SMART Table

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***Abstract* — An original engineering project featuring significant PCB design, the SMART Table is an integration of several technologies already present in the dining environment. Chiefly the SMART table uses various sensors to determine when a table may need service, and then calls the server. The server is summoned with what appear to be aesthetically pleasing accent lighting and notifications via a mobile application. This project aims to satisfy ABET's requirements for a significantly robust custom printed circuit board. As such, our custom designed board includes primarily surface mount components as well considerations for prototyping such as monitored power regulators. To better meet budget and reduce iteration time, the housing design was verified with the help of Virtual Reality.**

***Index Terms* — Engineering Students, Automation, Surface-mount technology, Embedded software, Light Emitting Diodes, Virtual Prototyping.**

I. Introduction

The SMART Table project was conceived out of a desire to simplify the activity of waiting tables in a restaurant. The principle issue being addressed is the difficulty diners can have flagging down a waiter. Regardless of the topology of the establishment, at least some individuals are seated with their backs to the staff, or otherwise less visible. In some cases, patrons have to turn around in their chair mid-meal or even stand up. This leads to lost tips, and reduced chances of a return visit.

Other motivations for this project include a desire to integrate various emerging technologies in a cohesive product. Restaurants are frequently employing decorative lighting, automation related kiosks, and a variety of data collecting devices. Decorative lighting is very common in restaurants. We believe that this type of lighting could be used to communicate the status of a table with waiters walking the floor. Simple cues such as a color change could indicate a need for service. The table also sends notifications to a server's mobile device.

In addition to exploring alternative signaling, data collection via integrated sensors is of interest. Spurred by the emergence of "Internet of Things", or IOT, we have selected several sensors to determine conditions where a party may need service. In addition to a convenient interface at the table itself, an intelligent beverage pitcher can be used to detect when a refill is needed. Additionally, other sensors such as motion, and ambient light can be used to determine which tables are occupied and enhance the dining experience by adjusting light volume.

II. Overview of Design

To achieve the functionality desired and satisfy ABET, a custom printed circuit board or "PCB" was developed. Then a custom fabricated housing was designed to protect all major PCBs. After some disappointment with the available off-the shelf modules during the bread-boarding stage, we opted to design our own capacitive touch boards in addition to our main PCB.

As such, our final system consists of three different custom PCBs.

A. Main PCB (Figure 1)
B. Touch Driver Board (Figure 2)
C. Hardware Block Diagram (Figure 3)

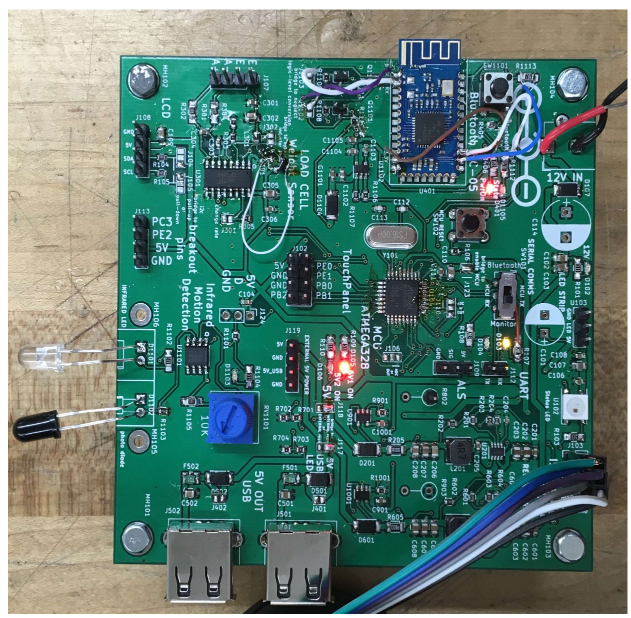

Fig. 1. Main Printed Circuit Board (PCB)

