Optimize your process with high-speed imaging

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The devil is in the details of every rapid-motion process. Clues to problems, solutions, and many other significant details are often lost in observations made at original speeds.

Obvious victories like those by the American Michael Phelps and the Jamaican Usain Bolt at the 2008 Summer Olympic Games in Beijing are rare. Yet the smallest unseen advantages regularly make the difference between victory and defeat for both competitive sports and manufacturing today. For a sports example, optimized motions – the turn of a hand, the twist of a leg, the arch of the back – deliver positive results (**figure 1**). Likewise in manufacturing, high-speed cameras reveal the movements of machinery and materials. The capture and analysis of high-speed information not only improves process performance but also results in better manufacturing yields and product quality.

Competitive industrials must cost-effectively optimize their production processes. Recurring disturbances in a process cause poor quality and lower through put, and lead to production-line shutdowns. Critical phases of the manufacturing process can be invisible to the human eye because they happen too fast. In many cases, engineers and technicians may incorrectly default to assumptions rather than rely on facts to locate the cause of trouble.

However, the trial and error route to solving invisible problems is the most expensive one, unnecessarily demanding much analysis time from technical experts. Such costs and hassles can be avoided with high-speed imaging systems that provide ultra-slow-motion playback. High-speed image analyses enables technical experts to gain insight to every step of a process. And once the causes of a malfunction are visualized, the solutions are often obvious.

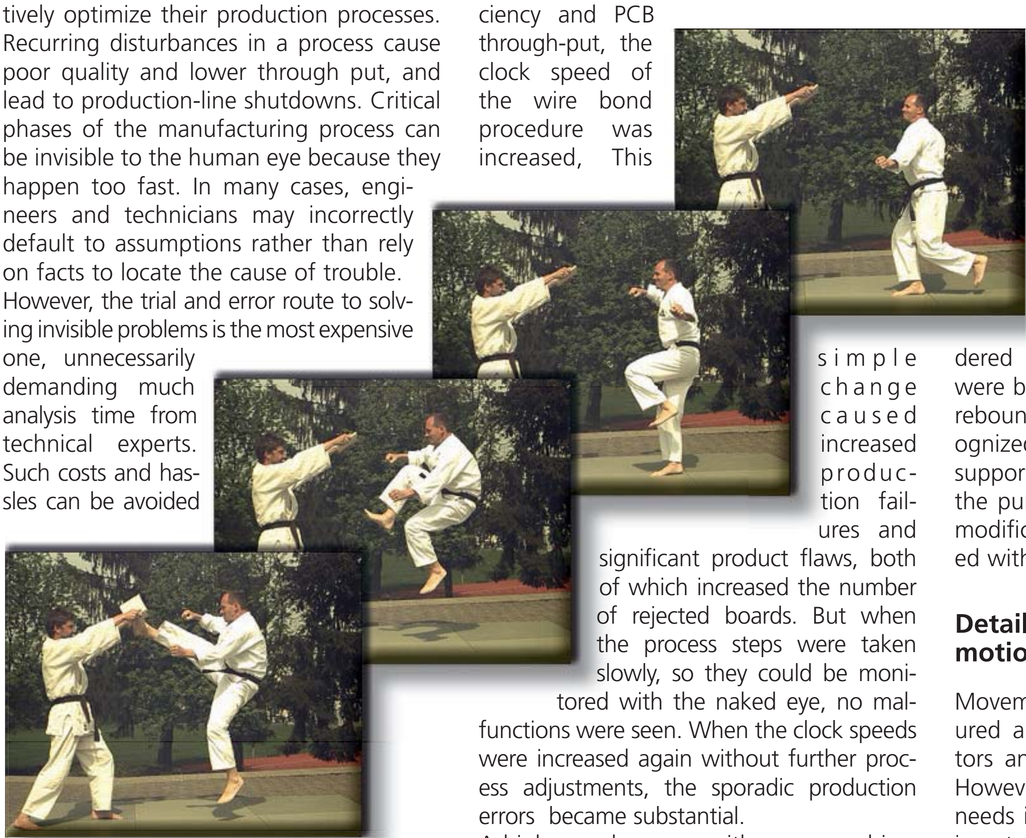

Figure 1: Martial arts motions as analysed by high-speed video images

More-rapid printed circuit board (PCB) production

In a printed circuit board (PCB) factory using pick-and-place machines, there was one case of frequent problems during the wire bonding steps, where semiconductor chips were connected to the boards by very thin wires with diameters between 25 and 50 µm.

