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Automatic water droplet splash photography: Design and analysis of an Arduino-controlled solenoid triggering device

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Abstract

Capturing transient water droplet splashes poses significant challenges due to their millisecond-scale corona formations, with manual methods achieving only 3 % success rates. This study developed an Arduino-based automated photography system that integrates a solenoid-driven droplet generator and optocoupler-triggered camera to address this limitation. The device calculates droplet impact timing using gravitational acceleration by synchronizing solenoid activation and camera triggering via an Arduino Nano. Experimental trials at a 50 cm droplet height demonstrated 100 % capture accuracy at 105 ms delays, outperforming manual methods (6 % success). Photographer evaluations rated splash aesthetics at 50 cm as optimal (9/10), emphasizing crown symmetry and height. The optocoupler-based system achieved sub-millisecond response times, surpassing electromechanical alternatives. By reducing memory waste from failed captures by 94 %, this approach enhances efficiency in high-speed macro photography. These results validate the system's reliability for studying fluid dynamics and surface interactions, offering a scalable framework for automated imaging applications in scientific and artistic domains.

Keywords: Arduino-controlled solenoid; high-speed macro photography; optocoupler camera triggering; water droplet dynamics; automated splash capture.

I. Introduction

Photography as a work of art can contain aesthetic value that reflects the thoughts and feelings of the photographer who wants to convey their message through visuals or photos [1][2]. There are various types or genres within photography, one of the genres that has gained significant popularity is macro photography. Macro photography involves capturing images from an extremely close distance, resulting in highly detailed photos that appear as if the subject has been magnified [2][3].

One of the unique and captivating subjects in macro photography is water droplets [4][5][6]. In addition to water droplets, photographers are also challenged to capture the moment when a droplet of water falls onto the water surface, creating splashes. The beauty and difficulty of capturing water splashes are what drive photographers to attempt to capture these moments. Furthermore, each water splash is distinct from the

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others, resulting in unique photographs for every capture. Here are some key points for reasons to do macro photography on water droplets: unique visual appeal [7]; exploring creativity [8]; highlighting small details [3]; dynamic moments [9][10]; nature's simplicity [10]; unpredictable results, scientific, and artistic fusion [8].

To capture water splashes in photographs, accuracy and precision are required in pressing the shutter button of the camera, as water droplets have a very short period from the moment they fall to the surface until they spread out again [11][12]. Due to this extremely short duration, photographers often take multiple shots to capture the moment of water splashing, as they may miss it. Certainly, with uncontrollable factors for photographers, this condition requires them to take multiple shots to achieve the desired results, which is time and storage-consuming.

Capturing water splash phenomena is not only an artistic pursuit but also a subject of scientific interest. The formation and dynamics of water splashes, particularly the crown-like (corona) splash, have been extensively studied in fluid dynamics due to their relevance in natural and industrial processes. Accurate photographic documentation of these events contributes to our understanding of the underlying physics, which has applications in environmental science, engineering, and even public health, such as modelling the spread of contaminants through droplets. Despite its significance, reliably capturing the precise moment a droplet forms a corona splash remains a major challenge [13].

Traditional methods for water splash photography rely on manual timing, where the photographer attempts to synchronize the camera shutter with the droplet's impact. This approach is highly inefficient, with success rates as low as 3 %, as demonstrated in the author's previous experiments (1 successful shot out of 30 attempts). The main obstacle is the extremely short duration of the splash event, which often occurs faster than human reflexes can respond.

Several prior studies and photographic setups have attempted to address this challenge by employing various triggering mechanisms. Early solutions included mechanical triggers or basic electronic circuits to synchronize the droplet release and camera activation. More recent advancements have involved the use of microcontrollers, such as Arduino or Raspberry Pi, to automate the process with greater precision. However, many existing designs are either complex, expensive, or lack the reliability needed for consistent results, and their success rates are rarely quantified or optimized for crown-like splash formation.

