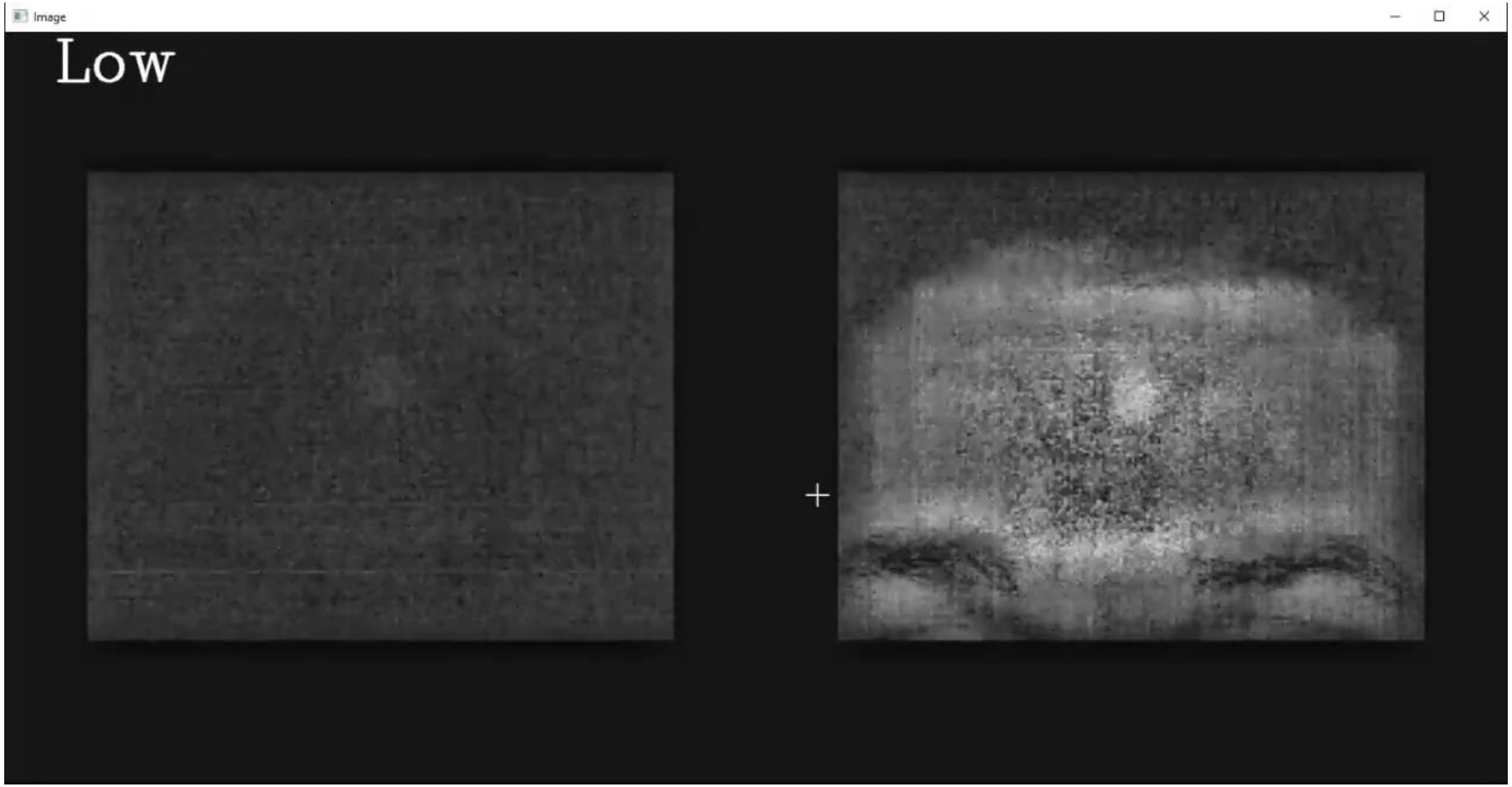
EVALUATION

It worked! Or did it?



