Smart Windows

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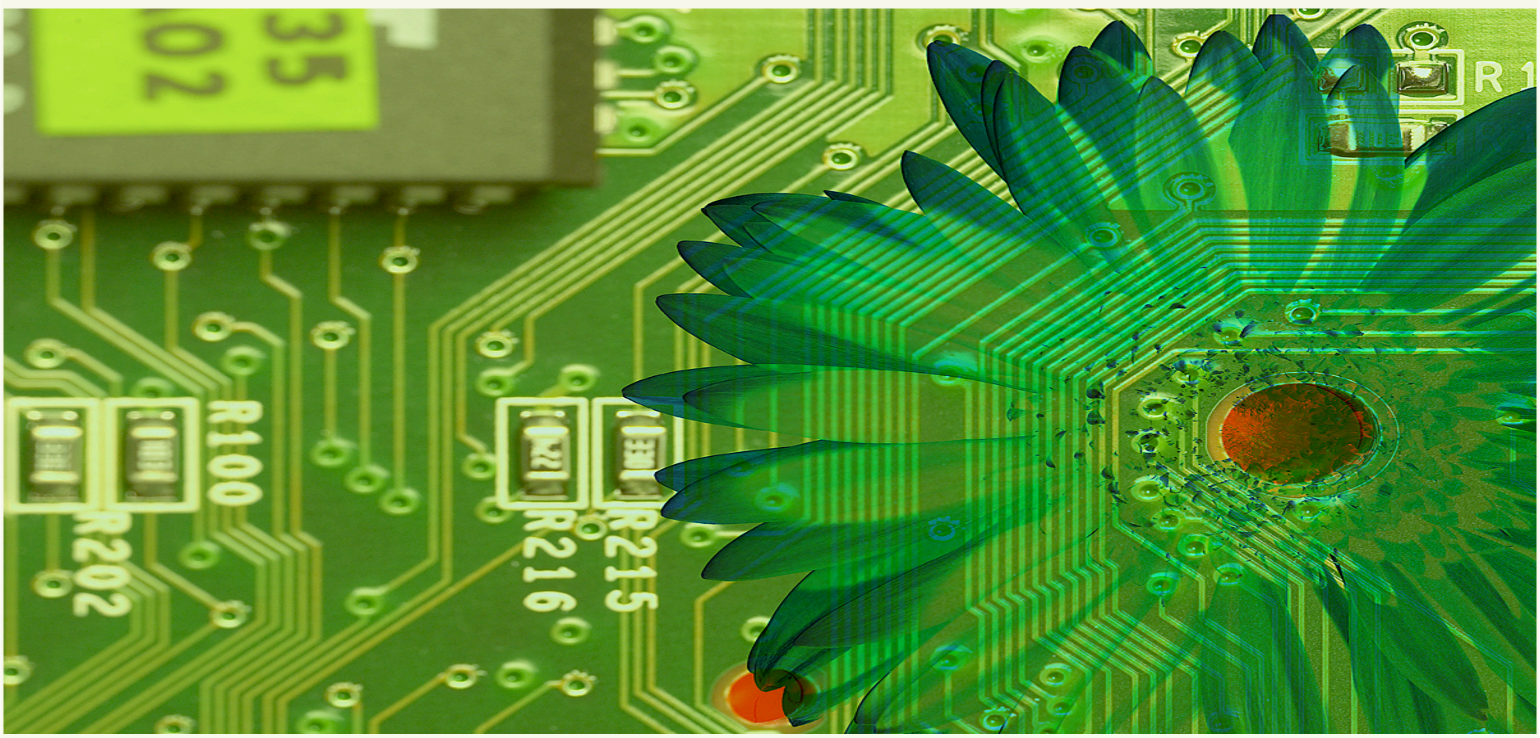

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Introduction

Exciting energy-saving technologies such as a “smart” grid have captured our cultural imagination. Meanwhile, many commonplace ways to save energy are quickly gaining impetus. Products like the compact fluorescent light bulb have shown the commercial viability of these everyday energy savers. As identified by the Department of Energy, one such solution is simple window treatments like blinds and shades. These window treatments are capable of reducing the load on household air conditioning units, thereby reducing energy usage. In addition to energy benefits, properly operated window treatments offer many benefits, such as security, to the homeowner. However, to maximize this return on window treatments, an automated system is needed to ensure their proper and timely opening and closing. Through the utilization of current technology paired with innovative engineering design, the proposed Smart Window is a solution to this problem of window treatment automation. The Smart Window will give the homeowner both central and in-room control over his window blinds, along with several powerful autonomous control modes.

Problem Description

In a world faced with rising energy demand and depleting energy supply, the next generation of technology must take into account energy usage at every level. According to the United States Energy Information Administration’s (EIA) Residential Energy Consumption Survey (RECS), air conditioning consumes a significant and growing portion of US electric power. From 1997 to 2005, the RECS shows that the percent of US residential electric power used for air conditioning rose from 14% to 20.2%. [1]

To fight rising energy usage, the US Department of Energy's Energy Savers program recommends reducing the stress on air conditioners while they are running. One important Department of Energy guideline is to use window treatments like blinds and shades to reduce the thermal gain through the windows due to radiant solar energy: "Install window shades or other window treatments and close the shades. Shades will help block out not only direct sunlight, but also radiated heat from the outdoors, and insulated shades will reduce the conduction of heat into your home through your windows." In fact, the Department of Energy says that reflective shades can reduce heat gain up to 45%. [2]