The device proposed in this research integrates a solenoid valve, controlled by an Arduino microcontroller, to precisely release water droplets and trigger the camera at a programmable delay. This setup enables accurate synchronization between droplet release and image capture, dramatically improving the success rate to 100 % under controlled conditions. In contrast to previous methods, this system is cost-effective, easy to assemble, and specifically optimized for capturing the aesthetically desirable corona splash. By systematically investigating the effect of droplet height and timing, the research identifies optimal parameters for achieving the best splash shapes, thereby contributing both a practical tool and new insights into splash photography.

II. Materials and Methods

There have been several studies conducted on triggering cameras to take photos. Desnanjaya et alresearch on how cameras can automatically capture photos using the ATmega328 microcontroller [14]. Desnanjaya successfully created a device that captures photos using a sound sensor. In other words, the camera will automatically take a photo when there is a sound trigger.

Desnanjaya's test involved capturing a photo when a balloon is burst, as shown in Figure 1. When the balloon bursts, the sound of the bursting balloon is captured by the sound sensor and transmitted to the microcontroller. The microcontroller processes the data from the sound sensor and converts it into a pulse signal that triggers a relay to capture the photo. Low conducted a study on how to trigger a camera to take photos using a servo motor that is mechanically designed to press the shutter button [15].

As shown in Figure 2, a servo motor is coupled with a gear that engages with a toothed rod, where the end of the rod is connected to the camera's shutter release cable. Thus, when the servo receives a pulse signal from the microcontroller, it rotates. Because the rotary motion of the servo is converted into linear motion by the mechanical design, the shutter release cable is pressed and pulled back to its original position. Mursalim researched how to capture timelapse photos using a camera [16]. Mursalim used an optocoupler component to trigger the camera to capture photos.

As seen in Figure 3, Arduino sends a signal to the optocoupler, where the LED inside the optocoupler lights up and then passes the signal to the camera through a 3.5 mm jack cable as a photo trigger. Based on the three studies conducted, a comparison of

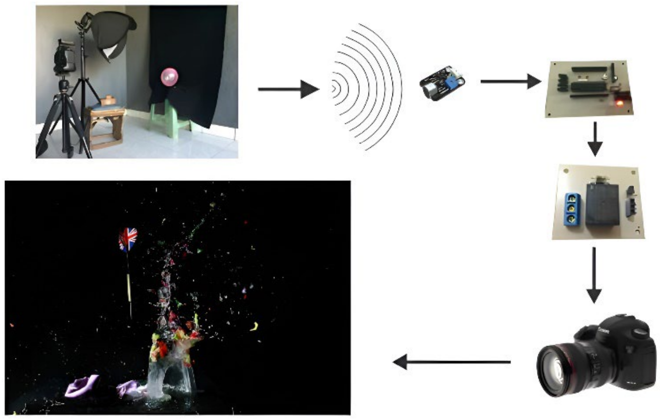


Figure 1. Desnanjaya's system to capture photos using a microcontroller.

methods for triggering the camera can be seen in Table 1.

In other words, if durability is required, then a servo should be used. If a fast response is needed, an optocoupler should be used. If a compact physical form is desired, optocouplers should be used. Based on the previous studies, the author combined certain aspects of these methods to create a new approach for the research. Firstly, the use of a solenoid to create water droplets was adopted due to the need for a component with a quick response [17]. Secondly, for capturing photos, the author employed optocouplers as electronic switches due to their faster response time and smaller size compared to other methods [16].

The system design includes the creation of block diagrams and flow diagrams to facilitate the process of building and maintaining the device in the future. The block diagram for the device can be seen in Figure 4. The design of the device consists of several parts. It starts with an input in the form of a push button that sends a signal to the microcontroller, Arduino Nano [18][19][20]. Then, the solenoid will be activated to release drops of water. Subsequently, the microcontroller triggers the camera to capture the water splashes.

Figure 2. Low's camera trigger using servo motor.

The working process of the device to capture mineral water splashes on the water surface involves the microcontroller reading the state of the push button. If the push button is pressed, the microcontroller processes the data and generates signals for the solenoid and the camera. The solenoid releases water drops, and the camera captures the droplets. The process then repeats as it continues to read the state of the push button until the system is stopped. The flowchart of the device design can be seen in Figure 5.