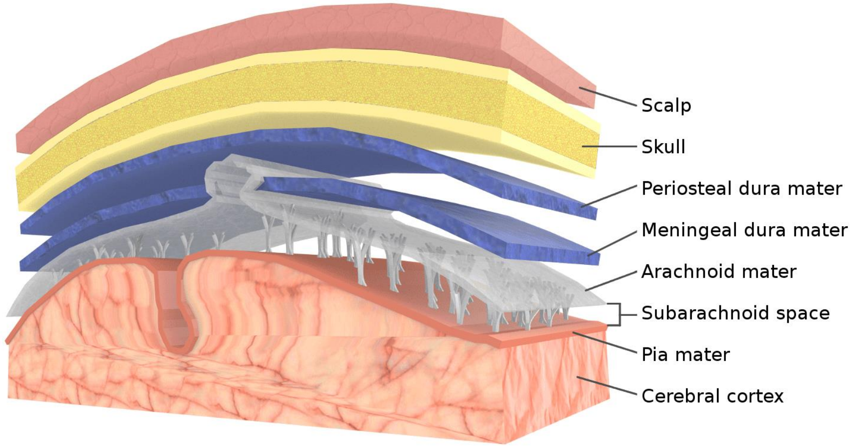


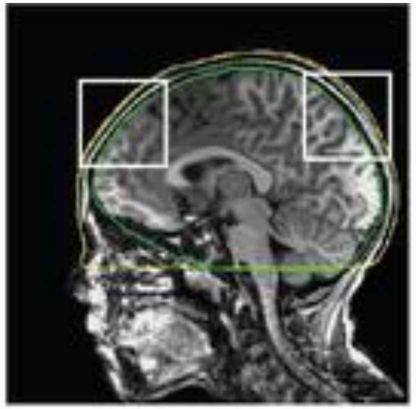
MODEL FAULT

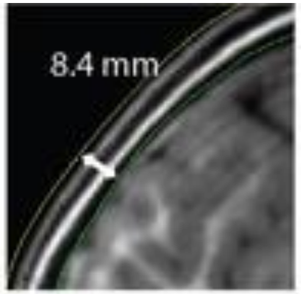


ISSUE WITH THE APPROACH

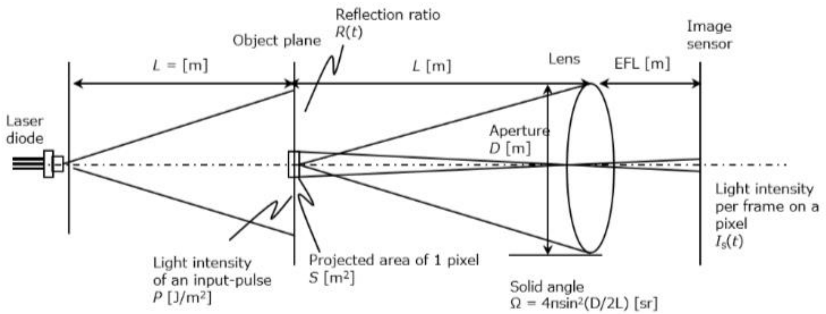
1. Diffusive properties of the head
2. Depth of brain tissue
3. Light intensity vs. signal-to-noise







