The Smart Window

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Abstract — **The Smart Window aims to solve problems with inaccurate weather predictions using its set of onboard sensors. The Smart Window also supports meaningful engagement with users of a wide range of technical ability, because of its integration of new and exciting technologies like PDLC films, transparent displays, and assistive technology like proximity sensors and an easy-to-read GUI alongside a mobile application.**

Index Terms - Sensor, PDLC, Transparent Display, GUI, mobile application

I. Introduction

In this paper the design choices, construction, and results of The Smart Window project are detailed. A group of four students, consisting of two from UCF's College of Optics and Photonics, and two from the Department of Electrical Engineering and Computer Science worked together to produce this device.

The Smart Window is designed to correct issues that currently exist with day planning, and obtaining weather information in our immediate areas. Our motivation to resolve these issues takes into account our connection to nature, typically done by looking out through a household window. The Smart Window team aimed to improve on the existing experience of determining the weather from a windows view by merging new technologies; such as transparent displays, on board weather sensors, proximity sensors, polymer dispersed liquid crystal (PDLC) film and mobile connectivity. All without removing the experience of enjoying the outside view.

These improvements include viewing the current outdoor temperature, humidity, and UV index. As well as the indoor temperature and humidity on the display's transparent user interface. Also included on the interface are important day planning aspects like upcoming events, phone notifications, and to-do list items, synced through the user's mobile device. Current time, news headlines, and a local forecast are also obtained over WiFi connectivity and displayed.

User privacy was also at the forethought of the design process. Through the use of a switchable PDLC film, the glass surface can be given an opaque appearance in fractions of a second. The PDLC film also can be used to reduce glare from outside, reduce the intensity of outdoor light, and cut down on undesired ultraviolet and infrared radiation.

II. Core Technology

A. Display

A transparent LCD display located at the top of the window supports the GUI for interfacing the suite of on-board weather sensors, showing phone notifications, and other updates relevant to the users day planning. Transparent displays are still emerging in popularity, and are typically prohibitively expensive for projects outside of large commercial enterprises.

However, by modifying a typical LCD display, our team has created a display panel approaching the limit of maximum LCD transparency. Our twenty inch panel covers 75% of the windows width, and shows high contrast during daylight conditions, perfect for supporting a rich interface and able to be read from a distance. To minimize weight and cost, while maximizing the display's transparency, we have opted to use the natural light from the sun as the windows backlight. The display unit for the Smart Window uses a standard HDMI connection to interface with the Raspberry Pi and sensor units. To account for the project's aesthetics and minimize any user hazards, the frame of the project provides a surface to safely route the cables of interconnecting components, ensuring no loose wires could pose a trip hazard, or electrical hazard.

B. PDLC Smart Film

Smart film is the name given to a type of film that can be applied to glass, acrylic or polycarbonate surfaces with the main purpose of giving otherwise clear glass two modes: transparent and opaque. This technology is also known as smart glass, as some vendors tend to sell the film already applied onto a surface. This technology can also eliminate the need for blinds or window shades while still providing energy savings which can make Smart Film technology a good financial choice, while supporting clean energy initiatives.

In the case of our project, the PDLC film covers the entire area of the 2ft x 3ft glass surface. This allows the entire window to change from transparent to opaque, using a single button to change the PDLC operating mode. Powered by a single AC adapter, the PDLC chosen uses only 3 W/m^2, which is similar in power consumption to a small LED desk light.

C. LED Lighting

Further supporting the energy efficiency of the project is the LED lighting bar featured at the top of the project's frame. The team decided to use two high-density LED strips, containing 60 individual LEDs per meter, to maximize light output per meter. Pairing the strips with individual PWM controllers allows for color mixing between 3000K and 6000K color temperatures. To support this wide range of colors, a diffusing sheet is placed over the LED strips, which are mounted onto a lightweight wooden backing. This diffusing sheet helps to better mix the colors, and scatter the light from the diodes. The range of colors possible from the LED strips is shown in Figure I.

Figure I: Range of LED Color Output

The LED light bar also provides additional project functionality, especially during low light hours when the transparent display has difficulties showing readable contrast. Totaling a light output of approximately 2200 Lumens at full power, the LED light bar provides adequate lighting for entire rooms.