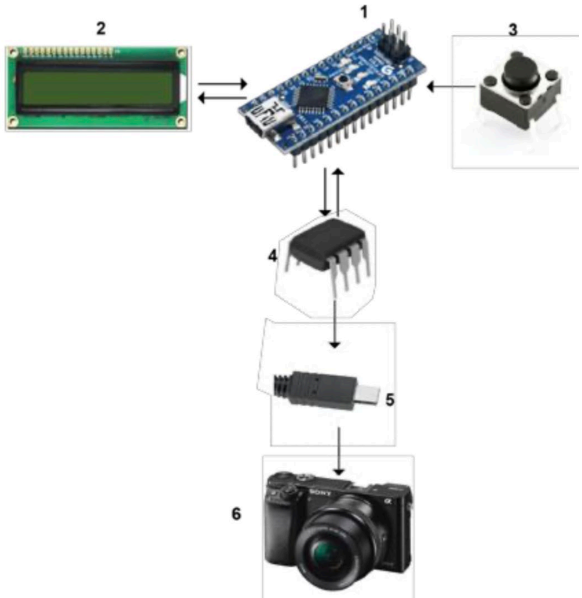


Figure 3. Mursalim's camera trigger system.

Table 1.
Comparison of a few methods for triggering the camera.

Researcher	Method	Durability	Response	Size
Desnanjaya	Relay (electro-mechanical)	Mid	Slow	Mid
Low	Servo (mechanical)	High	Slow	Mid
Mursalim	Optocoupler (electrical)	Low	Fast	Small

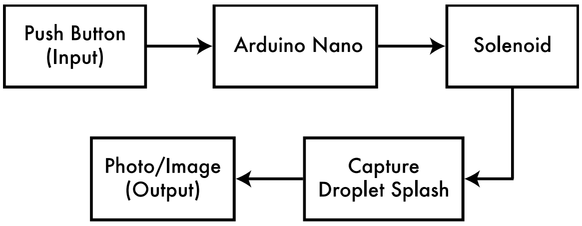


Figure 4. Block diagram of the device.

Based on Mursalim's research, the use of optocouplers as triggers for image capture is the best choice in terms of response and physical form. Therefore, in the design, optocouplers will be used. Furthermore, using optocouplers to activate the solenoid is also preferred due to the small size of the optocouplers. Figure 6 shows the electronic circuit design of the device.

From the design, the results of the mechanical, electronic, and control aspects were obtained. The mechanical design outcome can be seen in Figure 7. The container housing the solenoid is made from 3D printer plastic. The container will be connected to a light stand so that the solenoid is positioned above the water surface. As for the electronic circuit fabrication, it was designed to be as compact as possible to save space and improve circuit efficiency. Figure 8 shows the outcome of the electronic circuit fabrication. Figure 8 represents the result of fabricating the electronic circuit for the device using a plain PCB.

