Design of Sensor System to Monitor Napkin Usage for Sustainable User Behavior

by

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Submitted to the Department of Mechanical Engineering
In Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in Mechanical Engineering

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June 2019

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Abstract

This paper discusses the process of designing and integrating a sensor that is able to detect each individual napkin removed from a napkin dispenser to aid in long term data-collection with the implementation of eco-feedback designs. With the implementation of this sensor, we would be able to evaluate the effects of various design for sustainable behavior strategies and their influence on user sustainable behavior. To create this measurement method, multiple sensor types were tested for accuracy, sensitivity, and other features before down-selecting and integrating into a final sensor design. It was determined that the use of limit switch sensors connected by a lever could be used to collect more accurate results than the current method of hand measuring inventory or taking an approximate measurement of the height of total napkins remaining. Our results were promising, as we were able to successfully trigger our sensor once at almost every instance of napkin removal as well as solve our battery capacity issue. The main task that still needs to be tweaked are the edge cases, specifically the notorious case in which one napkin is removed at a slow speed, causing bouncing and multiple triggers to occur. With this sensor in place, we will be able to collect more accurate data and better analyze the effects of positive information, negative information, and feedback designs in napkin dispensers on long term user interaction.

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Title: Professor of Mechanical Engineering

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Chapter 1

Introduction

1.1 Motivation

With the steady increase in severity of pollution, waste production, and climate change, there is a clear need for the research and development of more environmentally cognizant products. While environmentally friendly products do exist, such as bio-degradable produce bags, jewelry made from plastics found in oceans, and even shoes woven from recycled water bottles, these products are often perceived as more expensive and lower quality than their traditional counterparts. Because of commercialism, there has been a lesser influence on sustainable behavior within the marketplace, as many will instinctually and unknowingly reach for the cheaper, less environmentally friendly products.

Even among the more environmentally conscious percentage of the population that actively tries to choose more sustainable products and services, the effect of eco-friendly products is often damped due to the "rebound effect." In energy economics and conservation, this phenomenon explains the take-back effects that arise due to increased consumption after the implementation of energy efficiency improvements that subsequently lower the price of energy. This effect can lower and sometimes even cancel out all environmental benefits initially introduced by the increase in energy efficiency.

The rebound effect can be seen in all fields of environmental awareness efforts not only energy consumption. For example, by ordering packages online, one may save money on gas or other transportation costs, but ordering too many packages would increase the amount of waste produced in packaging quantity and fuel spent to deliver said packages. Another example is installing higher quality insulation of a building but then blasting the air conditioning with the assumption that energy will not be lost to the environment, it completely negates all gains.

By focusing on the design for sustainable behavior strategies that products utilize instead of simply focusing on the creation of more environmentally-friendly products, we can develop a technology that will actually encourage more sustainable behaviors by providing the user with constant feedback and information that will train users to be more environmentally conscious. As a continuation of Qifang Bao's PhD research in the Ideation Lab at MIT and collaboration with MIT graduate student Jana Saadi, we began researching the effect of various design for sustainable behavior strategies on how it could promote eco-friendly behavior, specifically terms of how napkin dispenser designs can mitigate user-controlled napkin usage.

To further enhance the accuracy of data collection with the implementation of eco-feedback designs, we decided to develop and incorporate an apparatus that would be able to count individual napkin usage into our modified napkin dispensers. Handling paper is a challenging task, particularly for soft thin sheets of napkins, compared to printing paper which is relatively stiffer and more uniform. This paper will specifically explore the development and challenges faced during the creation of the experimental apparatus that would help to accurately evaluate changes in napkin usage in a real-world setting.

1.2 Background

User-centered design involves taking into consideration the interactions of end-users to help shape and develop a product [1]. There are also ways to influence user interactions and even promote new habits through specific design interventions [2]. First, the users' needs, capabilities, and behavior must be considered in order to design for their behaviors and needs [3]. As shown in Figure 1-1, the design strategy called eco-feedback designs, such as information and feedback, give more control to the user for how to interact with the product. Behavior steering and smart designs, on the other hand, are design strategies that take control away from the user and gives it to the product. There are many categories of design for sustainable behavior that can be applied to a variety of fields including material consumption (napkins, utensils, paper), disposables (recycling, waste, compost), energy use (light switches, coffee machines, dryer), and water usage (faucet, washing machine, shower, toilet) [4].

Past research in the Ideation lab explored the eco-feedback design concepts for energy usage, water usage, and napkin usage, and surveyed participants about the emotional effect of these designs as well as how likely these designs would change their behavior [4]. We are continuing this research by exploring the implementation of various napkin dispenser designs that promote sustainable behavior in the real world and exploring the long-term effects these designs can have on users.

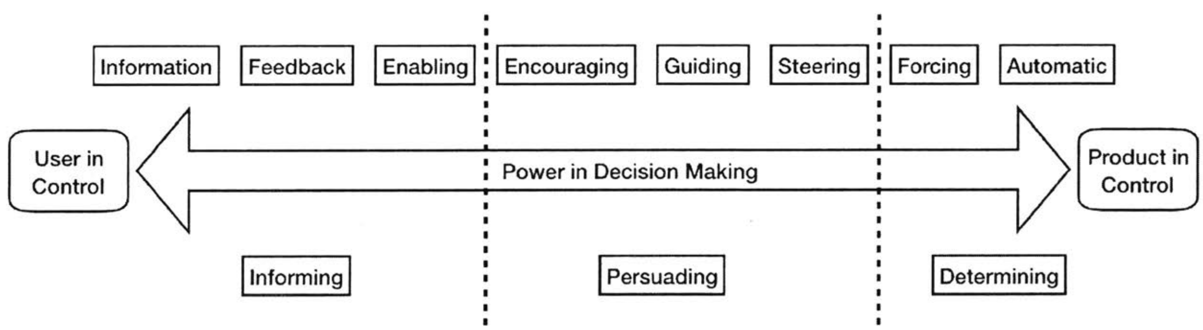


Figure 1.1: Design interventions that can be used to create new habits [2]

Chapter 2

Methodology

With Jana Saadi, the designer of the overall experiment, we brainstormed methods to incorporate design for sustainable behavior strategies into existing napkin dispensers. We later down-selected which ideas would be implemented and placed in the real world to be measured for their impact on user napkin consumption. The months of February and March were used as design and testing time, and napkin dispensers were rolled out in participating locations.

2.1 Design for Sustainable Behavior Napkin Dispenser Strategy Examples

During the brainstorm stage of this project, we generated designs that touched on each category from J. Zachrisson's defined groupings within power in decision making. Below are a couple examples of the concepts generated (See Appendix A for other ideas generated).