CALCULATING FEASIBILITY



$$P = \frac{E_{\text{pulse}}}{A_{\text{beam}}} = \frac{4.8\times10^{-7}\text{mJ}}{\pi r^2} = \frac{4.8\times10^{-10}\text{J}}{\pi(3.5\times10^{-3})^2\text{m}^2} = 1.247\times10^{-5}\text{J/m}^2$$
$$n = 2$$
$$S = 0.07\times0.07 = 0.0049\text{mm}^2 = 4.9\times10^{-9}\text{m}^2$$
$$R(t) = R(0.8) = 2.5\times10^{-6}$$
$$\Omega = 1.3\times10^{-3}\text{sr} = 1.3\times10^{-3}\text{m}^2/\text{m}^2$$
$$a = 1$$

$$I_s(t) = P\times n\times S\times R(t)\times\Omega/2\pi\times a$$
$$= (1.247\times10^{-5})\times2\times(4.9\times10^{-9})\times(2.5\times10^{-6})\times\frac{1.3\times10^{-3}}{2\pi}\times1$$
$$= 6.32114892\times10^{-23}$$

The energy generated from one pulse

$$n = \frac{Q}{e} = \frac{I\cdot S_{pd}}{e}$$
$$I = 6.32114892\times10^{-23}$$
$$S_{pd} = 0.27\text{A/W (from camera sensor spec)}$$
$$e = 1.602\times10^{-19}\text{C}$$
$$t = 11\text{ns} = 11\times10^{-9}\text{s}$$

$$Q = S_{pd}\cdot I = 0.27\cdot6.32114892\times10^{-23} = 1.70671021\times10^{-23}\text{C}$$
$$n = \frac{1.70671021\times10^{-23}}{1.602\times10^{-19}} = 1.06536218\times10^{-4}$$

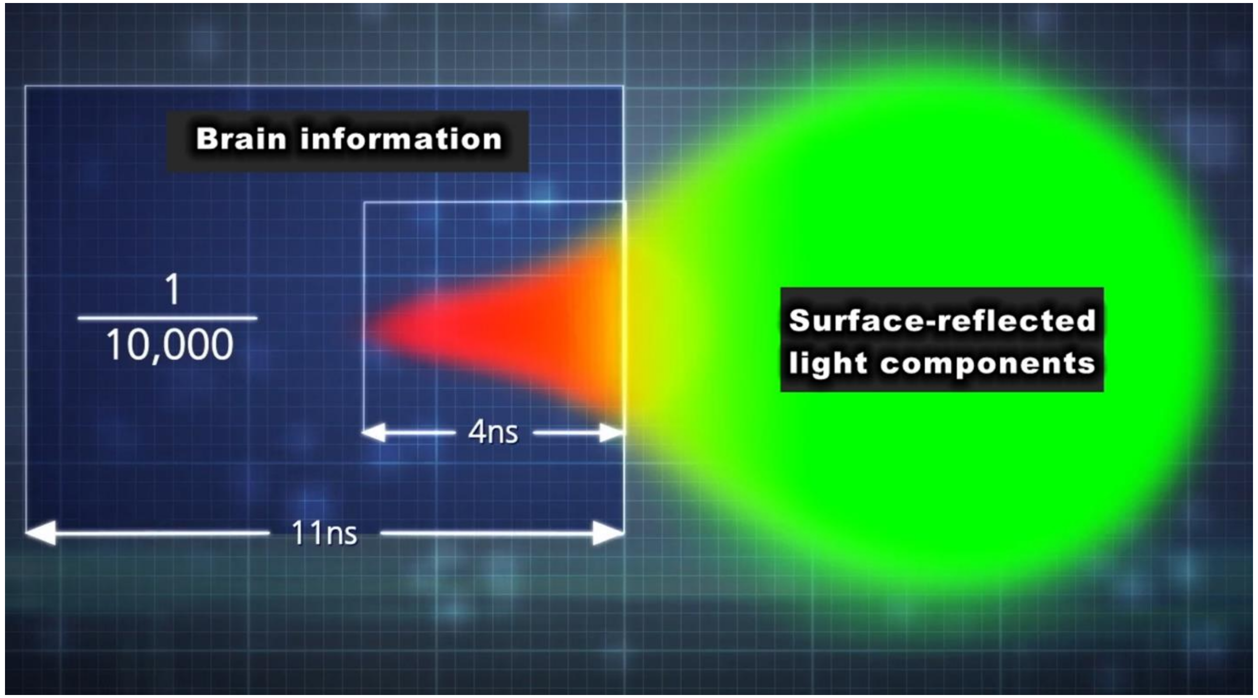
The number of electrons generated from a pulse