D. Sensor Suite

Weather sensors have been integrated into both sides of the window to provide real-time reading of temperature, humidity, and UV Index. These measurements are important for consumers, as it informs them of how to dress for outdoor activities, whether they need additional sun protection, and what activities they may fit into their daily schedule. For the temperature sensors onboard the Smart Window, the group decided to use sensors which have ±0.2 ℃ accuracy and 11-bit resolution. This level of accuracy allows the user to feel confident about their weather based decisions without having to rely on a weather app that can only approximate regional measurements. The indoor sensors provide information about the heat distribution in their house. They can compare the value on the thermostat to that displayed on the window and make appropriate decisions concerning heating, cooling, or insulating.

The humidity sensors are on the same chip as the temperature sensors and offer ±2 % relative humidity. Low relative humidity can make the air feel too dry whereas high relative humidity causes the air to feel sticky. Knowing the relative humidity percentage can help improve the comfortability indoors since the user will know if a humidifier or dehumidifier is needed at their location. The UV index sensor is located on the outdoor facing side of the compartment box. UV index values are integers ranging from 0 to 11+, and describe the amount of UV exposure in outdoor conditions. Knowing the UV index is essential to take care of your skin when outdoors since UV light can cause skin damage from minor sun burns to skin cancer.

E. The Smart Window Frame

To allow all parts of the project to integrate into a single unit, a wooden frame was constructed out of lumber. The wood is sanded and stained a single color. The bottom of the Smart Window frame features a component box for electronics and sensors, removable backing for the LED lighting bar, and grooved sides for the glass and PDLC layer, it provides a seamless structure for all components of the Smart Window. Cable guides help reduce clutter and are attached to the side of the frame.

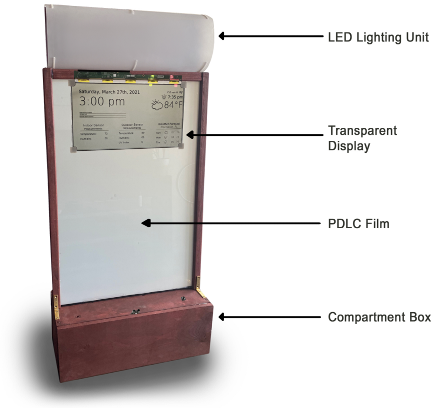


Figure II: Smart Window Frame

III. Hardware Design

A. Display Design

Display technologies considered for the project included transparent OLED and modified LCD. Liquid Crystal Display technology was implemented in the project for several reasons. LCDs use crossed polarizers to module image brightness, and could theoretically provide a maximum transparency near 50% for randomly polarized light. LCD displays can also be inexpensive, and several older LCD displays used as computer monitors were already in-hand for the project team from past use.

The significant challenge of implementing LCD technology is that because the displays are not self-emissive, they require a backlight to show an image. To modify an existing LCD panel for transparency, the OEM backlight would need to be removed, and the display would be disassembled. First, the electronics and the plastic frame were separated, revealing the electronics and cable connections seen below in Figure III, (1) and (2.)

The PCB connecting the LCD was mounted to the backlight with screws, which were removed revealing the standalone display module in (3) in Figure III. Finally, the anti glare film was able to be removed after allowing a wet cloth to soften the adhesive connecting it to the top layer of the display. This was done to maximize the transparency of the display, and the final LCD is seen in (4).

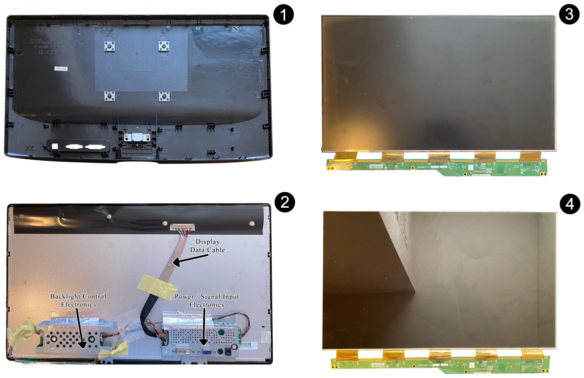


Figure III: Display unit disassembly

B. Smart Films

Active smart films use an electrical charge to transition between transparent and opaque modes. The options investigated included electrochromic, suspended particle devices, and polymer dispersed liquid crystals (PDLCs) as possible smart film technologies for our project. Most of these are prohibitively expensive or still being researched, however, PDLC films are already mainstream and offer the best performance within our team's budget.