Information

Feedback

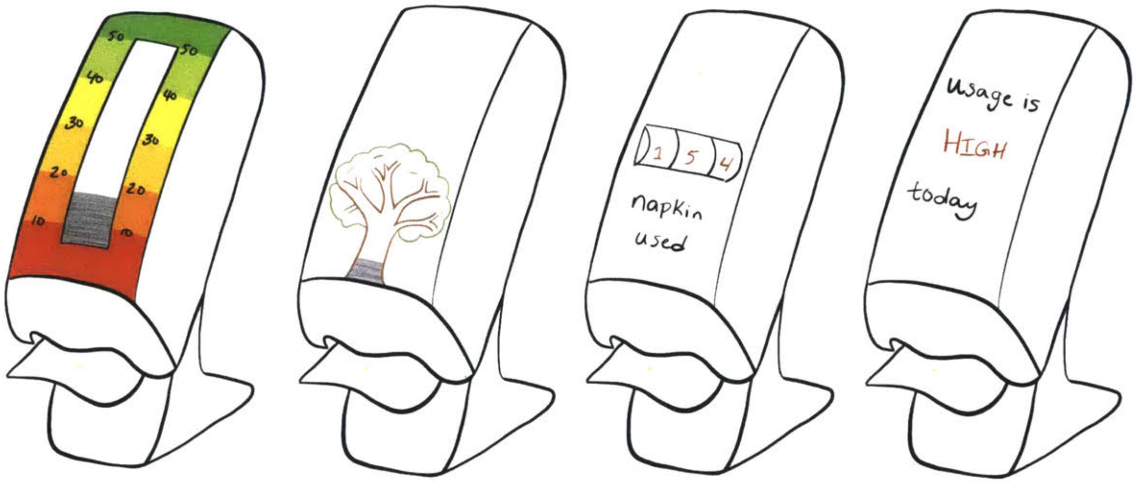


Figure 2.1: Example design for sustainable behavior strategies generated.

Given the scope of our project within a short amount of time, we originally planned to choose a few design for sustainable behavior designs that cover the entire spectrum of design interventions that can be used to create new user habits, ideally from each of the three categories (informing, persuading, determining). However, an unintentional result of our brainstorming was the potential influences positive and negative information displayed. Eco-feedback designs such as information, feedback, and enabling put the user in control of their actions, relying on emotional impact and altering the user's perception. We were interested in further investigating the effect of these cognitive type strategies to encourage behavior change and how positive and negative information can affect user appeal and action. Thus, we decided to move forward with one positive and negative information design, and one user-feedback design, as shown in Figure 2.2.

Figure 2.2: Final selected napkin dispenser designs.
Note: Positive (left), negative (center), feedback (right)
(Created with help from Anders Haggman's involvement and graphic design expertise)

2.2 Participant recruitment

Our plan was to target locations with mid to heavy food traffic and install our modified napkin dispensers in order to gather data on how the general public behaved with the implementation of control napkin dispensers and modified napkin dispensers. We wanted to focus on locations that had a flow of regular and new consumers daily and already use napkins that we could modify and monitor. Several locations that were considered were MIT dining halls (regular use by the same MIT students), coffee shops such as Flour and Darwin's (many regular customers), Café's and cafeterias on campus, and undergraduate lounges (course 2 lounge, banana lounge, CSAIL).

Ultimately, we decided on collaborating with MIT's dining service Bon Appetit, because they provide services for all campus dining halls as well as campus cafes and stores (Bosworth, café four). Upon reaching out, the company was more than excited to collaborate with us. In addition to helping the environment, a decrease in the number of napkins consumed at all their locations would also be an economic benefit for the company. Implementing control and modified napkin dispensers would be difficult to monitor and refill due to the extremely heavy traffic during dining hours, especially because the normal dispensers in all campus dining halls are smaller tabletop versions. Small tabletop dispensers are difficult to modify due to the low napkin capacity as well as the lack of space inside for any sensors, electronics, or other mechanisms. Cafés are much more likely to have larger counter or wall mounted dispensers in place. Therefore, we decided to choose Bosworth Café, Café Four, and Steam Café as the three locations where we trial our eco-feedback designs with the napkin dispenser shown on the left in Figure 2.3 (b).

The reason why there is a need for at least some regular customer interaction is that we want to observe the learned behavior over time in regular customer visitation as well as the rebound effect that among both the regular consumers as well as any others.

(a) (b) (c)

Figure 2.3: Comparing 3 types of napkin dispensers. (a) Short napkin dispenser that holds smaller brown napkins. (b) Tall napkin dispenser that holds smaller brown napkins (left) and tall napkin dispenser that holds larger white napkins (right). (c) Brown napkins used by Bon Appetit (left) compared to the white napkins (right) bought to fit the tallest napkin dispenser.

The larger dispenser in Figure 2.3 (b) is ideal because it has more ease of mounting due to a larger number of flat faces. Bon Appetit uses recycled napkins that are similar size to the brown napkin on the left of Figure 2.3 (c), but these napkins only fit and function well in the small dispenser and the left dispenser in Figure 2.3 (b). We determined that a larger dispenser would be better for displaying our eco-feedback design interventions and would require much less refilling and maintenance than the smaller dispenser in Figure 2.3 (a).

2.3 Data collection

Our napkin dispensers were placed in 3 locations and there was no good way to control how many bundles of napkins that employees put in, and it wasn't reasonable to ask them to keep track of all their inventory (we wanted to be as unobtrusive as possible). At most, it would be more reasonable to ask café employees to keep track of the number of bundles, measure the level in the dispenser each day with a ruler taped on the inside, then enter the number into a spreadsheet to calculate the total number of napkins consumed. While counting inventory by hand would be the most accurate and reliable method for collecting data, it can be very time consuming and would be difficult to coordinate with the cafés. Each café has different opening and closing times, and blocking off time to count the number of napkins consumed could potentially interfere with data collection by preventing consumers from taking napkins.

To tackle this issue, we decided to try to develop a sensor or mechanism to count individual napkins and display the number for easy tracking and documentation and use in-person counting as a backup method. While this sensor was in development, we taped in rulers to each of the dispensers rolled out for an easy measurement of the change in the level of napkins, which can be correlated to an approximate measurement of daily napkin usage by calculating the number of napkins added (using height of one bundle of napkins = 500 napkins, then subtracting and correlating that to the number of napkins added into the dispenser).

