Project DropSplash: Full Documentation And Quick-Start Guide

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Fall, 2016, Independent Study
For Professor Hertzberg

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QUICK-START GUIDE

INTRODUCTION

This quick-start guide will help you to get started taking quality pictures with the DropSplash kit as quickly as possible. Before you start, you should know that this is a highly trial-and-error intensive process. It's fun and rewarding when you finally get a beautiful picture, but a good bit of patience will be necessary before then. We recommend taking at least 4 hours if you want high-quality pictures.

You will likely run into various frustrating problems. Luckily, we have already encountered most of them and have compiled a troubleshooting section to help you out! Read the set-up instructions carefully before putting anything together, relevant pictures have been hyperlinked for your ease.

The troubleshooting guide, help with camera settings, advice for taking quality pictures, as well as some miscellaneous notes can be found in the full documentation at the bottom of this document. Various pictures with associated settings can be found in Appendix A. These will prove **extremely helpful** in your quest to capture the best moments in the life a Worthington jet. Hyperlinks in this document will link to other sections in the guide, not external resources.

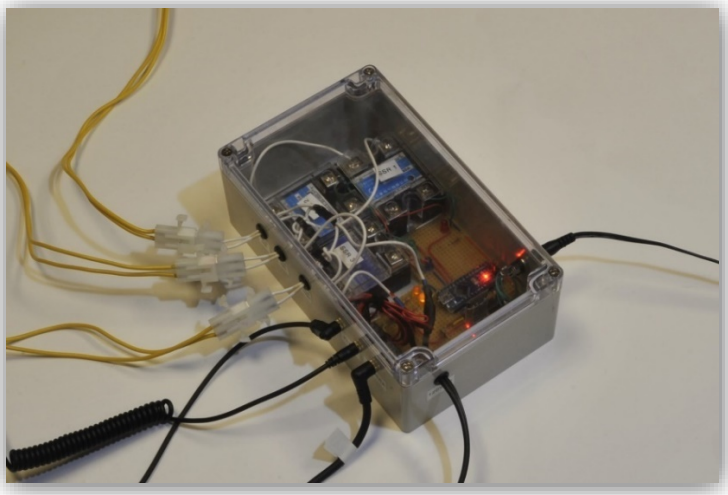
We extensively used resources provided on dropcontroller.com (Currey 2016), and are very thankful for the time and effort that was put into this open-source guide. If you need any extra help, this is a great place to look.

*Note that the table of contents can be docked to the left side of the page in word and word online through:

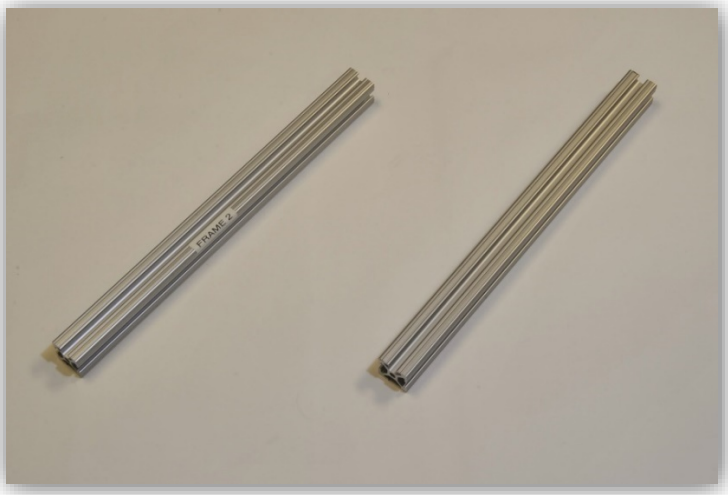
View->Navigation Pane.

KIT INVENTORY

Project Box



Frame 1 and 2: Feet

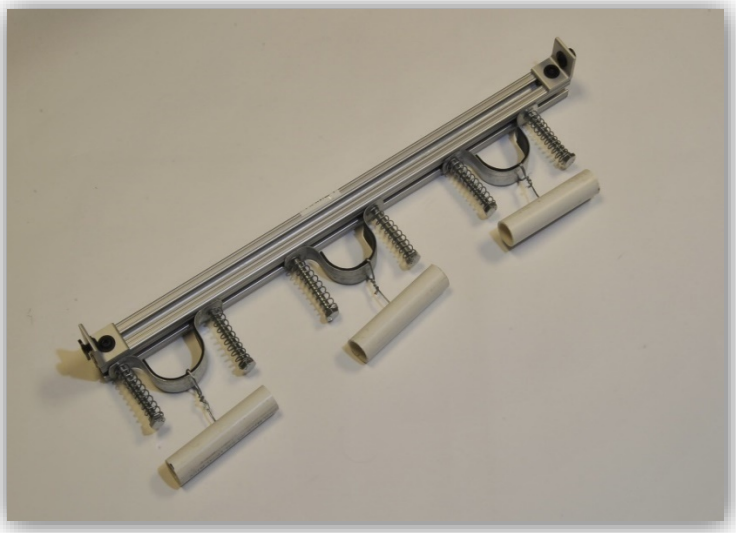


Frame 3: Tall leg with Alan wrench

Frame 4: Tall leg

Frame 5 and 6: Cross beams

Frame 7: Cross beam with reservoir mounts

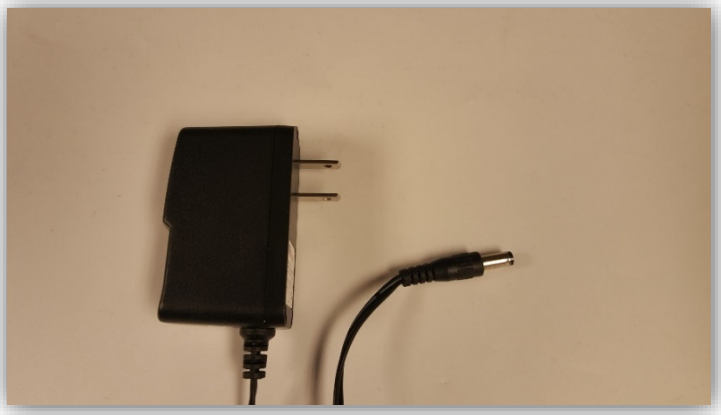


Solenoid valves x 3

Reservoirs x 3

Flash and Diffuser x 2

Wall Wart (5v DC power supply)



3.5mm to PC port cables[1]

3.5mm to Nikon Remote Release cable

[1] Cords have various connectors. One of the 3.5mm to PC port cables includes an extremely long PC Male to PC female. The 3.5mm to Nikon Remote Release cable actually consists of a 3.5mm Male to 3.5mm Male cord, a 3.5mm female to 3.5mm Female adapter, a 3.5mm Male to 2.5mm Female adapter, and the 2.5mm Male to Nikon Remote Release port.

Bag of extra 80/20 nuts

You will need:

- Camera
- Tripod
- Clear tabletop
- Camera remote release cable (if not compatible with Nikon) with 3.5mm male jack

Figure 1: Full DropSplash kit assembly

STAND AND VALVE SETUP

Find the pieces of aluminum framing labeled Frame 1 and Frame 3. Connect these in a T-shape by sliding the nuts on the end of the corner bracket assembly of Frame 3 into the slot on Frame 1 as seen in Figure 2, then lightly tighten the screws down using the Allen wrench attached to Frame 3**. Make sure not to tighten anything too tightly**, or the 80/20 nuts will become jammed in the slots. Repeat this process with Frame 2 and Frame 4 to end with two T-shaped pieces (Figure 3). Set these aside for a later step.

