Experimental Methods and Instrumentation in Physics
10467
High-Speed Digital Video and Image Analysis
June 2007

The goals of this exercise are to learn how to use high-speed digital video to investigate fluid flows and other types of complex systems and to get familiar with simple image processing tools including edge detection. The ideas will be illustrated by observing drop formation and drop oscillations in a simple setup and measuring the oscillation period and amplitude.

Introduction

In experimental complex systems physics and fluid mechanics the goal is to investigate structures and instabilities in fluids, granular materials, and soft condensed matter. The phenomena are often spatially extended and time-dependent macroscopic processes, which can be investigated conveniently using standard digital video with recording rates of typically 30 frames per second. Some phenomena, e.g., drop formation, are very fast and standard digital video does not provide the necessary time resolution. In such experiments it is advantageous to use high-speed digital video with recording rates of maybe 1000 frames per second and sometimes to go to very high recording rates like 100.000 frames per second. Digital video is either used directly to observe, e.g., the water surface during the break-up of a water jet into drops, or as component of a more involved experimental method, e.g., particle image velocimetry, which is designed to measure velocity fields in fluid flows by following tracer particles. The article by Brenner et al. (1995), see Appendix A, shows an example of a simple but very interesting experiment in which drop formation is investigated directly by observing the drop shape. The goal in the experiment is to measure the time evolution of the surface shape (top) and to compare the result with a theoretical model (bottom). In the drop experiment the digital images should be processed to identify the surface to make a quantitative comparison with theory. Some image processing tasks, e.g., finding the surface using edge detection, are fairly easy, whereas others, e.g., matching tracer particles in particle image velocimetry to obtain velocity fields, are complicated and can only be carried out using advanced algorithms.

High-Speed Digital Video and Drop Formation

The fluid mechanics laboratory at the Department of Physics has a high-speed digital video camera (Phantom v4.2, see Appendices B, C, and D) which we will use to investigate drop formation and drop oscillations.

1. Assemble the simple setup to study drop formation, set up the illumination, mount the high-speed digital video camera, connect the camera to the PC, and open the Phantom camera control software.

2. Get familiar with the camera settings, including image size (spatial resolution), frame rate (temporal resolution), and exposure time by adjusting the parameters using the camera control software. See the maximum recording speed versus image size table in Appendix D.

3. Record and store movies of drop formation and satellite drop oscillations at different frame rates. First try the standard frame rate of 2100 frames per second and the highest spatial resolution.

4. What is the highest frame rate that you can go to in the setup, and what is the best choice of frame rate to study drop pinch-off and drop oscillations given the limit on the size of the camera memory?

5. Record a reference image to obtain the image length scale.

Image Processing Using Camera Control Software

The camera control software contains simple image processing functions for intensity transformation and edge detection.

1. Open a cine file and check the information on image size, frame rate, and exposure time. Investigate the effects of adjusting brightness and contrast in the camera control software under image processing.

2. Go to filter and edge detection. Apply the edge Hipass, the edge Laplacian, the edge Prewitt, and the edge Sobel algorithms to a movie sequence and investigate the various edge detection methods.

Drop Oscillations: Period and Amplitude

The period and amplitude of the oscillations of the satellite drop formed in the pinch-off process can be obtained from the image sequence.

1. Estimate the drop volume and the drop oscillation period for the satellite drop formed in the pinch-off process. Use the reference image to convert from pixels to centimeters to get the dimensional volume.

2. In 1879 Lord Rayleigh modelled small amplitude oscillations of a spherical drop under the action of surface tension. Lord Rayleigh showed, see reference 2, that the lowest oscillation mode has the period:

$$T = \sqrt{\frac{3\,\pi\,\rho\,V}{8\,\alpha}}\,, \tag{1}$$

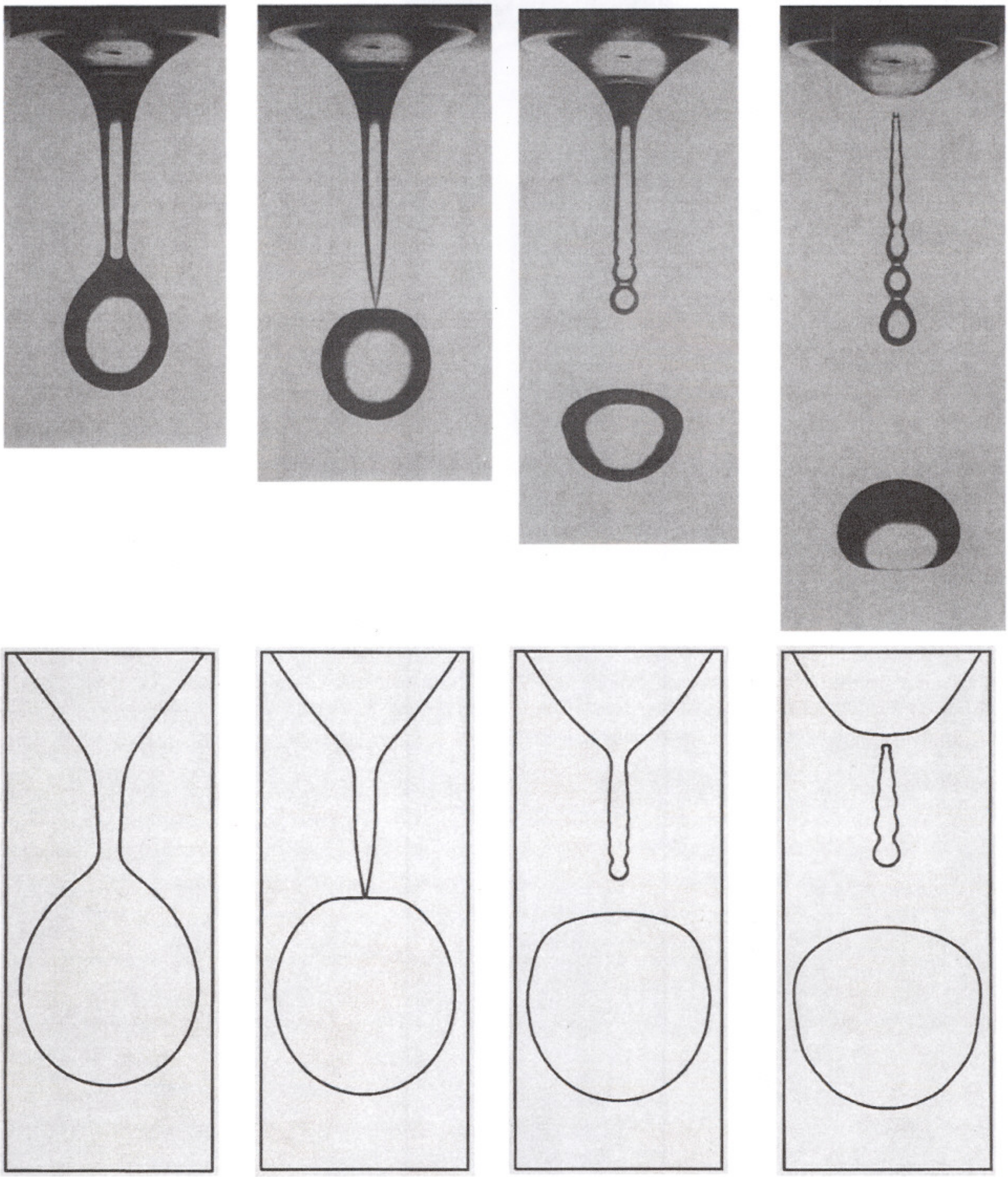
   where ρ is the density of the liquid, V is the volume of the drop, and α is the surface tension of the liquid-air interface. The density of water is $\rho = 997\,\mathrm{kg\,m^{-3}}$ and the surface tension of a water-air interface is $\alpha = 72.0\,\mathrm{mN\,m^{-1}}$ at 25°C. How does the experimental result compare with the oscillation period found by Lord Rayleigh?

3. Open Matlab and use the image analysis program to find the satellite drop shapes using the Sobel edge detection algorithm. Determine the period and amplitude of the drop oscillations accurately from the image sequence and compare with Lord Rayleigh's result.