Chapter 3

Design and Testing

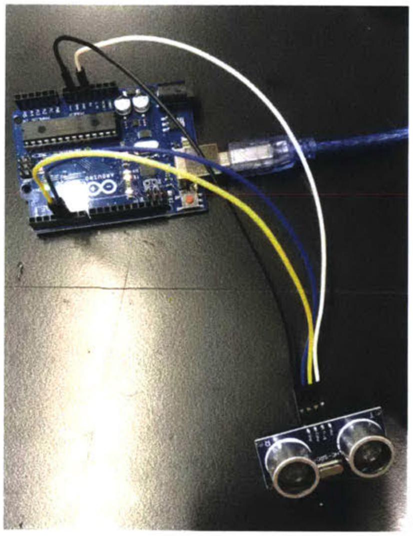
Detecting a single napkin taken from the napkin dispensers is an incredibly difficult task, as there are many factors that can influence the movement of a napkin as it is removed from the dispenser. The angle at which a user grabs a napkin, the force that a user yanks a napkin, the speed that a user pulls a napkin, and the level of napkins inside of the dispenser can all influence napkin movement and must all be taken into consideration when designing a sensor that is able to count individual napkins taken from dispensers. With this in mind, we tested four different sensors, an ultrasonic proximity sensor, a passive infrared motion sensor, a capacitive pressure sensor, and a switch mechanism controlled by either a limit switch or button switch, and down-selected from there.

3.1 Sensor Testing

Ultrasonic Proximity Sensor

Figure 3.1: WYPH Ultrasonic Module HC-SR04 Distance Measuring Ranging Sensor for Arduino
(Image Source: https://www.amazon.com/)

Ultrasonic proximity sensors work by emitting a high frequency sound wave and waiting the reflected ultrasonic waves to detect the distance of an object from the sensor by calculating the time delay between the signals, similar to radars and echolocation. The rationale behind testing this sensor was the potential to place this sensor in a location so that it could both detect the presence of a napkin hanging out of the bottom of a dispenser or detect the level of napkins inside of the dispenser (measure the level of napkins throughout the day and account for any increase in levels due to the placement of new bundles of napkins by employees).

(a) 

(b)

```
const int out=4;
const int in=5;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  pinMode(out,OUTPUT); //remember: the Trig pin is the speaker pin
  pinMode(in,INPUT); //remember: the Echo pin is the microphone pin

}

void loop() {
  // put your main code here, to run repeatedly:
  long dur;
  long dis;

  digitalWrite(out,LOW); //turn off the Trig pin incase it was on before
  delayMicroseconds(2); //a very short break

  digitalWrite(out,HIGH); //turn on the Trig pin to send a sound wave
  delayMicroseconds(10); //a short break to let the operation happen
  digitalWrite(out,LOW); //turn off the Trig pin to end the sound wave output

  dur=pulseIn(in,HIGH); //sensor the sound wave reflection time

  Serial.println(String(dur));

  delay(100);
}
```

Figure 3.2: Ultrasonic proximity sensor testing. (a) Connecting an ultrasonic proximity sensor to an Arduino. (b) Test code for an ultrasonic proximity sensor.

Benefits	Challenges

• Simple electrical wiring setup
• Can plug output data into equations to convert pulse time into an estimated unit of measurement
	• Lacks accuracy and repeatability between sensors in the same purchased set
	    o Accuracy varies between units, many were unable to detect motion reliably
	• Lack of timeout problem where sensor stops generating pings once no echo is detected, even after re-triggering a measurement
	• Ambient noise seemed to trigger the sensor slightly
	    o Our napkin dispensers would be located in high foot-traffic locations where there is a lot of background noise

Table 3.1: Benefits and Challenges of using an ultrasonic proximity sensor.

As seen in Table 3.1, the ultrasonic proximity sensor proved incapable at producing accurate and repeatable results between different sensors in the same kit. They exhibited a frustrating timeout problem in which sensors would stop generating pings and would no longer detect an echo. There were moments when ambient noise would trigger a slight signal, which is not ideal for a real-world environment with heavy foot traffic and a lot of background noise.

Passive Infrared Motion Sensor

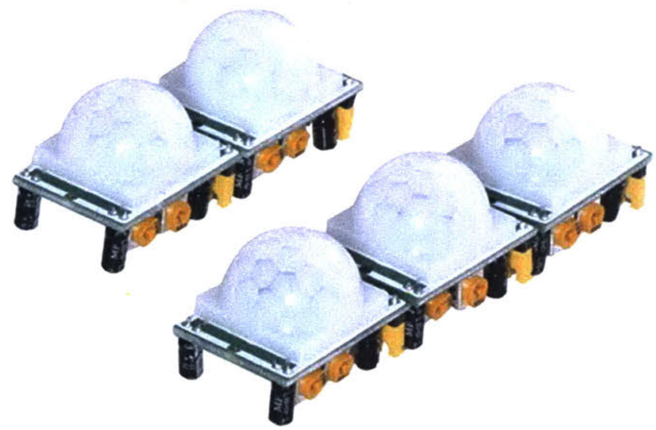
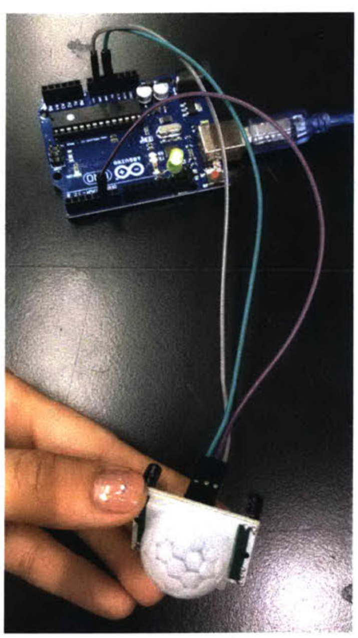


Figure 3.3: HC-SR501 PIR Motion IR Sensor Body Module Infrared for Arduino (Image Source: https://www.amazon.com/)

Passive infrared motion sensors measure the infrared light that radiate from objects in the field of view of the sensor. Since all objects are above a temperature of absolute zero, they emit energy in the form of radiation and the sensor only needs to measure this radiation and detect any changes in radiation, thus the name "passive infrared sensor." With a motion sensor, we could attempt to either detect a person approaching a napkin dispenser to keep track of the number of daily interactions or place the motion sensor in a location where it will be able to detect the motion of napkins and count at every instance of movement as one napkin taken.

