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RESEARCH ARTICLE

High speed imaging with high resolution

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High speed imaging with high resolution

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Cracks propagate in fractions of seconds. In the same timescale micro bubbles burst and bullets penetrate their target. To record such events requires high speed cameras which can be accurately synchronised at high frame rates and high resolution.

Many new materials are manufactured each year and often the computer simulation bears no relationship to reality, so the only way to establish behaviour is to undertake empirical tests. It is not that a material fails it is why and how it fails that is important to the engineers.

Test pieces are for example subjected to high compressional stresses, and the microscopic deformation processes are recorded by a high-speed camera. Or spheres of ice fired at a metal anvil to simulate hail striking the radar cover on commercial airliners. Testing concrete samples helps to design better civil structures that withstand earthquakes.

In these and numerous others instances, very high-resolution images, temporally separated by a predetermined interval, can detail important criteria that can ultimately cause product failure.

For more than a hundred years, high-speed photography has been used to record the physical characteristics of fast phenomena. Ernst Mach used very short high voltage electric discharges as light sources to capture the first images of in-flight projectiles in 1885. Since those early experiments, techniques and imaging equipment used have dramatically changed, incorporating new ideas and technologies not normally associated with high speed photography.

The once widely used moving film camera, has made way for the solid state CCD sensor based camera and in doing so has generated much discussion on the merits of both technologies. Many diehards will continue to argue that the image quality of the electronic camera does not compare to that obtained using film but cannot dispute the convenience provided by this technology. As the number of picture elements on CCD sensors continues to increase, the image quality will become less of an issue.

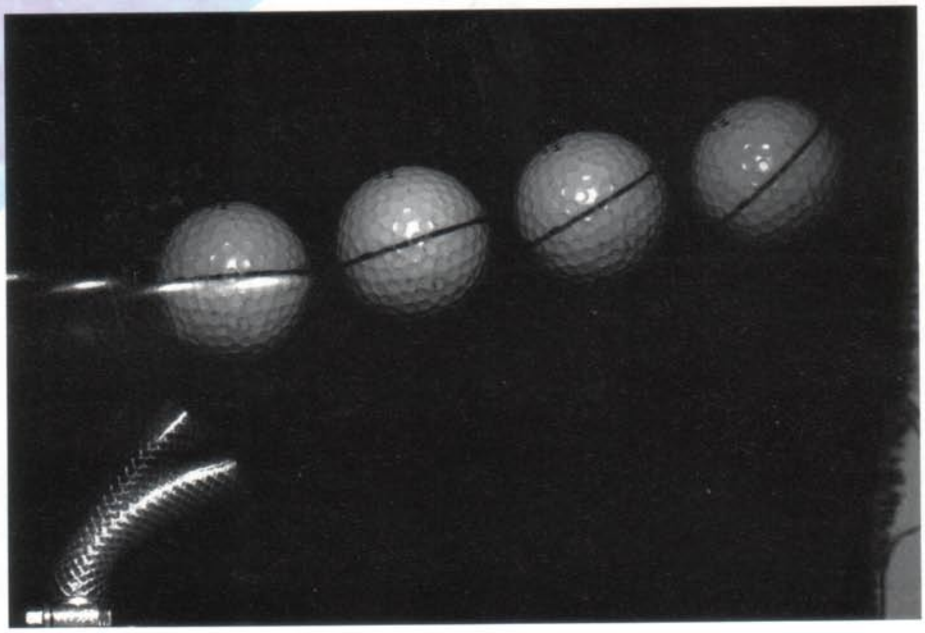

***Figure 1**: Four overlaid exposures of a golf ball being hit by a golf club, taken with a pco Sensicam by Ron Godwin, Pulse Photonics UK. The time between the exposures was about 200 µs*

Due to the short exposure time, the amount of light captured from each image is still a limiting factor.

Concept and Camera

A mechanical film camera has a solid glass prism in its optical path that rotates to capture separated images of fast events. To accelerate it to record events at framing rates up to 10,000 pps, takes about a second. Approximately 125 m of film are needed to accelerate the prism and then only record 30 or so images on 16mm film. It is virtually impossible to synchronise a random 20 µs event to the camera when running at maximum framing rate. With cameras that use electro optical devices, the only moving components are electrons, which by comparison have infinitesimally small masses consequently directional changes can be initiated in microscopic timescales.