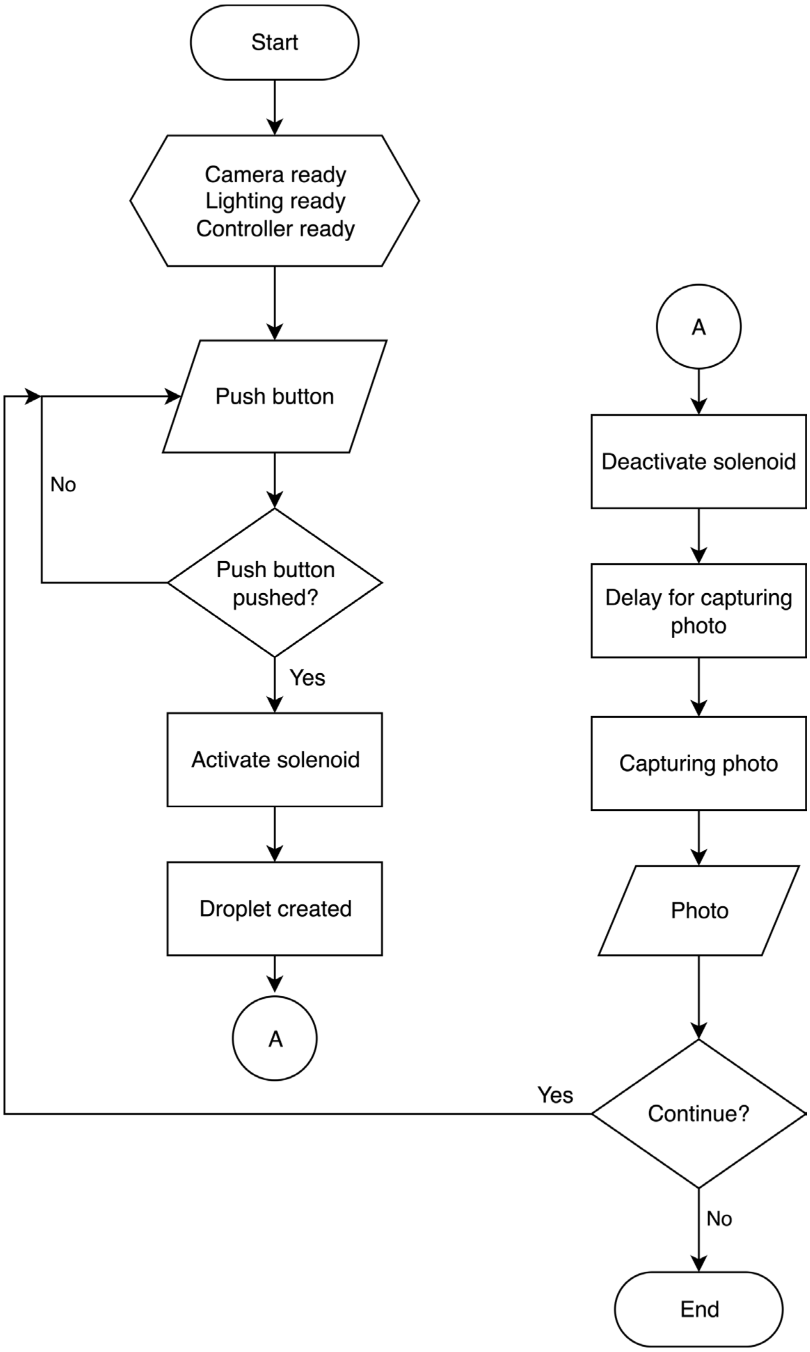


Figure 5. Flowchart of the designed device for a photographer to capture water droplet splashes.

