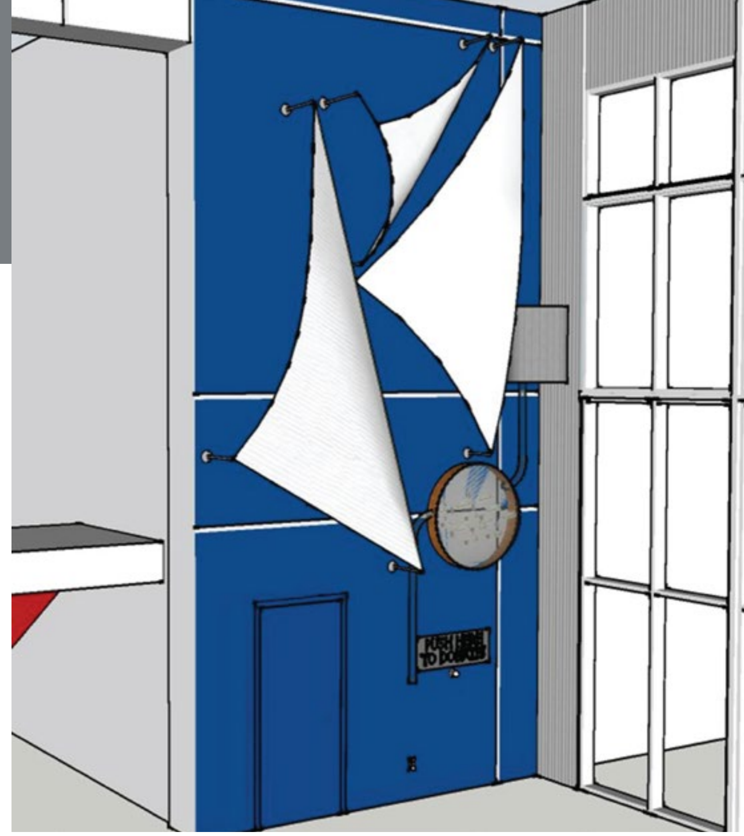
Museduino Case Study: Full Sails

Abstract

"Full Sails" is an interactive installation built in the lobby of the Santa Cruz Museum of Art & History, which pulls paper money donations through curved tubing into a glass porthole, and then inflates sails and lights them up as a reward. While its purpose is to accept cash donations to support the museum, it also pays tribute to Santa Cruz's history of sailmaking and shipbuilding.

https://vimeo.com/295454716

The museum commissioned local glass sculptor Biagio Scarpello to design and fabricate the installation and freelance museum technologist Jason Alderman to collaborate on electronic sensors and interactivity, both working with exhibition designer Justin Collins. They used a single Arduino with a Museduino shield and four satellite boards to control three fans, three sets of lights, a dust collector vacuum, a control switch, and two infrared sensors. The project was developed and completed in six months, and has been running continuously since 2017.



The original Sketchup file, showing the position of the kinetic sculpture in the atrium, with stairs to the second floor on the left and large bay windows on the right.

Concept Development

Initial Proposal

Justin Collins (exhibition designer) collaborated with Biagio Scarpello (a mixed-media sculptor and glass artist) to plan a kinetic sculpture in the atrium of the Santa Cruz Museum of Art and History that would accept donations and entertain visitors. Loosely inspired by Cash Machine in The New Children's Museum in San Diego (more), the installation (as originally planned) would have visitors push a large button to turn on a vacuum that would suction paper money donations into a large glass dome, and reward visitors by inflating and illuminating ship sails mounted on the wall. As a local art and history museum, the sails and the porthole-like dome in the interactive art installation would pay homage to Santa Cruz's long history of sailmaking.

Justin and Nina Simon (the museum's executive director) referred Biagio to Jason Alderman (a museum technologist who had worked with the museum in the past) to collaborate on the electronics, and Jason and Biagio put together a parts list and a working budget for the project in December 2016. Jason was keen to use a Museduino shield and satellite boards for this project because it would allow the project to be controlled by a single Arduino Uno R3 (and would provide power+ground for every Arduino pin).

After reviewing the proposal, the museum approved it; Nina requested two changes from the original concept:

1. that the sculpture not need a button press to activate, but sense visitors holding a dollar bill and turn on the vacuum, and
2. that color changing LED lights were not top priority for illuminating the sails; standard lights backlighting the sails would be enough, as Justin was overhauling all of the lighting in the museum's atrium.

Given the initial discussions and explorations of types of sensors, the team decided on a Sharp IR sensor for initiating the vacuum, and consumer-friendly relays (PowerSwitch Tail 2) for flipping on and off standard halogen lights and industrial fans.