The team then conducted a market analysis of the main PDLC film manufacturers, seen below in Table I, and chose Smart Tint, Inc, as the supplier for our film. In the transparent mode, Smart Tint's PDLC film blocks or reflects up to 99% of UV radiation as well as more than 80% of infrared radiation, and it has a haze coefficient of 5%. In the opaque mode, the film scatters 99% of UV light, 95% of infrared light, and has a haze coefficient of 93%. The film also has solar gain coefficients of 0.71 when transparent and 0.1 when opaque.

Parameter clear / opaque	Impel-Well	Magic Film	EB Glass	**Smart Tint**
Haze %	3 / 92	6 / 90	6 / 90	5 / 93
Light Trans. %	83 / 70	80 / 4	80 / 4	90 / 4
IR Trans. %	10 / 5	80 / 20	80 / 20	20 / 5
Switch Speed	45ms	60ms	200ms	40ms
Solar Gain	0.8/0.2	0.8/.06	0.8/.06	0.7/0.1
Power Req.	3W/m2	4W/m2	5W/m2	3W/m2

Table I: Market Analysis of Smart Films

The smart film was applied onto the glass pane by using the method recommended by the manufacturer. This involved cleaning the glass with isopropyl alcohol and using a squeegee when applying the film slowly to avoid forming any air bubbles that may impact the performance and overall look. Finally, a notch was built into the frame in order to fit it to the glass subsystem securely.

C. LED Design

The LED lighting bar was designed using two IP65 high-density strips from LEDSupply. Each LED strip is connected to a PWM controller capable of giving 0-100% power control without any detectable flicker. These PWM controllers are supplied power via an AC/DC adapter which inputs 12V/1A power to each individual strip.

The strips were attached to a lightweight wooden backing panel using the manufacturer's supplied adhesive. The diffusing film connects to the same backing by six plastic mounts designed in AutoCAD and printed in PLA plastic. Metal brackets were secured to the wood and mount into another set of PLA plastic mounts attached to the top of the Smart Window frame. The entire LED backing system is shown in Figure IV.

Figure IV: LED Lighting Bar

D. PCB Design

The final PCB was designed through Autodesk Eagle. Footprints for each component were downloaded through Ultra Librarian so that proper connections between traces and pads could be made. The microcontroller selection (STM32L432KC) was made based on the relative popularity of the chipset, extensive documentation, price, power, and integrated development environment.

A 20 pin header is necessary for programming the microcontroller via JTAG through an ST-Link programmer though there need only be four pin connections to the microcontroller itself. The reset pin header is used to connect the reset pin of the microcontroller to ground if shorted to reset it for programming. There will also be plenty of I2C pins for possible future implementations of compatible devices.

Input power to the board is supplied by a two pin header connected to the battery bank, fed to two different voltage regulators. One 5V regulator for the proximity sensor, and one 3.3V for the microcontroller, sensor, and programmer reference voltage pin. The regulators have the same footprint and pinout since they come in the same package. It should be noted that the 3.3V regulator should go closest to the microcontroller. Shown below in Figure V is a simplified schematic of the PCB.

The temperature and humidity sensor is placed as far away from any other components as possible so that any heat dissipation from those components affect the temperature measurement minimally. There are also four GPIO pins, two of which will incorporate the proximity sensor input and the output signal sent to the Raspberry Pi.