Further Reading

1. Digital Image Processing Using Matlab, R. C. Gonzalez, R. E. Woods, and S. L. Eddins, Pearson Prentice Hall (2004).

2. Lord Rayleigh, On the Capillary Phenomena of Jets, Proceedings of the Royal Society **29**, 71–97 (1879).



THE BIFURCATION OF LIQUID DROPS

Submitted by Michael P. Brenner, X. D. Shi, Jens Eggers, and Sidney R. Nagel
(Massachusetts Institute of Technology)

The breakup of fluid drops is one of the simplest and most ordinary examples of a hydrodynamic singularity, in which physical quantities diverge in a finite amount of time. These pictures document our experiments and computer simulations of the falling of a water drop falling from a nozzle. In the top panel we show a sequence of photographs[1,2] in which the drop firsts breaks at the bottom and then near the nozzle. The second row shows a numerical simulation of the process using modified long-wavelength equations.[3]

phantom v4.2

PHANTOM

Based on its award winning predecessor the Phantom v4.2 offers 2,100pps at its full resolution of 512x512 active pixels, with allocations up to 90,000pps!

Every day previous versions of the Phantom v4 camera system are successfully collecting data from critical tests. The v4.2 continues this tradition of performance and customer confidence by incorporating new and useful features that further extend this camera's horizons.

The v4.2 receives our advanced SR-CMOS sensor to improve the already excellent image quality that has always been expected from previous versions. Our customers expect excellent performance, and v4.2 delivers by effectively tripling the ASA/ISO sensitivity of previous models. Now all image sizes (aspect ratios) selected during setup are centered on the sensor's midpoint, and the Continuously Adjustable Resolution feature permits screen size adjustment in 16x8 pixel increments. The slightly smaller v4.2 includes Gigabit Ethernet to simplify camera network communications and speed file transfers.

- ***10-bit SR-CMOS sensor composed of 512 x 512 pixels; color or monochrome***
- ***2,100 pictures per second full resolution, up to 90,000pps maximum***
- ***"CAR" (Continuously Adjustable Resolution) in 16 x 8 pixel increments***
- ***4800 ISO/ASA monochrome, 1200 ISO/ASA color sensitivity equivalency***
- ***Global (snap-shot) on-chip shuttering to 10 microseconds, (optional 2 µs)***
- ***"EDR" Extreme Dynamic Range ™ exposure control***
- ***Auto Exposure control***
- ***Up to 2 Gigabytes DRAM, 6 Gigabytes non-volatile flash memory (optional)***
- ***IRIG-B timing capture, modulated or unmodulated, IRIG lock w/phase shift***
- ***Continuous video output (RS-170 (NTSC, PAL), SDI)***
- ***Rugged HYGE configuration (optional)***
- ***Gigabit Ethernet or RS232 control***
- ***100% compatibility with Phantom v4, v5, v6, v7, v9, and v10 cameras!***

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v4.2
Specifications

PHANTOM

Features

Auto Exposure
"EDR" Extreme Dynamic Range™
HYGE configuration (optional)
Continuous recording
Pre-trigger recording
Post-trigger recording
On chip global shuttering
Strobe sync
Segmented image memory
Continuous color video output
IRIG-B timing capture with phase shift
10/100/Gigabit Ethernet

Sensor: 512 x 512 pixel SR-CMOS sensor.

Image Bit Depth: 10-bit

Sensitivity: 4800 ISO/ASA mono-chrome, 1200 ISO/ASA color

Pictures per Second (PPS): Full sensor; to 2,100pps

Exposure Time: Variable, independent of sample rate, to 10 microseconds (2 microseconds option)

Trigger: Continuously variable pre/post

Imager Control: 10/100/Gigabit Ethernet, or RS232 serial interface

Preview and Focusing: Via computer monitor or continuous video out

Lens Mounts: 1" C-mount standard. Many other lens mounts available, including Nikon

Inputs/Outputs: via integrated quick-release connector:

Trigger: Rising/falling TTL pulse w/filter, or switch closure

Sync Image: TTL pulse

Event Marker: TTL pulse or switch closure

Ready Signal: TTL pulse

IRIG-B Timing: IRIG-B code, modulated or unmodulated input, with IRIG-B output, lock, and variable phase shift

Strobe Sync: TTL Pulse

RS232

Network: 10/100/Gigabit Ethernet

Video out: RS-170 (NTSC, PAL), and SDI (Serial Digital Interface)

Power: 24VDC/1.0 Amp

MEMORY

Standard: 256 Megabytes integral image memory. Records 1,024 images for 1 second of continuous recording at 1,000pps, full format. Longer recording times for lower sample rates and allocated formats (example: 10 seconds at 100pps).