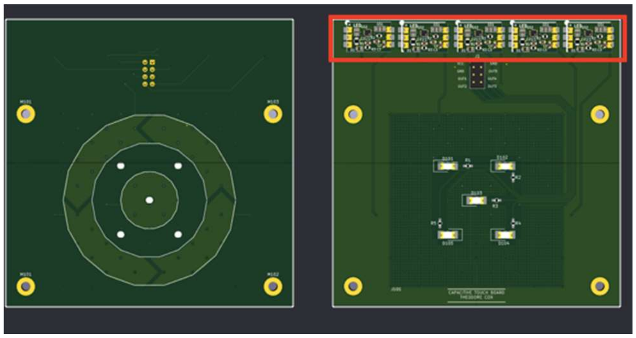

Fig. 2. Touch Driver Board (Front and Back)

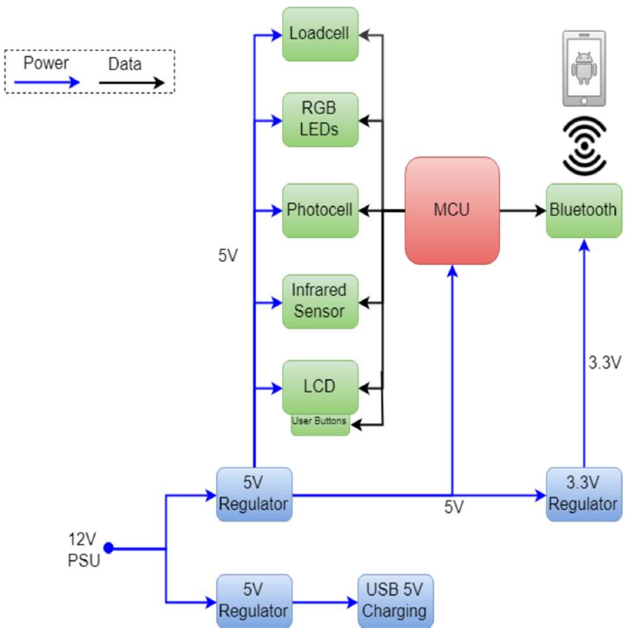

Fig. 3. Hardware Block Diagram

IV. Software

A. MCU Software Design

The topics covered in this section will outline the software design for the smart table project. The major software design sections that will be discussed is the MCU software design, and the mobile application development. The block diagram (54) provides an overview of all the various software interactivity and how it communicates with MCU and sensors.

There are three major stages of the software. At boot, the main loop should be in "Sleep Mode" where the MCU is waiting for a signal from the motion tracker. The MCU also receives a signal from the photocell sensor regarding the brightness level in the restaurant. The brightness level received from the Photocell sensor will help control the LEDs brightness when the table is woken from sleep mode.

The second stage is "initialization". In this stage, the table sends a signal to all the lighting elements to turn on. Mainly the LEDs should turn red to indicate the server that the guests have been seated and need to be greeted. Once the lights turn red the table will wait for the server to respond to a notification that has been sent through the mobile application. Once the mobile application notification is dismissed from the server, the smart table will enter a nominal state where the LEDs turns blue and executes its default checks in a loop.

The third stage is "nominal". This is the state in which the smart table will be scanning its subsystems for events. These events include checking if the guests drink is empty, waiting for a call server request, and continually checking that guests are still seated at the table. The nominal logic will loop continuously while the table is awake and running. Once an event is triggered it will send a notification through the Bluetooth module to the mobile application. When it comes to responding to mobile app notifications, the table should expect the server to dismiss the notification through the mobile application. In addition to these events the table will also continually adjust the brightness of the LEDs using the on-board ambient light sensor.

B. Mobile Application User Interface (FIG 55,58)

The section below will outline the design and user interface of the smart tables accompanying mobile application. The mobile application adds functionality to the smart table in situations where the table is out of sight and allows the server to continuously be aware of the status of their tables. The smart table mobile application is designed into three screens, the home screen, notification screen, and add table screen.

The home screen is the main screen upon opening the application. The home screen has a list of all the tables that the server is connected to. The list will scale based on how many tables the server currently has. If there are any notifications from a particular table, it will show the number of notifications and the table's tile will be enumerated so that the server can quickly access which tables need to be addressed.

The second screen is the notification screen that allows the server to see a list of notifications from a particular table. These notifications include anything that the smart table is capable of detecting with its array of sensors. This includes detecting when guests are seated, detecting when a beverage pitcher is low, and signaling when the call waiter button has been pressed. The notifications will be in chronological order, with the oldest notification on the top.