$$I = 5.9334\times10^{-19}$$
$$P = \frac{5.9334\times10^{-19}}{2\times(4.9\times10^{-9})\times(2.5\times10^{-6})\times\frac{1.3\times10^{-3}}{2\pi}\times1} = 1.17\times10^{-1}\text{J/m}^2$$
$$E_{\text{pulse}} = (1.17\times10^{-1})\cdot\pi(3.5\times10^{-3})^2$$
$$= 4.50268767\times10^{-6}\text{J} = 4.50268767\times10^{-3}\text{mJ}$$

The amount of energy needed to generate 1 electron

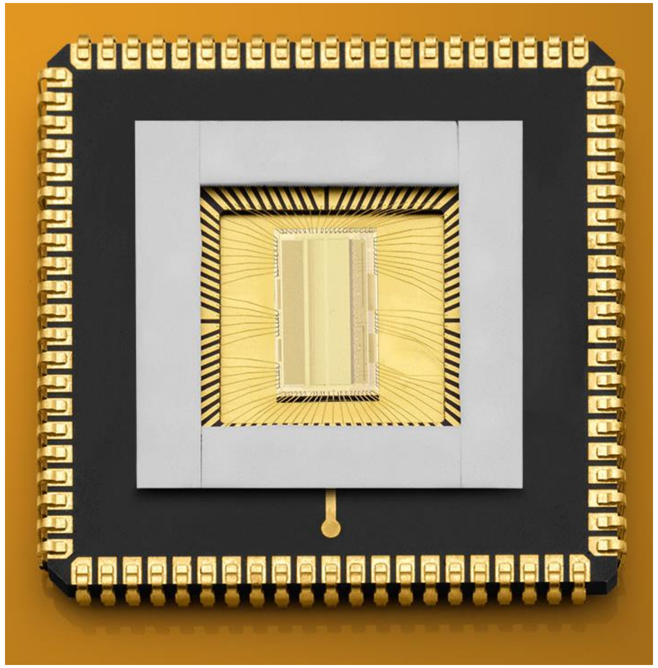
MY NEW APPROACH

DIFFUSE OPTICAL TOMOGRAPHY



GATED SINGLE PHOTON DETECTION

- Deep tissue reflects low amounts of light
  - Single photon detectors are extremely sensitive
- Gating removes surface reflections



Has been successfully demonstrated in the research domain:

www.nature.com/scientificreports

SCIENTIFIC REPORTS
natureresearch

OPEN

Non-contact acquisition of brain function using a time-extracted compact camera

Takamasa Ando[1*], Tatsuya Nakamura[1], Toshiya Fujii[1], Teruhiro Shiono[1], Tasuku Nakamura[1], Masato Suzuki[1], Naomi Anzue-Satoi[1], Kenji Narumi[1], Hisashi Watanabe[1], Tsuguhiro Korenaga[1], Eiji Okada[2] & Yasunori Inoue[1]

A revolution in functional brain imaging techniques is in progress in the field of neurosciences. Optical imaging techniques, such as high-density diffuse optical tomography (HD-DOT), in which source-detector pairs of probes are placed on subjects' heads, provide better portability than conventional functional magnetic resonance imaging (fMRI) equipment. However, these techniques remain costly and can only acquire images at up to a few measurements per square centimetre, even when multiple detector probes are employed. In this study, we demonstrate functional brain imaging using a compact and affordable setup that employs nanosecond-order pulsed ordinary laser diodes and a time-extracted image sensor with superimposition capture of scattered components. Our technique can simply and easily attain a high density of measurement points without requiring probes to be attached, and can directly capture two-dimensional functional brain images. We have demonstrated brain activity imaging using a phantom that mimics the optical properties of an adult human head, and with a human subject, have measured cognitive brain activation while the subject is solving simple arithmetical tasks.