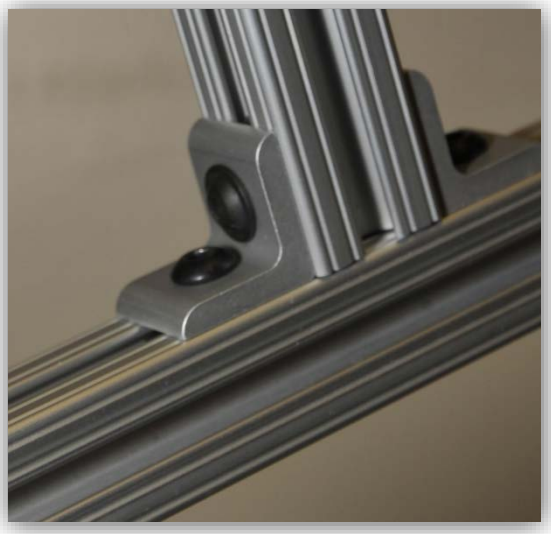


Figure 2: Side (F3/F4) to foot (F1/F2) attachment

Figure 3: Frame sides

Frame 5 and Frame 6 are interchangeable, and both act as mounts for valves and allow for height variation and angle adjustment. Attach Valve A to the bar by sliding the nut into the slot, and tighten it down lightly with the thumb screw. Extra 80/20 nuts can be found in a small separate bag, if needed. Make sure the frame piece is oriented with the corner assemblies pointing up, and the valve attached to the front, hanging down (Figure 4). If this is your first time using the DropSplash kit, it is a good idea to only use one valve.

Figure 4: Close-up of valve attachment to Frame 5

Figure 5: Fully assembled frame

Frame 5, 6, and 7 will be crossbars that connect these two legs of the frame. Connect Frame 5 (Or Frame 6 if you mounted the valve there) to the legs by sliding the nuts of the corner bracket assemblies into the slots on Frame 1 and Frame 3. Slide it down the length of the frame until the valve tip is 8-12 inches above the ground/tabletop. Make sure that the feet are perpendicular to the crossbars as seen in Figure 5. Attach Frame 6 and Frame 7 similarly, making sure Frame 7 connects across the top of the structure. When all three crossbars are positioned as desired and perpendicular, tighten the screws to lock them in place starting with the top crossbar (Frame 7). Sometimes this is easier done lain down on a table, especially if done without a partner.

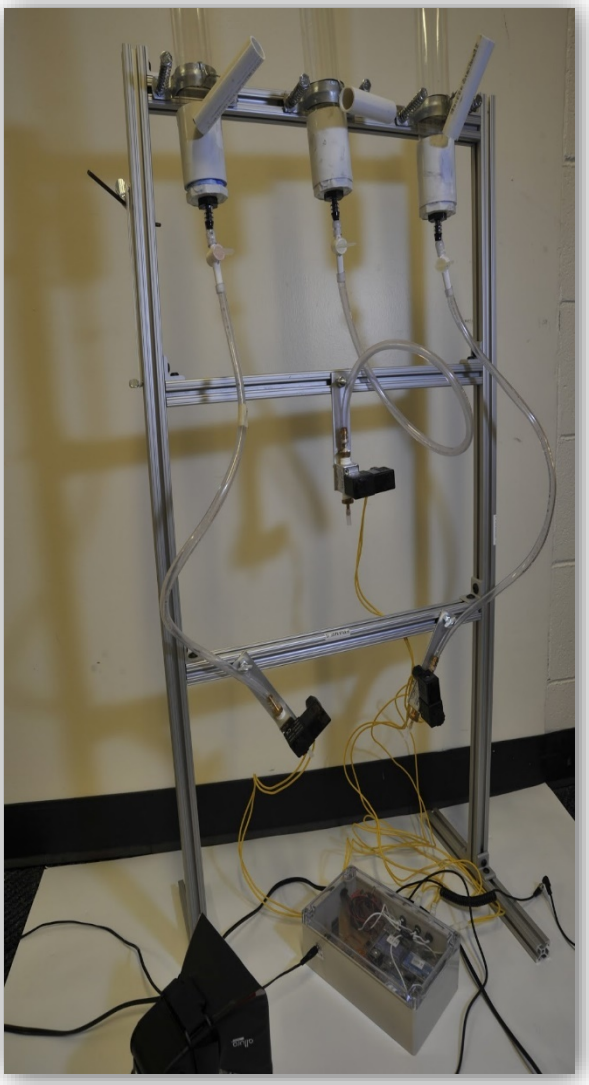


Figure 6: Full Assembly

Rotate Frame7 back a little. Using the handle, pull a reservoir clamp away from the frame and slide a reservoir into the clamp. Make sure to brace the frame while pulling - if you are alone, this can be accomplished by pushing the thumb and pinky of the pulling hand against the heads of the bolts.
There is some flexible plastic tubing coming out of the valve. Slide the free end of this over the end of the small plastic valve at the bottom of the reservoir. Make sure to push it up at least a quarter-inch to ensure the connection is airtight.

The project box has two power sources which need to be plugged in, a standard power cable and a 5V wall wart. Connect the power cable of the project box to a 120V wall outlet. Plug the wall wart into the 5v power supply of the project box, and the other end into another wall outlet. Connect the “Camera” port on the project box to the camera using the 3.5mm to Nikon Remote Release Cable. Connect the yellow wire coming from Valve A, B, and C to the Molex connectors coming out of the project box. Flash 1 and Flash 2 are connected to the “flash” ports on the project box by the 3.5mm to PC port cables. The flashes need to be turned on via a button on the back of the base. If only one flash is desired, the other flash must still be plugged in (but can be left off).

Breakdown

Make sure that the camera and flashes are turned off and the 5V wall wart and 120V power cable are unplugged. Drain the reservoirs and tubes and return parts to the box and golf bag as organized as possible.

IMPORTANT: If you use food dye or any liquid other than water, make sure to rinse all reservoirs, tubes, and valves thoroughly, directly after each use, by pouring water into reservoir and running valve.

App Settings

Connecting via Bluetooth App on an Android Phone

When the 5V power supply is connected, there should be lights from within the project box. Initially, there will be a steady light on the Arduino microprocessor and a blinking light on the (vertical) Bluetooth chip. First, connect to HC-06 in phone settings, the password is 0000. Navigate to the DropControllerBT app. On the “Drop Control” tab (Figure 6), select the blue button in the top left corner and then choose “HC-06” from the available Bluetooth devices. When a connection is formed, the light on the Bluetooth chip will stop blinking and become steady (the button may still say “Not Connected”, but it should be if the light is steady). Use the “Start” button to activate the system, and see the “Settings” tab (Figure 7) to configure valves, drop count, etc. Depending on the height of dropper and the camera settings, it may require some experimenting with the time settings to successfully trigger the flash while the camera’s aperture is open and the droplet is in view. The time settings (start, size, flash trigger, camera trigger) are given in milliseconds. See this link on dropcontroller.com for additional help.