The server will then have the ability to press the notification, which will dismiss it and remove it from the list.

The add table screen is the last screen of the application where server has an ability to add a new table. The add table screen will show a list of all the Bluetooth devices in the area. Upon successful completion of adding a table, it will notify server that table has been added and it will appear on the home screen.

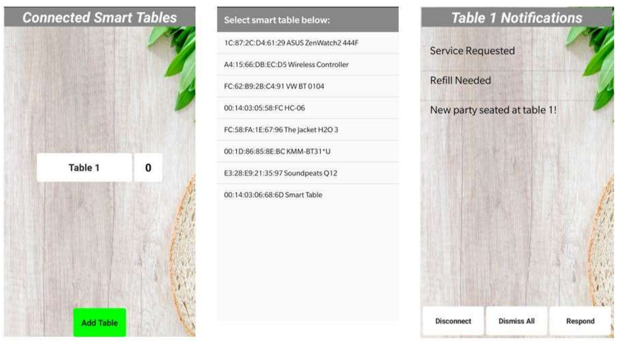

Fig. 4. Mobile Application User Interface

C. Mobile Application Design (FIG 57)

The software and Bluetooth backend will be communicating via simple message passing over the UART. The application is meant to be backwards compatible as far back as Android KitKat to support legacy devices. Additionally, the message passing occurs via simple string and char data types. To prevent hacking, input sanitation is implemented by the table.

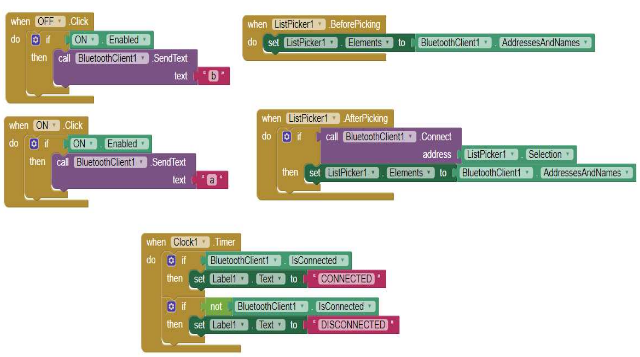

Fig. 5. MIT App Inventor 2 Bluetooth Logic Stack

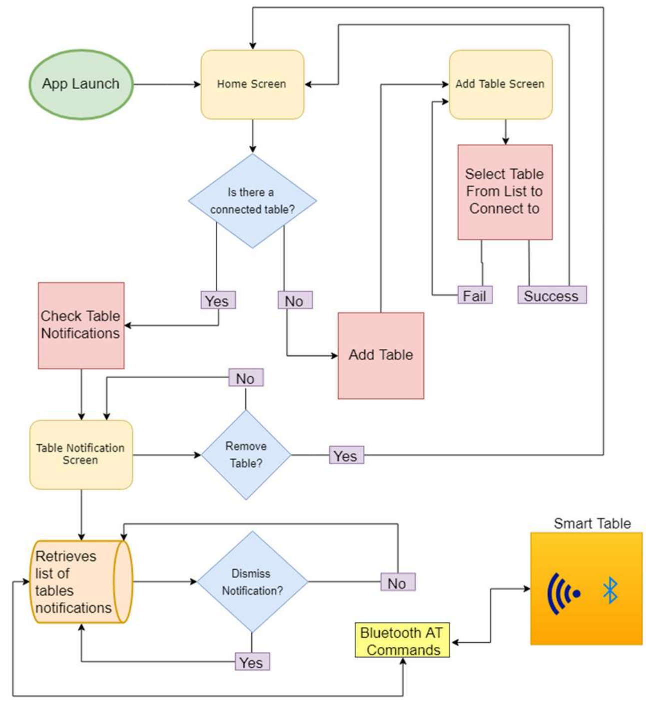

Fig. 6. Mobile Application Design and Flowchart

V. Hardware Detail

A. Microcontroller (PCB FIG)

Microcontroller is responsible for handling and managing information received from the sensors. Our custom designed PCB features the new ATmega328-PB. This chip is a relatively recent addition to microchip's lineup. As such, this new MCU seeks to address some of the previous limitations of the 328-P. The principle difference is the number of communications channels. The 328-PB has additional I2C channels and more of the GPIO pins support analog signals in addition to the digital functionality. The biggest improvement over the 328P is the additional of a second serial UART. In our design we desired one channel dedicated to the Bluetooth and another for debugging.