Solid state high speed multiple framing cameras have multiples (sometimes 4, 8 or 16) of intensified CCDs interfaced to an optical beam splitter. Framing rates of 200 million fps are possible providing good quality images for qualitative interrogation of the microscopic timescales in which fast events occur. Needless to say that recording is limited to a maximum of 16 images.

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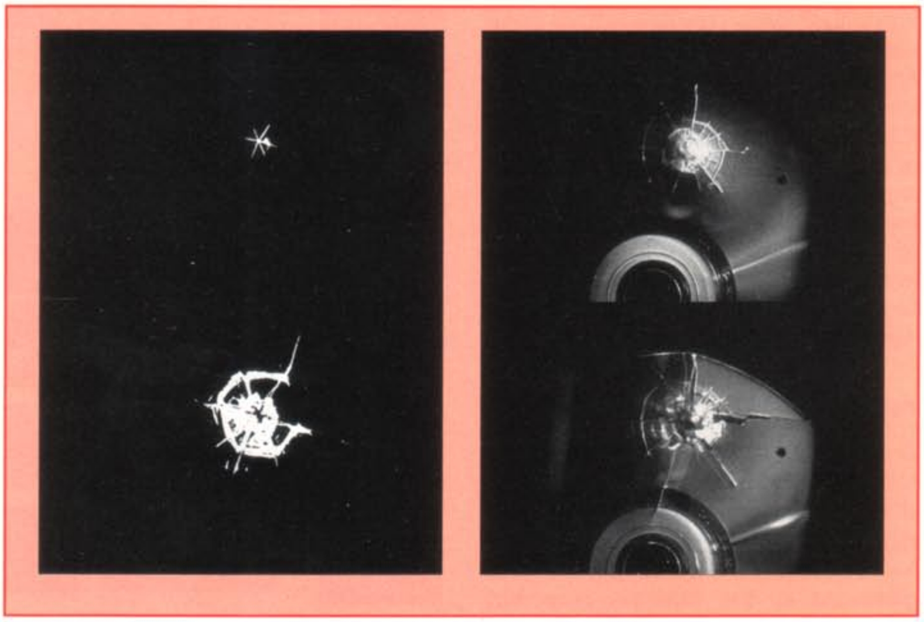

Figure 2: Crack propagating in acrylic plastic, recorded with the SIR2 (interframe time 200 μs)

The high cost of manufacturing these complex imaging systems is reflected in the price, which can be as much as fifteen times the cost of a single sensor camera. Single sensor cameras can offer full resolution framing rates of around 40 pictures per second. The single sensor high speed video camera can record full resolution images of 1000 x 1000 pixels at typical 500 pps but at faster framing rates, for example 10,000 pps, the resolution is much reduced with images of 150 x 40 pixels.

To increase effective framing rates, the trend with single sensor high speed CCD cameras has been to overlay a number of images in a single field which for applications where an object is moving in space can provide adequate detail to complement results where other means of capturing data is used. However, irrespective of the number of overlaid images captured, the sum of the information points in those images only add up to the pixels on the sensor (**figure 1**). The SIR2 on the other hand offers images with the full 4008 x 2672 pixel resolution of the sensor, the minimum separation between those images being 200 μs. The minimum exposure time is 20 ns, short enough to capture detail from very fast events. Overlaid images can be readily programmed into the set up parameters should this be considered necessary. For some investigations, overlaid images can provide relevant information, others require separate images. If the object is moving across the field of view like the golfball in figure 1, it is possible to measure its mechanical parameters. But if the two images in **figure 2** were overlaid, it would not be possible to establish the velocity of the cracks because each crack would be a continuation of the previous image so it would not be possible to say where the crack in the first image ended and the crack in the second image started

The minimum interframe time constraint is caused by the charge transfer time and further influenced by the choice of material for the phosphor screen on the image intensifier. The screen's decay characteristics necessitate this time duration to avoid degradation resulting from image retention. Phosphor screens that exhibit much shorter decay characteristics have a much reduced conversion efficiency, necessitating amplification processes that can introduce noise, which manifests itself by reducing the dynamic range of the image. The phosphor used for the SIR2 has decay characteristics of less than ten microseconds to 10% of the maximum output (**figure 3**). The lower intensity residual glow then remains for a few tens of microseconds hence the need for the 200 μs time separation between images. The image intensifier is effectively behaving as an electronic shutter to provide exposure times down to 20 ns.

