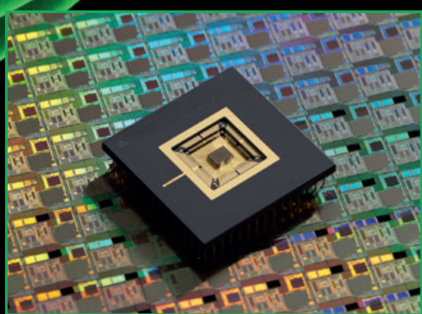
PHOTON FORCE

Single-Photon Sensitive Cameras and Sensors

The highest throughput, fastest time-resolved single photon counting technology on the market



Photon Force offers
SPAD array cameras and sensors
with the ability to timestamp
500,000,000 photons per second

Our technologies are accelerating
progress in multiple areas
including photonics, quantum optics,
and research in other scientific
and engineering fields

Quantum Optics **Research** **Photonics**

About Photon Force

Photon Force launched in 2015, as a spin-out from the renowned CMOS Sensors & Systems Group at the University of Edinburgh.

As part of the image sensing community, Photon Force has built on over a decade of successful research experience in time-resolved imaging to provide innovative, high quality and accurate sensor technology that facilitates scientific, academic and commercial research.

Our Belief

We believe people should have access to better tools for faster progress. Through our technology, we bring an order-of-magnitude acceleration to single-photon imaging and data processing, and we support our customers with a wide variety of processing challenges to enable further enhanced techniques.

We believe that time-resolved single-photon imaging has the ability to revolutionise a wide range of fields, from energy production to biomedical research. We aim to help bring about that revolution through the mass manufacture of single-photon avalanche diode (SPAD) sensors. By making our detectors widely available to researchers and companies, we are enabling them to develop applications and technological advancements that have not previously been possible.

Our Innovation

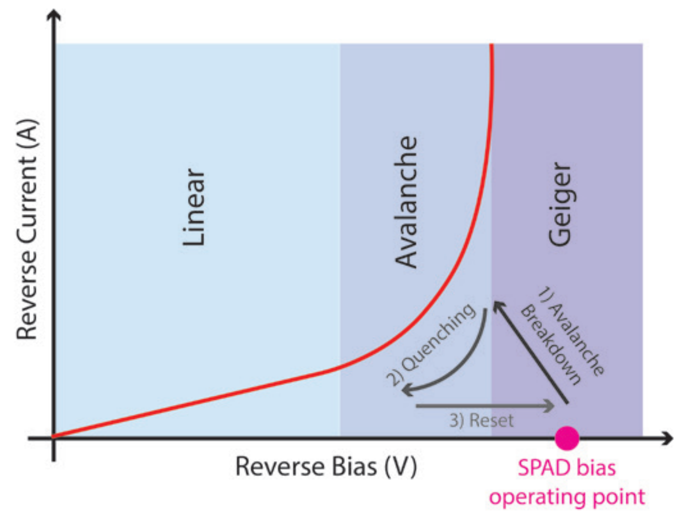
Our PF32 time-resolved camera product range offers the highest throughput single-photon-counting cameras on the market. Since the launch of our initial camera range, we have continued to innovate, developing and launching new products and services that build on our market-leading technology.

We also work with umbrella organisations such as Innovate UK to play a role in crucial R&D projects aimed at creating next-generation technologies with impact.

What is a SPAD?

A Single-Photon Avalanche Diode (SPAD) is a photodiode that has been specifically designed to be operated beyond its reverse breakdown voltage, in the so-called “Geiger mode”. While a conventional photodiode would immediately break down if biased in this region, a SPAD can sit stably in this configuration for a period of time, until disturbed by an incoming photon or other noise source.