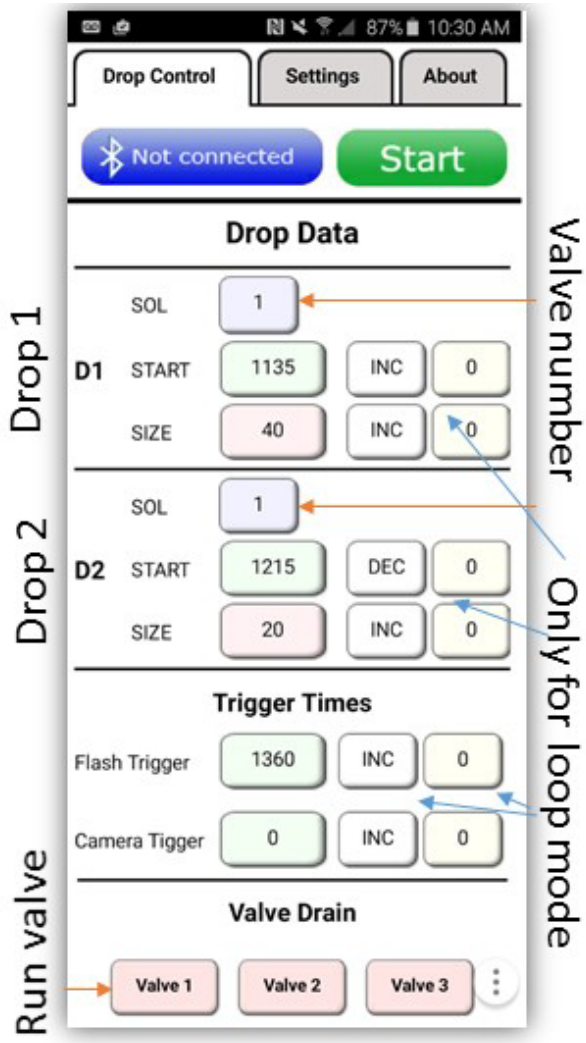


Figure 7: Main app page

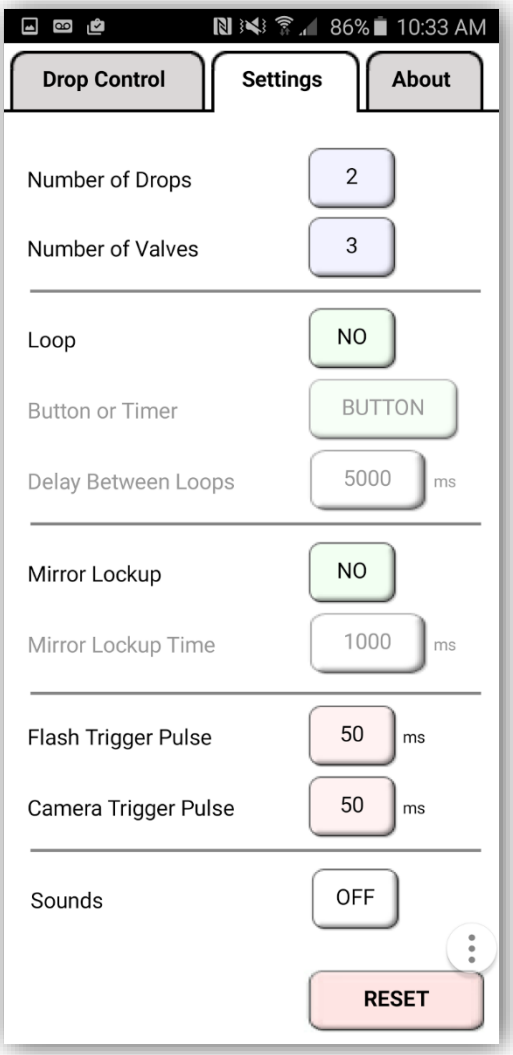


Figure 8: Settings app page

Connecting via Bluetooth App on a Laptop

The computer app doesn't work nearly as smoothly and is much more of a pain to connect to. It is **strongly recommended** that you use the Android app.

To connect using the Thinkpad X200, you must first turn on the Bluetooth using Fn + F5. See this link on dropcontroller.com for extra help connecting and this link for help with the app. The team got the computer app working only once, but could not get it to work regularly. This may be due to the computer used and a different computer may cause fewer difficulties.

TIMING

See Appendix A - Example Photographs with Values for example photographs and values to get started. It is **strongly recommended** to start with one single drop, get an idea of how the whole system works and adjusting the impact timing of the drop before moving on to a second drop. Doing this after every change in setup will help to adjust more quickly. After the first drop has been experimented with, add a second with a time difference between 70 and 100 ms to give a collision.

Timing can be the trickiest part of this process to get correct. The Nikon D700 has a delay of just over a second and varies depending on if the LCD screen is on or off. To solve this problem, use an exposure (set on the camera) of 0.5 seconds. **Keep the flash trigger set between 1200 and 1500** to make sure that the flash is always triggered while the shutter is open. The idea here is that the flashes actually "take" the pictured. Note that this long exposure can give a "ghosting" effect in a bright room, so move to a darker place, if you see this. For this reason, it is generally easier to change the droplet release timing than change both the flash and camera timing. This means that if you wish to see later in the droplet's life cycle, you should adjust the timing to release the droplet earlier. Making a droplet larger will also make it fall slightly faster.

Through the use of a high-speed camera, it was found that the drop size and valve diameter were often separating drops into multiple. Trial and error showed that a first-drop size of 13 ms and a second-drop size of 27 ms solved this problem. On the other hand, sometimes it's easier to get droplet collisions when the first drop is larger (30-40 ms) than the second (15-20) ms. This does sometimes cause multiple drops fall when only was is desired.

LOOP MODE

Under the settings tab, loop mode can be activated by setting the Loop button to YES. This allows consecutive pictures to be taken autonomously for as long as desired. In loop mode, the INC/DEC field and the following time field will increment or decrement the timing or size of the droplet by the value entered after each iteration. This can be useful for getting a time-lapse of a droplet collision to observe the entirety of its behavior. ***This function is broken*** (see "Looping" Doesn't Work)

Documentation Details

Introduction

This documentation completes the requirements for Kyle Walters' and Kyle Hollis' Fall, 2016, independent study with Professor Hertzberg. The project aimed to design and fabricate a method to take pictures of a free-falling droplet colliding with the Worthington jet from a previous drop. The product and documentation requirements set out prior to beginning are listed below.

This documentation section includes information on both the use of the product and its replication. Help with camera settings, taking quality pictures, and troubleshooting common problems is provided here in detail. After these, replication instructions, impediments encountered, and recommendations for improvements on similar future projects are listed.

To capture a photograph of one drop colliding with another, after it has bounced, takes timing with a resolution of only a few milliseconds. To accomplish this, the design team used an Arduino microcontroller and code from dropcontroller.com (Currey 2016). The sequence of events which the Arduino sets into motion lasts about a second and a half in total. First, it opens the camera shutter (it takes about ¾ of a second just to open and). While the shutter opens, the valve releases the first drop followed by another approximately 1/10 of a second later. By the time the second drop approaches the water surface, the first drop will have hit the water and rebounded in what is called a Worthington Jet (Inglis-Arkell 2015). If successful, this second drop will contact this jet creating a mushroom, crater, hat, bubble, etc. effect. At precisely this moment, the Speedlight will flash, illuminating the droplets and effectively taking the picture.

Product Requirements

Time resolution
Axi-symmetric accuracy
Variable initial droplet height
Volume control of drop
Adjustable timing with flash and/or camera
Must work with Nikon D700
Control surface reflections
Robust and compact packaging

Documentation Requirements

Quick-start guide (including photos with info)
Explanation of product
Bill of Materials
Difficulties
Circuit Board Diagram
Video demo
CAD

Stretch Goals

Compatible with other cameras (and phones)
Second drop can be slightly offset
Triggering system for high-speed camera
Multiple valves
Impact on spinning surface

Camera Setup

Focus

Once the camera, frame, and water tray are positioned correctly, you'll need to focus the camera. A good way to do this is to have someone put their finger directly below the valve, where the droplet will contact the surface. It's important to have the focus be accurate, especially using large apertures.

Aperture

Larger apertures (smaller f-stop) let in more light but decrease the depth-of-field. Starting out, high f-stops should be used as it eliminates the need to precisely adjust focus but will require a brighter flash. Once other aspects of this technology have been learned, playing with the f-stop to focus on a certain depth can create interesting effects. This is adjusted (on the Nikon D700) via the dial on the front right part of the camera, directly in front of the shutter-release button.

Shutter Speed

Leave the shutter speed (adjusted via the dial on the back right side of the Nikon D700) at ½ second (On the D700 this is displayed as a 2, whole seconds have a quotation mark after). Note that this works because the flash is what actually takes the picture.

ISO (Sensor Speed)

The ISO speed adjusts the sensitivity of the sensor. High sensitivities mean brighter, but grainier pictures. In general, the graininess will not be noticeable at or below 400. For final pictures, especially if it will be cropped, an ISO of 200 or below is recommended. This can be adjusted on the D700 by pressing the ISO button on the top left of the camera and turning the dial on the back right.

Getting Quality Pictures

Once everything is set up, the process of finding the desired picture can begin. Make sure to run the valve(s) for a few seconds (see Figure 6) to fill the tubing up with water, and squeeze any remaining bubbles out with your fingers. If the valve tip doesn't retain water, try covering the end with your finger and drip a few drops. Positioning the valve tip closer to the water surface increases the accuracy of the droplet. If desired, you can pull the small plastic tubing tip off of the valve to slightly increase spatial precision at the loss of temporal precision.

Still Water

After timing is approximately correct, make sure to wait approximately 10 seconds for water to become completely still. Any perturbations in the water can cause the Worthington jet to emerge at an angle and miss the second drop.

Water Level

Maintaining the water level near the container's brim often produces the best pictures with the least shadows.

White, Acrylic Diffuser

Generally, the large diffuser should be submersed in the water and at least few inches behind the droplet impact site, creating a solid line between the backdrop and basin. This is far from a hard rule, sometimes leaving the plaque behind the container can create interesting pictures, especially in circular bowls or cups. This diffuser is vital to taking high-contrast photos.

Flash Position

To attain the highest contrast, flashes should be behind the large diffuser, but offset so as not to be directly in the picture. One flash, with a colored polystyrene sheet inside the on-flash diffuser, set to the side of the large diffuser but still behind the droplet adds interesting colors. Flashes on the camera-side of the drop quickly reduce contrast.

