Automatic Ethanol Sprayer Attachment

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1 Executive Summary

All objects entering a sterile environment such as a biosafety cabinet (BSC) are sterilized with a decontaminant, often aerosolized via spray bottle. For example, in a basic cell passaging procedure, a researcher will pick up an ethanol spray bottle around 20 times and pull the trigger between 40 and 50 times to sterilize everything entering the BSC and incubator. Compared to the total length of a passaging procedure, the time invested in sterilizing may seem insignificant, yet the length of this time becomes considerable over routine cell culture maintenance and experimental procedures. Reducing the time spent sterilizing by increasing convenience and ease of use of ethanol sterilizers can have significant benefits for all research requiring sterile environments.

Our solution is an automatic ethanol spraying device which attaches to a wide range of spray bottles and uses object detection to activate a motorized trigger mechanism. This product addresses a large target market, which includes biological research laboratories in academia and industry. To our knowledge, there are no products specifically tailored to this goal, nor are there products made to attach to preexisting spray bottles currently on the market. Our pioneering product is an easily manufactured and maintained device that is valuable in a diverse set of research environments by increasing efficiency and convenience.

2 Problem Statement

2.1 Vignette

As a Bioengineering graduate student at the University of California, Riverside, Brock spends most of his time in a Biosafety Level 2 research lab performing *in vitro* stem cell experiments. Brock picks up the ethanol spray bottle to sterilize his gloved hands before retrieving a stack of well plates from the incubator. He quickly checks the plates on the microscope, then brings them to the BSC to change the cell's media. Before he begins, he picks up the ethanol spray bottle, sprays his gloves, and then sprays each well plate, pausing between plates to spread the ethanol evenly over the entire surface with his fingers. After Brock has changed media, he again sprays his gloves and each plate before moving the cells back to the incubator. The ethanol spray bottle is a central player in cell culture routine. How might we help wet lab researchers conduct mundane routine operations faster and more easily while working on cutting-edge experiments?

2.2 Need Statement

Industry, graduate, and undergraduate researchers in wet labs need a device that saves them time and energy while completing routine tasks. An automatic spraying mechanism attached to existing lab spray bottles eliminates the need to physically touch a spray bottle every time an object needs to be sterilized, reduces the risk of dropping cells, and minimizes hand fatigue by removing the need to pull the spray bottle's trigger.

2.3 Design Criteria

Our proposed device needs to:

1. activate spray based on proximity detection of an object.
2. attach to a wide range of spray bottles.
3. retain manual squeeze-trigger capability.
4. be simple to attach and intuitive to operate.
5. be inexpensive.

2.4 Scientific Background

Ethanol kills microorganisms by dissolving their membrane lipid bilayer and denaturing their proteins, and is effective against most bacteria and fungi and viruses. Alcohol molecules are amphiphile chemical compounds, allowing alcohol molecules to bond with and break down the protective membrane of bacterial cells. When this occurs, the core components of the bacteria are exposed and dissolve, losing their structure and ceasing to function. Ethanol's action on non-lipid-containing viruses is variable. For highest effectiveness, sterilizing ethanol should be used at concentrations of approximately 70% (v/v) in water: higher or lower concentrations may not be as germicidal. A major advantage of aqueous solutions of alcohols is that they do not leave any residue on treated items [1].

3 Current Market

3.1 Target Market

Our primary target is scientific laboratories, whether in industry or academia, which emphasize efficient biological experiments in everyday research activities. As a secondary target, companies pursuing materials researches might benefit from our product, as material development often requires controlled and consistent treatment, which can include sterility.

With regards to industry, since the reliable manual spray bottle remains prevalent, we project that small companies and start-ups would channel their financial power somewhere else rather than automating their spraying processes. Therefore, we would like to target developed companies that have more emphasis on research robustness and efficiency, areas which our device enhances. Several examples of companies who might benefit from our product are Roche, JJ, Novartis, etc.

With regards to academic setting, universities in the United States offer undergraduate and graduate research positions for students. For instance, UCLA has averaged nearly $1 billion in research grants and contracts. In conjunction with other research universities, the size of the academic research market is large. Similar to industry setting, our device can increase the efficiency and robustness of the research process.