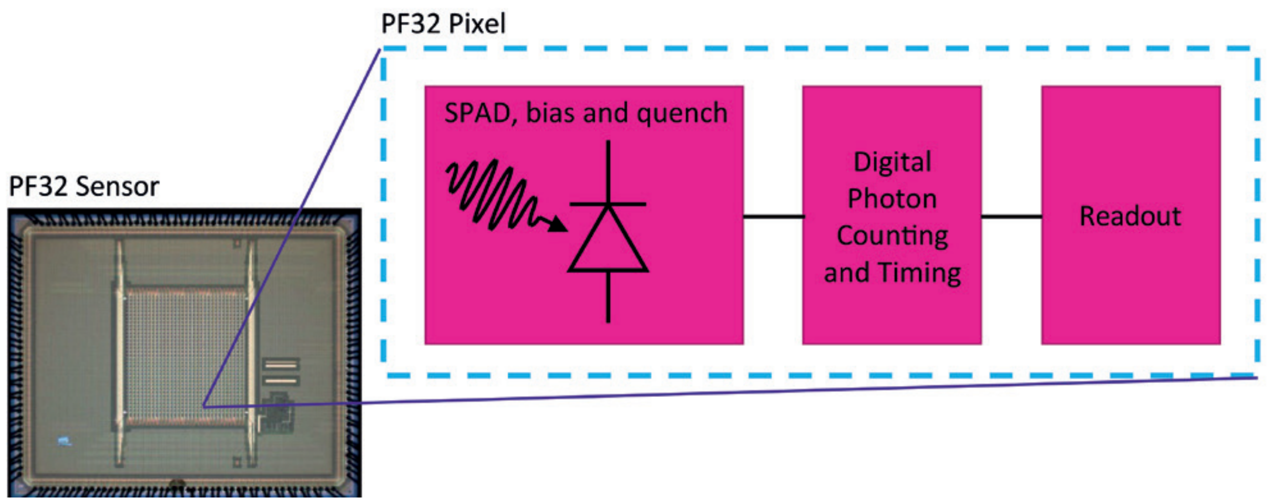
When a photon is absorbed within the device, creating an electron-hole pair, the resulting avalanche due to impact ionisation provides a rush of current, easily detectable by the surrounding circuitry. The SPAD therefore provides digital detection of a single photon.



Unparalleled Integration – The CMOS Advantage

Photon Force sensors utilise advanced CMOS manufacturing technologies to combine a SPAD along with bias/quench, photon counting/timing and readout electronics into a compact pixel. This pixel is then replicated to form an imaging array. Since every pixel provides self-contained photon detection and counting/timing, our arrays offer unparalleled throughput of up to 500M photons/s*.

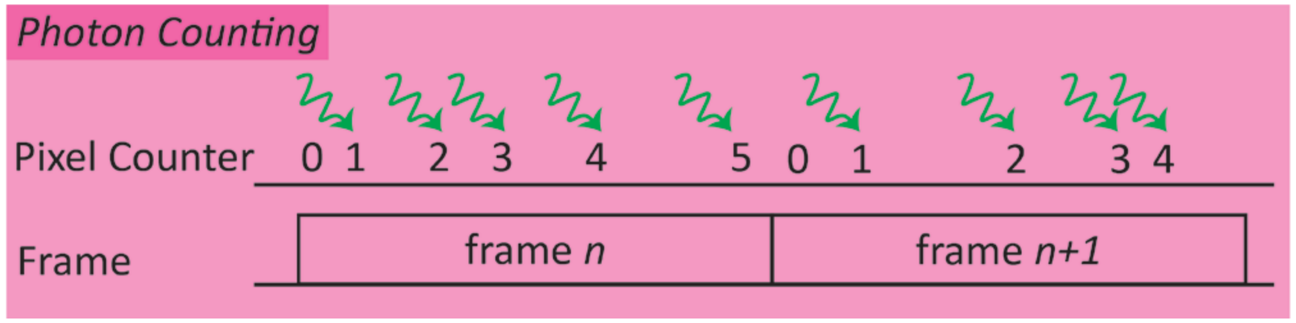
**Subject to model and operating mode.*



Digital Photon Counting and Timing

Photon Counting:

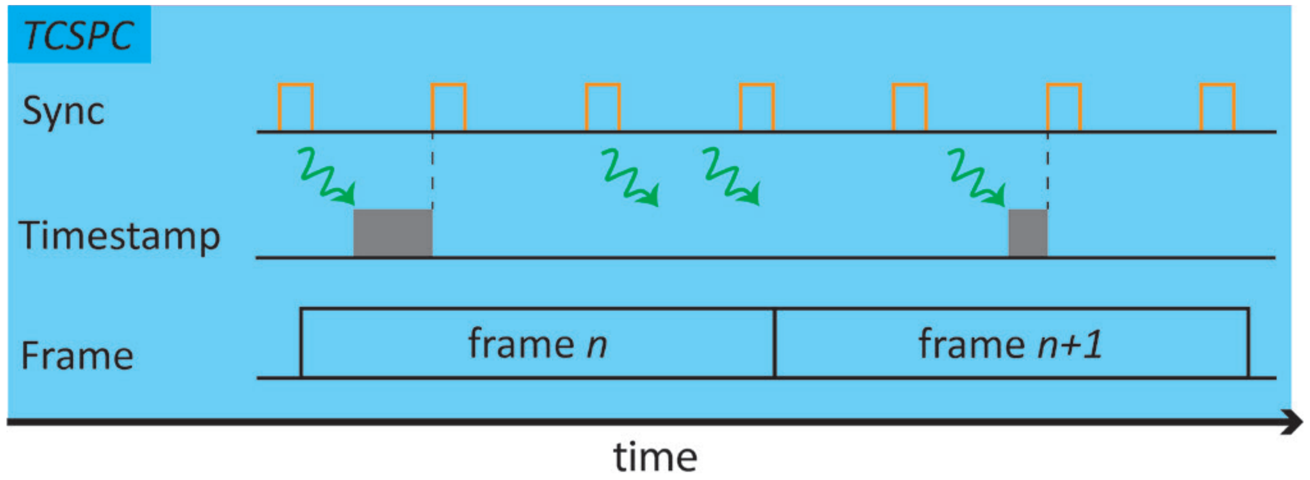
SPADs allow true digital single photon counting, with no analogue read noise. Every detected photon increments the in-pixel counter. Photon Force cameras allow for flexible, ultra-high speed readout - crucial for applications such as diffuse correlation spectroscopy.



Time-Correlated Single Photon Counting (TCSPC):

SPADs are unique in providing time information for every detected photon, directly into the digital domain - ideal for integration with timing and readout circuitry. With Photon Force sensors, the first photon detected in every frame can be timestamped with a resolution of just 55ps with respect to a synchronization reference. Combined with high speed readout, our technology delivers time-tagged data with unprecedented throughput, providing up to half a billion single-photon timestamps per second!

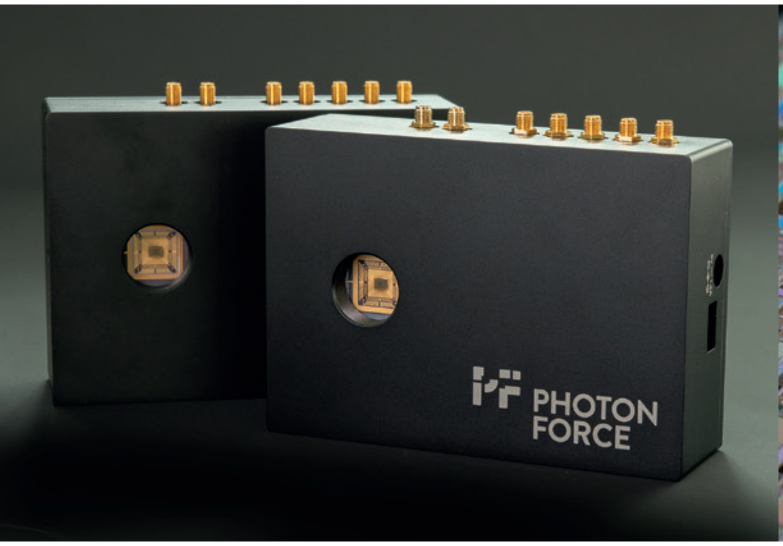
Read on to learn about the range of applications our sensors and cameras have been applied to.