TABLE I

ATMEGA328PB SPECIFICATIONS

Clock Speed (MAX)	20 MHz
Operating voltage	1.8 – 5 V
EEPROM	1 KB
SRAM	2 KB

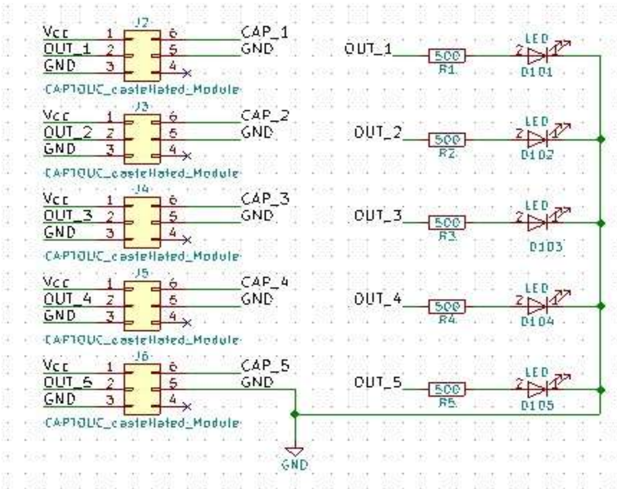

Fig. 7. Multi Touch PCB

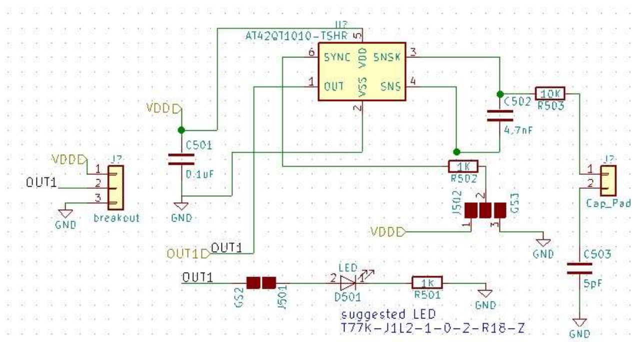

Fig. 8. Multi Touch Driver PCB

B. Custom capacitive multitouch sensor

Multi-touch capacitive board is a custom designed PCB with a unique circular touch interface surrounding a center pad. The outer ring is divided into four separate zones that function in addition to the center button. The multi-touch has five identical driver boards. The boards driver boards are based off Microchip's AT42QT1010-TSHR [6] but are tweaked and fabricated to fit flush with our larger multi-touch PCB.

To control user input for prompts provided by the LCD screen, we have chosen to design our own capacitive touch pad device. The device uses the presence or absence of static voltage on the capacitive input to detect a "press". This feature is very useful for the project because it always us to design a product that a person can interact with without worrying about damaging the device. This device can also be more sanitary by users only making contact with a bezel that can be easily cleaned. Capacitive touch sensors work by measuring the changes in electrical properties of a given device. The electrical field of the capacitive object can create positive and negative charges depending of the polarity of the voltage applied to it. Capacitive touch sensors use alternating voltage which causes the devices charge to reverse polarity continuously. The change polarity causes a small alternating current to occur which is detected by the sensor. In our case, we designed a PCB board that uses exposed copper to create our conductive capacitive layer. The change in voltage allows the IC to detect the distance at which the target is to the probe. The target being the human finger, and the probe being the copper layer leading to the pin of the specialized IC.