Early Prototyping

Biagio was near the museum, but Jason was 460 miles south. While they figured out a time that would make sense for both of them to be on-site at the museum for in-person collaboration, Biagio sent a section of tubing to Jason to begin testing sensors.

The initial requirements were for sensors to detect

- when paper money / a hand was at the mouth of the tubing
- when paper money entered the glass dome successfully and actuators

- to turn on the fans
- to turn on the lights
- to switch on the vacuum for a set duration of time.

Jason began making several small Arduino sketches to individually test the sensors and ready the electronics for on-site testing, while Biagio began fabricating and testing physical hardware. During this initial testing, the team found out three important issues:

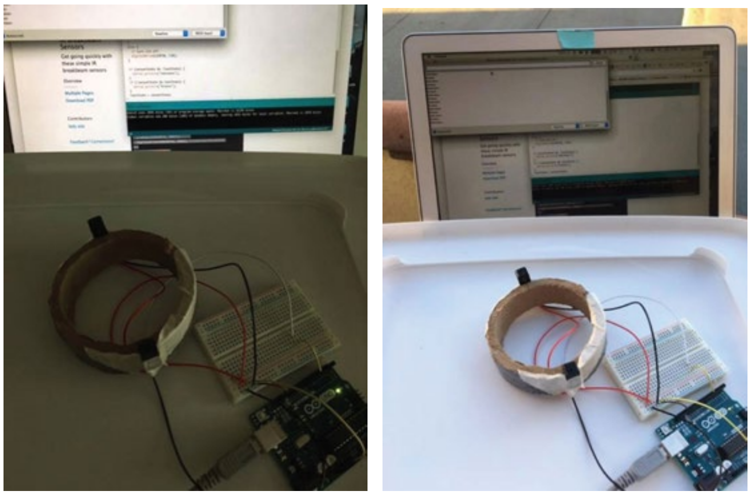


Photo of IR break beam sensor on tubing canister ring, being tested indoors, and then in shade outdoors.

1. IR break beam sensors (the first choice for detecting when money entered the glass dome) performance was unreliable in sunny conditions. The atrium of the museum was flooded with sunlight, especially afternoons, and the installation would be by large bay windows. The sensors would need to be shielded.
2. When would the vacuum turn off? Would it be when the paper money entered the dome? Would break beam sensors (or another sensor) reliably detect that? Would the vacuum need to run for a few more seconds to swirl the money in the dome? The installation would need code for a timer, and it would probably be best to decouple the vacuum timing from a second sensing event — have it run for a set duration every time the Sharp IR was triggered.
3. As Justin and the museum had had further conversations with Biagio, they requested that the installation have a few different modes — that they would be able to turn it off completely, that they could have an autonomous mode that deactivated the donation tubing sensor and cycled the fans and lights, and that they could inflate the sails without the lights to project upon the sails for special events in the atrium. These modes meant that the relays controlling the lights and fans would need to be normally-closed instead of normally-open so that they could be controlled by frontline museum staff with lightswitches, independent of the Arduino. (This would also make sure that the Arduino wasn't a single point of failure!)

On-site Testing

With these things in mind, Jason flew out to work with Biagio in late February 2017. They began to assemble the separate Arduino sketches, crimp wires to connect sensors (since the initial Museduino satellite boards did not have screw terminals), and made a few important discoveries over a weekend of working together and visiting the atrium in person.

- In early tests, loose wires were a frequent culprit when things failed to work. Jason and Biagio were crimping wires by hand, and figuring out how to properly crimp a pin to the end of a jumper wire helped considerably.
- The original timer library in the Arduino sketches, which counted the elapsed milliseconds, was failing. Switching to a lower-level library with callbacks called SimpleTimer fixed these problems.
- Possibly due to fluctuating light levels in the atrium, the Sharp IR sensor at the mouth of the tubing was returning a lot of false positives; Jason updated the code to average over a set of values to smooth the readings.
- The original shop-vac vacuum wasn't powerful enough, so the team returned it and tried a more powerful model. Bills were still getting stuck in the tube (along the sides), so they upgraded to a dust collector for more powerful suction.
- Due to the break beam sunlight issues, the team tried alternatives. Piezo-vibration sensors did not work, likely because of too much noise and vibration in the tubing from the vacuum itself. Ultrasonic sensors relied on the positioning of the paper money, and the sensors on hand didn't work well at such a short range. An IR time-of-flight sensor worked in test sketches, but it required I2C and too much memory when put into a full sketch, so it added constraints. In the end, the IR break beam receiver was shielded by recessing it, putting it at the end of a plastic pen barrel darkened with duct tape, making it more reliable.
- When testing the PowerSwitch Tail 2 relays meant to control fans, Biagio and Jason often used lights, because it was often easier and faster to see that they had switched on or off.