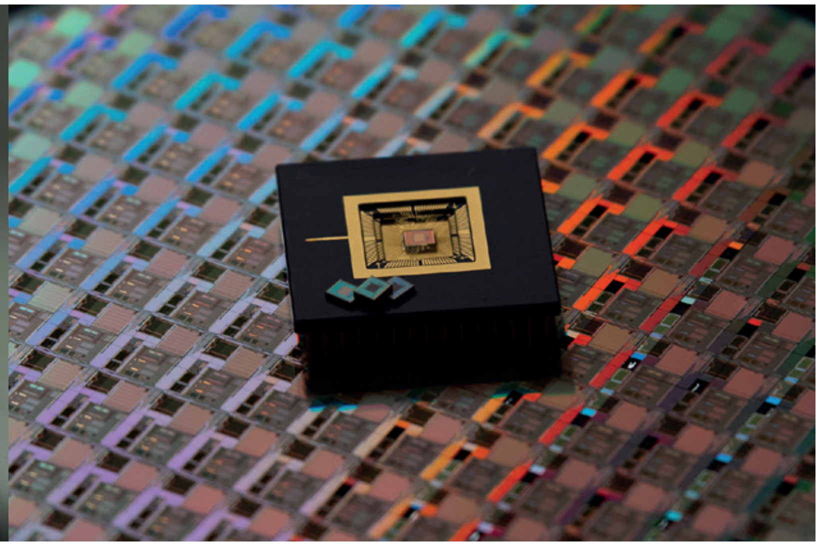


Our Products and Services

Photon Force offers a range of products and services all aimed at the acceleration of scientific and commercial research that incorporates single-photon counting and timing.

Our camera range currently includes two PF32 models. The PF32-500k offers an entry-level unit, whilst the PF32-1M offers extreme speed for applications that require flexibility in readout modalities.





Cameras

The Photon Force range of PF32 cameras are the highest throughput SPAD array cameras on the market today.

- 32x32 TCSPC pixel array
- 55 picosecond resolution
- Two models; 500k and 1M
- Two modes; TCSPC and photon counting
- Up to 500,000,000 photons timestamped per second

Sensors & ROICs

We offer a design and manufacturing service to provide custom sensors and readout integrated circuits (ROIC) spanning resolution, size and architecture options.

These provide hardware acceleration for your application's processing needs, or simply meet OEM requirements for ultrafast single-photon imaging.

Firmware

Photon Force can provide customised firmware to accelerate your research by performing the data analysis within the camera itself (only available with PF32-1M).

Software

Our off-the-shelf software provides a flexible API for easy integration with other applications. Common programming languages that we link with include MatLab, LabView, Python, C and C++.

Where are Photon Force technologies used?

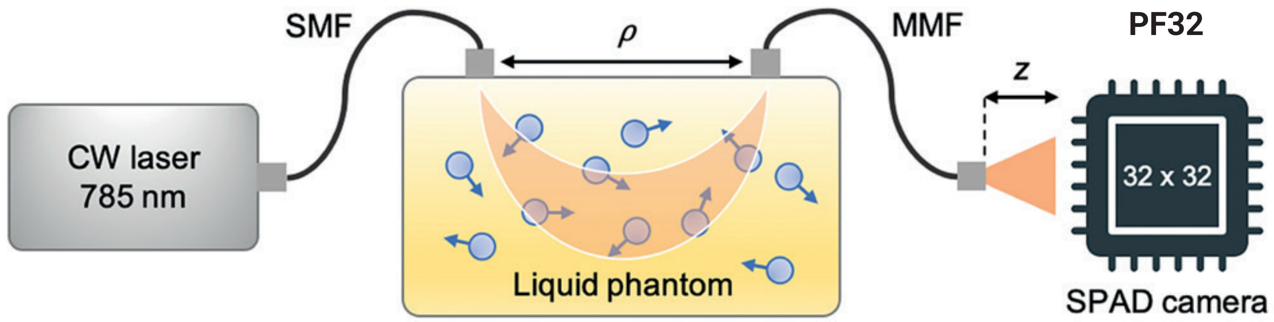
Photon Force products and technologies are used across a wide range of sectors to enable ultrafast, Time-Correlated Single Photon Counting with the ability to timestamp half a billion photons per second.