C. Environmental Sensors (FIG 28)

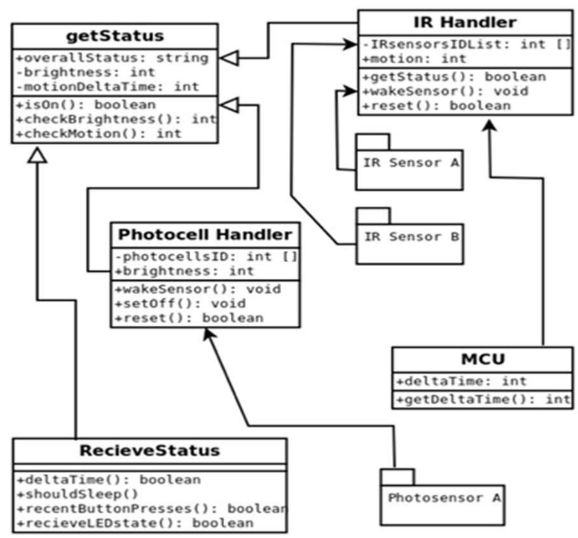

Fig. 9. UML class diagram for Infrared and Photocell Sensors

Our project has an ambient light sensor (full spectrum photocell) and an Infrared sensor (Infrared emitter + photocell + potentiometer + opAmp). These sensors work in tandem to gather information about the environment the table is in. Essentially the table will recognize when it is in a bright room and increase the relative volume of the signal LEDs to promote maximum visibility. Likewise, the table is smart enough to tone down the brightness of the LEDs in a dark room. The Infrared sensor array is implemented directly on our custom PCB. Using an infrared emitter and receiver the circuit will transform the analog current value to a digital signal. The sensitivity of the array is adjusted via the embedded potentiometer. The IR array will detect new guests and help in deciding when the table is empty. When guests are seated according to sensor, the software routine will turn on the tables ambient lighting LEDs and notify the server that guests have arrived. If no movement is detected for a set period of time the lighting on the table will be turned off to save energy.

D. Beverage Pitcher

The Loadcell will be used to monitor the weight of the beverage pitcher resting on our device's platform. Underneath the platform will be a loadcell with 4 signal wires entering the PCB. E+, E-, A+, and A- are the 4 signals loadcell will send/receive. The loadcell is a device that is usually made up of an aluminum material machined in the space of a long-sided cube. In the center of the metal a large hole is drilled from the cube. This allows a bending motion to occur about the center most point of the metal block. Electrically there are usually a few resistive tapes, called strain gauges that are glued to the edges of the block near the center where the hole was drilled. The physics behind the load-cell mechanism is once a force is applied to the metal, the upper strain gauge is stretched, and the lower strain gauge is compressed. The Wheatstone bridge has multiple fixed (and known) resistor values with one resistor variable to the strength of the force applied to it. The difference of resistance is very minute though, so that voltage change is sent to an amplifier to be readable by the microcontroller. The loadcell amplifier is implemented onto our custom designed PCB and calibrated via software

E. Bluetooth

Bluetooth is another element of this project. Bluetooth is a bridge that connects communication between the mobile devices and the smart table application. Upon conducting research on different Bluetooth module, we have decided to use HC – 05 Bluetooth 2.0 module. It helps establish two-way wireless functionality with help of USART at 9600 baud rate [5]. The reason why we chose Bluetooth 2.0 instead of 4.0 is because of the availability of legacy mobile devices and the lack of sensitive data involved. In theory a restaurant would be more comfortable giving out less valuable legacy devices to employees in such a moist and potentially theft prone environment. Indeed, it would seem the case that legacy devices are plentiful as 4/5 of the handsets among group members were running android 5 or below.

TABLE II

Range	< 100 m
Operating voltage	4 – 6 V
Operating current	30 mA
Supporting baud rate	9600, 19200, 38400, 57600