3.2 Status Quo

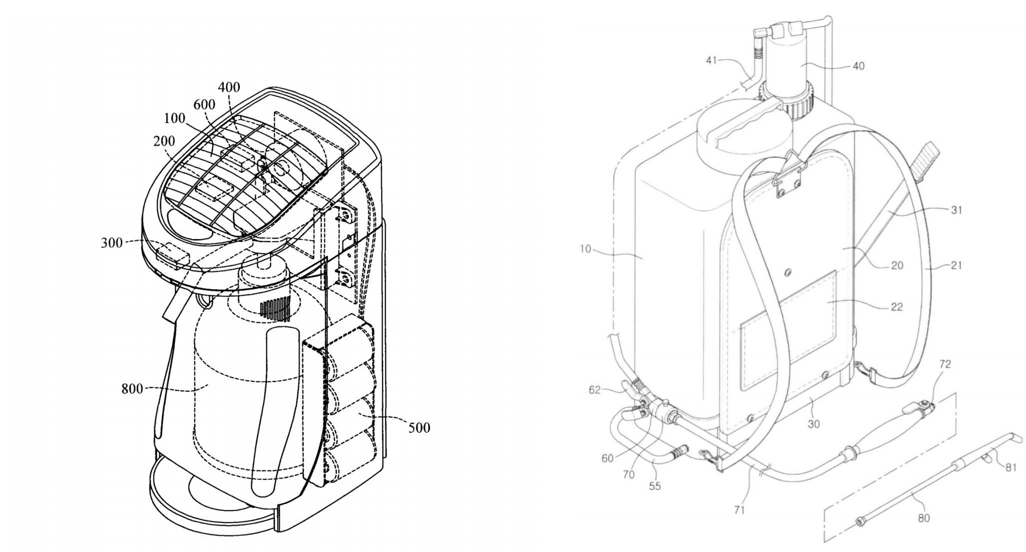
There is currently no standardized sprayer design on the market and many different suppliers manufacture spray bottles for many different industries. These spray bottles can be designed for spraying or even improvised if spray bottles are not available. Most spray bottles are actuated via a mister and pump mechanism, which utilizes pressure changes to aerosolize ethanol that is stored within a larger chamber. Some spray bottles are actuated via squeezing a flexible chamber and forcing ethanol to be administered via volume displacement. To our knowledge, there is no current product that offers all parts of our design criteria in a single package.

3.3 Patent Review

The following patents detail products similar to our proposed device, but neither one is filed in the United States, nor do they set out to do exactly what our device does.

A Chinese patent discusses an automatic spray bottle with an environmental sensing unit and solar energy unit. This bottle automatically performs the actions of a disinfecting spray agent without the need for human applied force through the environmental sensing unit and then converts stored solar energy into kinetic power. The benefit to this product is a control of power supply, and reduction to power cost and battery replacement frequency [2].

A patent filed in Korea presents a combined automatic and manual spray wherein the user can selectively use the manual or automatic spray function and/or both functions can be used simultaneously to increase the spray's volume and power. Both systems use nebulizers to operate the bottle's pump, but powering the automatic motor requires a battery [3].



(a) (b)

Figure 1: Existing patents. (a) Integrated automatic spray device patented in China. (b) Combined automatic and manual spray device backpack patented in Korea.

4 Design Review

4.1 Design Requirements

Objective	Method
1.1 The device shall detect an object within a short distance from spray bottle.	The infrared (IR) sensor mounted on top of the case emits an infrared beam which reflects off nearby objects and is sensed by the phototransistor, sending a signal to the microprocessor.
1.2 The device shall activate the spray mechanism once per detection event.	The spray mechanism is activated by a servo motor attached by a wire to the bottle trigger. The servo motor is controlled by the IR sensor and a software delay, which controls how frequently the servo activates if the IR sensor is continuously activated
2.1 The device shall be adjustable to fit on a variety of bottles.	Our design features two sliding, ridged clamps for the head and neck of the bottle, joined by cables and electrical wires with extra coiled length, allowing the assembly to adjust to different bottle dimensions.
2.2 The device shall be securely affixed to the spray bottle during routine handling.	The sliding clamps are attached to tensioned springs which pull the clamp tight around any sized bottle head and neck, and a taut elastic band around the bottle body supports the battery pack.
2.3 The device shall retain functionality given variance in bottle and spray mechanism design.	Our critical components (IR sensor and servo) are attached to the head and neck clamps, which maintain their relative positions to the spray bottle mechanism regardless of bottle variations.
2.4 The device shall not adversely affect stability of fully assembled system.	The servo is positioned along the clamp center, and the battery pack is placed low on the body of the bottle. However, a thorough center of mass analysis has not yet been conducted.
3.1 The device can be actuated by hand.	Our device does not obstruct the original manually operated trigger mechanism nor alter its function.
3.2 The device shall not be damaged or inhibited by correct manual operation.	Our mechanism uses a taut cable to pull the trigger. When a user manually pulls the trigger, the cable deforms, and the servo arm feels no forces.
3.3 The device shall not inhibit the ability to pick up and manually actuate the bottle.	Our device is not overly heavy and does not significantly change ergonomics of the device, although center of mass analysis still needs to be conducted
4.1 The device can be attached in under 5 steps.	There are 4 steps to attach our device to a spray bottle - (1) Slide elastic band around bottle body. (2) Fit clamp around neck. (3) Fit clamp around top of head. (4) Fit trigger cup over trigger.
4.2 The device shall retain fundamental mechanism of action of the system.	Our solution leverages the previous trigger mechanism already understood by users.
5.1 The device can be obtained for under $20.	The current prototype design is slightly too expensive, but investigating cheaper alternative parts could bring our price down.
5.2 The device components can be easily replaced.	Our design is open source, with code, CAD, and electronic schematics displayed or linked throughout this document.