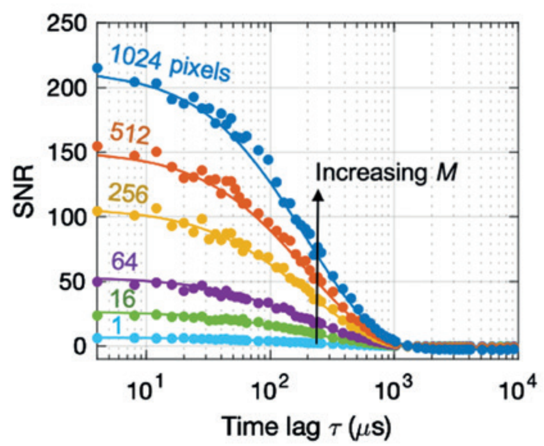
Our cameras and sensors are primarily used in the fields of photonics, quantum optics and other scientific research to enable next generation technologies and products in a wide range of industries, spanning neuroscience, energy, communications, automotive, and beyond.

Can your brain communicate directly with a computer?

At Facebook Reality Labs, the team are trying to answer this question through their research on Brain-Computer Interfaces using the Photon Force PF32 camera, our customised firmware and multispeckle Diffuse Correlation Spectroscopy.

With a requirement to develop a scalable method of monitoring cerebral blood flow and measuring cortex functional activation tasks, the Facebook team turned to Photon Force for help with increasing the Signal-to-Noise Ratio (SNR). Using the Photon Force PF32 camera achieved this; facilitating a 32-fold increase to SNR. The ultimate goal is to create a brain/computer interface.



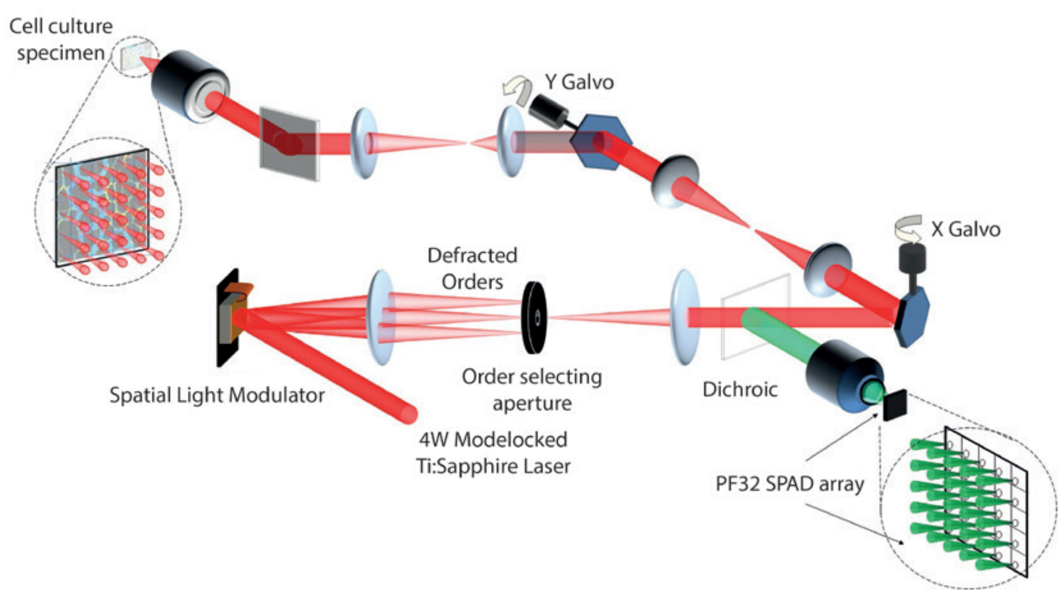


Fast Fluorescence Lifetime Imaging Microscopy (FLIM)

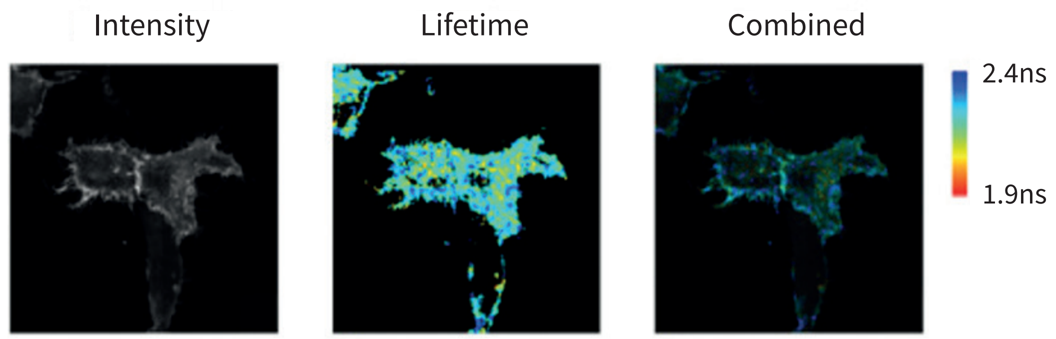
The PF32 family can be used as widefield FLIM cameras, imaging 1,024 independent TCSPC spatial points simultaneously at high speed. Alternatively, the camera can be used as a 'bucket' detector for high-speed scanning systems, with the advantage of all 1,024 pixels being able to simultaneously detect and timestamp photons.