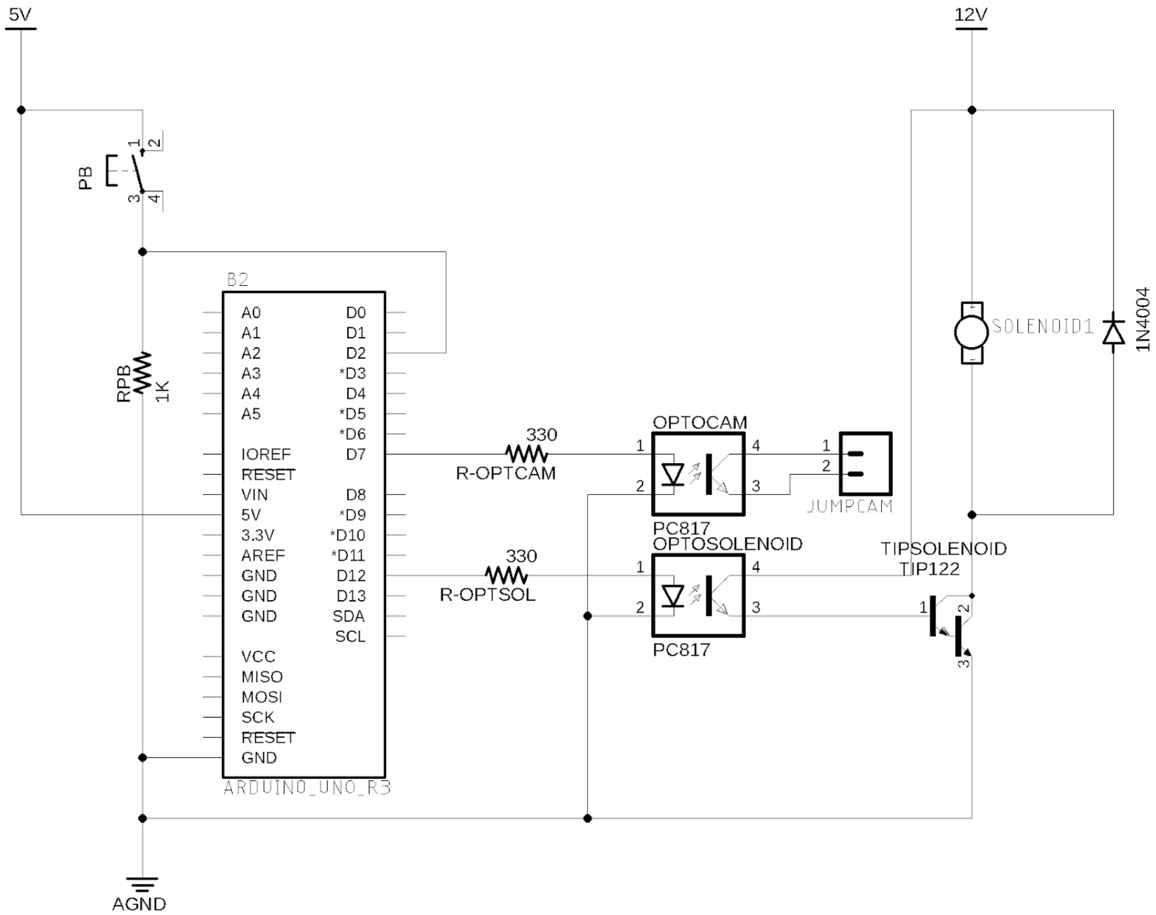


Figure 6. Electronic circuit design.

III. Results and Discussions

A. The way device tested

To determine the time it takes for a water droplet to fall from a certain height to the surface, this testing was conducted using a stopwatch as a time measurer. In this test, a height of 50 cm was chosen as the initial reference because it represents the maximum height of the device; for details, please see Figure 9.

B. Determining the success of the device

After obtaining the photos from the testing, opinions from photographers are required to determine the success of the device. Several categories determined the ideal water splash shape according to the photographers:

1. The better the water splash, the higher the produced water crown is.
2. The sharpness or pointedness of the crown's tip or edge, the sharper, the better the water splash.
3. The symmetry of the water splash, the more symmetrical, the better.
4. The smoothness of the water splash spread, the more spread out, the better the water splash.

For visualization of the photographer's criteria, see Figure 10.

C. Water droplet time testing

This test aims to determine the time it takes for a water droplet to fall from a certain height to the surface. The test is conducted using a stopwatch as the time measurer. A height of 50 cm is chosen for this test as the

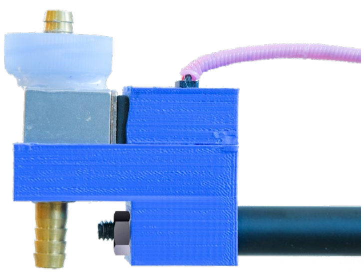


Figure 7. Result of solenoid holder.

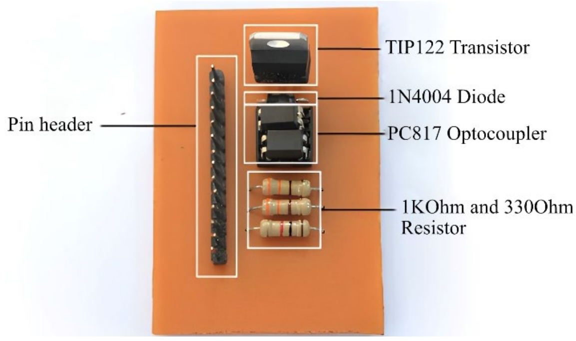


Figure 8. Electronic circuit of the controller.