An image of the event is projected onto the photocathode of an image intensifier using conventional photographic optics. This incident radiation generates an emission of photoelectrons in proportion to the incident light, these are then accelerated to a micro channel plate (MCP) electron multiplier. The transit through the MCP releases orders of magnitude more electrons and in so doing increases the available energy that is dissipated as they reconstruct the image produced on the phosphor output screen. The reconstruction of this intensified facsimile of the original subject results from the energy acquired by the electrons from the high voltage potential between the MCP output and the phosphor screen. The rare earth materials, from which the phosphors are produced, are not electrically conducting so a thin aluminium film is deposited over the surface to provide an electrical connection. This aluminium film serves a twofold purpose as it also prevents secondary emission that could result from light generated at the phosphor finding its way back to the photo cathode, although this is less of a problem in MCP intensifiers. Fibre optic or lens coupling then relays this facsimile image to the silicon based CCD sensor.

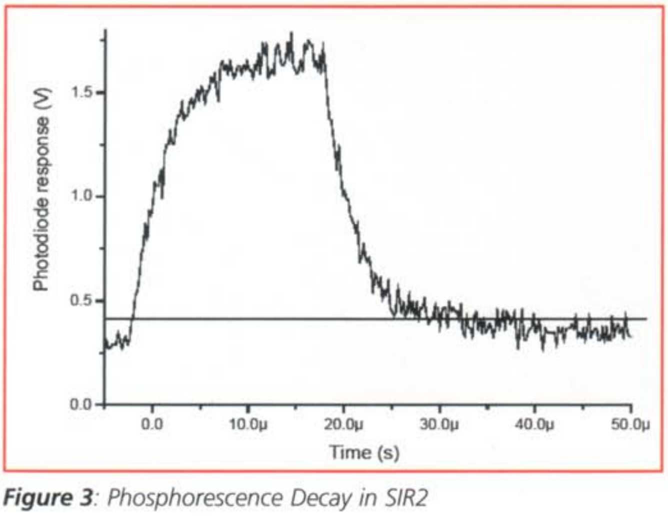

Figure 3: Phosphorescence Decay in SIR2

The ease with which the camera can be synchronised with nanosecond accuracy allows the temporal sampling of events, which may have a longer duration, and therefore the detailed capture of fast phenomena within these events. This means that high resolution results can be obtained without the need of the more expensive multiple framing cameras.

Another important benefit provided by intensified cameras is a marked increase in sensitivity, which reduces the reliance on large banks of auxiliary lighting. Whilst it would be possible to capture images without additional lighting, the high gain necessary to run the image intensifier would introduce noise, which would degrade image quality. However, short duration

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Xenon flash lamps provide adequate illumination to capture images of even the fastest events. Their small size provides high intensity for 30 µs which allows for greatly improved image quality with a minimum of inconvenience: These flashlamps do not require special power supplies as would be the case with normal tungsten illumination of similar luminosity. For events that take longer timescales, several flash units can be synchronised by the SIR2, or extended duration flash lamps can be used.

Applications

The classical field of application for high speed imaging is the evaluation of flight characteristics of projectiles and bullets. High speed projectiles for example are surrounded by a sabot to contain the gases generated by the explosive propellant. However, this sabot must be discarded on leaving the barrel so as not to slow the projectile down or reduce either the accuracy or effectiveness. Considerable interest is centred on the mechanisms of sabot separation. The images in **figure 4** were recorded by a SIR2 high speed camera, specifically designed to withstand the harsh environment encountered on the proofing range. The projectiles had velocities between 1300 and 1700 m/s, the images were displayed within a few seconds of being captured allowing the continued progress of the trial:

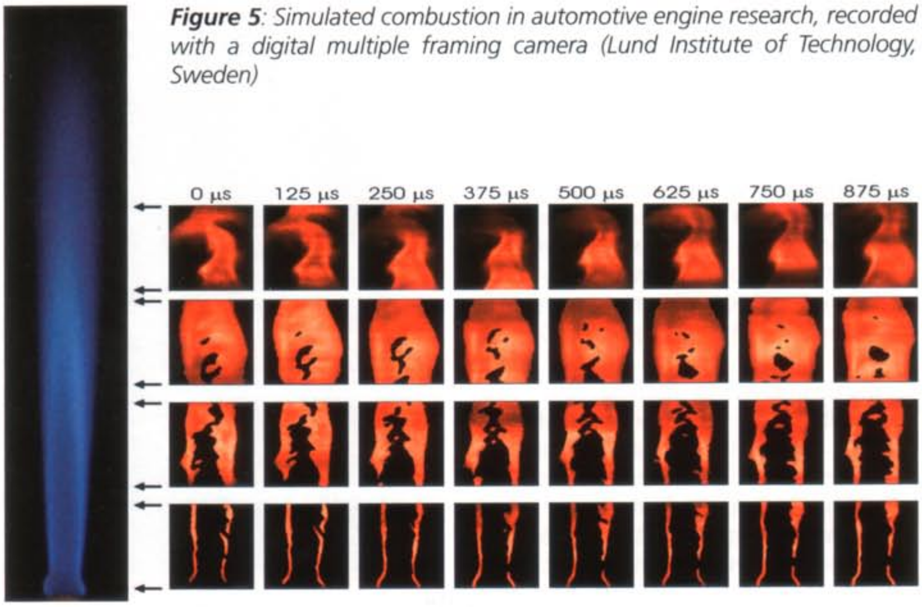

***Figure 5**: Simulated combustion in automotive engine research, recorded with a digital multiple framing camera (Lund Institute of Technology, Sweden)*

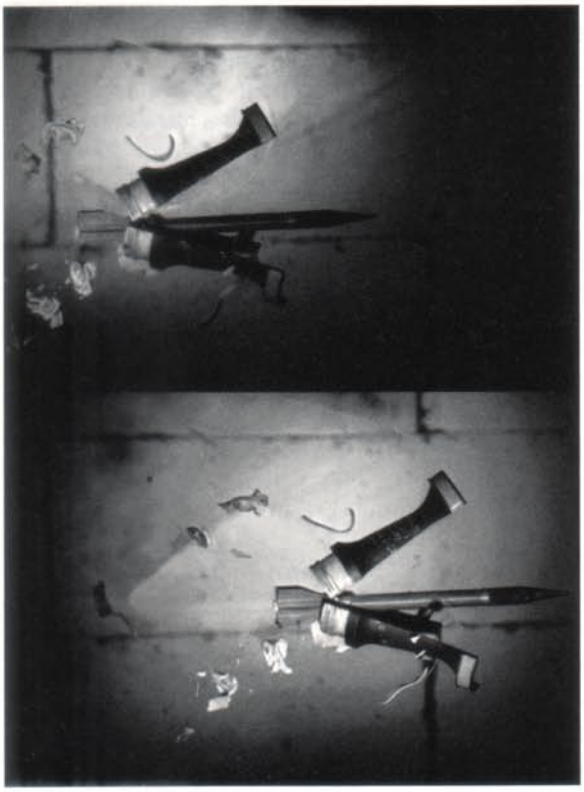

***Figure 4**: Double frame record of a 120mm FSAP (Fin stabilized armour piercing) round, recorded with SIR2 (QinetiQ UK)*

A consideration which is particularly relevant for cameras designed for recording in flight characteristics of projectiles is that the field of view covered by a long focus camera lens is quite small because of the dangerous nature of the test the camera has to be positioned quite a distance back from the flight path. This necessitates a single or double imaging device that has very high resolution that will record and resolve phenomena at long stand off distances. By comparison the multiple framing cameras are invariably used for laboratory research projects where the field of view is confined, the subject is stationary and the recorded changes occur within that subject. One example is shown in **figure 5**: the combustion physics group at The Lund Institute of Technology in Sweden recorded the flame characteristics of an experimental fuel system to help reduce emissions from automobile engines. The images enabled the researchers to analyse combustion parameters to improve engine efficiency.

Further examples, that can also be recorded with the SIR2, are crack and fracture propagation in industrial materials, cavitation around propellers, the rupturing of micro bubbles used for transporting medicines to inoperable tumours, the behaviour of the aqueous fluid in the eye to laser beams that are used to reattach retinas, shock waves generated on aircraft structures in wind tunnels – the list is extensive.

All of these applications require sequential time resolved images to temporally dissect the mechanical processes that occur in microsecond timescales. It is suggested that a picture is worth a thousand words, a sequence even more so as it visually confirms processes that are too fast for other diagnostic methods.

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