Optional: Up to 2,048 megabytes of integral image memory. Records 8,096 images for 8.0 seconds continuous recording at 1,000pps, full format. Longer recording times for lower sample rates and allocated formats (example: 80 seconds at 100pps).

Optional: Non-Volatile Flash Memory, up to 6 gigabyte (recommended for all HYGE applications)

ENVIRONMENTAL

Ambient Temperature
32°F and 104°F (0°C and 40°C)

Maximum humidity: 80%, non-condensing, at 5°C

SOFTWARE

Phantom® operates in a Windows environment with familiar commands found in familiar places. Standard functions include:

Acquisition: Image capture, IRIG-B timing capture & standard time annotation. Field of view & focus. Sample rate & aspect ratio selection. Shutter speed. Histogram. Brightness, contrast, & gamma adjust. Trigger modes. Continuous record. Save & recall setups.

Analytical playback: Immediate playback of cine. Variable playback speed in forward or reverse, including freeze frame & endless loop. Random Go-to-Image. View single images at random from any cine. Tile/cascade multiple images on one screen. Timing data displayed with each image. Cine editor. Multi Cine Viewer.

Measurements: Linear or angular measurements. Displacement. image. English and metric units. Generate Velocity. RPMs. 100 data points per measurement reports. Report files & images are compatible with spread sheet software, and image analysis software such as TrackEye®, Image Express®, or Falcon®.

Image processing: Smooth, sharpen, psuedocolor, negative image, and edge detection. Brightness, contrast & gamma adjust. 3x3 and 5x5 filter matrix for custom image processing.

File management: Organize, save, compress and export cines, or single images. File formats are compatible with most word processing, desktop, publishing, and presentation software.

DIMENSIONS

Size: 4.25 x 3.37 x 8.25 inch (HWD) (10.8 x 8.56 x 20.96 cm) (HWD)

Weight: 4.5 lbs (2.0kg)

Power: 24VDC/1 Amp

Mounting: 1/4-20 inch and four 10-32 threaded hole pattern in base and top

Mounting Axis: Any position

Material & Finish: Machined aluminum housing, plated finish

Country of Origin: The United States of America

STANDARD ACCESSORIES

Phantom® software, Single user license*

256 Megabyte integral image memory

Ethernet, Sync output pulse, trigger, pretrigger, video out, and IRIG-B

110/220VAC -24VDC International Power Adapter, 12 foot (3.7 m) power cord

One year warranty

QUESTIONS?

For technical assistance, systems integration, custom options, or information on imaging techniques or training please call us tool free:

1.800.RESOLUTION

(US & Canada 1.800.737.6588)

For the most up-to-date information, specifications and options, please visit our website:

www.visionresearch.com

VISION RESEARCH

Specifications and features subject to change without notice.

(Other options available) Phantom is manufactured in the USA under US Patent Number 5625412 and patents pending. Phantom®, EDR®, and Memory Gate® are registered trademark of Vision Research Inc. Windows™ and Windows logo are trademarks of Microsoft Corporation.*

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Rev 11/9/06

PHANTOM®

v4.2 Maximum Recording Speed vs. Image Size

The Phantom v4.2 camera system can record up to 2,100 pictures per second using the full 512 x 512 pixel SR-CMOS imaging sensor array. The operator may also specify other aspect ratios to increase speeds or extend recording times.

The chart below details the Phantom v4.2 aspect ratio choices available in the setup screen pull down menu. Using the CAR (Continuous Adjustable Resolution) feature, speeds between these values are continuously adjustable in 16 x 8 pixel increments.

Resolution	Rate
512 x 512	2,100
512 x 384	2,840
512 x 256	4,219
512 x 128	8,196
512 x 64	15,625
320 x 240	6,622
256 x 512	4,219
256 x 256	7,407
256 x 192	9,708
256 x 128	14,285
256 x 64	25,641
160 x 120	20,408
128 x 128	22,222
128 x 64	38,461
64 x 64	52,631
32 x 32	90,000

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