In an attempt to improve machine efficiency and PCB through-put, the clock speed of the wire bond procedure was increased, This simple change caused increased production failures and significant product flaws, both of which increased the number of rejected boards. But when the process steps were taken slowly, so they could be monitored with the naked eye, no malfunctions were seen. When the clock speeds were increased again without further process adjustments, the sporadic production errors became substantial.

A high-speed camera with a macro objective (image field 1 x 1 mm^2) was employed, and revealed the process problem: increased oscillations occurred with the deceleration of the bonding wire supplied. The obvious solution was introducing a short delay between the wire feeding and the actual bond process – the wire needed time to settle so it could be bonded precisely. This understanding enabled a further increase of the supply speed to equalize that delay. After these modifications, the production process not only performed perfectly but also in a more cost-efficient, shortened production time.

In another PCB manufacture case, flaws occurred in the same part of the circuit board and accumulated with each PCB manufactured. This time high-speed cameras delivered a slow-motion view to fully understand each of the manufacturing steps. Technicians sought data not only when the individual circuit boards were manufactured in larger 'panels' but also after all components were placed and soldered, then separated by a combined punch-shearing procedure. The high-speed image sequence revealed that the PCBs are extremely bowed by the punchers before rebounding into the initial position (**figure 2**). Soldered joints and electronic components were being damaged during this bow and rebound cycle. After the problem was recognized, a relatively easy solution involved supporting the PCB as well as optimizing the punching tool process. The successful modifications were verified and documented with the same high-speed camera.

Detailed high-speed motion analysis

Movements of objects can also be measured and analyzed by acceleration adaptors and an adequate measuring system. However, each important part of the object needs its own acceleration adapter, which in return needs its own individual channel on the measuring system via a data link. The volume of technology involved

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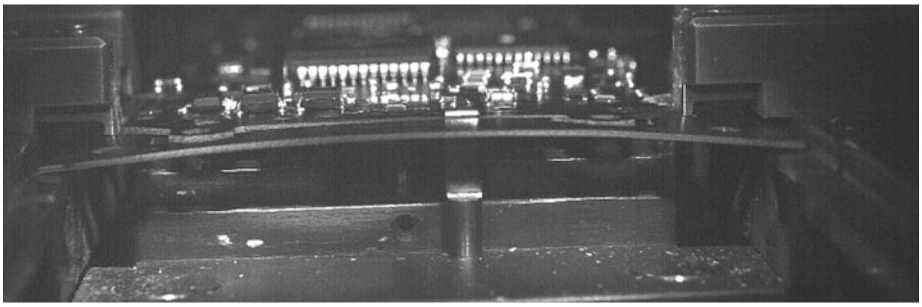

Figure 2: The high-speed X-pri camera (captured at 1000 fps with 1280 x 600 pixel resolution) reveals the deformation of individual printed circuit boards (PCBs) during the manufacturing process

becomes enormous, yet only those parts equipped with a sensor supply data for measurements. And no visual image of the motion supplied.
Alternatively, cameras set for extremely long exposure times visualize rapid motions using stroboscope illuminations, such that the object leaves multiple images per indi-