Techniques for imaging in the presence of scattering media are crucial to the fields of biometrics and biomedical neuroscience. Near-infrared spectroscopy (NIRS)[1,2] uses source–detector probes located far apart when monitoring blood haemoglobin levels in the cerebral cortex to enhance the detection of deep component signals. Researchers at NIRS have recently developed a high-density diffuse optical tomography (HD-DOT) technique[3–8] to improve spatial resolution by using multiple probes with additional short source–detector (SD) distances. HD-DOT can image quantitative[8,9] haemoglobin concentration changes three-dimensionally by solving the inverse problem with spatial sensitivity distribution. Time-domain functional near-infrared spectroscopy (TD-fNIRS)[10–14] can be used to monitor tissue oxygenation using a picosecond ultrashort pulse laser and a

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Fast-Gated Single-Photon Avalanche Diode for Wide Dynamic Range Near Infrared Spectroscopy

Alberto Dalla Mora, Alberto Tosi, *Member, IEEE*, Franco Zappa, *Senior Member, IEEE*, Sergio Cova, *Life Fellow, IEEE*, Davide Contini, Antonio Pifferi, Lorenzo Spinelli, Alessandro Torricelli, and Rinaldo Cubeddu

***Abstract*—We present a novel technique for wide dynamic range optical investigations. It is based on a fast-gated silicon single-photon avalanche diode (SPAD) in time-correlated single-photon counting (TCSPC) setup. The SPAD is gated-ON and OFF in 500 ps so as to detect photons only within a given time interval. This technique is particularly useful in applications where a large amount of unnecessary photons precede or follow the optical signal to be detected, such as in time-resolved near infrared (NIR) spectroscopy, optical mammography, and optical molecular imaging. In particular, in time-resolved reflectance spectroscopy, it is desirable to minimize the source–detector separation to improve system performance. This leads to the saturation of the detection electronics because of the huge amount of "early" photons back scattered by superficial layers. Our setup is able to reject these photons and detect only "late" photons from the sample, thus allowing an increase in the dynamic range and the injected power. We acquired diffusive curves of two phantoms with 95 ps time resolution and 10^7 dynamic range with a measurement time three orders of magnitude shorter than what is currently possible with a standard TCPSC setup.**

***Index Terms*—Avalanche breakdown, infrared spectroscopy, time domain measurements.**

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A. Dalla Mora and A. Tosi are with the Dipartimento di Elettronica e

I. Introduction

It is well known and widely discussed in literature that red and near infrared light can be used to noninvasively probe highly scattering media such as biological tissues [1]. In particular, in biomedical optics, photon migration phenomena can be exploited for different and innovative applications, such as functional brain imaging [2], mammography [3], or molecular imaging [4]. In reflectance optical spectroscopy measurements, the diffusive medium is illuminated from a point source and diffused photons are collected at a given distance from the source. Different techniques can be employed to probe media, such as continuous wave, frequency domain, and time domain. Among these, time domain techniques can provide higher sensitivity and penetration depth by exploiting the timing information of scattered photons [5]–[7].

These techniques allow the noninvasive detection *in vivo* of brain cortex activation by monitoring cerebral hemodynamics (e.g., concentration changes of both oxygenated and deoxygenated hemoglobin), which produce localized changes of optical absorption coefficients [8]. The key point of these measurements is the possibility of increasing the penetration depth of investigation, in particular for functional brain imaging, where skin, skull, and cerebrospinal fluid (CSF) heavily mask the brain signal [8]. In time-resolved techniques, it has been demonstrated