(a)



(b)

```
int ledPin = 13;                // choose the pin for the LED
int inputPin = 2;               // choose the input pin (for PIR sensor)
int pirState = LOW;             // we start, assuming no motion detected
int val = 0;                    // variable for reading the pin status

void setup() {
  pinMode(ledPin, OUTPUT);      // declare LED as output
  pinMode(inputPin, INPUT);     // declare sensor as input

  Serial.begin(9600);
}

void loop(){
  val = digitalRead(inputPin);  // read input value
  if (val == HIGH) {            // check if the input is HIGH
    digitalWrite(ledPin, HIGH);  // turn LED ON
    if (pirState == LOW) {
      // we have just turned on
      Serial.println("Motion detected!");
      // We only want to print on the output change, not state
      pirState = HIGH;
    }
  } else {
    digitalWrite(ledPin, LOW); // turn LED OFF
    if (pirState == HIGH){
      // we have just turned of
      Serial.println("Motion ended!");
      // We only want to print on the output change, not state
      pirState = LOW;
    }
  }
}
```

Figure 3.4: PIR motion sensor testing. (a) Connecting an ultrasonic proximity sensor to an Arduino. (b) Test code for a PIR motion sensor.

Benefits	Challenges

• Simple electrical wiring setup
• Detects thermal radiation
    ○ Useful for detecting heat from a hand without picking up arbitrary movement of napkins
	• Long lag time (timeout delay) where sensor is idle after detecting motion
	    ○ Sensor would not be able to actively detect a rapid succession of movement in the case of multiple napkins taken
	• Lacks accuracy and repeatability between sensors in the same purchased set
	    ○ When testing different sensors from the same set, many were unable to detect motion reliably
	• Can be easily triggered by light source, heat from grills or hot drinks without user interaction

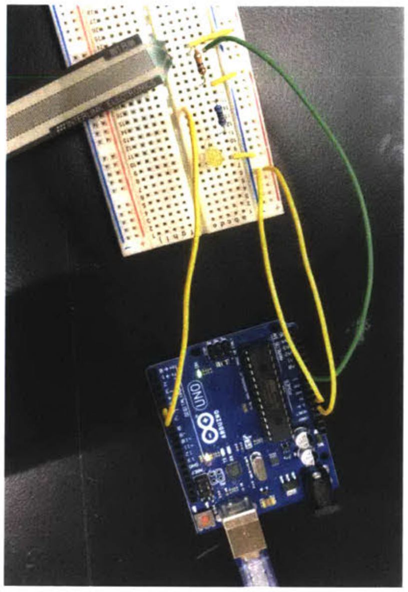
Table 3.2: Benefits and Challenges of using a PIR motion sensor.

As seen in Table 3.2, PIR motion sensors had the potential of being valuable to this design, as they are able to detect thermal radiation and could potentially be used to detect heat from a hand without picking up arbitrary movements of napkins. However, we noticed long timeout delays where the sensor remains idle after detecting motion, preventing the sensor from detecting a rapid succession of movement. The sensor can also be easily triggered without user interaction by other sources of thermal radiation, such as warm light sources and heat from grills. This will cause an undesirable lack of accuracy in our measurements.

Force Sensitive Resistor (Pressure Sensor)

Figure 3.5: Adafruit Extra-long force-sensitive resistor (FSR) - Interlink 408
(Image Source: https://www.amazon.com/)

Pressure sensors work by detecting pressure signals due to strain on its conductive surfaces. As the diaphragm and pressure cavity inside the sensor deforms under pressure, capacitance decreases, allowing the sensor to detect a range of pressures. We decided to try putting a pressure sensor around the rim of the opening of a napkin dispenser to test whether we could detect each instance that a napkin gets pulled out.

(a) 

(b)
```
//Constants:
const int ledPin = 3;     //pin 3 has PWM funtion
const int sensorPin = A0; //pin A0 to read analog input

//Variables:
int value; //save analog value


void setup(){

  pinMode(ledPin, OUTPUT);  //Set pin 3 as 'output'
  Serial.begin(9600);       //Begin serial communication

}

void loop(){

  value = analogRead(sensorPin);       //Read and save analog value from potentiometer
  Serial.println(value);               //Print value
  value = map(value, 0, 1023, 0, 255); //Map value 0-1023 to 0-255 (PWM)
  analogWrite(ledPin, value);          //Send PWM value to led
  delay(100);                          //Small delay

}
```

Figure 3.6: Force sensitive resistor testing. (a) Connecting a force sensitive resistor sensor to an Arduino. (b) Test code for a force sensitive resistor.

Benefits	Challenges

• Will detect changes of pressure anywhere along the strip
  ○ Beneficial for variable location and force of removal of napkins by user
• Very sensitive output with wide range of forces detected
• Strip configuration allows for manipulation of shape and orientation for mounting and sensing
	• Pressure sensor is sensitive enough to detect a napkin resting on it
	  ○ Will require user testing to find an acceptable force cutoff range for a napkin removal
	• Requires more complex mounting to secure pressure sensor in place without affecting user experience
	• Edge case: Difficult to measure if a user decided to abandon removing napkin mid pull

Table 3.3: Benefits and Challenges of using a force sensitive resistor (pressure sensor). Note: If triggered in two places, output # is higher

As shown in Table 3.3, pressure sensors proved to be more beneficial than the two sensors tested previously. During testing, they were very sensitive to changes in pressure along the entire strip, and the convenient strip orientation could allow for greater manipulation of its orientation during mounting and sensing. The downsides include more complex mounting required to secure the pressure sensor in place without interfering with the user experience, as well as finding a balance between choosing a low enough cutoff force to count a napkin, but also ignore the signal from a napkin resting on the sensor.

Limit Switches and Button Switches

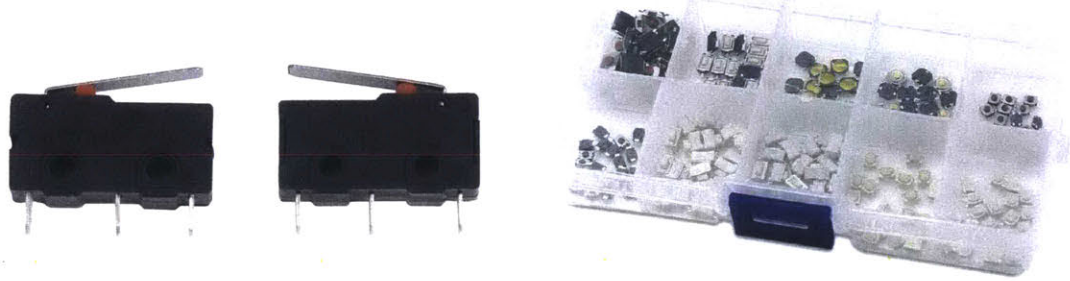


Figure 3.7: 5A 125V Limit Switch for Arduino and Tactile Push Button Switch Micro Momentary Tact Assortment Kit
(Image Source: https://www.amazon.com/)

A button switch connects to open circuits and, once triggered, work by completing the circuit. Limit switches work very similarly and are mostly operated by the motion of a machine part or presence of another object. They are typically used to control machinery or count objects that pass a certain point. By integrating a limit switch or a button switch into a lever that mounts on the napkin dispenser, we can create a reliable mechanical system with less variables that may skew results. After testing a few button configurations, we decided not to move forward with button switches because unlike the limit switch, the button switches required forces higher than what pulling a napkin could generate, and required very precise placement inside a dispenser in order to trigger it.

