High-speed Photography with a Still Digital Camera

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12/2/99

Abstract

High-speed photography involves capturing images of fast events, traditionally on film. This is usually done by illumination of the subject with a flash of very short duration to obtain a sharp, clear image of the event. By employing a digital still camera, these images can be taken with instantaneous results, eliminating the need for film or developing processes. By finding a way to time the event with the shutter and flash of the still digital camera, it is possible to obtain good digital high-speed images. Using these techniques, high-speed photographs were taken of balloons burst by a BB traveling approximately two-thirds of the speed of sound.

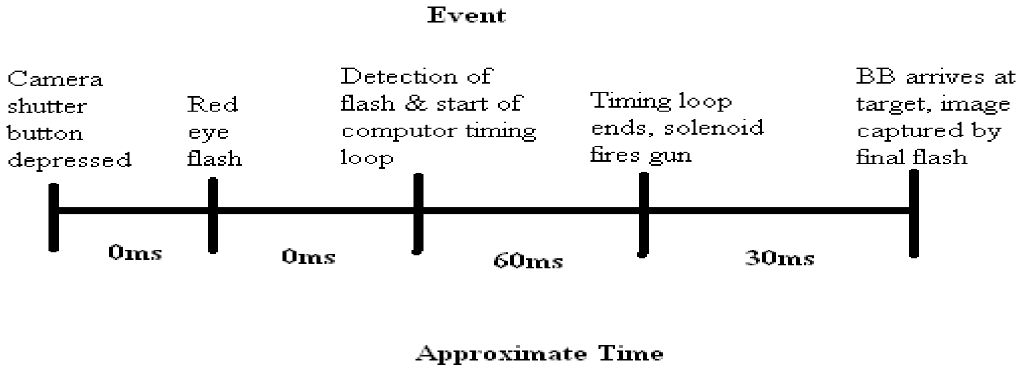
Presentation of Problem

In high-speed photography, it is usually possible to open the shutter of the camera before the event being photographed is to occur, and capture the image with a flash. This flash is precisely triggered to illuminate the high-speed event in progress at the desired instant. This process is made difficult by the digital still camera's shutter speed being short, making co-ordination of the fast event, flash and shutter difficult. This is because the digital camera uses a CCD, or charge-coupled device to capture the image. This takes the place of a mechanical shutter in a conventional camera. The CCD cannot be controlled manually in the camera used, and only stays open for a few milliseconds. Because it is not possible to trigger the shutter of the digital camera externally, it is necessary to ensure that the flash and event happen during the short time that the shutter of the camera is open. By triggering the event with the camera's pre-flash and a delay, it is possible to have the shutter, flash and event coincide.

In his experiments, Andrew Davidhazy used a similar technique and made successful digital photos using an Agfa ePhoto 1280 camera (1). Davidhazy used this digital camera in combination with a microflash unit to produce sharp images of a .22 caliber bullet passing through a playing card. In his experiments, a timing circuit driven by a 556 timing IC did the timing between the camera and the gun. In the present experiment, timing was done by the Apple II+ microcomputer. Also, the camera's flash was used for the photographs instead of an external source as in Davidhazy's experiments, as extremely short flashes were not needed for the slower air rifle.

Description of Technique (subdivided)

Timing of all the events for a photograph is quite complicated. The events fall as they appear on the following time line.



To make it possible to co-ordinate the event to the time when the camera's shutter is open, the pre-flash must be used to signal the high-speed event. For this experiment, a BB traveling at approximately two-thirds of the speed of sound was chosen to photograph. The solenoid was connected to the air rifle trigger (3). This allowed the gun to be fired electrically. The first step in the experiment was to find the timing of the flashes of the digital camera. This was made difficult by the camera's circuitry, which refused to take a picture in the dark. The solution that made this experiment possible was ‘tricking’ the camera with a flashlight as the shutter button was depressed half way. This set the exposure lock, and the camera would then work in complete darkness as long as the shutter button was held at this half way position after the flashlight was removed.

From observation of the flashes in red-eye reduction mode, it was evident that the camera used, an Olympus D600-L, was producing more than just a pre-flash and a final flash to capture the image. There appeared to be at least two pre-flashes. In order to determine the timing of these flashes, a rotating disk was used in conjunction with a digital video camera. A Cannon Optura in progressive scan mode was used. The disk was black with a white stripe, and was attached to an electric fan motor with variable-speed controller. The rotating disk used was set to a relatively slow rate of 400 rotations per minute for the experiment, to ensure that the disk did not rotate around more than once when the flashes were discharged. The digital video camera was used capture images of the disk as the camera photographed. From the digital videotape, the disk was visible in three positions in three separate video frames as a result of the camera’s flashes. The times between each successive image were calculated using the frequency of the disk and through which it rotated between images. This calculation yielded the time between the pre-flash and the final camera flash that was used to take the image. This time was later needed to calculate the delay time for the solenoid.