Figure 9. Sketch of how this device was tested.

initial reference, as it represents the maximum height of the device.

From the conducted tests, it was found that the time it takes for a water droplet to touch the surface is between 100 ms and 120 ms shown in Figure 11, with an average of 104.67 ms. This average time will be used as the reference for the delay on the microcontroller to signal the camera to capture the photo after the solenoid releases the water.

D. Water droplet time testing using arduino

This test aims to determine the time it takes for a water droplet to fall from a certain height to the surface using an Arduino Nano as the microcontroller. The test will be conducted by setting delays on the Arduino with values of 105 ms and 110 ms since 104.67 ms falls between these values. The selection of 105 ms and 110 ms is to facilitate the test with a delay interval of 5 ms.

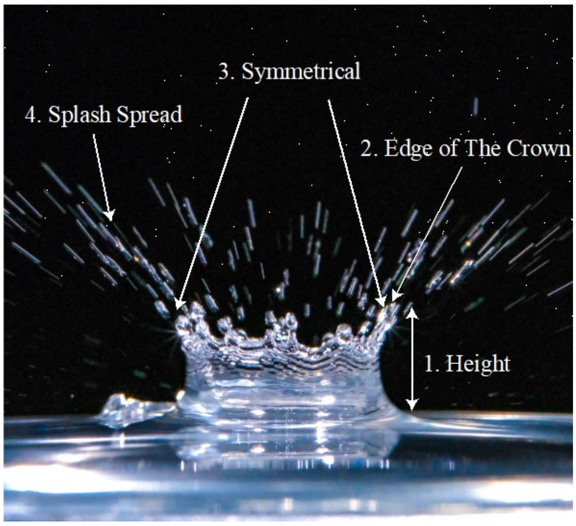


Figure 10. Visualization of a good splash shape.

In Table 2 and Table 3, which contain photos from the testing results using delay times of 105 ms and 110 ms, respectively, all five test shots successfully captured water droplets in the form of crowns or corona splashes. The average time of 104.67 ms proved to be the precise moment to capture the water droplets in a crown shape, and the delay times of 105 ms and 110 ms were appropriate delays to be used in the Arduino.

E. Testing the precision and accuracy of the device and photographer

This test aims to determine the precision and accuracy of the device in capturing water splash photos based on the predefined delay times. Table 4 shows that the research device is capable of producing water splash