Benefits	**Challenges**

• Limit switch and tactile push buttons will reliably trigger with a specific force
  ○ Need to tune switch or button so that napkin removal force is always higher than switch actuation
• Ability to sense rapid succession of motion from pulling out multiple napkins in one visit
• Small and unobtrusive to user experience
	• Triggering button actuation with a napkin pull can be difficult with the limited surface area on button switches and force required to press the button
	  ○ Will need to build a surrounding mechanism to ensure successful actuation
	• Difficult to mount in napkin dispenser

Table 3.4: Benefits and Challenges of using limit switches and push button switches.

As shown in Table 3.4, the limit switch turned out to be the most reliable sensor for detecting single napkin removal from napkin dispensers. They reliably triggered with a force that could be generated with the removal of a napkin, and have the ability to trigger successfully even with a rapid succession of motion. Difficulties that we would face if moving forward with this sensor is the challenge of mounting this sensor inside a dispenser unobtrusively.

3.2 Sensor Down-Selection

	Repeatability	Sensitivity	Electrical Setup Simplicity	Unobtrusive to user	Easy to mount	Response to Fast Stimuli
Ultrasonic Proximity Sensor						
IR Motion Sensor						
Pressure Sensor						
Limit/ Button Switches						

Table 3.5: Sensor comparison chart for down-selection

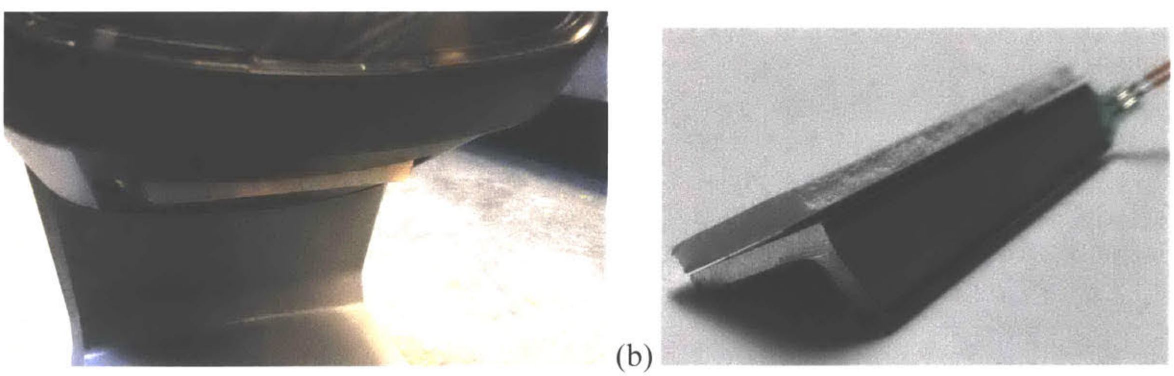
Though the ideas of sensing the movement of a hand taking a napkin were promising, ultrasonic proximity sensors and IR motion sensors were removed from our list of potential after preliminary accuracy and reliability testing. Pressure sensors and limit/button switches look more promising and deliver on repeatability and sensitivity, which were our most critical criteria for the sensors tested.

Further Pressure Sensor Testing and Mounting

Based on the manner of which a napkin is typically removed from a dispenser, we determined that mounting the pressure sensor to the inner rim of the opening of a napkin dispenser, shown in Figure 3.8, would be the best location for measuring the force that arises when a napkin is pulled across the rim and out the bottom opening. We realized that this method of mounting would be somewhat challenging, given the shape and dimensions of the sensor, as it is relatively wide compared to the opening of the dispenser and very long. Although a pressure sensor strip down to a shorter size does not affect the ability to measure inputs of force, we quickly realized that bending the sensor to fit around the inside of the opening skews the output of the sensor due to the strain imposed on the sensor.

Figure 3.8: Pressure sensor wrapped around inner rim of dispenser opening.

Switching to an angle bracket, shown in Figure 3.9 (b), that can be mounted to the interior of the dispenser opening helped relieve the issue we were facing when forcing the sensor into a bent orientation, but this had its own issues. Despite polishing any sharp corners and edges, the side of the bracket with the pressure sensor attacked stuck out just enough to cause ripping in some of the napkins removed. There was also a challenge with a napkin not fully contacting the surface of the pressure sensor, especially if removed from the sides or straight down, which we intended to solve with the first design concept where we wrapped the sensor all the way around the opening.



(a) (b)

Figure 3.9: Pressure sensor mounted flat on inner front rim of dispenser opening. (a) Sensor mounted inside of dispenser. (b) Isometric view of sensor and angle bracket outside of dispenser.

Further Limit Switch Testing and Mounting

The pressure sensors did not give us the results that we were hoping for, so we decided to further test limit switches to see if they could perform better than our other options thus far. A single limit switch is very small and would not be able to cover a large trigger area. After some quick user testing, we quickly noticed a couple extreme cases that the sensor needed to be able to account for: pulling a napkin out from the left and right corners of the dispenser opening and pulling straight out towards the user. A single limit switch is relatively small compared the size of the bottom dispenser opening, and adding more switches to cover the entire opening can lead to extremely complicated circuitry. To address this challenge, we connected two limit switches with a singular wooden piece for balance and easier mounting on the dispenser, but only connected one of the switches to an Arduino for counting purposes because their motion is always mirrored.

We tested a few geometries of the wooden lever, shown below in Figure 3.10, for unobtrusiveness to the user and effectiveness for triggering with a napkin pull. We chose the wooden lever design that bowed outwards, away from the lever, as it was the most effective at sensing when napkins were pulled out, but was relatively unnoticeable for the user, even if is necessary to reach into the opening of the dispenser to grab a new napkin when there are not any hanging out.