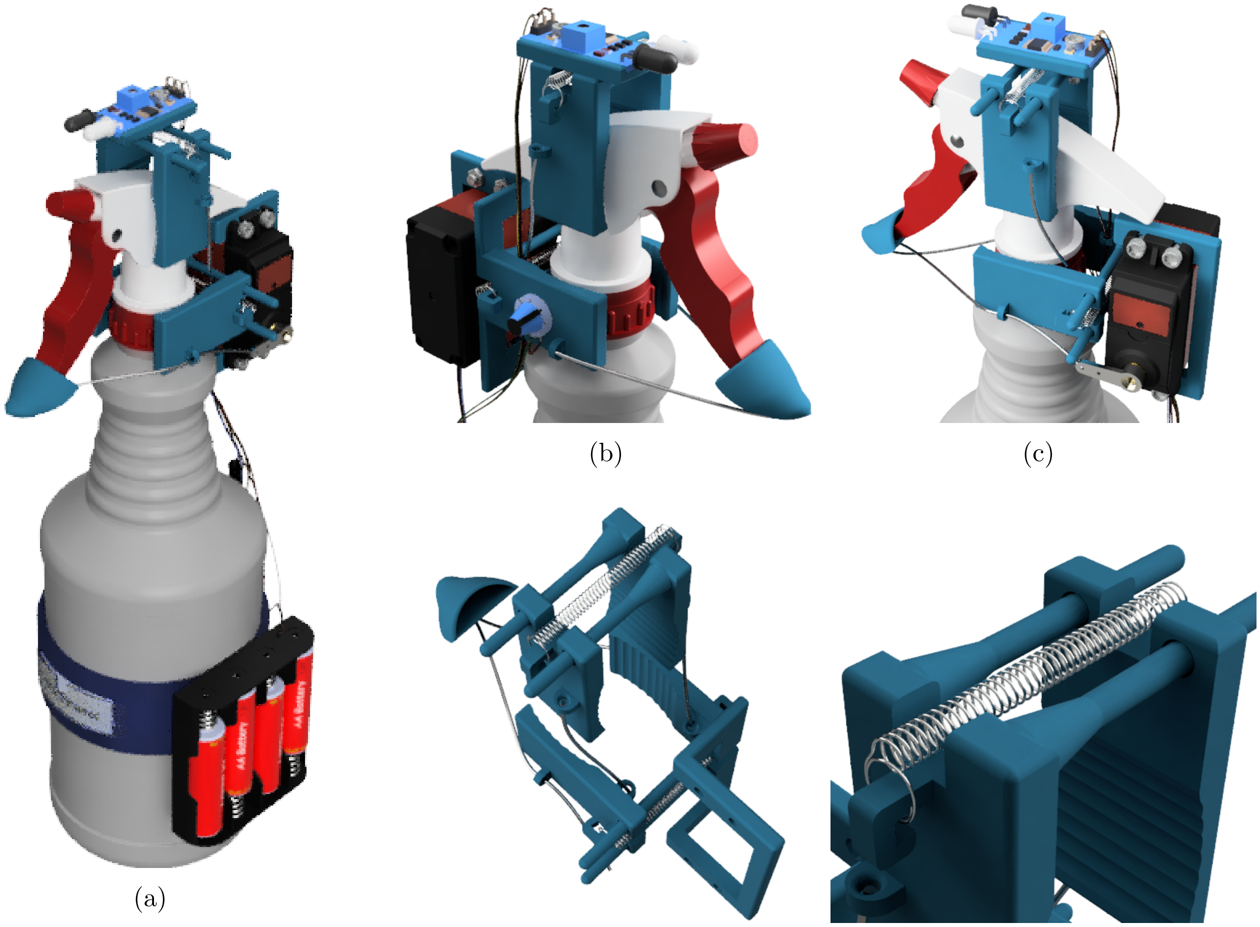
4.2 Final Design

Our device is designed to fit onto a wide variety of spray bottles with two spring-tensioned sliding mechanisms (see Figure 2e) which clamp onto the top of the head and the screw-on neck piece. These are the most ubiquitous aspects of spray bottles and thus the best targets. The clamps also are ridged and curved to give the best grip on the bottle. We also employ an elastic band around the bottle itself to provide support for the battery pack and microcontroller. These components are all connected by thin steel cables and electrical wires.

We actuate spray by pulling the trigger. We fit a snug printed cup over the end of the trigger and attach this cup to a thin cable running between a fixed point on one side of the neck clamp and the servo motor arm on the other. The servo motor is mounted on the back of the neck clamp, balanced in the center but with its arm on one side of the neck (see Figure 2c). To pull the trigger, the servo arm turns from pointing forward, towards the trigger, to pointing 180° away, pulling the cable with it and forcing the trigger to close.

This mechanism is controlled by an IR sensor and a potentiometer. The IR sensor is mounted on the top of the head clamp to detect objects in front of the spray bottle up to 9 cm. The sensing distance is adjustable with a screw driver. The maximum speed of spray is adjustable with a potentiometer on the neck clamp (see Figure 2b), allowing researchers to choose how quickly the bottle sprays when an object remains in front of it (i.e. a 500 mL cell media bottle requiring sprays from multiple angles).

For a visual demonstration of our device mechanism, see this CAD video. For a 360° view of our device, see these other CAD videos.



(a) (b) (c) (d) (e)

Figure 2: Spray Bottle CAD Model. (a) CAD model of entire spraying device mounted on example spray bottle. (b) Side view of potentiometer. (c) Side view of servo-cable mechanism. (d) Bare assembly. (e) Clamp mechanism.

4.2.1 Electrical

We began our project in the Arduino Integrated Development Environment. The main purpose of the Arduino and breadboard is to proove the whole system works successfully together to perform its ultimate function. Simply put, the system reads whether there is an object in close proximity using the IR sensor. If so, an attached servo motor performs a 180° rotation. Other than the IR sensor, a potentiometer also controls the frequency of the servo motor movement. Both potentiometer and IR sensor are supplied by using power from the Arduino Nano board. The Nano itself is connected to a 5V voltage linear regulator that receives its power from a 6V external power source. The servo motor must be powered directly from the battery as the Nano cannot supply enough current for the current spikes common in servos [4]. Our servo can be directly connected to the power source as it falls along the input voltage range. See Figure 3 for our prototype schematic.