Colored Droplets

A significant amount food dye is necessary to produce visible color in a droplet (roughly 1/3 a container per reservoir). The flashes must be set up for optimal contrast to capture the color. This means a container full to the brim, two flashes behind the large diffuser at the same level as the edge of the container, and only white light.

TROUBLESHOOTING

ASSEMBLY OR DISASSEMBLY TROUBLE

80/20 NUTS ARE STUCK

Often, the 80/20 nuts get stuck to the frame when the screw is tightened down too much. To loosen it up, thread a screw so that the tip just passes through the nut. While supporting the frame, tap lightly to moderately on the screw head with a mallet. If this doesn't want to work, sometimes inserting the Allen wrench and tapping on that works or just using a little more force.

APP TROUBLE

APP REPORTING "BROKEN PIPE ERROR"

Although this seems like a pipe is probably broken; in fact, your Bluetooth has just disconnected. Check to make sure the 5V cord is plugged in then press the blue "Not Connected" button to reconnect to HC-06. (remember that the button always says "Not Connected")

THE "START" BUTTON SWITCHED TO SAY ACTIVE

Press the button again to reset it.

This is an app or Arduino code problem which was not able to be fixed. Ideally, after running a droplet sequence, the Arduino sends a flag (a "#") back to the app to let it know it has completed. For some unknown reason, this is not occurring. Solutions attempted include reinstalling app, removing and re-uploading Arduino code, and adjusting Arduino code. None have been successful.

"LOOPING" DOESN'T WORK

This problem is related to The "Start" Button Switched to Say Active problem. Without a signal that the process has finished, the app doesn't know to start again.

THE "START" BUTTON ISN'T ACTIVATING THE SOLENOID VALVE!

First check that the valve is plugged into the same plug on the box as the number shown on the main app page.

Next, check the lights in the project box. Both the Arduino microprocessor and Bluetooth chip should have steady unblinking lights. If there are no lights at all, check the 5v power supply to the project box. If the Bluetooth chip is blinking, it means the Bluetooth chip has not paired with any devices, refer to the Connecting via Bluetooth App on an Android Phone in the quick-start guide on how to do so. If the RGB (red, green, and blue) LEDs are not flashing when triggered, check to make sure you have the Bluetooth app configured correctly. If the RGB LEDs are flashing when triggered but the solenoid valve is still not activating, check the 120v power supply, and the Molex connection to the solenoid valves.

The "Start" Button isn't Activating the Camera!

Check that the flash and camera LEDs in the project box are lighting up when triggered. If they are not, check the 5v power supply. If they are, check the connections to the flash units and the camera. Note that both flash units must be plugged in (but not necessarily turned on), even if only one flash is desired. Also check that the camera is set to a mode that is accepting of remote triggering.

Flash Trouble

The flashes aren't triggering!

Because the flashes are wired in series, both must be connected to complete the circuit, although they don't both have to be on. This means that every connection on both flash cords must be checked. If this doesn't solve the problem, try disconnecting and reconnecting them where they connect with the box. If this still doesn't work, restart the whole box by disconnecting and reconnecting the power supply.

The flashes are triggered twice

Occasionally this occurs for no apparent reason. Try turning the flashes off and on, unplug and replug them, and turn the box off and on.

Valve Trouble

The dripper drips too many drops or not enough drops!

It takes a while for the system to "warm up" when first set up. Running the valve (using the button in the Bluetooth app) for 10 seconds, or 60 seconds for a new valve, will increase this reliability. Dripping a few dozen drops also seems to help, and performance usually improves throughout a session. Make sure the size of the droplet is reasonable for the fluid being dropped. For some ballpark values, water tends to not reliably form a droplet at sizes smaller than 10 ms, but will separate into several droplets at sizes greater than 50 ms. Olive oil droplets worked with a size between 30 ms and 80 ms.

Also, Valve A may be broken, as it continually drips even when not powered. This is suspected to be due to a faulty solenoid valve, and may require replacing.

The second drop from the same valve is not aligned with the first drop!

This is probably the most frustrating and prevalent problem encountered, and doesn't have an exact solution. Take a few pictures to see if the second drop is consistently striking in the same location relative to the first droplet. If this is the case, it is likely that the valve tip is angled, which imparts horizontal velocity to the second droplet (but not the first). The valve tip tubing has a natural curvature that can make this difficult to observe. First, try to make the tip tube exit parallel to the water surface. If this doesn't solve the problem, try moving the tip in the direction of the second drop impact point

towards the first. If the problem persists, try moving the valve tip closer to the water surface, increasing the droplet size, or removing the valve tip tubing. Lower the drop distance also helps with accuracy.

Timing and/or impact location is highly inconsistent

This occurs much more often without the plastic tip tube. Because the brass nozzle is more hydrophobic than the tip tube, the water doesn't tend to bead up at the tip, so the amount of water in the nozzle itself is variable and causes inconsistency. Usually adding a tip tube solves this problem. If the tip tube is attached and the problem persists, make sure that the tube is full of water. To do this, place your finger over the tip, almost covering it. Drip a few drop or run shortly to fill it up. Otherwise, the valve may just be having a bad day. Try adjusting the angle or height or just use a different valve. Ensuring that the reservoir-to-valve tube is filled entirely with water can also help. This is not especially easy, but can be done by leaving the reservoir open and slowly taking part of the tube off at the reservoir to let the air escape.

Camera Trouble

The Camera Randomly Turns Off

This is usually a battery problem. The battery with a green mark on it doesn't work well. Switch batteries.

My camera doesn't fit the 2.5mm to Nikon Remote Release Cable!

Every camera has a different remote shutter release port. You may need to buy a cable to connect to your camera. These are sold by your camera's manufacturer and generally cost between $10 and $30. Make sure to buy the cable with a 2.5mm or 3.5mm male jack on the other end, not the cable with a button for remote release.

The picture is completely black!

First, check that the lens cap is not covering the camera lens. Otherwise, it is likely that the flash is not triggering while the shutter is open. If the camera is set to auto-focus, there will be three distinct clicks: one when it is triggered, the second when the shutter opens, and the third when the shutter closes. The flash needs to trigger between the second and third of these clicks. This window can be increased by lengthening the exposure. An exposure of ½ second is generally enough to distinguish the relative timings of the camera aperture and the flash by observation.

The flashes also have some amount of down time before they can take another picture, especially when low on battery. See if waiting a few extra seconds helps.

The picture is there, but too dark

Either the flashes aren't being triggered at all or aren't triggered while the shutter is open. See Timing or The picture is completely black!

The edges of the drop look fuzzy and out of focus

Most likely, this is because you're out of focus. It may also have to do with the long exposure, especially if you're in a bright room. To solve this, move to a darker location or shorten the exposure time if there is nowhere darker. If you adjust the shutter speed, you will likely have to adjust the trigger timing on the app. Around 1250 should work for shorter exposures.

Notes

Valve 3 Light

The blue, valve 3 light does not always light up when valve 1 or 2 is also activated, although the valve does still work. This is likely because the 3 Valve-indicator LEDs were wired with a common resistor, and the higher-power blue LED does not receive enough current to illuminate when other valves are also active. Following the reconstruction suggestion indicated in Appendix D - Circuit Board Drawing would likely fix the issue.

Valve Orientation

The black part of the valves can be rotated to get it out of the way by loosening the circular/star-shaped knob as seen in Figure 9.