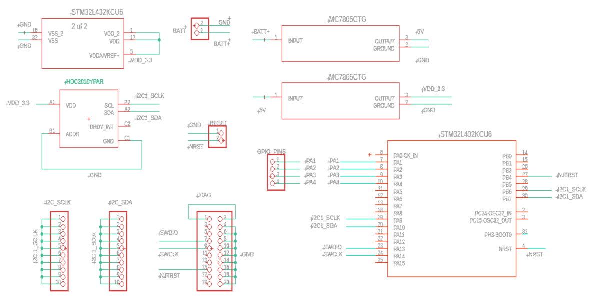


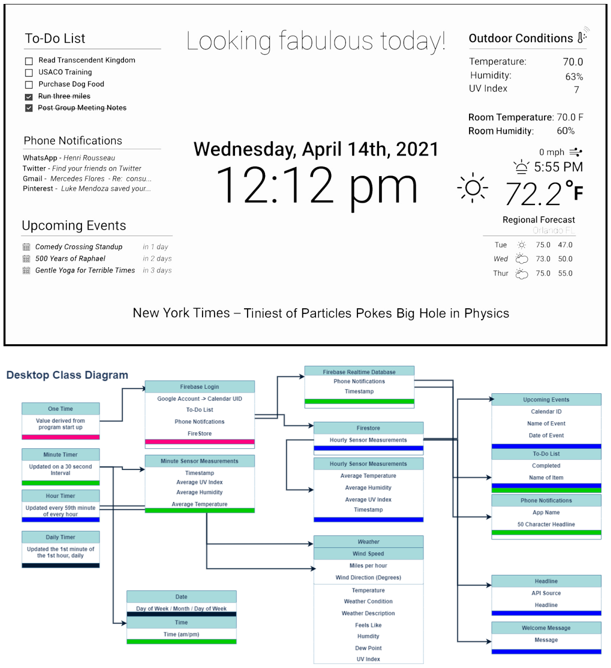
Figure V: Core PCB Schematic

IV. Software Design

A. Desktop Application

The desktop application runs onboard the Raspberry Pi, and interfaces with the sensor suite to provide real time updates for the temperature, humidity, UV Index and online data modules. To adequately display all of this information, the desktop application is designed to use the full 1600x900 pixel resolution of the display. NodeGUI, a cross-platform package which runs on Node.Js was used in combination with the Qt widget toolkit to create the GUI and desktop application, and is displayed via the Webkit rendering engine.

The desktop application, and accompanying backend class diagram is visualized in Figure VI, and shows day-planning modules on the left side of the interface, and sensor readings alongside weather forecasting on the right side of the GUI. To prevent possible slowdowns of sending new data to the GUI, Multiple worker threads run in separate intervals, ensuring that the display will always display the correct time. This allows different aspects of the UI to update at different times, such as updating the weekly forecast as a slower rate than the current wind speed.



To-Do List

☐ Read Transcendent Kingdom
☐ USACO Training
☐ Purchase Dog Food
☑ ~~Run three miles~~
☑ ~~Post Group Meeting Notes~~

Phone Notifications

WhatsApp - *Henri Rousseau*
Twitter - *Find your friends on Twitter*
Gmail - *Mercedes Flores - Re: consu...*
Pinterest - *Luke Mendoza saved your...*

Upcoming Events

Comedy Crossing Standup in 1 day
500 Years of Raphael in 2 days
Gentle Yoga for Terrible Times in 3 days

Looking fabulous today!

Wednesday, April 14th, 2021

12:12 pm

Outdoor Conditions

Temperature: 70.0
Humidity: 63%
UV Index 7

Room Temperature: 70.0 F
Room Humidity: 60%

0 mph
5:55 PM
72.2°F

Regional Forecast
Orlando FL

Tue	75.0	47.0
Wed	73.0	50.0
Thur	75.0	55.0

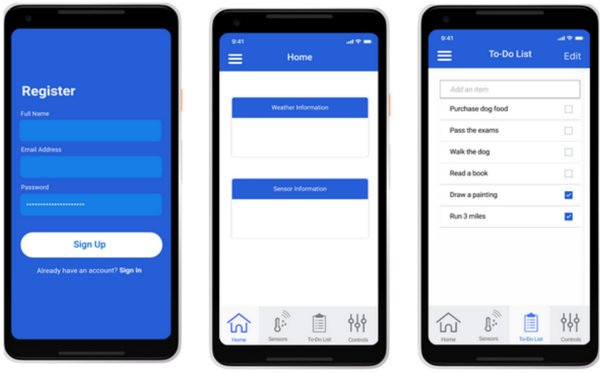
New York Times – Tiniest of Particles Pokes Big Hole in Physics