Having measured the time delay between the first pre-flash and main flash for the digital camera, the amount of time for the gun to fire and the BB to arrive in the camera’s field of view was found. This factor is dependent both on the speed of the BB as it exits the gun barrel, and the time between solenoid activation and the BB exiting the barrel.

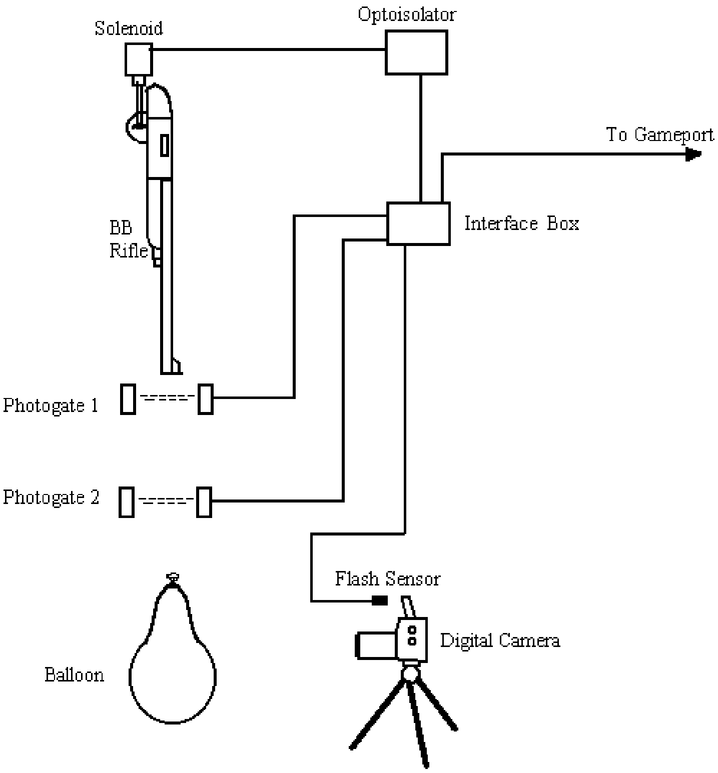
Precise timing was needed to measure both of these times, and the Apple II+ computer was used.

The Apple II+ was equipped with a software program that was designed to measure the two time intervals (3). The interface between the computer and the gun stand was connected to the game port of the computer (2). This interface was in turn connected to two photogates, one directly at the end of the barrel of the gun and the other 10cm away. The box was also connected to an optoisolator, used to fire the solenoid. The software fired the solenoid and ran a timing loop in assembly code until the BB passed through the first photogate (4). A second timing loop was then started, and ran until the BB passed through the second photogate. The assembly code loops on the Apple II+ require a certain number of clock cycles, each of which takes a certain amount of time. By counting the number of times the timing loop runs very precise times can be found. The program then multiplied the number of loops by the amount of time per loop to obtain the time value. The first time was the acceleration time of the BB, the time between the solenoid pulling the gun trigger and the BB passing through the first photogate. In this time, the BB is accelerating inside of the gun barrel. The second time given was the time to pass between the two photogates, 10cm apart. This value was used to measure the speed of the BB as it left the gun.

Combining the results from these two experiments, photographs were taken. By subtracting the gun delay time from the time between the first and last flashes, the value for the delay loop was found. This value is how long after the pre-flash that the computer waits before the gun is fired. The value for this delay loop was then entered into an intervalometer program on the Apple II+. This program waits for a signal from a phototransistor placed near the flash of the camera. Once this first flash was detected, the program waited a set amount of time, and then fired the solenoid. This computer control allowed for easy and precise adjustment of the time delay.