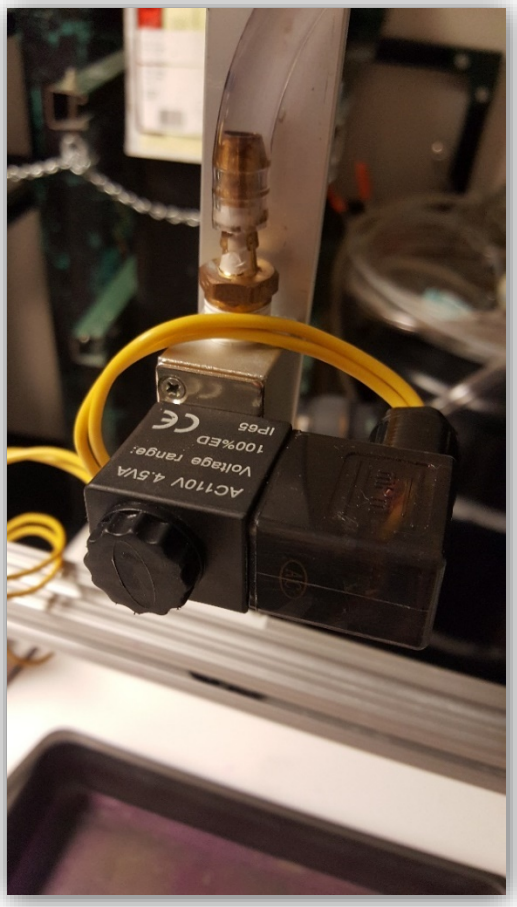


Figure 9: Solenoid valve

Molex Connectors

Avoid pulling on the wires connecting to the Molex connectors as they can pop out. These have also been a significant annoyance throughout the project and choosing a different connector for replication is recommended.

Flash Headaches

When taking many photos, repeated exposure to the flash can cause headaches. To avoid this, briefly close, cover, or avert your eyes when you hear the first click of the camera aperture.

Water Reservoirs

The height of water in the reservoirs affects the velocity of the water droplet as it leaves the dripper. Make sure to note the height of water when testing if you wish to recreate the same setup later.

Replication Instructions

Arduino

See this link on dropcontroller.com for instructions, libraries, and the sketch to program the Arduino. This project used an Arduino Nano, but any Arduino should work.

Project Box

The water-resistant project box contains all electronics, and the interior is mostly occupied by the three solid state relays and the perf board. The wiring on the perf board is limited to 5V logic, but the wires connecting the 120V-AC power supply to the valves carries enough voltage to be dangerous. Whenever the power cable is plugged in, take the appropriate precautions to handle the live 120V safely. One suggestion is to keep one hand behind your back so any accidental contact with high voltage won't pass through your heart.

Place the solid state relays in the box (but don't use the command strips yet) and mark how much remaining space there is. Cut this shape out of your perf board so that it can fit inside the box. On the circuit diagram (Appendix D - Circuit Board Drawing), everything below the solid state relays (SSR's) will be on the perf board and connected with jumper wires, with free-standing jumper wires connecting the bulkhead jacks to the board for the 5V power supply, camera, and flash ports. Drill four holes in the box so that the camera, 5V power supply, and two flash jacks can pass through the wall of the project box.

The solid state relays have an output (high voltage) and control (low voltage) side, each with two leads. Orient them in the box so that the control side is next to the perf board. Connect the wires to the leads as shown in the circuit diagram. This can be done by loosening the screws on the SSR leads, slipping the wire end under the metal tab, then tightening it back down. A multimeter is very useful for verifying that a tight, secure connection has been made.

The remaining wiring handles the 120V AC that controls the solenoid valves, so make sure to use the 22 AWG wire and liberally employ heat shrink wrap and electrical tape to cover any exposed joints. You will need to drill four more holes in the wall of your project box, sized to fit the rubber grommets. These are for the three valve ports and the 120V AC power supply. The power cable is a tight fit through the grommet, but it can be done. Strip the tip and wire it to the 22 AWG as shown in the diagram – you may need to use a multimeter to identify which of the two strands is hot (120VAC). Switching the hot and neutral lines won't affect the electronics or how the system performs, but it makes the Molex connectors dangerous as one lead would always be hot, even when the corresponding valve is not activated.

FRAME/PLUMBING

Cut a foot-long section out of the tube guard to make the body of the reservoir. The PVC coupling goes on one end, the PVC adapter fits into the coupler, and the PVC bushing screws into the adapter. Use gorilla glue between the tube and the coupling, and PVC primer and cement between the coupling and the adapter. Use plumbers tape to seal the bushing into the adapter. Cut about two inches of the flexible tubing and use it to connect the shutoff valve (polyprop stopcock) to the bushing. At this point, the reservoir assembly should be watertight. The shutoff valves are fairly cheaply made, and sometimes leak out the knob when closed.

The solenoid valve assembly requires wiring the valve itself, machining the valve mount plate (Appendix C - CAD Drawings), and attaching the two with screws. This YouTube tutorial will help to wire the valve (Valves 2013). Use the thicker gauge wire, as they will be powered to 120V when the valve is open[2]. Screw a hose barb into both sides of the valve, using plumber's tape to ensure a watertight connection. The two metric screws attach the valve mount plate to the valve. Use the two metric nuts here to add a space between the valve and the valve mount plate (PICTURE). The top end of the valve mount plate takes a ¼-20 nut and thumb screw to attach to an 80/20 nut in a crossbeam. Cut a section of the clear flexible tubing about two feet long, and slide it over the end of the upper hose barb. This creates the tube that connects to the reservoirs. Cut a small (about one inch) section of the small stiff tubing, and slide it on the lower hose barb. This creates the tip tube, which (usually) helps with making liquid drops reliable.

The frame is made from 1010 series 80/20, T-slotted on all 4 sides. There are 7 sections, cut as detailed below[3]:

Section Name	Purpose	Length (inches)
Frame 1	Foot	12
Frame 2	Foot	12
Frame 3	Side Support	39
Frame 4	Side Support	39
Frame 5	Crossbeam and Valve Mounting	17.5
Frame 6	Crossbeam and Valve Mounting	17.5
Frame 7	Crosssbeam and Reservoir Meeting	17.5

This totals to 154.5 inches (12' 10.5") of 80/20[4]. The joints between the Foot and Side Support each use two corner bracket assemblies, where each corner bracket assembly consists of a corner bracket, two nuts, and two screws. The three crossbeams have a corner bracket assembly on each end to attach them to the side supports. Two ¼-20 nuts with thumb screws are used to create a place to wrap and store the Allen wrench when not in use.

[2] Wiring is rated by amperage not voltage, so the larger gauge is more of a safety precaution than necessity.
[3] The exact lengths are not especially important as long as Frame 3 & 4, and 1 & 2 are close and 5, 6 & 7 are almost exactly the same.
[4] 80/20 can only be purchased online and charge a minimum of $10 for shipping, so it is strongly recommended to buy significantly more nuts and screws than called for.

There are three reservoir clamps that are used to hold the reservoirs to the top crossbeam. To make one, cut out a strip of the thin rubber sheet and glue it to the inner surface of the metal pipe strap using super glue. Cut the spring into two sections the length of the long ¼-20 shoulder bolt. The bolts should also be cut so that the threading doesn't extend outside of the 80/20 to allow the clamp to move freely. Put two 80/20 nuts into the T-slot of the crossbeam, and connect the long ¼-20 bolts through the springs, then the holes in the metal pipe clamp, and into the 80/20 nuts. Create the handle by looping some wire around the middle of the metal pipe strap and fastening it to a 4" section of PVC pipe.

Impediments Encountered

Computer Bluetooth

The Bluetooth COM port on the computer (ThinkPad X200) was not being seen by the PC app, so it could not find the Bluetooth adapter (HC-06) in the project box. Significant time was put into solving this problem, and on one (but only one) occasion, it worked. Eventually the computer was abandoned in favor of the android app, which is more user-friendly anyway. A different computer, Arduino, or Bluetooth chip may solve this problem.

Arduino

It took several days to figure out how to successfully connect the Arduino board to a computer. The computer could not find the correct COM port. After updating all drivers and searching the internet for solutions, the team went to see Dan Godrick in the ITLL. His office may be magical, because it started working before he touched or suggesting anything.

Finding Easily Replaceable Valves

Most solenoid valves are made and shipped from China. A shorter shipping time and better return policy[5] was desired. Although DropController uses DC solenoid valves, it seems that AC valves have shorter response times (Engineering Information: Solenoid Valves n.d.). The 120V AC Airtac 2V025-08 is one of the only valves fulfilled by Amazon.com, so it was chosen. This decision led to some complications from the higher voltages such as the need for a solid state relay instead of a simple optocoupler. Higher gauge wire was used for the 120V lines to be safe even though the current is on the order of milliamps.