Figure 3: Stroboscope images of a bouncing basketball, captured at 25 fps (courtesy: M. Maggs / R. Bartz, Wikimedia Commons)

vidual frame (**figure 3**). Medical physicians use endoscopes and stroboscopes to analyse vocal chord movements. To be most effective the observed object should be able to be seen as isolated as possible. A dark background environment is optimal. Extremely rapid procedures can be imaged with high-speed cameras that produce more than one million frames per second. However the amount of light needed is very high, and an extremely accurate triggering is necessary. Due to the enormous amount of data created at such extreme high frame rates, the recording time is limited to a fraction of a second, often as short as a few microseconds. For such applications, camera systems with an image resolution like VGA and a frame rate of 200 pictures per second are usually adequate. There are image sensors developed especially for use at high frame rates.
Another important part of high-speed camera systems is the bandwidth of image data. Imaging systems are optimized by using the best and most modern available hardware and software technologies. The best camera systems available use rapid standard data interfaces like Gigabit Ethernet or Firewire B (IEEE1394b).
Standard data storage protocols for hard disk drives in most computers are usually not fast enough, so cameras like the AOS X-PRI use solid-state memory modules in the camera itself (with capacities up to 10 GBytes), or else the image data are transferred via fast data interfaces to the RAM of a connected computer. Using these transfer technologies, most any commercial computer can be used to store high-speed sequences that range between a few seconds to several hours.
Figure 4 shows a Promon PC portable system for high-speed imaging: including a notebook, camera, and software. Imaging systems of this kind are available for a few thousand Euros. The return on investment of such systems is often very fast as well, especially when the costs of production interruptions, time-consuming improvement attempts, product losses, and sinking customer satisfaction flow into the cost-use calculation.

Various applications

Aside from the optimization of manufacturing processes, high-speed camera systems are used in many other applications including: process development, material tests,

Figure 4: Promon PC portable high-speed imaging system: a notebook computer, high-speed camera, and software

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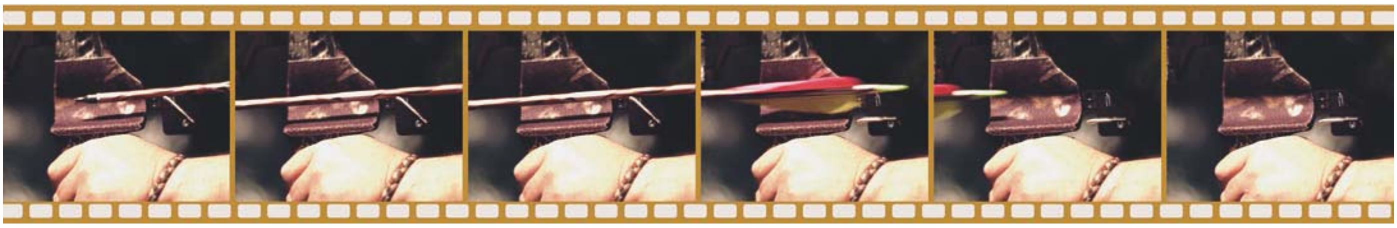

Figure 5: An archery bowstring release sequence captured at 1000 fps with 800 x 600 pixels resolution

and tool optimization, and the documentation of prototype developments. Additional equipment is helpful in some high-speed imaging applications. For example, an endoscope can be attached to a high-speed camera to access difficult places to gather data. Similarly, discovering small holes of just a few millimetres in the housings of printing presses remedies their malfunction in photograph productions.

High-resolution trade-offs – even faster or more details

Higher resolution high-speed cameras image even faster and more detailed events. With 1280 x 1024 pixels resolution, the high-speed camera can capture the smallest details or achieve reduced resolution images with framing rates of up to 32,000 images per second. For example, high-resolution, high-speed cameras can capture the details on bursting material tests or production flows of beverage cans. Adaptable high-speed camera systems are needed to analyse and optimize the performance of archery athletes, where frame rates of 1000–2000 pictures per second are required (**figure 5**).

Conclusion

A wide variety of applications depend on image analyses enabled by high-speed cameras, including those in research, engineering, medicine, manufacturing, and sports. Capturing and recording images of rapid events no longer requires specialists and unique systems. Instead, high-speed camera systems can be customized to most every requirement.

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