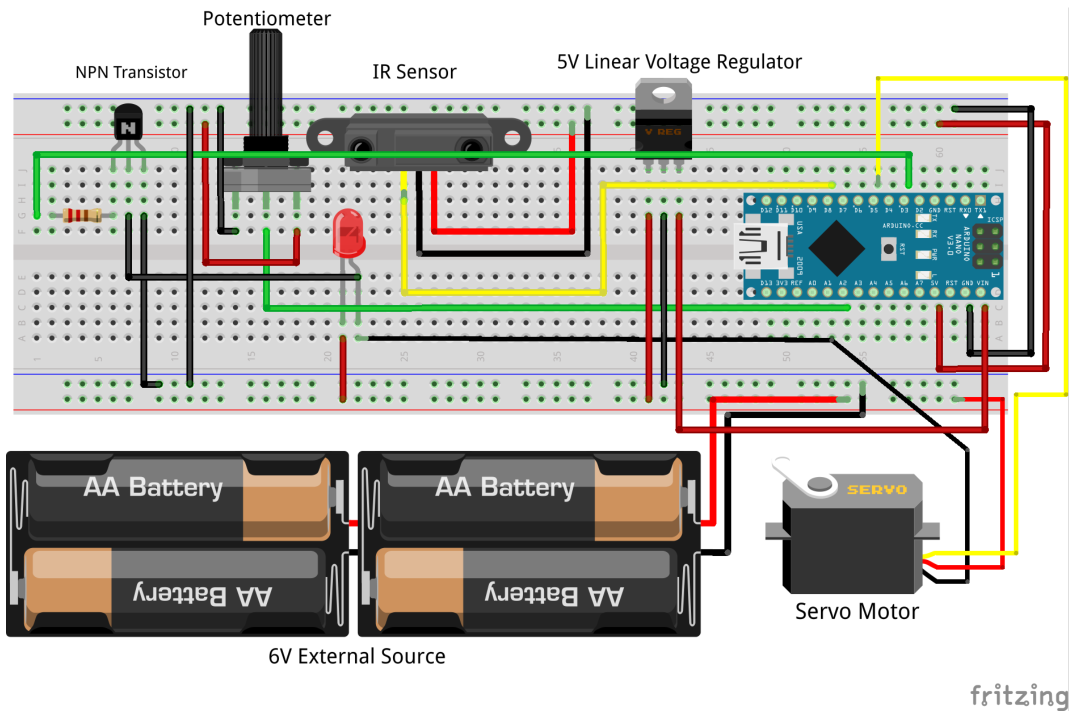


Figure 3: Breadboard schematic with Arduino Nano as a preliminary proof of concept. Figure was generated by Fritzing.

After testing our project on a breadboard, we designed a printed circuit board (PCB) using Eagle, which can be seen in Figure 5. A PCB is advantageous because it saves space and allows us to make our design permanent. The PCB we designed has dimensions of 1.050 by 1.274 inches, which is around 10 percent smaller than the breadboard version.