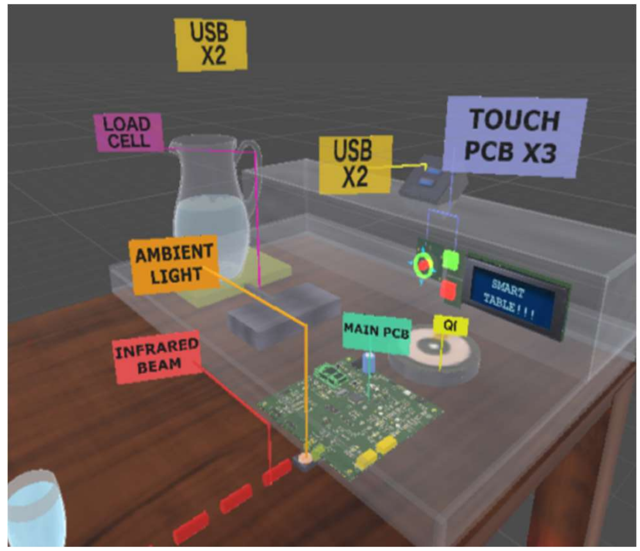

Fig. 10. Components layout in VR

F. Information Display

The purpose of the information display is to provide a medium to transfer information to the guest in the restaurant setting. There is a need to communicate with the guests at the table whether the server has been successfully called as well as to provide helpful information such as operating instructions or daily specials. It was decided that this project would implement some form of text display to achieve this information display functionality. To communicate this information to the guests a few different methods were considered, like specific color illumination with the light emitting diodes, LCD screens, OLED screens, and potentially LED matrix arrays to display text.

The component that was ultimately selected was the Smraza 2004 Character LCD display. This component was selected because it was decided that affordability was a major concern. Additionally, the low power usage, and long-life span where major considerations in selecting this component.

From the perspective of the guest the Smraza Character LCD will provide adequate functionality, and fulfil all the requirements, including the 122.5 degree viewing angle requirement that this component provides. This viewing angle helps to compensate for height differences and allows both users to see the screen

TABLE III
Smraza 2004 Character LCD

Pixel Resolution	4 x 20 Character
Viewing Area	3" x 1"
Operating voltage	5 V
Current Draw	30 mA
Interface	I2C

V. THEORY/PROTOTYPING

To accurately model the evolving system, we chose to breadboard and develop software with the ATmega 2650 MCU. To plan the dimensions, we used Microsoft's new 3D paint program which shipped with Windows 10. Eventually we created a 3D virtual reality simulation with Unity and Google Cardboard. With virtual reality we were able to rapidly iterate through the housing design and collaborate on ergonomics decisions without making a single cut of wood. The end result was a housing that was amicable to development and cable management.

VI. CIRCUIT BOARD DESIGN

By the end of senior design, ATmega family MCU was chosen along with several components known to have surface mounts configurations in addition to breakout board configurations.

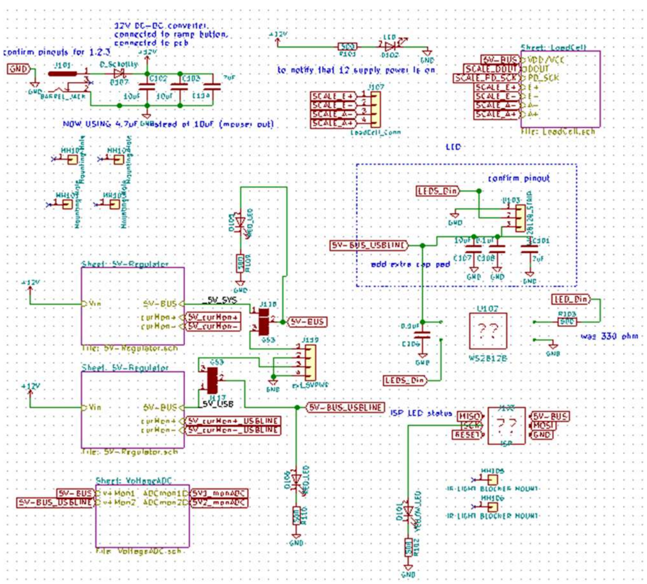

Fig. 11. Custom Microcontroller Schematic

While most subsystems were 3.3V compliant, the WS2812 LEDs were not when operated at full power. Additionally, the LEDs require a sufficiently fast MCU (16 MHz). While a 3.3V variant of the 328 was attractive, these chips are down-clocked to 8 MHz. Thus, even with logic level shifting up from 3.3V to 5V the LEDs would not function within specifications. Ultimately the MCU and all components except the Bluetooth module run at 5V via switching regulators integrated into the main board. The Bluetooth has a separate 3.3V LDO for power and a logic level shifter to lower the 5V signals coming from the MCU to safe levels [1].