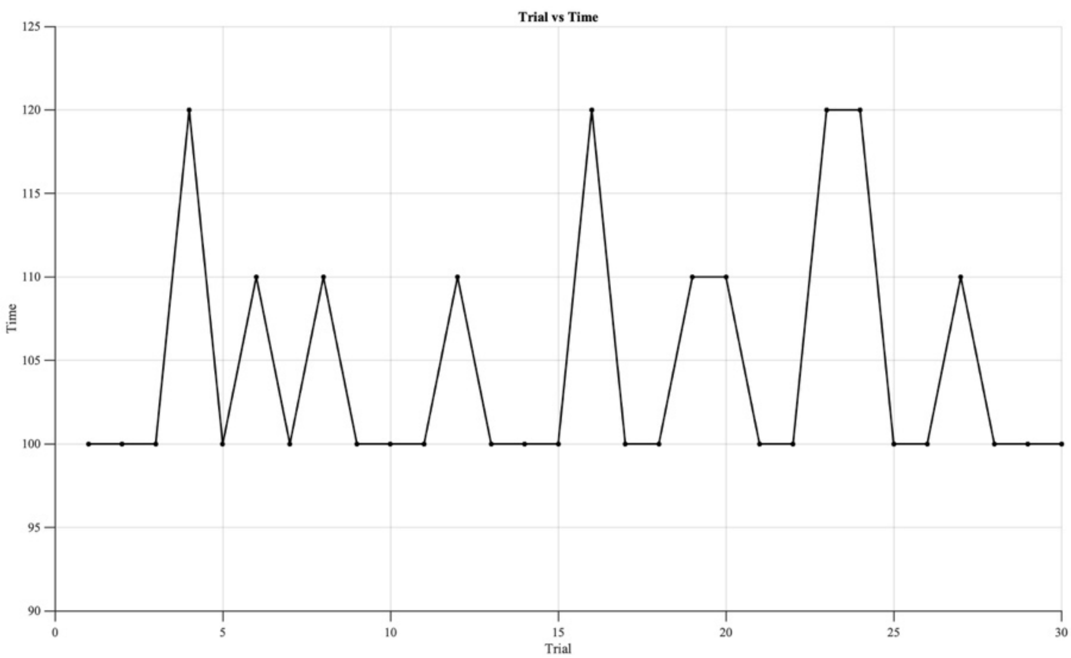


Figure 11. Graph of time for water droplet touches surface.

Table 2.
Trial using 105 ms delay to capture water droplet splash.

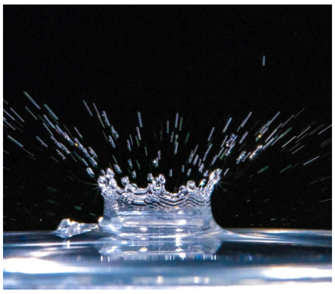
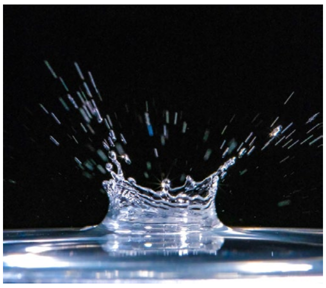
Trial	Result	Information
1		A successful take of a water droplet splash picture
2		A successful take of a water droplet splash picture
3		A successful take of a water droplet splash picture
4		A successful take of a water droplet splash picture
5		A successful take of a water droplet splash picture

Table 3.
Trial using 110 ms delay to capture water droplet splash.

Trial	Result	Information
1		A successful take of a water droplet splash picture
2		A successful take of a water droplet splash picture
3		A successful take of a water droplet splash picture
4		A successful take of a water droplet splash picture
5		A successful take of a water droplet splash picture

photos with success rates of 100% at both 105 ms and 110 ms delays, as the success rate criteria already mentioned before.

Using the same delays, the next test is to compare the capabilities of the research device and the photographer in capturing water splash photos. The experiments are conducted with the same settings, the difference being that in this test, the photographer takes the water splash photos themselves. The test results are presented in Table 5.

Based on Table 5, the research device successfully captured water splash photos with a success rate of 100 %, while the success rate of the photographer in capturing water splash photos is only 6 %.

Based on the data analysis in Table 4, this method operates perfectly with 100 % success in automatic photo capture, similar to previous researchers

Table 4.
Success rate of the device.

Trial	Delay 105 ms	Delay 110 ms
1	✓	✓
2	✓	✓
3	✓	✓
4	✓	✓
5	✓	✓
6	✓	✓
7	✓	✓
8	✓	✓
9	✓	✓
10	✓	✓
Success rate	100 %	100 %

Table 5.
Success rate of device and photographer.

Trial	D	P	Trial	D	P	Trial	D	P
1	✓	✗	11	✓	✗	21	✓	✗
2	✓	✗	12	✓	✗	22	✓	✗
3	✓	✗	13	✓	✗	23	✓	✗
4	✓	✗	14	✓	✗	24	✓	✗
5	✓	✗	15	✓	✗	25	✓	✗
6	✓	✓	16	✓	✗	26	✓	✓
7	✓	✗	17	✓	✗	27	✓	✗
8	✓	✗	18	✓	✗	28	✓	✗
9	✓	✗	19	✓	✗	29	✓	✗
10	✓	✗	20	✓	✗	30	✓	✗
D: Device			Success rate device				100 %	
P: Photographer			Success rate photographer				6 %	

✓ = a successful take of a water droplet splash picture
✗ = a failed attempt to take a of water droplet splash picture

[14][15][16]. The advantage of this method is that it can also be used for other cases, such as capturing photos of water droplets split by a thread.