Limiting factors

1. Price
2. Photon Detection Efficiency

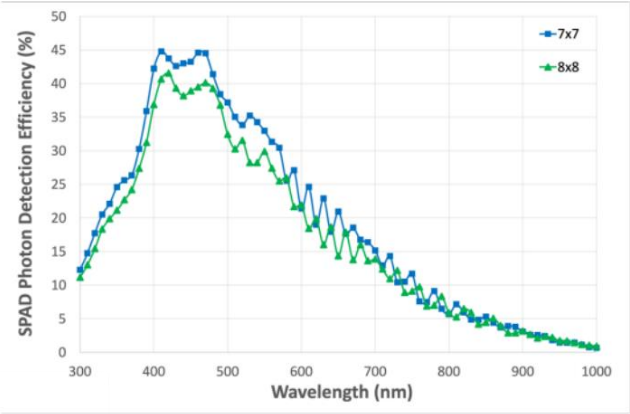
CHALLENGES

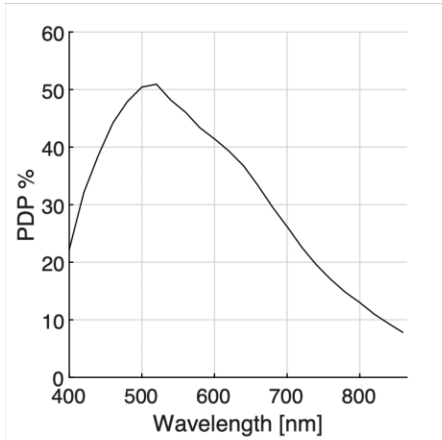
1. PRICE

Prices for the SPAD512 vary from $40k up to $55k depending on the models (with or without micro-lenses, standard speed or high-speed). Prices for the SPADα vary from $54k to $57k. Lead time is 12-16 weeks for all models. Please find both brochures attached below. Tariffs are not included, those products are manufactured in Switzerland, so the current tariffs rate is 39%, but we are hoping to see that rate go down to 10%-25% in the next few weeks.

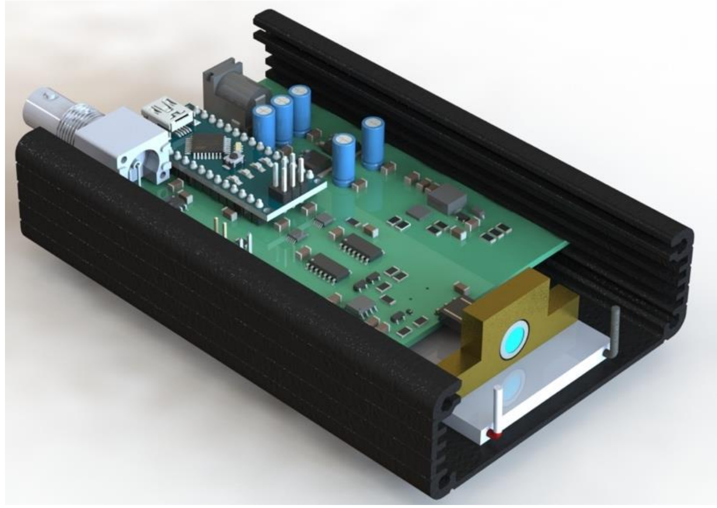
In terms of pricing, a HiCATT with a Gen III intensifier such as GaAs would work for both your wavelengths: 760nm and 830nm. Unfortunately, Gen III intensifiers are the most expensive. A 25mm GaAs HiCATT with one of the gating units that I described above is ~$160k. The HiQE Red only comes in 18mm (this is not for 25mm intensifier. The price for a HiCATT 18mm with HiQE Red is $124k. Is this within your budget?

2. PHOTON DETECTION EFFICIENCY





- Create a custom gated single-photon detector
  - Cost: ~$200
  - Would need to develop mostly from scratch



FUTURE DIRECTIONS

FUTURE DIRECTIONS

- Leverage IITs (Image Intensifier Tubes) from night vision technology
    - Cost: $3,000 - $5,000
    - May have issues gating