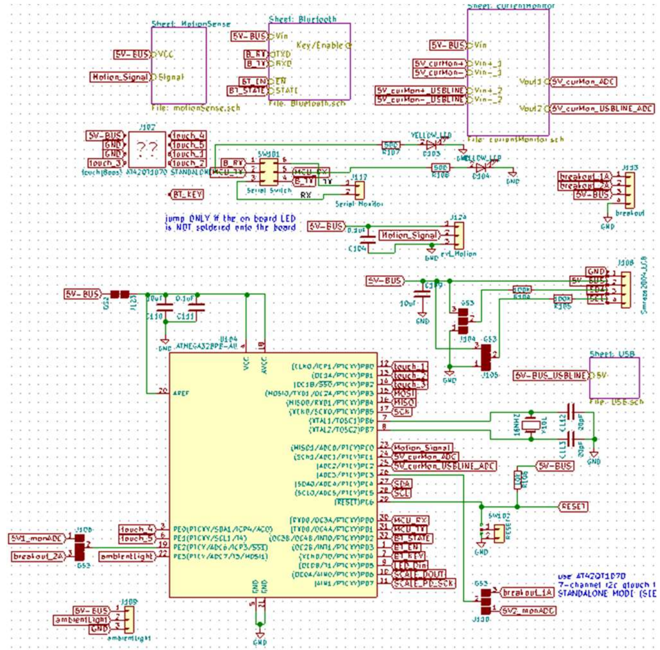

Fig. 12. Custom Microcontroller Schematic

To power the main board 12V DC was selected as an input because they are common enough to increase the chance of being able to recycle existing power supplies. To address polarity issues which may not be apparent in a variety of power supplies, we have included reverse voltage protection in the form of series diode. We have also clearly indicated the polarity via silk-screen to avoid confusion.

The main PCB furnishes two separate 5V regulators and a 3.3 V regulator. The power traces are 40 mil to reduce impedance [2]. The current draw is monitored via an arrangement of shunt resistors and an op-amp. The voltage differential that results from this geometry yields a measurable analog signal we can monitor. This feature enhances safety and debugging as we were tasked to design a robust prototype. To better facilitate debugging, our final prototype includes onboard status LEDs and numerous silk-screened markers. There are also spare breakout pins for expansion as well as optional replacement pin-outs for some components of concern. For calibration and programming manual controls such as a potentiometer and switch are included. Lastly, optional solder bridges are included in the design to make small adjustments.

VII. HOUSING

The dimensions of the hub were considered based on a few different factors like, the size of the average restaurant pitcher, the size of the electrical components, and the size of the average restaurant table.

Upon conducting a research, it was found that the average size of the pitcher's base diameter is between 4.5 – 5 inches. These finding influenced the dimension of the square plate that the beverage pitcher rests on at 6.5 x 6.5". The second factor that was mentioned with respect to choosing the dimensions of the smart table hub was the size of the custom printed circuit board design, and other electronics. The PCB is 100 x100 mm, which is converted to 3.93 inches by 3.93 inches. The tallest electrical component will be less than ¼ of an inch, therefore by providing two inches on the bottom plane of the hub, the PCB can sit nicely on the bottom toward the back center of the box. The LCD and other sensors were given a generous 3-inch depth on the top plane of the device so that they could easily be integrated into the box. The third factor that was mentioned with respect to choosing the dimensions of the smart table hub was the average size of a restaurant table. The smart table hub is designed to fit mostly any size table. It was found that by having a bottom plane dimension of 18 inches by 12 inches the device would likely fit on nearly any table it would be integrated onto. Therefore, the dimension of the box is 16" x 12" x 8". The prototype housing also features a special PCB viewing window through which the main PCB can be viewed in operation. The back panel of the housing is removable to showcase the internals such as the auxiliary PCBs.

Fig. 13. Smart Table Housing

VIII. Citing Previous Work

In order to make the smart table project a success, insight from other similar products, or at least products that might coexist in the same context is beneficial. The technology and features of this project have been around in different formats for some time. While evidence of a smart table for a restaurant has not been discovered, there are several "smart tables" on the market. The hope is that by reviewing these products is that the prototype will reflect the market needs and for many mistakes to be avoided.