Figure VI: The Smart Window Desktop GUI and Backend Class Diagram

B. Mobile Application

The mobile application for The Smart Window connects through a user's Android mobile device to sync notifications, to-do lists, and upcoming events. The team used React Native to program the mobile application for its ease of use, and ability to integrate with many other services. Firebase Admin SDK is used as the users database, which serves two main purposes: storing user display settings for the desktop application and storing atmospheric data from the sensors. The forecasting data from the OpenWeather API will be stored in the database for analysis and statistics for twenty-four hours before being overwritten.

This will decrease the amount of storage needed for the database and decrease the time for calculations and data retrieval. The weather data will be sensor tables organized by hourly averages for a day. The data from the API is temporarily stored for analysis and statistics, before being overwritten. The mobile app seen below in Figure IX shows the login screen, home screen to view current sensor readings, and the to-do list organizer where users can update their Smart Window with current items.



Purchase dog food ☐
Pass the exams ☐
Walk the dog ☐
Read a book ☐
Draw a painting ☑
Run 3 miles ☑

Figure VII: Smart Window Mobile App

V. Interconnection

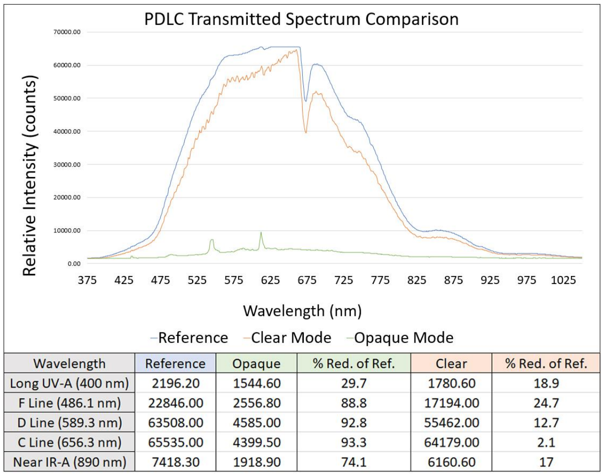
The main power for the microcontroller and sensors will be supplied by a micro-USB connection from the RaspberryPi. This is done to ensure that the microcontroller is provided with the right voltage and ensuring that the attached sensor PCBs will operate as expected. The weather sensors connect to the microcontroller via I2C for communication and are powered by its 3.3V pins. The data read from the sensors is sent from the microcontroller to the Raspberry Pi.

The proximity sensor connects to a different regulator for power since it requires a higher voltage compared to the other sensors. Its output is an analog signal which is then connected to the analog to digital converter of the microcontroller. The microcontroller triggers a high or low GPIO output value when the user enters or exits the sensor's proximity. This signal is sent to the Raspberry Pi. The Raspberry Pi then displays the GUI to the transparent LCD through an HDMI cable It will also connect to the user's Google account through WiFi such that the calendar and to-do list will be displayed.

Barrel connectors between the LED components allow the connectors to be easily connected or disconnected during transportation of the project. Holes were drilled into the component box at the bottom of the Smart Window frame to route cables into the box, reducing trip hazards and electrical hazards to the users and members of the project team. Cable clips are attached to the outside of the frame, minimizing tangles and loose wires.

VI. Results

The team tested the relative intensity of light transmitted through the PDLC film using a broadband fiber light source aimed at a spectrometer located behind the glass subsystem. This test measured the change in intensity of the light through the PDLC film in its opaque and clear states compared to a reference at various wavelengths. The results of this test, and the corresponding spectrometer measurements are shown in Figure VIII.