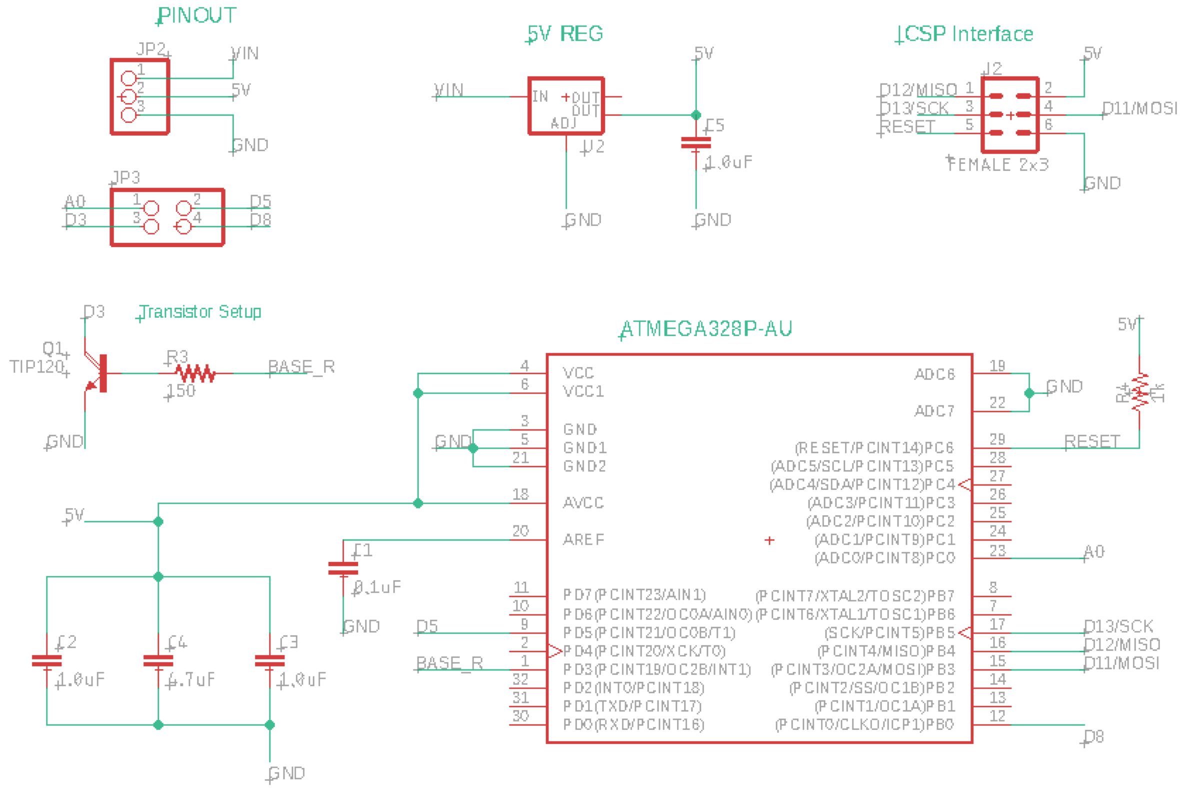
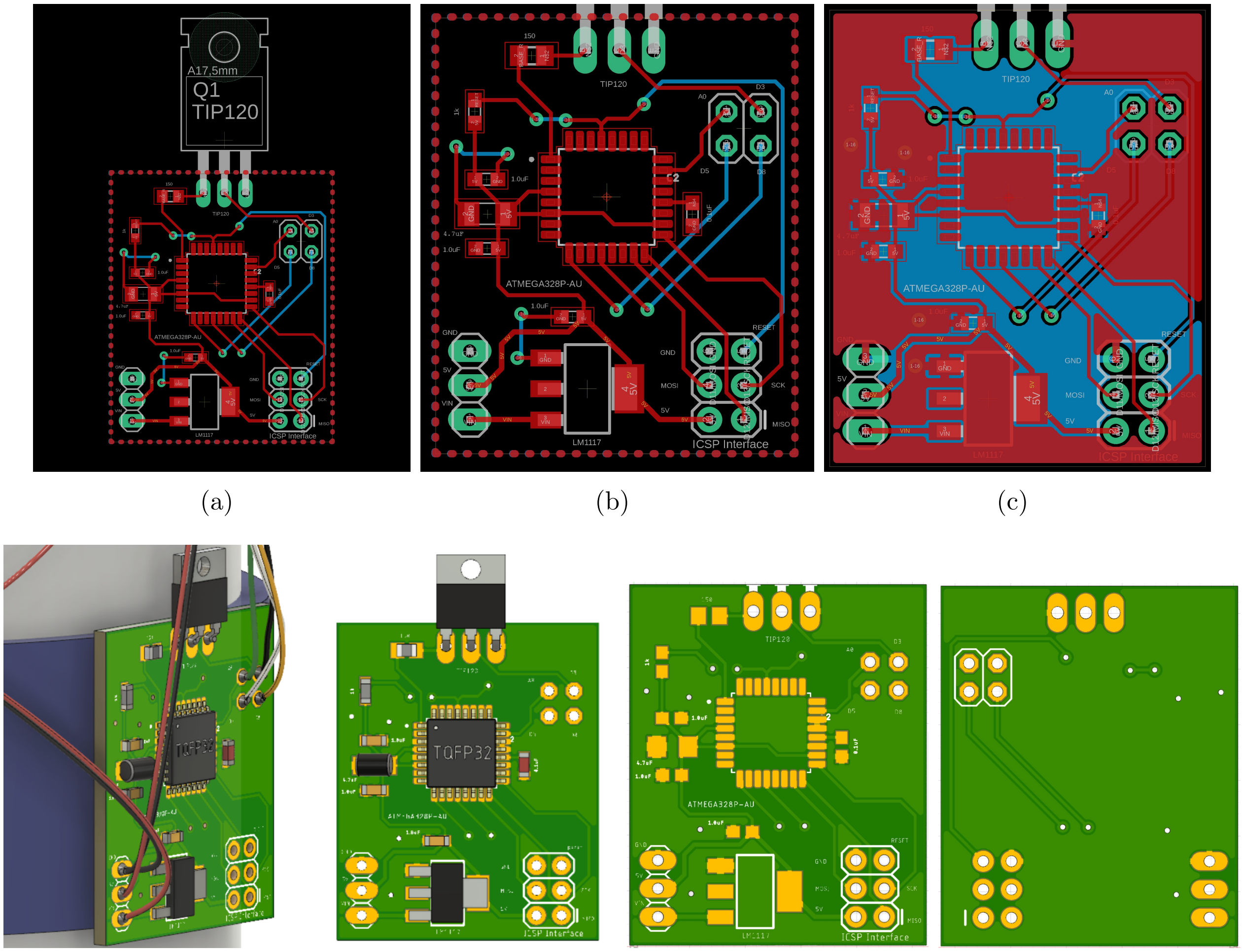


Figure 4: Whole system electronic schematic based on [5].