Powering the Ultimate High Speed FLIM Instrument

While confocal microscopes are the workhorses of biomedical imaging laboratories, setting the gold-standard in image contrast and quality, the acquisition of an image point by point is inherently slow. To break through this speed barrier, Photon Force customers have used the PF32 to build the pioneering multibeam confocal microscope architecture: replacing the single beam and pinhole of a typical confocal microscope with an array of beamlets to rapidly scan the image plane. The returning points are aligned with the photosensitive areas of the SPAD array, which act as virtual pinholes, rejecting out of focus light. Since each beamlet and SPAD array pixel pair are fully independent and operate in parallel, the resulting system can accelerate confocal fluorescence lifetime microscopy by orders of magnitude



As with conventional confocal microscopes, the output image resolution is dependent on the scan parameters and optics (and not the number of pixels of the sensor), allowing customers to capture stunning high-fidelity images at record speed.



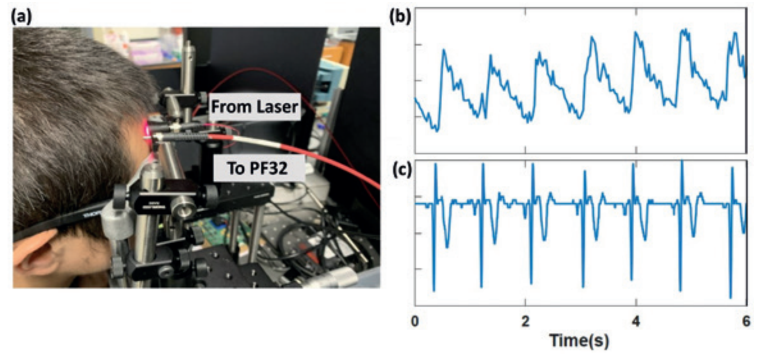
"A high speed multifocal multiphoton fluorescence lifetime imaging microscope for live-cell FRET imaging," Simon Poland *et al.*, Biomedical Optics Express, 6 (2), 277-296, 2015.

Using the Photon Force PF32 to increase sensitivity for Diffuse Correlation Spectroscopy (DCS)

At Duke University, Wenhui Liu *et al.* use the Photon Force PF32 SPAD camera's high frame rates and photon counting mode to record single-photon images at over 300kfps.

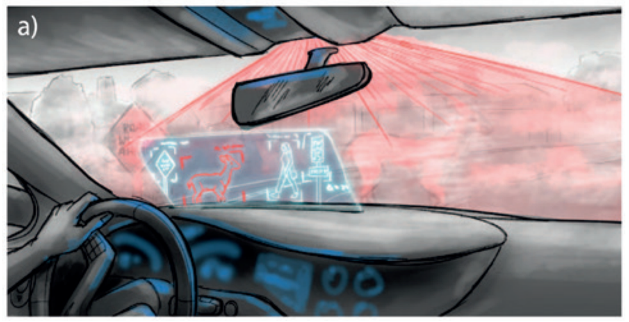
The Duke University experiment showed real-time measurement of blood flow in human tissue. Image (a) shows the set up for the in vivo forehead blood flow and image (b) demonstrates the results using the Photon Force PF32. Image (c) validates the results by comparing them to results from a commercial electrocardiogram monitor.