Wavelength	Reference	Opaque	% Red. of Ref.	Clear	% Red. of Ref.
Long UV-A (400 nm)	2196.20	1544.60	29.7	1780.60	18.9
F Line (486.1 nm)	22846.00	2556.80	88.8	17194.00	24.7
D Line (589.3 nm)	63508.00	4585.00	92.8	55462.00	12.7
C Line (656.3 nm)	65535.00	4399.50	93.3	64179.00	2.1
Near IR-A (890 nm)	7418.30	1918.90	74.1	6160.60	17

Figure VIII: Glass subsystem transmitted light spectral measurements

After the spectrometer test, the team conducted a photometric test using an LX1330B light meter in order to measure the illuminance transmitted through the PDLC with sunlight as the reference. This test was repeated for both clear and opaque modes of the PDLC and at three different locations of the window to reduce error from changes in sunlight conditions. The results of this test, which are all in units of Lux, are shown in Table II.

	Reference	Clear	Opaque
Top	1475	1225	965
Middle	1450	1250	1025
Bottom	1425	1202	957
Average	**1450**	**1226**	**982**

Table II: Glass subsystem photometric measurements

Analyzing the data from Table II shows that an average of 84.5% of incident light being transmitted through the PDLC in its transparent state, and 67.7% of incident light being transmitted in the opaque state. To measure the transparency of the modified LCD display, photometric measurements were taken with the same LX1330B light meter for 5 positions on the manufacturer supplied LCD backlight. Measurements were then taken in the same positions with the LCD display between the light meter and backlight. The average testing data compiled below in Table III, showed the display transparency to be nearly 48%.

Position	1	2	3	4	5	**Avg**
Backlight	5770	5780	5950	6210	6960	**6134**
Display	2810	2790	2890	2960	3270	**2944**

Table III: LCD Subsystem Measurements

VII. Conclusions

In this work we have presented the viability of leveraging multiple technologies together to create a Smart Window. The combination of en-suite weather sensing, displayed on a transparent display interface and PDLC enabled glass subsystem is unique and not currently commercially marketed, to the best of the project group's knowledge.

Temperature and humidity were measured using an HDC2010YPAR sensor, to ±0.5 degrees fahrenheit, and to ±2% humidity. UV Index was measured using a SI1131 sensor, but due to indoor testing, and inclement weather during the testing times, the sensor never outputted a nonzero UV index value. However, to the best of the group's knowledge, all sensors were working within expected ranges.

The modified LCD display used in the Smart Window project shows transparency near the theoretical limit for its panel type. The manufacturer-supplied display electronics works without issue after the display disassembly process. The group's experience during the testing process has shown readable contrast for the display in conditions ranging from clear sky to clouds and rain. The PDLC film testing offered results supporting the manufacturer's marketed specifications of transparency and power consumption.

The LED lighting unit passed all engineering specifications, outputting a brightness of over 2000 lumens without any detectable flicker while color mixing both LED strips. Real time measurements of temperature, humidity, and UV index values were read by the microcontroller and transmitted to the Raspberry Pi via UART transmission, then shown live on the Smart Window GUI. The Raspberry Pi also uses it's onboard WIFI connectivity to successfully update the clock, local forecast, and sync the user's google account through the Smart Window mobile application for updating the to-do list items on the desktop interface.

VIII. Biography

Jake Pivnik is studying at CREOL to obtain his Bachelor's degree in Photonic Science and Engineering. He plans to enter the photonics industry after graduation to translate his knowledge gained during undergraduate research and independent study to work in a hands-on capacity. Jake plans on working in either the display sector or solar energy sector before returning back to higher education to complete his Master's Degree in Optics.

Pablo Calzada is studying at CREOL to obtain a Bachelor's degree in Photonic Science and Engineering. After graduation, he will be joining Northrop Grumman Space Systems in Redondo Beach, CA as an Optical Engineer. He also has the intent of pursuing a Master's Degree in Optical Sciences while working full-time.

Shaneal Findley will be graduating from the University of Central Florida in May 2021 with her Bachelor of Science in Computer Engineering. Post-graduation, Shaneal plans on moving into a full-time position at Intel Corporation as an Firmware Engineer under the Non-Volatile Memory Solutions Group.

James Brunner is studying at CECS in pursuit of a Bachelor's degree in Electrical Engineering. After graduation, he will be joining the Naval Air Systems Command as an Electrical Engineer in Patuxent River, MD. He aims to design and launch a satellite to low-earth orbit to establish a communications link greater than 100km, map the Earth's landscape using synthetic aperture radar, and take photos of the Earth and Space.

IX. References

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