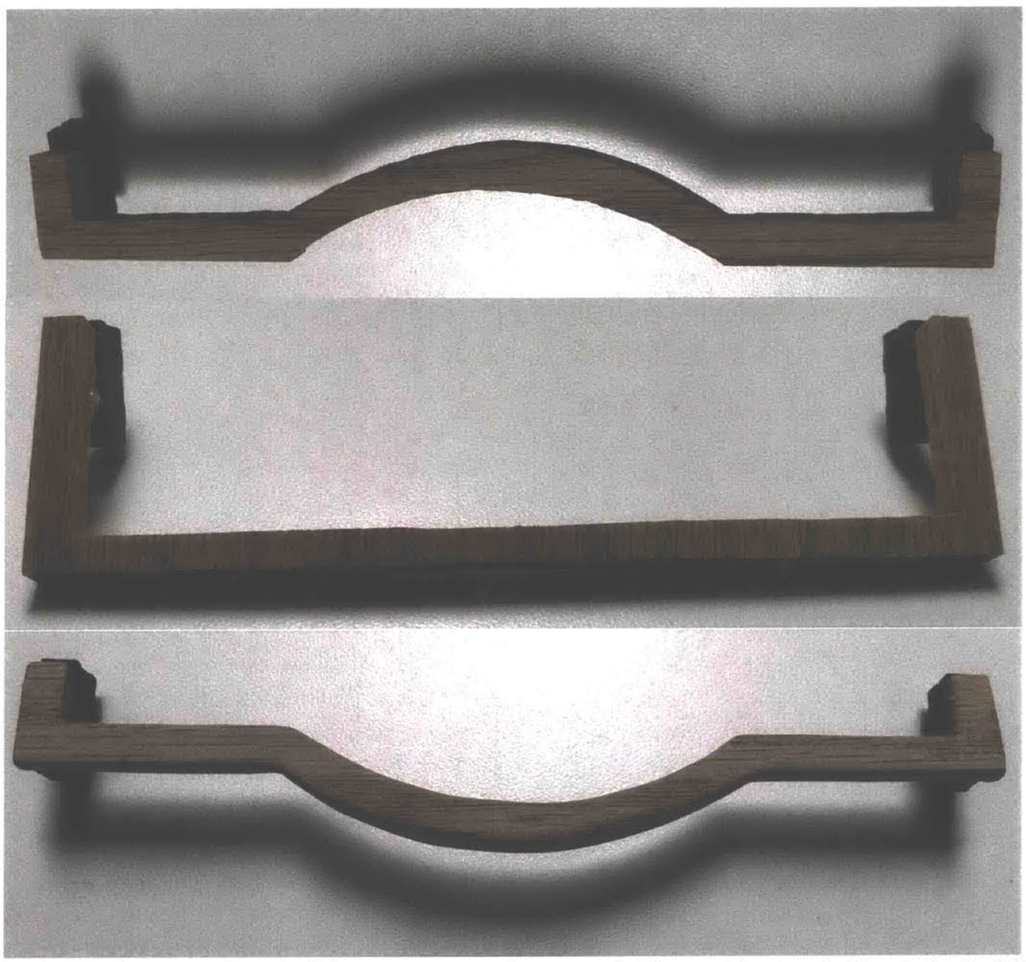


Figure 3.10: Various mechanical lever geometries tested. Bowed in (top), Straight (middle), and bowed out (bottom).

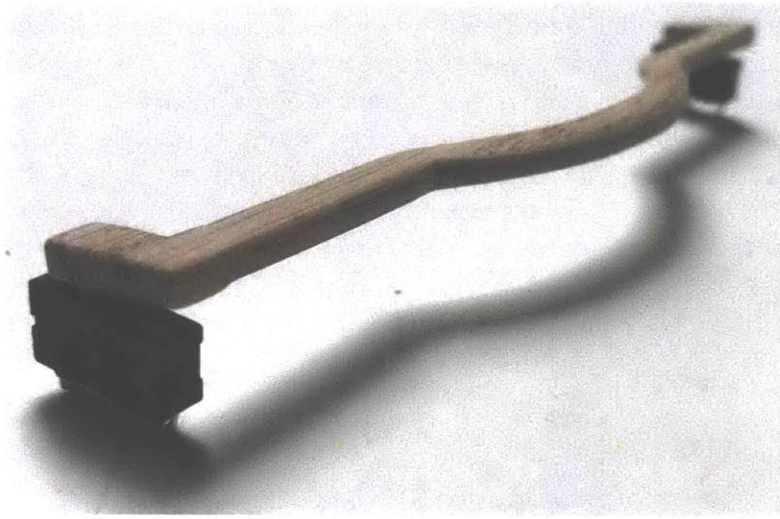


Figure 3.11: Photo of final mechanical lever – bowed out geometry chosen

One downside of this design is that, mainly seen for slower napkin removals, when the mechanical lever is just barely at the threshold of triggering, there can be some switch bounce or "chatter." We decided this was not a big issue because from user testing, almost all users remove napkins at a very fast rate, causing one distinct trigger in the lever. Every so often, there could be a double trigger, but this occurs rarely enough that it is within a reasonable margin of error.

3.3 Limit Switch Mechanical Lever Final Design

After down-selecting from all of our sensor options to a pressure sensor and limit switch, then further narrowing down to a limit switch lever mechanism, we worked on integrating this final design into our napkin dispensers.

To prevent this lever from triggering by the weight of napkins when a dispenser is fully stocked, we added in a ledge for the napkin stack to rest on. The lever sticks out from under the ledge, remains untriggered in its resting position, and gets actuated with a napkin pull, as shown in Figure 3.12. We tested two variations of this ledge, shown in Figure 3.13 (a) and (b), and while both designs were good for keeping the weight of the napkins from triggering the lever with a half-filled dispenser, the design in Figure 3.13 (a) added more complications to our design. The ledge had more surface area than the design in Figure 3.13 (b), therefore it added more friction, especially with a full stack of napkins, and caused more tearing during napkin removal.