Further Refinement

Having worked together to set up most of the electronics, Jason left it with Biagio; he continued software development remotely on a smaller setup and emailed code updates to Biagio to test.

Biagio continued fabricating and wiring the parts of the installation. He hung the dome on the wall of his house in a spare room (https://www.instagram.com/p/BRybjtaBAgp/), and he experimented with Justin to add internal grates and baffles inside the dome to ensure that the air would circulate well to make the donated dollars spin inside.

Dust collectors — as would be expected with a vacuum that's roughly four times as powerful as a heavy-duty shop-vac — are quite noisy. While the original diagram showed the housing for the vacuum inside the atrium, Justin began working on a housing for the dust collector outside the museum, to help muffle the noise.

Jason continued to work on smaller individual "test" Arduino sketches for each new component. He developed a mode switch for the installation, using a knob from a motorboat dashboard and a voltage divider circuit to switch between three modes (https://www.instagram.com/p/BR6jExLjA9V/), and mailed it to Biagio for installation on-site.

Adding the new switch on a new satellite board using Museduino port D introduced a new issue — the digital pins on port D include 1 and 0, which are the pins that the Arduino internally uses for the Serial communication. If sensors were plugged into those pins, you couldn't upload new sketches, and the Serial Monitor went haywire due to the feedback loop, so the team swapped the satellite boards for the Sharp IR (originally port A) and the mode switch.

These smaller sketches (including the mode switching and randomization for the autonomous mode) were then slowly aggregated into the main sketch as they proved successful. Working in this way helped to isolate (and minimize) software bugs. (Overall, there were a total of 33 sketches —

15 versions of the main sketch and 18 test sketches.)

Final Installation

In early May 2017, Jason flew out again to help with final installation and fine-tuning the sensor code.

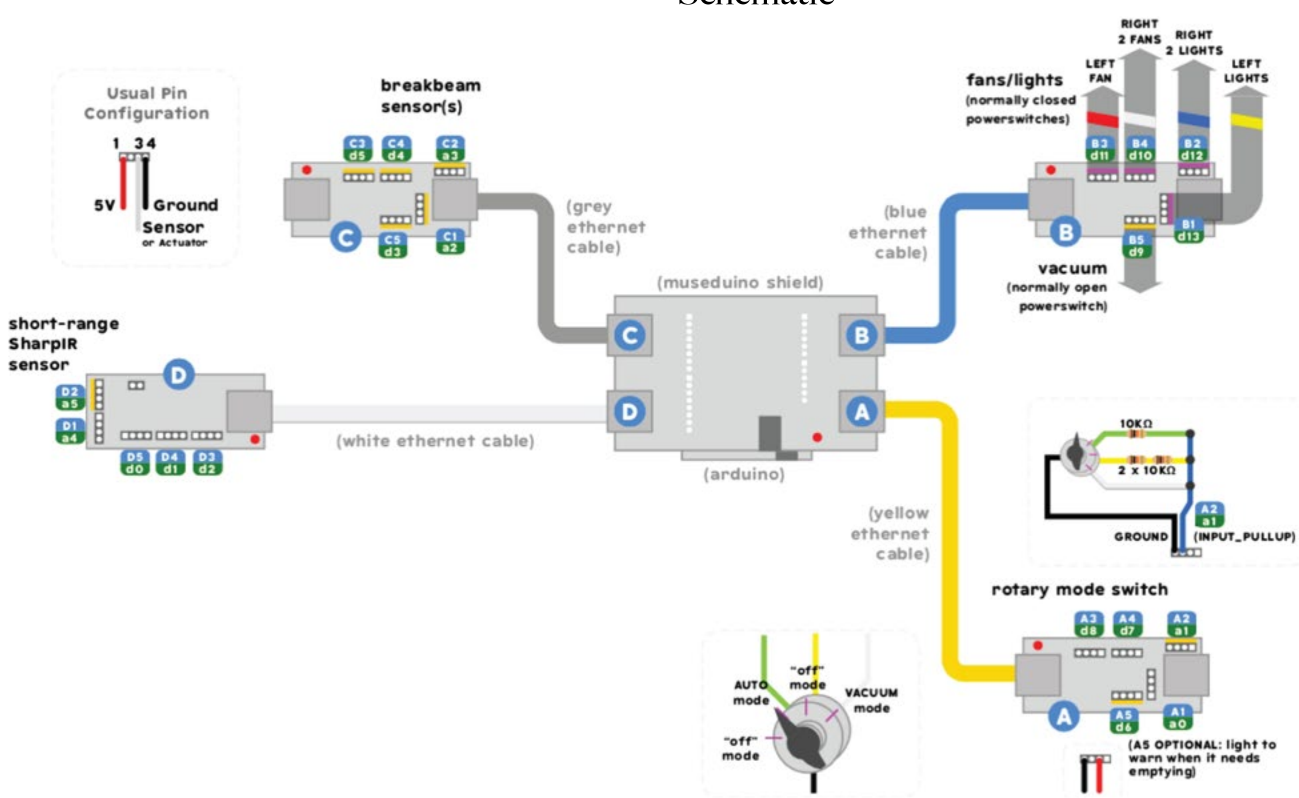
Since the kinetic sculpture in the atrium spanned two floors, Justin and Biagio put the central Arduino, Museduino shield, and PowerSwitch relays on a platform in the drop-ceiling behind the wall of the installation, and left a 10-foot USB cable attached to the Arduino, so that sketches could be updated without needing to have a computer in the ceiling next to the brains of the installation. The team used colored electrical tape and labeled each cord and cable for easier maintenance later.