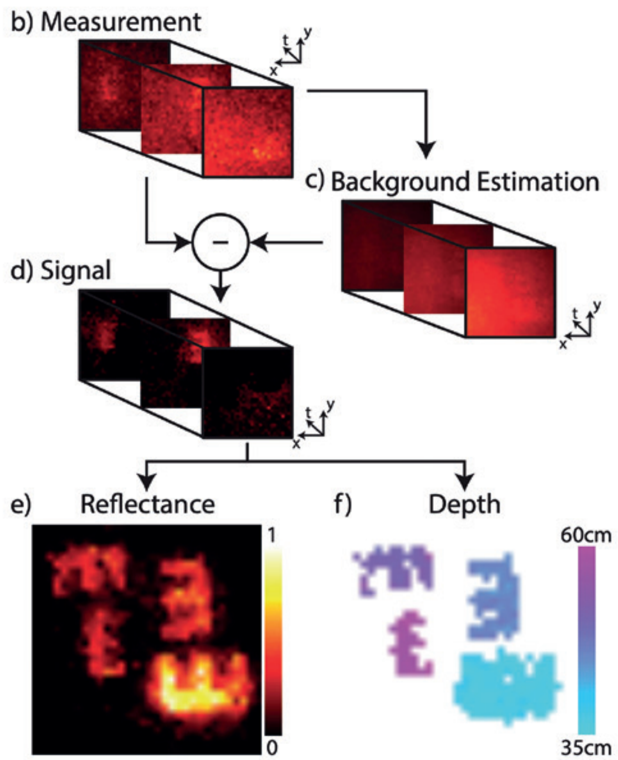
"Fast sensitive diffuse correlation spectroscopy with a SPAD array," W. Liu *et. al.*, in Biophotonics Congress: Biomedical Optics 2020 (Translational, Microscopy, OCT, OTS, BRAIN), OSA Technical Digest (Optical Society of America, 2020), paper SM3D.3.



Imaging through scattering media

Researchers at MIT utilised the measurement capability of the PF32 camera to computationally remove inclement weather conditions such as fog, and produce a photo and depth map as if there were no fog present, with contrast improved by 6.5x in dense fog conditions.





"Towards photography through realistic fog," G. Satat *et. al.*, 2018 IEEE International Conference on Computational Photography (ICCP), 2018, pp. 1-10.

For a comprehensive list of published papers featuring the PF32 SPAD array camera, please visit https://www.photon-force.com/journalreferences

What our clients say:

"The camera is truly a transformative technology that has allowed us to use the picosecond timing resolution to take ultrafast imaging and LiDAR applications to the next level."
- Prof. Daniele Faccio, University of Glasgow

"A paradigm shift in the acquisition of fluorescence lifetime data... There is no longer a need to compromise between accuracy, speed, and spatial resolution."
- Dr. Simon Poland, King's College London

"The high temporal resolution of the SPAD camera by Photon Force makes it a unique tool to explore new science and technology in a single-photon LiDAR, non-line-of-sight imaging and so forth."
- Prof. Feihu Xu, University of Science and Technology of China

"The PF32 SPAD array's single-photon sensitivity and high frame readout opens up new and exciting possibilities for deep-tissue biophotonic measurement. The array's thousand plus detectors greatly enhances standard methods of diffusive light measurement, such as diffuse correlation spectroscopy, and takes biomedical optical measurement to the next level."
- Prof. Roarke Horstmeyer, Duke University

PF32 Camera Specifications

Sensor Dimensions	
Array Size	32x32 pixels 1.6 x 1.6mm
SPAD active area (diameter)	6.95µm
Pixel pitch	50µm
Optical fill factor	1.5%