An ATmega328P-AU chip is used to replicate the Arduino Nano on our PCB, and we have used only the necessary pins [6]. We used surface mount components, including a LM1117 voltage regulator to provide a constant 5V and capacitors to reduce noise. The In-Circuit Serial Programmer, or ICSP, interface is used to program the microcontroller. A TIP120, which is a NPN power Darlington transistor, and a resistor to limit current are added to control the power to the servo motor [7]. This transistor was chosen because it was switch loads up to 60V, which makes it useful for controlling motors. One pin header component is used to connect the board to Vin, 5V, and GND. Another is used to connect the pins on the chip to our servo motor, transistor, IR sensor, and potentiometer. The pin headers were used to make it easier to connect all the components. We made sure not to cross digital and analog signals or power and signal lines to reduce electrical interference between traces [8]. We also created two GND planes to reduce routing complexity.



(a) (b) (c)

(d) (e) (f) (g)

Figure 5: PCB board with dimensions 1.050 x 1.274 inches. (a) Board layout with transistor. (b) Zoomed in view of board. (c) Board showing GND planes (red). (d) Wired PCB on bottle. (e) Front CAD view. (f) CAD without board components. (g) CAD back view without board components.

4.2.2 Code

We control our device through the Arduino IDE after burning bootloader onto our ATmega328 once. Our code reflects the elegant simplicity of our design. To more easily reference our code, see our GitHub Repository.

```
#include <Servo.h>                  // include servo library
Servo myservo;                      // create servo object

#define potPin 0                    // analog potentiometer input
#define irPin 8                     // digital IR sensor input
#define servoPin 5                  // digtal PWM servo control pin
#define transistorPin 3             // digital transistor control output

int maxTime = 3000;                 // longest time interval between IR reads (ms)
int minTime = 1350;                 // shortest time interval between IR reads (ms)
int servoSpeed = 30;                // control servo speed
unsigned long time_now = millis(); // enable delay between spray

void setup() {
  pinMode(irPin, INPUT);            // IR sensor input
  pinMode(transistorPin, OUTPUT);  // transistor output
  myservo.attach(servoPin);         // attach servo
}

void loop() {
  int potDelay = analogRead(potPin);                      // read delay
  potDelay = map(potDelay, 0, 1023, minTime, maxTime) ;  // map delay to time scale

  if (potDelay <= minTime + 50) {}                        // do nothing (potentiometer turned off)
  else if (!digitalRead(irPin) && (millis() > (time_now + potDelay))) { // object present, delay satisfied
    time_now = millis();                                  // update delay for next spray
    digitalWrite(transistorPin, HIGH);                    // turn on transistor, allow current through servo
    delay(50);                                    // ensure steady state transistor performance

    for (int pos = 0; pos <= 180; pos += 10) {    // move servo from 0 to 180
      myservo.write(pos);                         // move servo
      delay(servoSpeed);                          // control servo speed/allow higher torque
    }
    delay(200);                                   // allow servo to fully complete move
    myservo.write(0);                             // move the motor back to 0 without delay
    delay(500);                                   // allow servo to fully complete move

    digitalWrite(transistorPin, LOW);             // turn off transistor, block current through servo
  }
}
```

Figure 6: Arduino code to control sprayer.

4.2.3 Safety

The elastic band has a sleeve to label the chemical inside of the bottle with information obtained from the safety data sheet (SDS). Additionally, to warn the user of pinch points such as the moving motor, there is a warning sticker. A case to act as a guard and cover the moving components is also an option under development.

5 Manufacturing

5.1 Case

Custom parts were designed in Autodesk Fusion360, Inc and 3D printed in polylactic acid (PLA) using Prusa Mk3s and Raise3D Pro 2 3D printers in the UCLA Boelter Hall Makerspace. The 3D printed clamp pieces for the bottle head and neck are held together by extension springs hooked around tabs on either end of the clamp. The two clamps are connected by a cable tied to 3D printed rings on all clamp pieces. The spray head assembly is connected to the elastic bottle body piece by electrical wiring between the battery pack, the PCB, and thehead assembly.

5.2 Mechanism

The bulk of the mechanism consists of purchased electronics pieces. These include the servo motor, IR sensor, and potentiometer, which are fastened by screws and nuts tightened across through holes in our 3D-printed assembly. The battery pack and PCB are fastened to an elastic band around the body of the bottle by cable. The trigger is held by a 3D printed sleeve attached to a steel cable tied between the servo motor and a stationary 3D printed ring on the opposite side of the bottle.