It is proof that the research device consistently achieves success in capturing water splash photos compared to the photographer, who was only able to capture water splashes directly once. Furthermore, this also proves that the device can assist photographers in capturing extremely brief water splashes.

F. Photographer's opinion

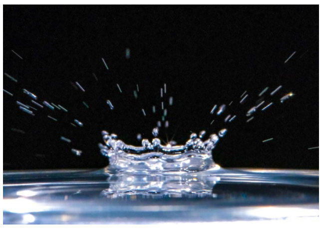
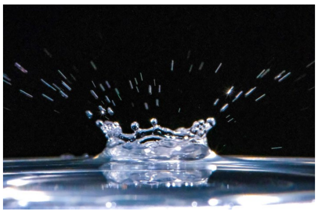
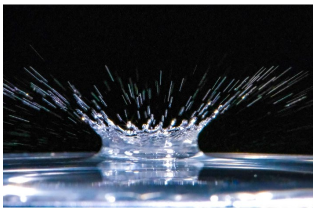
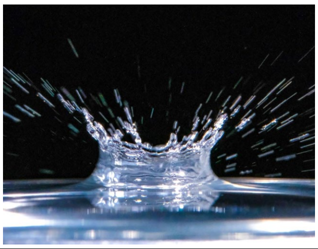
Assuming that different heights of water droplets will result in different water splash photos, testing was conducted to prove this. This section discusses the ideal height that produces the best water splash shape. Each photo was evaluated by the photographers, and they gave a score from 1 (not good) to 10 (excellent).

Based on Table 6, it can be seen that the height of the water splash depends on the height from which the water droplet is released. This aligns with the laws of physics, specifically the laws of collision and energy conservation at a given height, expressed by the formula:

$$p = mv \tag{1}$$

Collision momentum (p) is the product of mass and velocity. To determine the velocity before the collision, the law of energy conservation is applied, where the energy in the initial state equals the energy in the final state. In this case, the initial energy condition refers to the moment when the water droplet is about to be released from a certain height, during which only potential energy (E_p) is at work. Potential energy depends on the mass of the object (m), the height of the object (h), and the Earth's gravity (g). The final energy condition refers to the moment just before the droplet collides with the water surface, where only kinetic energy (E_k) is at work. Kinetic energy depends on the mass of the object (m) and the speed of the object (v). Based on the law of energy, the height of the water droplets will affect the speed of the water droplets before they collide with the water surface, which can

Table 6.
Photographer score for photo taken by device from different heights.

Height (cm)	Result	A	B	C	D	E	Average
20		5	6	5	6	6	5.6
25		5	6	5	6	6	5.6
30		6	6	5	6	6	5.8
35		7	8	8	8	7	7.6
40		7	8	8	7	7	7.4
45		8	8	8	8	8	8
50		9	9	9	9	9	9

A-E = Each photographer's score

cause water splashes. For the decomposition, it can be seen in equation 2 to equation 4.

$$E_p = E_k \quad (2)$$

$$mgh = \frac{1}{2}mv^2 \quad (3)$$

$$v = \sqrt{2gh} \quad (4)$$

Thus, based on Table 6, the results are consistent with the laws of physics, demonstrating that the water splash height depends on the velocity of the water droplet, as supported by previous research [21][22].

IV. Conclusion

After conducting testing and analysis of the research results, it was concluded that the development of the photography device for capturing water splashes functions perfectly with 100 % effectiveness. Water droplets are generated using a solenoid controlled by Arduino, and the collision process of the droplets with the water surface, which produces water splashes, was successfully captured using the developed photography device. The best splash shape occurred at a droplet height of 50 cm from the water surface with a delay time of 105 ms. The further development of this research includes capturing photos of water droplet collisions with a thread or photos of water droplet splitting with a thread. Additionally, other equipment can be developed to work automatically and practically without compromising the original results.

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Declarations

Author contribution

All authors contributed equally as the main contributor of this paper. All authors read and approved the final paper.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The use of AI or AI-assisted technologies

During the preparation of this work, the author(s) used **ChatGPT** to help paraphrase and correct the grammar of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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