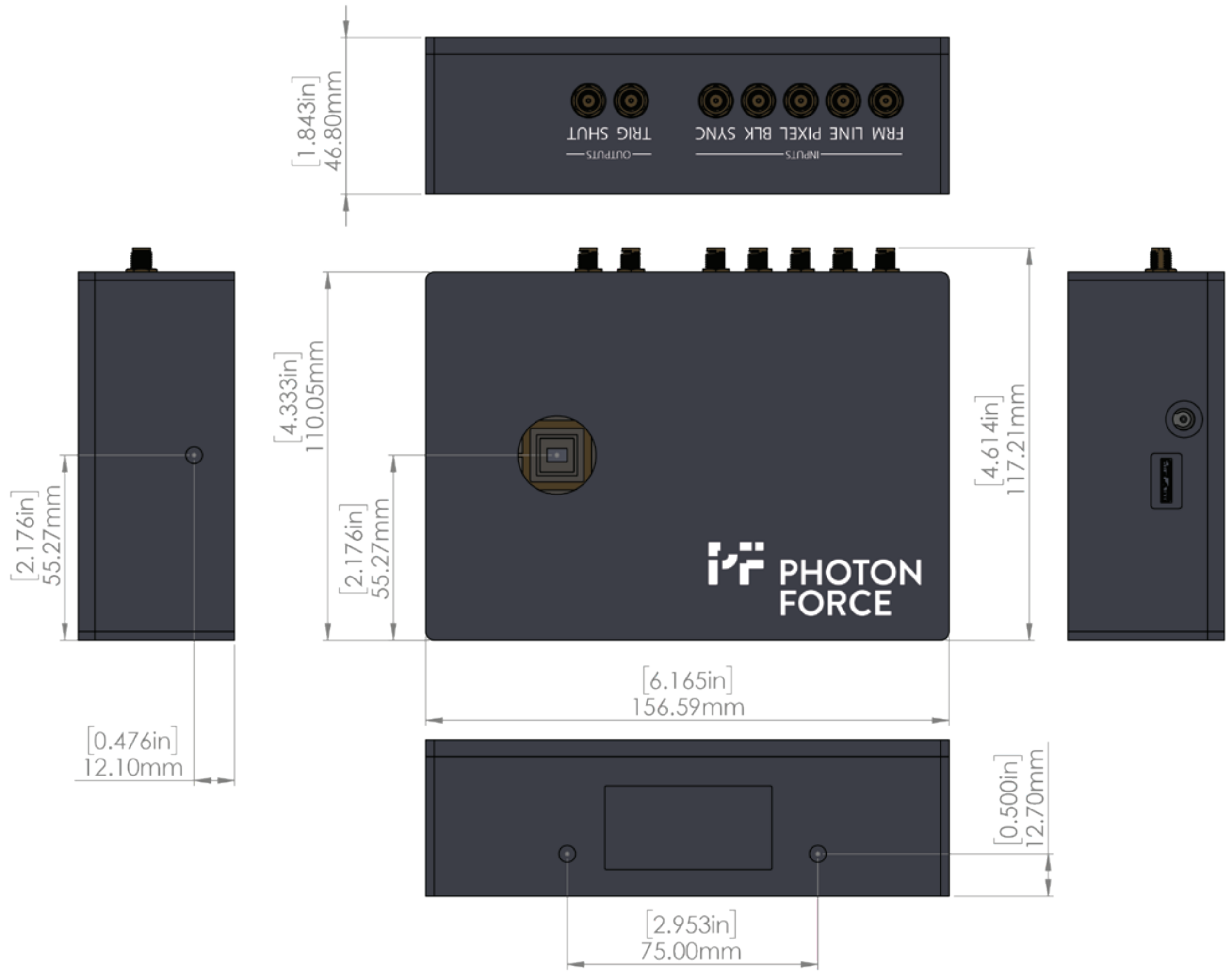
Optical/Electrical Performance	
Photodetection efficiency	Peak 28% at 500nm
Dark count rate	<100cps for more than 80% of pixels
Afterpulsing	<0.02%
Optical/Electrical crosstalk	None
Timing jitter	~200ps FWHM

Photon Counting Mode	
Photon counting	7 bit in-pixel 16 bit in firmware
Maximum count rate per pixel	50MHz

Time Correlated Mode	
Temporal bin	55ps
Temporal range	55ps - 57ns
TDC resolution	10 bit
Maximum laser sync frequency	100MHz
Laser sync input amplitude	NIM / 1.2V / 3.3V
Laser sync output amplitude	3.3V

Readout & Control	
Raw data streaming rate to PC	
PF32-500k:	150kfps (16-bit) 225kfps (8-bit)
PF32-1M (*export licence controlled*):	150kfps (16-bit) 300kfps (8-bit)
Inter-frame dead time	<50ns
X/Y scanner sync input signals	Pixel, line and frame clock
Exposure sync signals	Blanking (3.3V / 5V input) Shutter (3.3V output)

Camera is supplied with: manual, test data sheet, USB cable, power supply and aluminium travel case.



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