Apparatus and Techniques

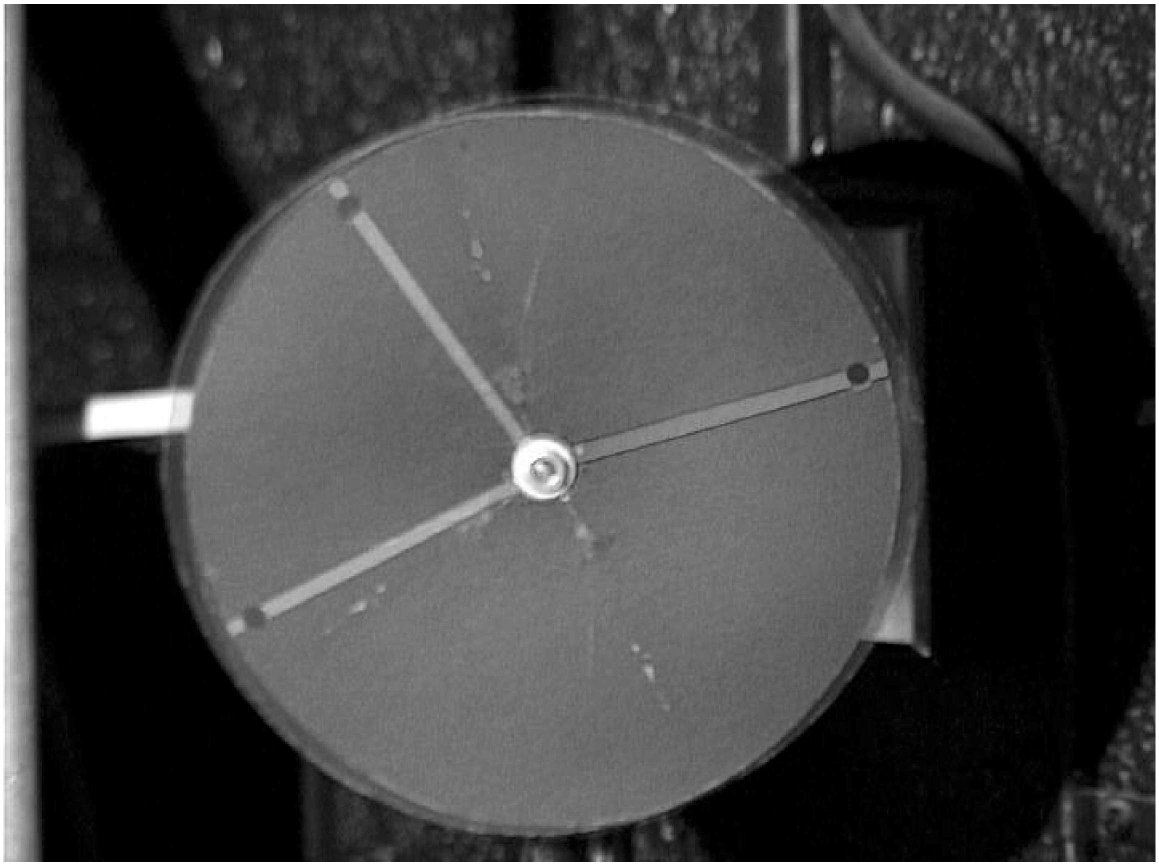
The gun and sensors were arranged according to this diagram. The interface box was connected to the Apple II+, and the various inputs were connected.



The gun used in the experiment was housed in a stand vertically, firing down into the target. The stand also held the two photogates used in the experiment, and provided a place to mount the solenoid linked to the trigger. The target, in this case a balloon, was suspended from the stand near the floor. This arrangement was used with the digital camera on a short tripod. The flash sensor and both photogates were connected to the interface directly. The solenoid was connected through an optoisolator, which eliminated the possibility of damaging the computer with the high voltage of the solenoid.

Discussion and Analysis

From the spinning disk experiment, three fames of video captured the disk in three different positions. These three frames were overlaid so that measurements could be taken more easily.



The three flashes of the digital camera illuminated the spinning disk. The disk was rotating counter-clockwise. This image is an overlay of three video frames.

The angle between the first and second, and second and third disk image was 81^o and 170^o respectively. The disk frequency was measured with a stroboscope to be 400 rpm, or 2400^o s^{-1}. The time between the first and second flash was found to be 33.8 ms and the time between the second and third 70.8 ms. The total delay between the pre-flash and final flash was 104.6 ms. This value was sufficiently large to allow time for the gun to fire between the flashes. The uncertainty in the measurements comes both from the speed of the disk that is always changing slightly and the measurement of the angles produced, and is estimated to be ±5%. This measurement was taken from a printout of the overlaid image of the three disks.

Finding the delay between solenoid activation and the gun firing proved to be more difficult. This process was dependent on two photogates that detected the BB as it left the gun. Sensitivity of these photogates was an issue in detecting the fast moving BB. This problem was solved with the addition of a potentiometer, a variable resistor used to increase the resistance of the phototransistors to just below the threshold. This allowed for a smaller resistance increase to be detected, making the circuit more sensitive. The schema for the detector and emitter are shown below.