[5] One valve was shipped broken, and another broke within a few months of light use

Consistent Droplet Accuracy and Timing

Although the solid state relays and solenoid valves proved, through testing, to have a time resolution near one millisecond, the tube which actually drops the droplets can cause a significant deterioration in both time and positional accuracy. The brass hose barbs don't bead up water at the end very well which leads to variation in the time and size of droplets. By attaching a small, plastic tube to the end and ensuring it is full of water, this problem was largely overcome, but created axi-symmetric accuracy difficulties. By carefully aligning the face of the tube parallel to the ground, this problem is mitigated, but still can cause problems.

Various attempts were made to solve this, including cutting the plastic tube at an angle, using a glass pipette-like tube with a small opening, and using a plastic pipette tube cut to different sizes. The smaller openings created a jet as opposed to a droplet, even after lowering the reservoir. The original solution with simple plastic tubing was determined to be the best option.

App Doesn't Receive Termination Notice

See The "Start" Button Switched to Say Active.

Design Improvement Recommendations

Reservoir Attachments

Although various iterations were made to the reservoir attachments, the final solution is not optimal. It is not an especially aesthetically pleasing assembly, the action is not smooth, occasionally locks up, and requires a relatively significant amount of force at an odd angle. Some sort of latch which closes over the valves and locks in place may have been a better answer.

Droplet Tube

The tube from which the droplet falls causes various problems. The large aperture often creates more than one drop and makes the size vary by some amount. The tube also curves, which means the whole valve has to be adjusted to force the aperture parallel with the ground. The tube was added after the brass nozzle was found to drip highly-inconsistently sized and timed droplets due, but did not entirely solve the problem. A hypodermic needle may be the solution, but was not tested.

Polyprop Stopcocks

The ball valves connected to the reservoirs leak very slightly. A slightly more expensive alternative would probably be worth it.

Conclusion

The final product met all requirements for this project and all stretch goals have either been met or left possible for future improvements. These requirements included creating a product which allows for a picture to be taken regularly of a falling droplet colliding with a Worthington jet from a previous drop, a quick-start guide and help for usage, and replication instructions with impediments and recommendations for future products.

For stretch goals, the system can be adapted for use with almost any DSLR with the appropriate cable substitution, but phones were not tested. With multiple valves and the ability to adjust the height of each, the second drop can both be offset and enter with a different velocity. High-speed video cameras can and were used, but did not need a direct triggering mechanism, instead relying on human reaction time which proved to be easy enough. Although an impact on a spinning surface was not captured, the frame was made sufficiently wide to allow for a spinning platter to fit underneath.

APPENDIX A - EXAMPLE PHOTOGRAPHS WITH VALUES

GENERAL SETUP

This appendix contains a series of pictures[6] obtained using the DropSplash kit, along with the settings that were used to create them and a short description of what is happening in the image. The settings are:

D1 - The release time of the first droplet

D2 - The release time of the second droplet (if applicable)

S1 - The size of the first droplet

S2 - The size of the second droplet (if applicable)

FL - The time delay of the flash.

All these values are in milliseconds. The "size" setting is therefore how long the valve is open. The camera is always set to be triggered at 0, and the liquid used was cold water both in the reservoir and in the tray. The camera was angled about 10 degrees down at the impact location to give optimal reflection.

SETTINGS

Distance from tip of nozzle to water = 22 5/16" for all sample photos.

Reservoir between ½ and full (low levels tend to lead to less consistency

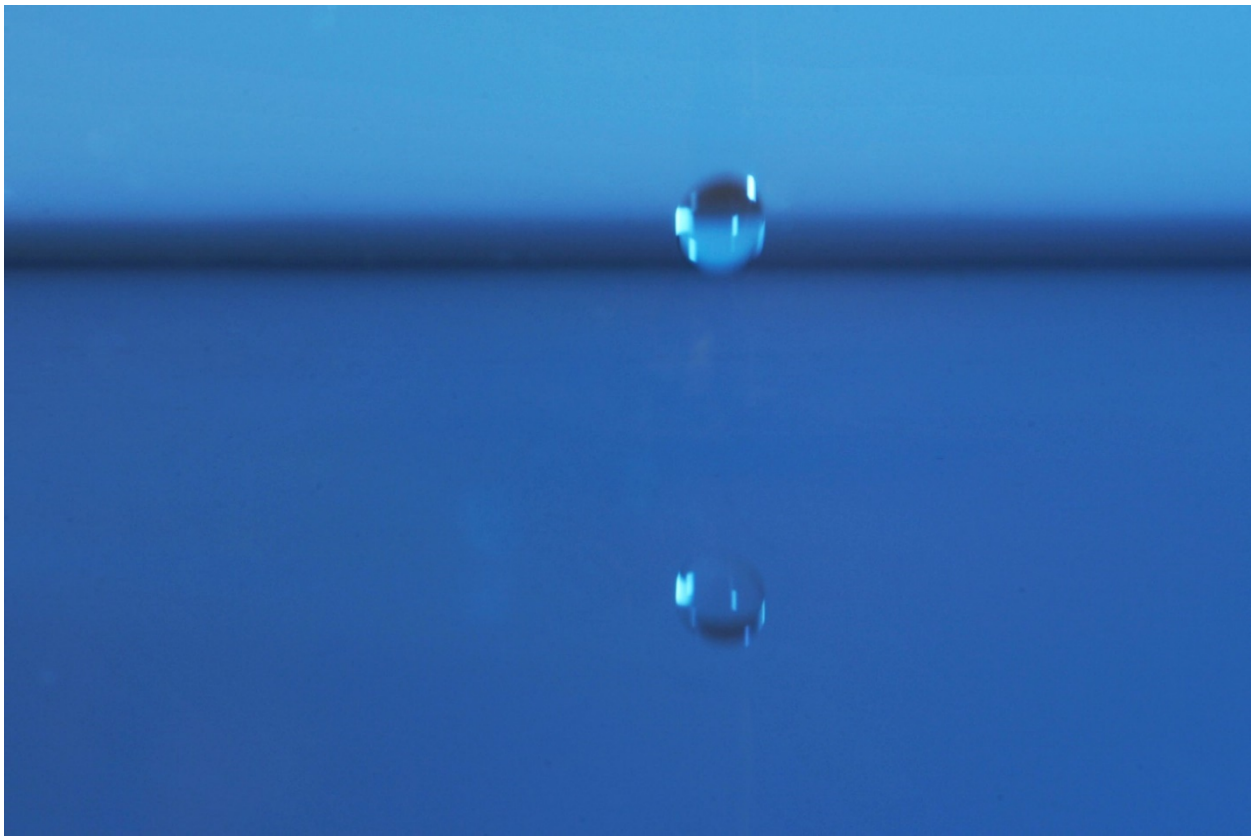
Flashes generally at 4 power blips

.5 second exposure

ISO 400

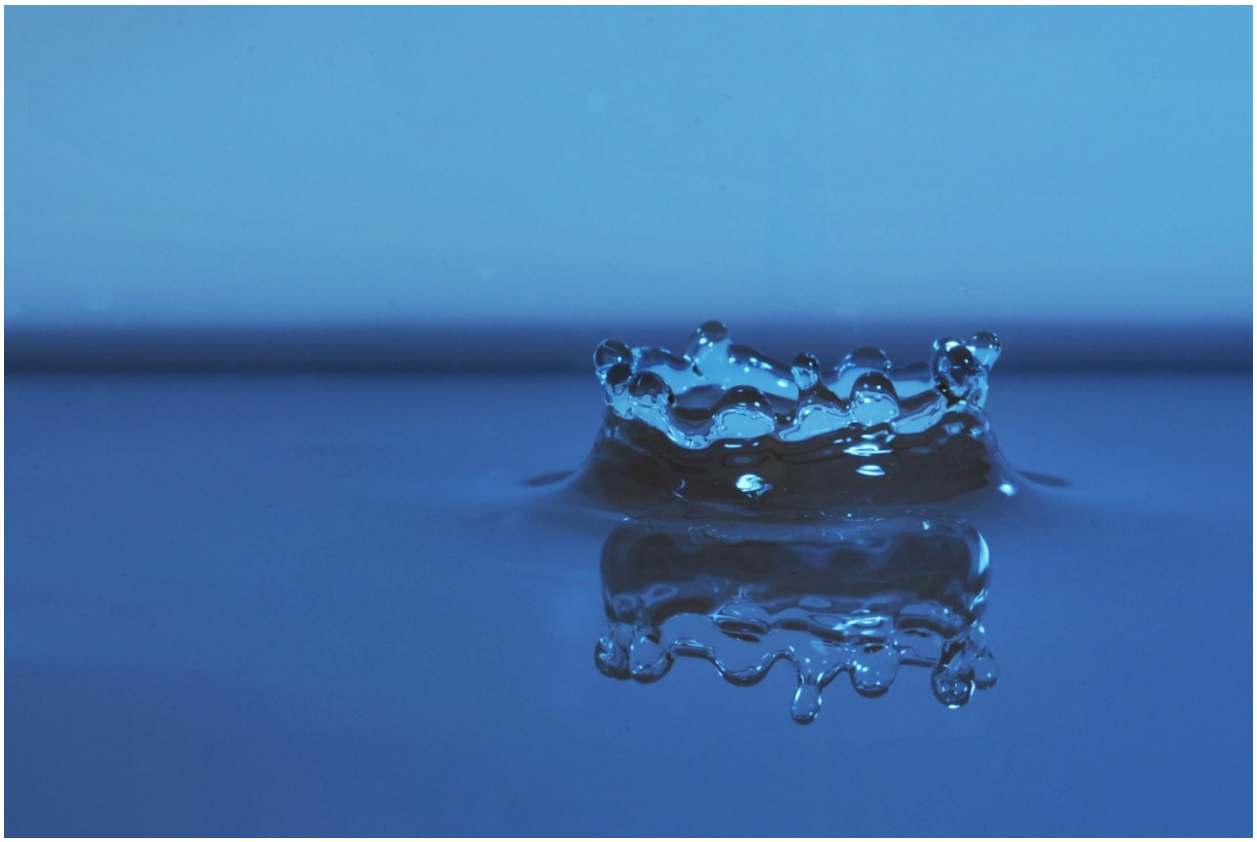
F22 or F32 (gives large depth of field which is much easier when first learning)