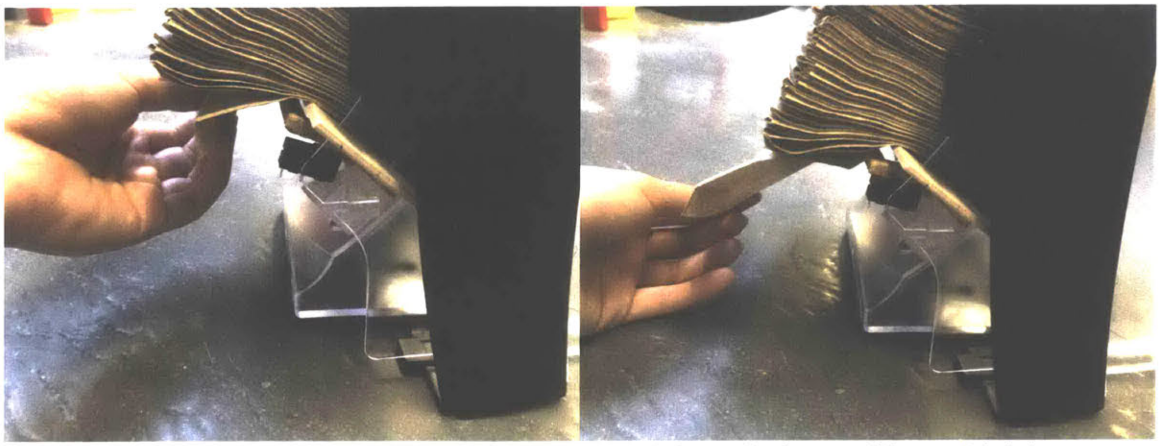
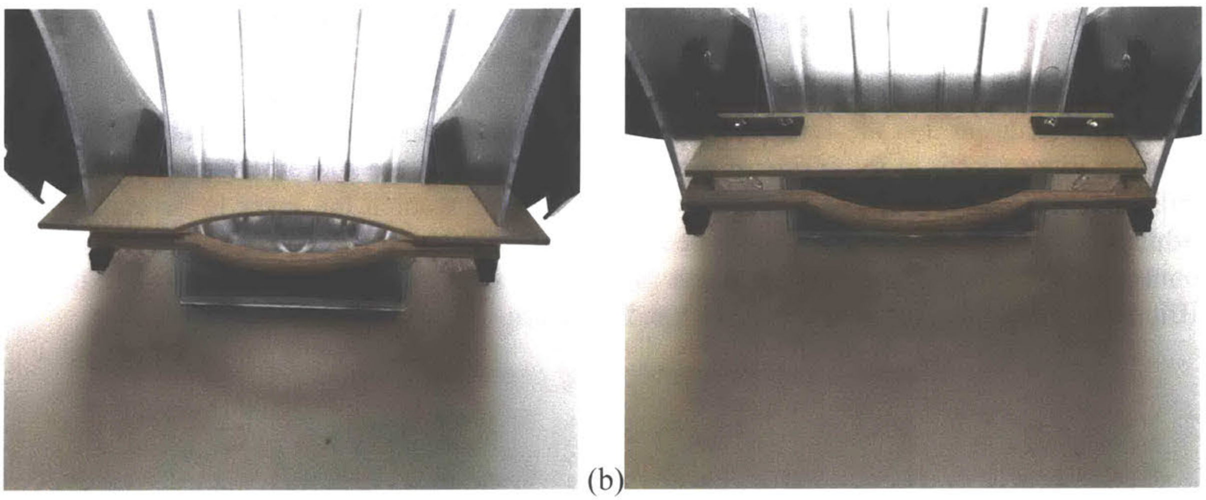


Figure 3.12: Photo of untriggered lever (left) and triggered lever (right)



(a) (b)

Figure 3.13: Two designs for sensor ledge that napkins to rest on. (a) Larger ledge with bowed in center to allow for users to reach napkins if they get stuck. (b) Smaller ledge to reduce friction felt during napkin removal.

We also noticed that with a fully loaded dispenser, the force on the lever by the weight of the napkins was noticeably higher. While it would not immediately trigger the lever, the weight would prevent the lever from springing back fully to its original location, and would occasionally prevent continuous measurements of napkin removal. Even without any modifications done to napkin dispensers, dispensers do not do a great job at keeping the force felt by napkins constant as more stacks are added, causing increased difficulty when removing napkins and causing more tearing of napkins. Noticing that typical napkin dispensers have rails that protrude into the napkin storage cavity closer to the bottom opening, we added two small support pieces, shown in Figure 3.14 (b), that helped relieve some of the extra force felt from a fully stocked dispenser.

Figure 3.14: Supports inside napkin dispenser to keep weight of napkins distributed. (a) Increased force of removal of napkins and tearing that occurs when napkin dispensers are full. (b) Supports added in to our napkin dispenser sensor mount to prevent unwanted triggering with a fully stocked dispenser.

The Arduino that the lever mechanism connects to can be easily mounted using Velcro, shown in Figure 3.15, to the inside of the napkin dispenser in the space between the outer black walls and inner clear walls that contain the napkins. We wanted the lever to be connected via Arduino to an external battery source, because most cafes do not have power outlets nearby to connect to, and these dispensers often get moved and stored overnight, we wanted to minimize difficulties for employees who would be handling them.

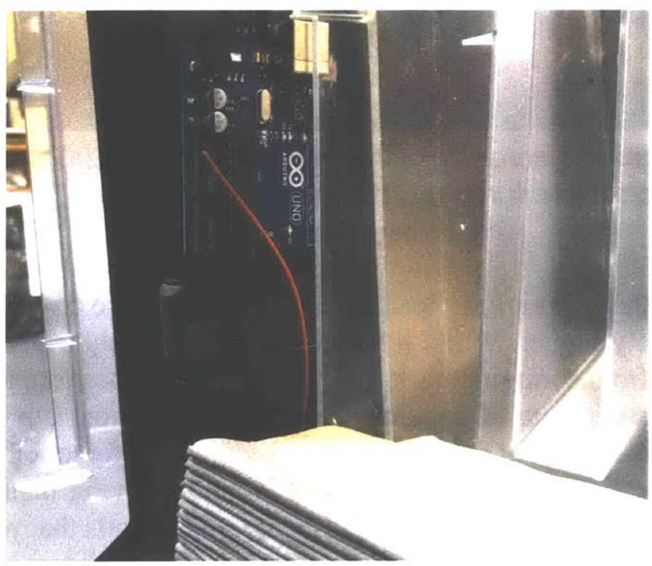


Figure 3.15: Photo of Arduino mounted to dispenser with Velcro. The Arduino is hooked up to the limit switch and is mounted out of the way from napkins.

When using an Arduino, the lever mechanism is able to actively sense and count napkin removal, but would not be able to output this count unless it was still connected to a computer, therefore we added a numerical display for ease of data collection. A problem we immediately ran into was finding a battery with a capacity to last a full 24 hours whole for measurement purposes. Realizing that the lights on the Arduino Uno and the constantly on count display take a lot of power to keep both on all day, we decided to switch to an Arduino Mini and incorporate a second switch that made the count display for 5 seconds on the LED display when triggered for a lower total energy consumption, as shown in Figure 3.16. With 6 AA batteries, the Arduino Uno lasted approximately 12 hours with the display on at all times, and the Arduino Mini lasted for over four days.