With the potentiometer installed, valid data was obtained. The delay between solenoid activation and the BB arriving at the end of the barrel was determined to be 31.7 ms, and the time between the two photogates was 0.455ms. Using the distance between these two, the BB was determined to be traveling 220m/s ± 11m/s as it left the gun. The uncertainty has been estimated to be 5% of the speed calculated.

The uncertainty is due to the variation of the gun between shots. As it is a mechanical process, variations of this magnitude were recorded in the data.

With all of the delay times known, the two parts of the experiment were combined to begin taking photos. Subtracting the BB acceleration time of about 33ms from the time between the pre-flash and final flash of 104ms, the delay between the pre-flash and solenoid activation was found to be 71ms. This delay was entered into the intervalometer program on the Apple II+. A balloon was first used for testing the timing of the apparatus, because it gave clear indication if the BB had already passed through, or had not yet arrived. Through trial and error adjustment, a delay loop time of about 56 ms was determined, and several good photos of the balloon mid-burst were taken using these settings.

The BB has just passed through the balloon, and is visible at the bottom of the frame, having been shot from above. The balloon has ripped up one side completely, and a partial rip is visible in the center.

This photo was taken much later in the burst than the photo to the left. The balloon has completely ripped into fragments.

Some of these photos were out of focus, which was attributed to the flashlight 'tricking' procedure before each photo. By using a flashlight to trick the camera into taking a picture in the dark, the auto focus mechanism was focusing on the flashlight as well.

Because this process was not perfectly repeatable, the focus of each photo varied. This produced some crisp images, and some that were out of focus.

In order to eliminate this focus problem, the focus lock option of the camera was used. This involved setting the camera to take pictures with a set distance each time. In this mode, the camera did not require an automatic exposure setting, so the flashlight procedure was eliminated in this mode. Several photos were taken, and it was discovered that changing into focus lock mode also changed the flash timing of the camera. Again using experimentation, the solenoid delay was found to be twice as long of that before, or about 120ms in this mode. The focus lock not only allowed more delay time for the event, but solved both the focus and exposure problems as well. Several more

In this photo the BB has entered the water from above, and is the blurred copper colored streak near the bottom of the image. The cavity left behind is clearly visible, but is quite blurred.

This image was taken at a later point in the water entry, and the cavity left has separated in the middle. Less blurring in this image is likely the result of slower speeds.

photographs were taken with these new settings, producing consistently clear images of the bursting balloon. Photos were also taken of the BB entering a tank full of water instead of the balloon. These photos were very consistent in the timing of the BB. In several successive images, the BB was nearly in exactly the same position in the tank. This is a testament to the repeatability of the experiment and the precision of both the BB gun and computer timing device. The images taken in the water tank were blurred, not giving sharp detail of the motion of the BB or water. This was due to the automatic adjustment of the flash duration by the camera by reflected light. Bright subjects reflect more light, and the camera detects this. Because more light is reflected, the flash does not need to be as bright, and lasts for a shorter time. In the balloon tests, the balloon was close to the camera and very bright, the flash was set to be short, eliminating blurring. In the water tank, the black background absorbed much of the flash, causing the camera to use a brighter and longer flash, which resulted in blurring. One way to eliminate this problem is to choose bright subjects like the balloons, and photograph them from short distances. The addition of an external flash would allow almost any subject to be photographed.

Conclusion

The still digital camera was successfully used to take high-speed photographs. This process was repeatable, and produced clear images of the bursting balloon in the first experiment. The timing sequence was precise enough to expect to obtain a good image of the bursting balloon in about one in every two trials, as variations of two milliseconds allow time for the balloon to pop completely. This trial and error nature of the experiment can be linked to the mechanical portion of the experiment, the firing of the BB gun. The camera and computer are both very precise in their timing, being digital devices. Neither device would be expected to produce variation greater than .1ms. The process of firing the gun mechanically must be the cause of the variations experienced.

The blurring of the image in the water tank photographs was a result of the camera's flash being controlled automatically. The photography of balloons produced clear images because of the brightness of the object being photographed and its location close to the camera. This worked well in the balloon experiments, but caused blurring in the water tank photographs. Because there is no control over the camera's flash, the only way to amend this problem is through the use of an external flash, the next goal of experimentation with this camera.

Acknowledgements

Dr. Loren Winters was a great help during this study from beginning to end. He supplied the electronics, camera equipment, and knowledge to make the experiment possible.

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