[6] All of these pictures have been edited to improve colors and brightness and remove splotches from the camera and water on the diffuser.



D1=965, S1=30, FL=1360

This image shows the water droplet (and its reflection) just before the impact. Note that it's hard to avoid motion blur while the drop is in free fall.
Lighting is created with a diffuse, blue-filtered Speedlight from near the camera. Note that the pictures below with the Speedlight behind the drop look much better.



D1=940, S1=30, FL=1360

When the droplet first collides with the water surface, it creates a crown on the water surface. Lighting is created with a diffuse, blue-filtered Speedlight behind from near the camera.

D1=875, S1=30, FL=1360

The crown caused by impact slams back together, creating a tall structure known as a Worthington Jet. Lighting is created with a diffuse, blue-filtered Speedlight behind from near the camera.

D1=830, S1=30, FL=1360

With the right conditions, the top of the Worthington Jet will separate into a droplet, as seen here. This can lead to a series of progressively smaller and quicker jets until the water re-settles. Lighting is created with a diffuse, blue-filtered Speedlight from near the camera.

D1=860, S1=20, FL=1360

After the top of the Worthington Jet separates into a new droplet, the jet itself retreats into the water surface to become ripples. Here the droplet is caught before it plunges back into the surface, showing a perfect sphere suspended above the expanding ripples.

D1=850, S1=30, D2=950, S2=20, FL=1353

Here there is a Worthington Jet that has been impacted from above by a second droplet, creating a crown on a stem. Timing is critical for this formation, and can vary with both the size of the droplet and the distance it must fall. If the second droplet is slightly off trajectory, the crown will be angled. Lighting is created with a blue-filtered Speedlight behind opaque acrylic.

D1=860, S1=50, D2=950, S2=20, FL=1353
By making the first drop larger (and drop a little later), the stem-and-crown formation is short with a much wider crown. Lighting is created with a blue-filtered speedlight behind opaque acrylic.

D1=830, S1=20, D2=940, S2=20, FL=1353
The second droplet impacted in front of the first droplet, and the rim of the crown formed merged with the Worthington Jet, creating a glorious three-pronged formation. Lighting is created with a Speedlight behind opaque acrylic pointing up from the ground and another diffuse, red-filtered Speedlight from the side and behind.

[pic 6372]
D1=830, S1=40, D2=950, S2=20, FL=1353
The first droplet is large to make a short, squat Worthington Jet. The second droplet is smaller and caught at the exact moment of impact, revealing a crater reminiscent of an asteroid collision.

APPENDIX B - BUDGET AND BILL OF MATERIALS

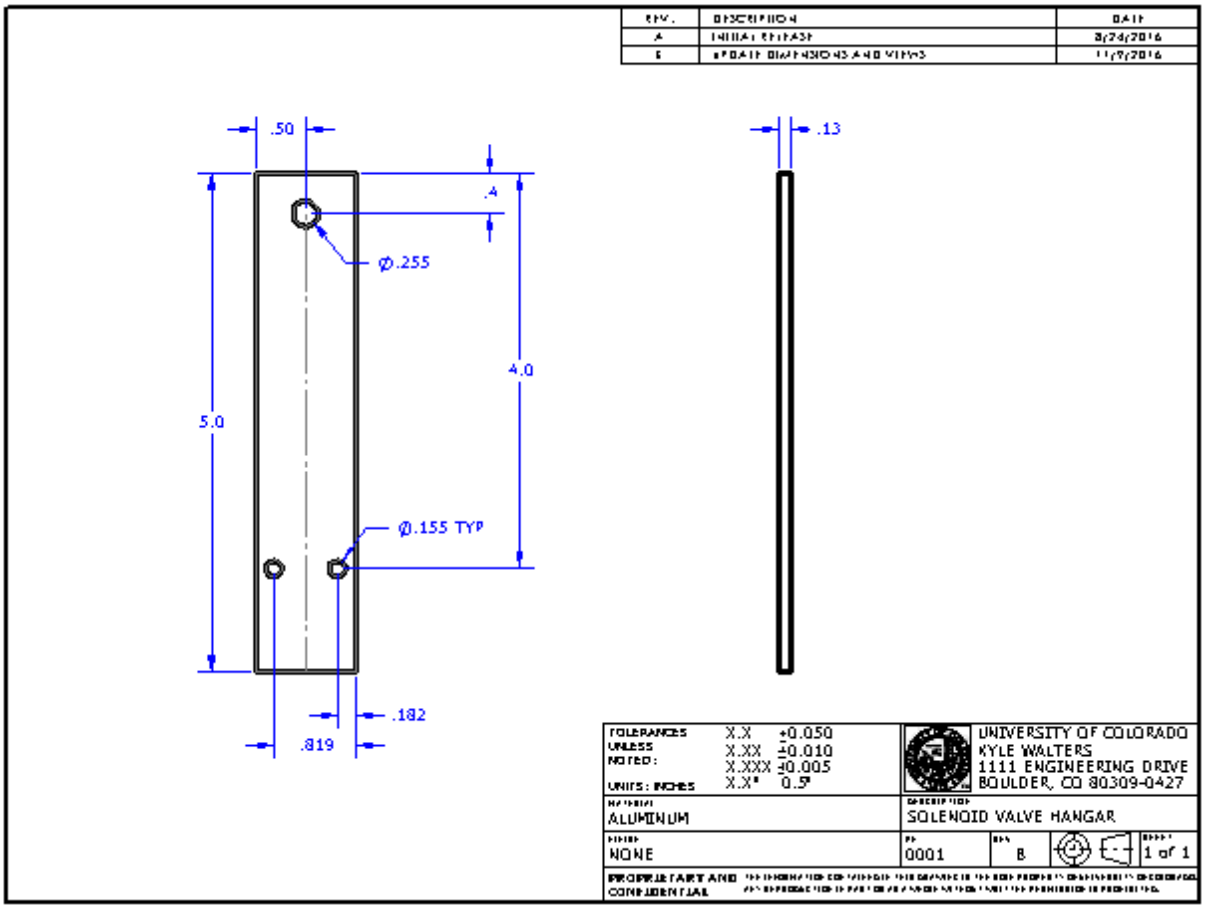
Part	?	#	PN	Cost	Source & Manufacturer
80/20 10 series T-slotted profile	F	12.5'	1010	$0.23/in	https://8020.net/
80/20 10 series 2-hole corner inside bracket	F	10	4119	$2.90 ea	https://8020.net/
80/20 ¼-20 x .500" screw	F	20	3061	$0.23 ea	https://8020.net/
80/20 ¼-20 slide-in T-nut	F	31	3382	$0.21 ea	https://8020.net/
3.5mm to 3.5mm cable	C	1	13256806	$1.99	McGuckin Hardware
¼-20 x 0.500" Thumb Screw	FV	3	22159105	$0.34 ea	McGuckin Hardware
¼-20 ⅜" Hex Nut	V	3	QAW	$0.08 ea	McGuckin Hardware
Zinc M4 Hex Nut	V	6	22473010	$0.11 ea	McGuckin Hardware
4ft T12 Tube Guard	R	1	5060927	$2.99	McGuckin Hardware
8mm PolyProp Stopcock	R	3	4376075	$4.49 ea	McGuckin Hardware
Clear flexible tubing	RV		DAL	$1.49 / ft	McGuckin Hardware
1-¼" Metal Pipe Strap	F	3	4201510	$0.49 ea	McGuckin Hardware
Neoprene Rubber	F	1	4708300	$0.05 / yard	McGuckin Hardware
¼-20 Shoulder Bolt	F	6		$0.54 ea	McGuckin Hardware
#54 Compression Spring	F	3	22330154	$2.49 ea	McGuckin Hardware
1-¼" PVC Coupling	R	3	4346525	$2.99 ea	McGuckin Hardware
1-¼" x ½" PVC Bushing	R	3	4376075	$1.59 ea	McGuckin Hardware
1-¼" x ½" Hosebarb Adapter	R	3	4250145	$1.29 ea	McGuckin Hardware
Command Strips	P	1	1581792	$3.99 / pack of 9	McGuckin Hardware