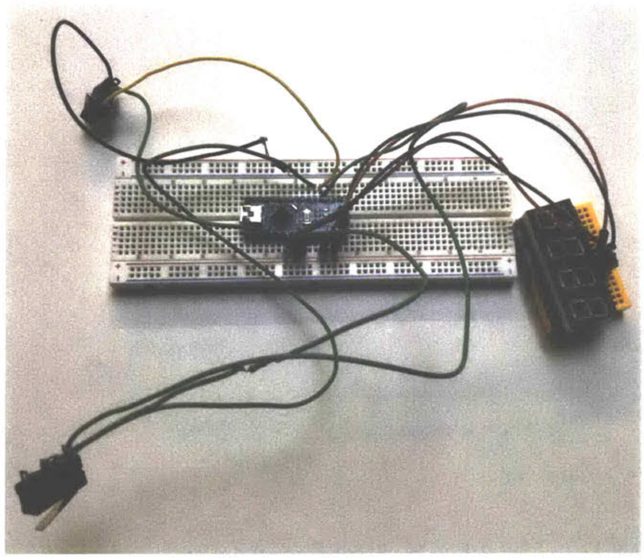


Figure 3.16: Circuit connecting two limit switches to an Arduino mini. One limit switch is mounted to the lever to count napkins, and second switch turns on count display for 5 seconds when triggered to save battery.

Chapter 4

Conclusion

Developing a sensor with the ability to successfully detect each individual napkin removed from a napkin dispenser has proved to be a very challenging project to undertake. We were able to successfully connect two limit switches with a wooden lever, mount them unobtrusively inside a napkin dispenser, and trigger this mechanism with almost all napkin removal motions. While a lot of progress was made in the right directions for creating a sensor that is able to do this, there are still edge cases and sensitivity issues that could be improved on. Napkin dispenser designs in general do not do a great job at keeping the force from the weight of napkins constant at the bottom opening of a dispenser, which in turn not only caused some issues with our sensor design but also interferes with the user experience when taking napkins. This sensor design can be implemented in the next round of data collection for validation, as the current method we have been using in the meantime works, but with much less sensitivity and accuracy.

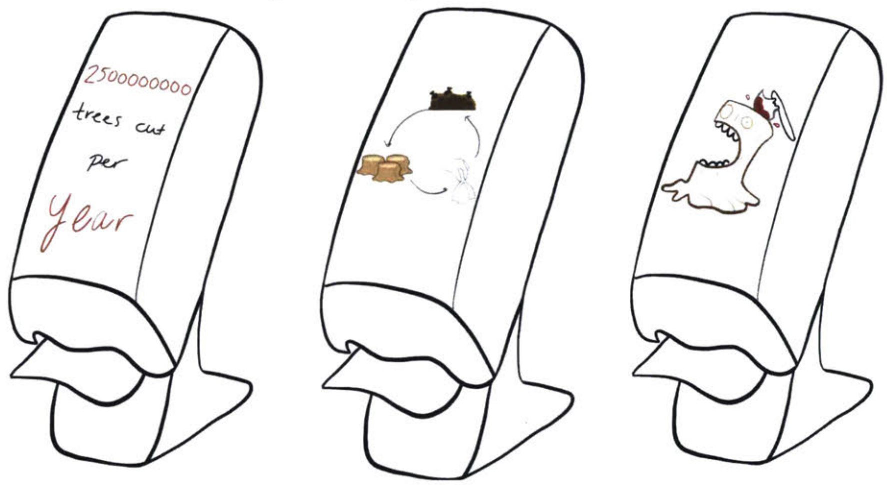
4.1 Future Work

While this design is fairly accurate in detecting individual napkins being removed from dispensers, I would like to iterate on a couple aspects of the apparatus to make it even better. The first part of this sensor system I would improve on is the support pieces that distribute weight. The variable forces due to the weight of napkins seems to be a problem that most napkin dispensers still have not fixed, and could be iterated on to help lessen the load even with a fully stocked dispenser. The design of the ledge could also be improved to provide increased ease with napkin removal by testing different materials and coatings for a lower coefficient of friction. Finally, I would like to lower the entire lever mechanism, since it is currently sitting farther from the opening than the initial design intent, by finding a lower but secure attachment point. This could help better the user experience in cases where the user needs to reach in to the dispenser opening to pull out a new napkin that may be stuck.

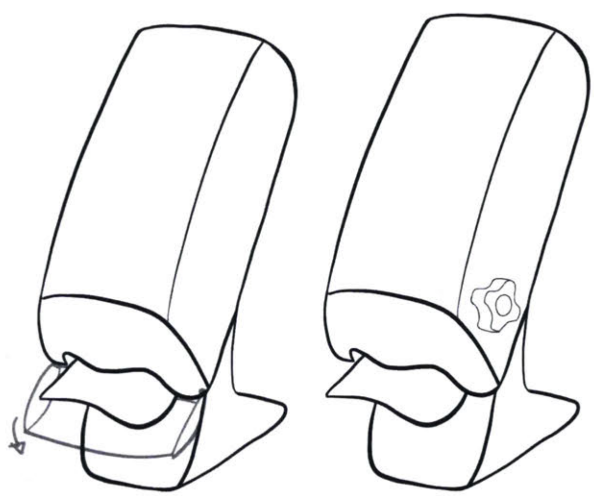
Appendix

Appendix A: Additional Brainstormed Ideas

Information (continued)



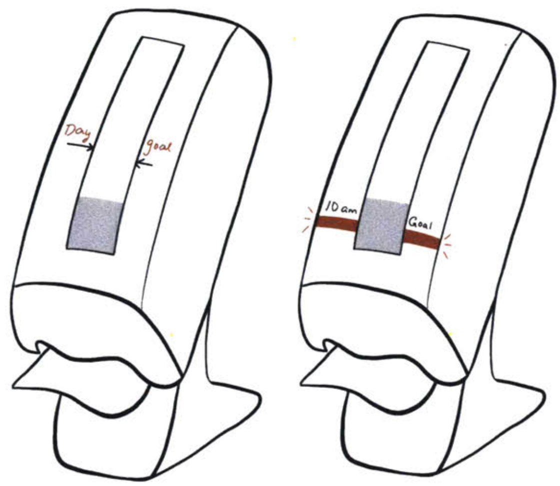
Enabling



Encouraging

- Users must pay for a napkin
- Reward at end of each week/day if napkin usage below a specific amount

Guiding



Forcing

- Give one napkin to each user

Automatic

- Sensor on napkin dispenser that only dispenses one napkin at a time
- User must scan ticket/receipt to dispense napkin

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