At the museum's front desk, underneath the stairs, Justin installed a lightswitch panel to allow frontline staff to toggle on the fans and lights separately, and switch modes from OFF (Sharp IR ignored, vacuum never turns on), to VACUUM (Sharp IR triggers vacuum), to AUTO (Sharp IR ignored, vacuum never turns on, fans and lights turn on and off in a semi-random pattern).

"Full Sails" was well received when it launched at a First Friday event in downtown Santa Cruz (https://www.instagram.com/p/BTvKWghDCgw/). In subsequent tests, especially at different times of day, the museum staff found that the IR break beam sensors would not always trigger when paper money rocketed past them into the dome. This bug turned out to be an unexpected "feature," as the unpredictable reward fanfare led people to donate more money to see if they could trigger the lights and fans.

Installation Design

Schematic



Parts List and Budget

If this is something that is helpful for creating any ancillary materials, here was my final budget for only the electronics side of things, including the airfare for two trips out to install.

Troubleshooting and Lessons Learned

- **Keep it simple.** Where possible, this design used relays to switch power on and off to simple electrical devices (fans, spotlights, vacuum). Doing so kept costs down with off-the-shelf equipment and lowered the complexity of the circuitry.
- **"Voltron" together several small sketches.** We tested each component added to the overall system with a separate Arduino sketch (.ino file) before adding it to the aggregate file.
- **Iterate on components.** We prototyped early and often, frequently in the space where the installation would be, and discovered things we could not have foreseen when sketching.
    - A typical shop vacuum did not have enough suction power to pull paper money through the length of tubing. We opted for a dust collector, a vacuum that is four times more powerful. (Keep receipts for quickly returning equipment that does not work for your needs!)
    - We moved the dust collector itself outside the building so that the motor sounds would not be too loud in the acoustics of the museum lobby. This required building an accessible, weather-guarded enclosure for the dust collector.
    - We tested many different sensors to detect paper money at the mouth of the tube and the entry to the porthole, and each had different challenges.
        - Passive Sharp infrared sensors, tuned for different ranges of distance, had to find the right range and then do software averaging to account for the noise from sunlight fluctuations in the space.
        - Piezoelectric sensors couldn't detect vibrations because the paper money was too quiet, and dust collector vibrated the whole apparatus too much.
        - Ultrasonic sensors and infrared time-of-flight sensors were not fast enough and needed more distance, respectively, for paper money that was rushing by.
        - Infrared break-beam sensors were good, but were sensitive to IR in sunlight at certain times of day, and needed to be shielded. (We mounted a darkened ballpoint pen barrel around the sensor to shield it from direct sunlight.)
- **Color code and label your wiring**. The colors in the schematic reflect the colors of ethernet cable and electrical tape on the components, making it easier to track down which wire or relay controls the thing you're looking for.
- **Always doublecheck the wiring.** Use a multimeter and patiently check that your wires are connected properly. Opt for screw terminals over pin terminals wherever possible; pin connectors on wires can be tricky to crimp reliably.

Conclusions

Without a Museduino, this project would have been much more difficult to complete, and would have had many more points of possible failure. Miriam, Rianne, and the Museduino team consulted at several times, helping troubleshoot issues with satellite board power, and recommending simplifications to the design. Overall, using open-source hardware made the experience feasible for a local museum on a shoestring budget, and (due to the standard hardware and well-documented components) made maintenance learnable for museum staff.