The SOBRO Smart Side Table (2018) is a crowd funded project started to make a smart side table for the bedroom. The primary constraints were keeping the components silent while bedroom occupants are sleeping as well as having the lighting elements cater to a sleepy setting. Otherwise, many of the goals and features of this project align perfectly with those in our smart table for restaurants. The features of this side table are: charging for smartphones (complete with elegant cable management), decorative adaptive lighting via "smart LEDs", motion sensor enabled lighting, Bluetooth, and finally noiseless refrigeration. The tables are supposed to be shipping in October of 2018 for about $400 [3].

In 2013 a group of researchers at the University of Regensburg used off the shelf components to make an interactive dining table similar to some of the original ideas for this project [4]. Ultimately a project of this nature was too dependent on off the shelf technology such as Xbox Kinect to include significant design in terms of printed circuit boards, however this experiment proves that "smart tables" exist even if not commercially viable.

IX. Reducing Cognitive Load

One of the principle goals of this project was to make it easier for a waiter to determine a table's status at a glance. Cognitive load in our context refers to the mental effort required by a waiter to monitor the tables they are responsible along with the complexity of challenges such as navigating with heavy plates or recalling orders. Human perception is analogous to digital systems in the respect of GIGO or "garbage in – garbage out".

Reducing the cognitive load can be achieved by avoiding unneeded complexity and reusing established social conventions regarding visuals. Intricate patterns that could be subjectively considered "beautiful" could certainly add to an establishment's appeal, however such patterns could be distracting to staff. Essentially each individual signal pattern should be limited to only one or two colors. These two colors also need to be as far opposite as possible on the color wheel to be perceived as distinct. Mauve and purple would be an example of two poor color choices. Lastly, in regard to simplicity, a minimum number of possible distinct table states would be preferred. Ideally a table can either be "nominal" or "needs attention" rather than waiting special states like needing a "refill" or "ready for bill".

A good example of utilizing existing social conventions would be the use of "traffic lights" in the windows decorations of Apple's aqua interface. Using colors like red for closing a program is intuitive because red has been established socially as the color of stopping in brake lights, stop signs etc. Signal patterns of a predominantly red pattern might make sense for indicating that a party needs attention. A poor example of re-using establish social conventions would be the floppy disk save icon used in many word processing suites. As a general design rule iconography is a more difficult aspect than color.

CONCLUSION

The SMART table is the dream of four engineers with experience in customer service. Carrying a stack of heavy plates is not the time a server wants to be taking orders. Being able to determine which tables need attention at a glance would save steps and let staff manage their time better. The SMART table reduces workload by intelligently reporting the perceived needs of the customer. Ultimately, the table uses the new IOT type technologies along with decorative lighting to be beautiful and functional.

ACKNOWLEDGEMENT

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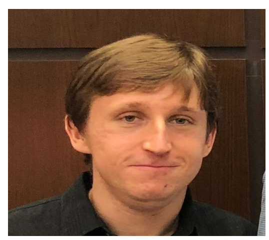
THE ENGINEERS

Christopher Corley, a computer engineering student at the University of Central Florida will be graduating in the summer of 2018. Christopher has accepted a position at Lockheed Martin Missiles and Fire Control as a Systems Engineer, where he is looking forward to starting his engineering career.

Theodore Cox is a C.p.E undergraduate student at the University of Central Florida, and will be graduating at the end of the summer 2018. Theodore has had multiple years' experience designing and testing embedded systems for the physics department of the University of Central Florida as a part of a team (Micro Gravity Research Center) developing cube satellites.

Dhaval Desai is a senior at the University of Central Florida and will be receiving his Bachelors of Science in Computer Engineering in the Summer of 2018. Dhaval excels in many technical fields such as electrical analysis, circuit theory, computer programming, and web designing. He aspires to work for a large corporation such as Apple or Facebook.



Mikey Garrity is a graduating computer engineer at the University of Central Florida. Mikey's skill set includes working with complicated state machines such as those found in game engines along with more hardware oriented skills such as circuit diagnostics. Mikey also has interests in the human psychology related to computer graphics and human vision.

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