5.3 Printed Circuit Board

The printed circuit board (PCB) was designed using Autodesk Eagle based on existing designs for the Arduino Nano, our stepping stone to the PCB. The PCB was designed with best practices in mind, including not crossing power and signal traces, keeping analog and digital trace paths separate, and minimizing the number of vias [8]. The PCB also includes a ground plane for convenience. PCBs can be ordered from Bittele Electronics. The circuit elements would be purchased separately and soldered to the blank PCB using the soldering irons and fans in the Boelter Hall Makerspace.

5.4 Price Breakdown Of Materials

Part	**Unit Cost**	**Number**	**Total Cost**
Metal waterproof servo [9]	$13.92	1	$13.92
4xAA Battery Holder [10]	$2.41	1	$2.41
ATMEGA328P-AU [11]	$2.01	1	$2.01
IR Sensor [10]	$1.00	1	$1.00
Potentiometer [12]	$1.00	1	$1.00
TIP120 NPN Transistor [11]	$0.93	1	$0.93
AA Batteries [10]	$0.22	4	$0.88
PLA Filament [13]	$0.053/gram	10	$0.53
PCB Estimate [14]	$0.46	1	$0.46
LM1117 Voltage Regulator [11]	$0.44	1	$0.44
40x1 Female Pin Header [15]	$1.50	0.275	$0.41
M3 Hex Head [10]	$0.04	5	$0.20
2x1 Male Pin Header [11]	$0.05	3	$0.15
Extension Spring [10]	$0.05	2	$0.10
1 uF 0603 Capacitor [11]	$0.02	3	$0.06
4.7 uF 0603 Capacitor [11]	$0.03	1	$0.03
2" width elastic band [10]	$0.03	1	$0.03
150 Ohm 0805 Resistor [11]	$0.02	1	$0.02
0.1 uF 0603 Capacitor [11]	$0.01	1	$0.01
1kOhm 0603 Resistor [11]	$0.01	1	$0.01
5mm LED [9]	$0.01	1	$0.01
1mm steel cable [10]	$10.00	0.001	$0.01

Total Cost = $24.62

6 Future Outlook

6.1 Regulatory Pathways

As part of due diligence regarding regulatory pathways, we investigated several methods by which our device could possibly be controlled. Ultimately, we came to the conclusion that our device falls under no special regulatory pathways.

One common regulatory pathway in scientific research within the United States is the FDA Medical Device Pathway. Per section 201(h) of the Food, Drug, and Cosmetic Act, our device and its intended functions do not meet the requirements of being a medical device. It is not 1) recognized in the official National Formulary or United States Pharmacopoeia, 2) intended for the diagnosis, treatment, cure, etc. of disease in man or other animals, nor 3) intended to affect structure or function of the body in man or other animals.[16]

There are some regulations surrounding electronic components of the device that are important to identify. This may include Title 21, section 862 of the Code of Federal Regulations regarding Clinical Chemistry and Clinical Toxicology Devices [17] and Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) regulations regarding battery-driven devices [18]. Ultimately, however, considering the novelty of our device and the lack of pre-existing products, new ground would have to be broken regarding regulations.

6.2 Conclusions

Over winter and spring quarters during the 2019-2020 school year, the autosterilizer BMES design team at UCLA designed an automatic spray bottle device for research sterilization procedures. Our device, once placed on a spray bottle, is able to detect objects held in front of the nozzle and automatically pull the trigger, while simultaneously preserving the original manual trigger capabilities. Additionally, our device attaches to a wide selection of existing spray bottles, reducing costs and material waste by increasing adaptability. Our simple, intuitive, and effective design is meant to integrate seamlessly into researchers' needs, providing convenience and efficiency to every sterilization-dependent procedure.

While our project has been highly successful thus far, there remain some challenges. The projected price of 1 unit, ∼\$30 is too high, given that spray bottles themselves cost only ∼\$10. This price could be reduced by finding a less expensive servo motor, though there are concerns it may be unable to provide the force required to actuate the trigger. At the same time, a more powerful motor is bulkier and heavier than a less powerful, smaller motor. The extra weight at the top of the spray bottle may make it more top heavy and prone to falling over when the bottle is almost empty. A heavier motor will only exacerbate this issue further. One potential solution would be to incorporate a weighted base attachment to support the bottom of the bottle.

While we acknowledge remaining opportunities for improvement, our design should be functional and fully satisfies 11 of 13 Design Requirements. Given the significant project limitations imposed by external factors, this project has been a success.

7 Acknowledgements

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