Power cable	P	1	5101670	$1.99	McGuckin Hardware
22 AWG Solid Wire	P	2		$2.99 / 25'	McGuckin Hardware
2.5mm F to 3.5mm M cable	C	1		$4.99	McGuckin Hardware
Promaster Remote Cord – Nikon MC30	C	1		$6.95	Mike's Camera Shop
Molex	CP	3		$1.10 ea	EE Shop
16-Value Resistor Kit	P	1	RRS50PCS2N3906	$8.99	https://www.amazon.com/ RioRande
Bulkhead 3.5mm jack	P	3		$0.25 ea	EE Shop
LED	P	5		$0.10 ea	EE Shop
Bulkhead Barrel Jack	P	1		$0.25 ea	EE Shop
Perf Board	P	1		$4.00	EE Shop
Rubber Grommet	P	4		$0.25 ea	Tim May
140 Pcs Breadboard Board Jumper Cable Wire Kit	P	1	B00W8YFSPI	$5.25	https://www.amazon.com/ uxcell
Project Box	P	1	s16070300am0369	$14.57	https://www.amazon.com/ uxcell
5V AC/DC Adapter	C	1	B0194B7X06	$7.99	https://www.amazon.com/ Gearpros
3.5mm to PC M cable, 12'	C	1	15S	$7.99	https://www.amazon.com/ SimpleStudio
Speedlite Flash Bundle	C	2	AP-UNV1	$34.99 ea	https://www.amazon.com/ DigitalGoja
2.5mm F to 3.5mm M cable	C	1		$5.95	https://www.amazon.com/ ienza
3.5mm to PC port cable	C	1		$8.23	https://www.amazon.com/ LAMZIX
Optocoupler	P	2	DIP-4	$4.36 / 10pcs	https://www.amazon.com/ uxcell
Mini USB Arduino Nano	P	1	CH340G	$7.48	https://www.amazon.com/ OSOYOO
Arduino Bluetooth Chip	P	1	HC-06	$7.99	https://www.amazon.com/ JBtek
120 V AC Solenoid Valve	V	3	2V025-08	$11.67 ea	https://www.amazon.com/ Airtac

Solid State Relay	P	3	BEM-14840DA	$7.38 ea	https://www.amazon.com/ uxcell

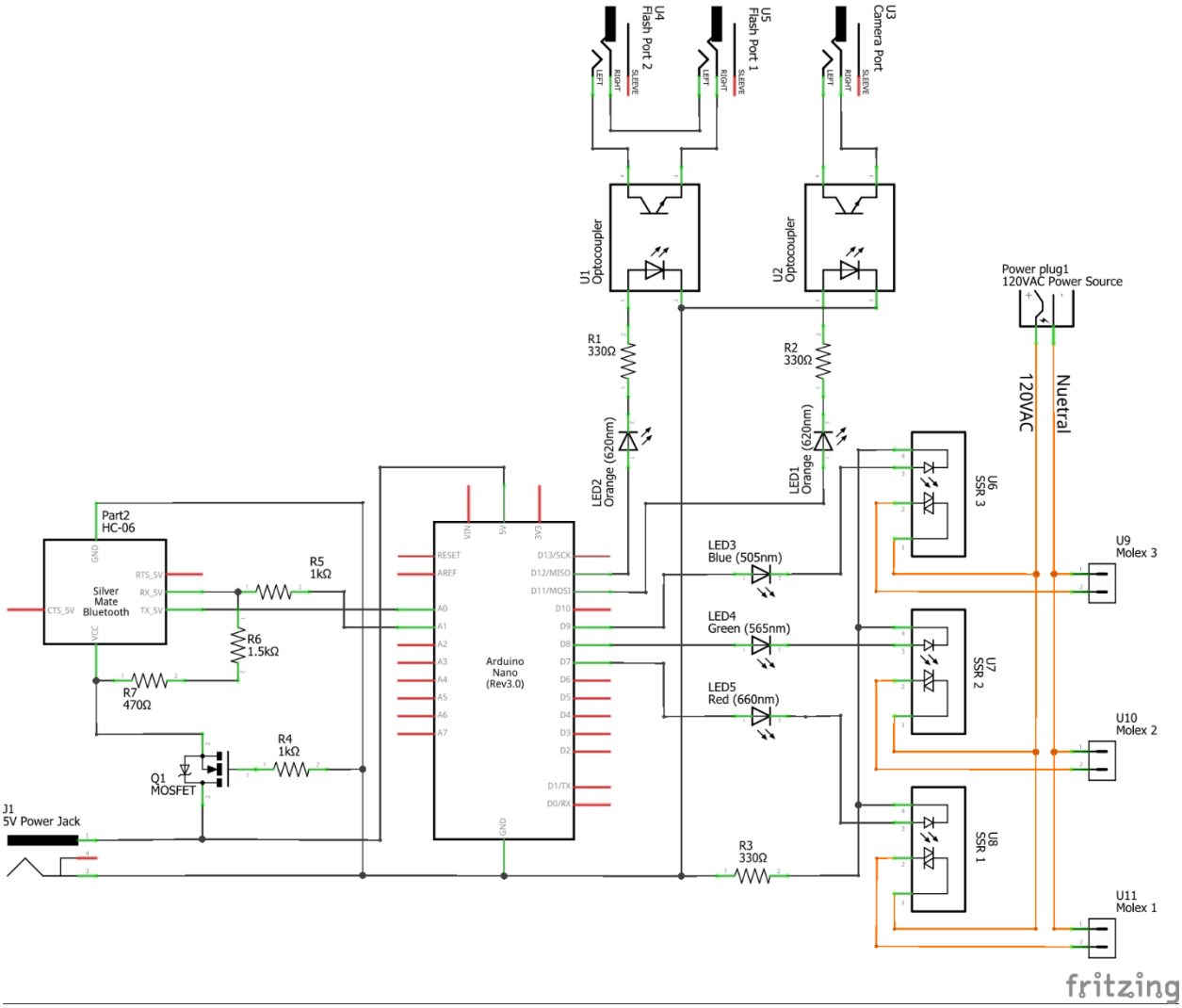
Assemblies: F – Frame R – Reservoir P – Project Box V – Valve C – Cables & Speedlites

APPENDIX C - CAD DRAWINGS



APPENDIX D - CIRCUIT BOARD DRAWING

The below schematic shows how the DropSplash Project Box was wired to control the valves. U3, U4, and U5 are 3.5mm audio jacks, and J1 is a standard barrel jack. All these jacks are bulkhead jacks that pass through the wall of the project box. Notice the orange-colored wires on the right of the diagram – these are the wires that carry 120V. Use a larger gauge wire and observe the proper safety precautions. The rest of the wiring is 5V logic. If you wanted to recreate this system from scratch, it may be preferable to omit R3 and instead use a similar Resistor before LED3, LED4, and LED5.



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