In addition to reducing air conditioning energy consumption, window treatments have other functions. For example, the September 23, 2009 edition of the University of Notre Dame and Saint Mary's College newspaper *The Observer* recommends window treatments as a crime prevention tool. In an article entitled "Burglars Target Off-Campus Housing," South Bend Police Captain Phil Trent notices, "There's people with their front windows right open and I can see a 50-inch plasma screen from the street. You can see someone with the lights on in their house and they're working on a laptop computer…A burglar can do an assessment of what they can steal just by walking down the street looking in the windows." The article states, "To prevent burglaries, students should keep their windows and curtains closed."[3]

These benefits of window treatments are only effective, however, if the homeowner is diligent in opening and closing them. To access the energy benefits of window treatments, the homeowner must monitor sunlight exposure and close treatments at the appropriate times. To access the security benefits, the homeowner must close every treatment prior to leaving the house. Since few homeowners can afford to give this level of attention to their window treatments, the benefits of properly operated window treatments are rarely utilized. For these benefits to be tapped into, the windows must operate automatically in the homeowner's stead. It is this problem of maximizing window treatment utility through automation and electronic intelligence that the Smart Window design addresses.

[1] EIA online RECS 2005 Status Report. <http://www.eia.doe.gov/emeu/recs/contents.html>.

[2] DOE Energy Savers. <www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12353>.

[3] Mervosh, Sarah. "Burglars Target Off-Campus Housing." *The Observer*. 23 Sept 2009. <http://media.www.ndsmcobserver.com/media/storage/paper660/news/2009/09/23/News/Burglars.Target.Off Campus.Housing-3780142.shtml>.

Proposed Solution

As a solution to this market gap, the Smart Window is designed to maximize window treatment utility. As designed, the Smart Window system will feature a central, software-based window treatment management utility running on an ordinary PC. This management utility will wirelessly communicate with on-window control modules located on supported windows throughout the home. The homeowner will interact with these on-window units through in-room controls consisting of a remote control and a set of on-window buttons.

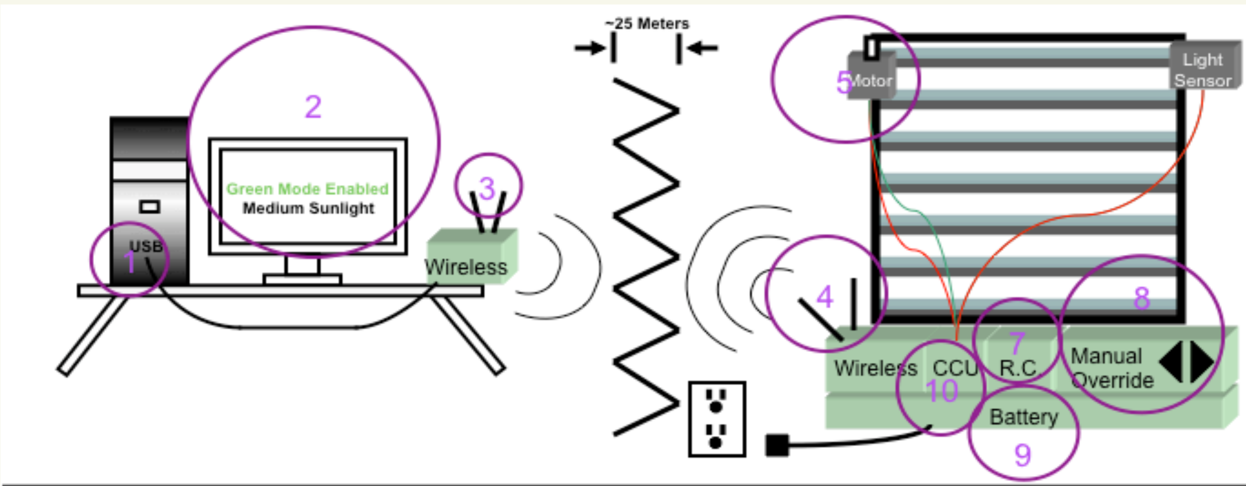
This computer application will be capable of setting each connected window unit into one of two *modes*. Based on the mode of the window, the program will then have the ability to set the *state* of each window treatment to open, half-open, or closed. In manual mode, the user of the software application will be able to remotely set the state of the window treatment from the PC application or with in-room controls. The in-room controls consist of on-window buttons and a wireless remote control. In green mode, the on-window unit will sense the amount of light flux through the window using a window-mounted light sensor. If the light level is too high, the on-window control will close the window treatment, decreasing heat gain through the window and reducing stress on the air conditioning unit.

In addition, the PC application can be set to safe mode. Here, all window treatments will close automatically. Upon exit of safe mode, the windows will recover their previous mode and state. When not changing the mode of any windows, the PC application can be safely powered off and the window modules will continue operating in their current mode.

The on-window unit, in addition to receiving instructions from the PC control application and the in-room controls, must have several other functionalities. It will have a window-mounted light sensor capable of determining the light flux through the window. To avoid blocking wall outlets, it will have an energy storage unit attached to it. To avoid excessive cost, it will also have a charging circuit to recharge the energy storage unit.

The most important aspect of the on-window control unit is the window treatment driver, a motor or other actuator, driving the motion of the window treatment. This actuator will have the ability to reliably set the window treatment to a fully open, half-open, and fully closed. Particular emphasis must be put on controllable step size and low power consumption, since the motor will be battery operated.

The total proposed system is shown in **Figure 1**.



1- The main command module connects to a PC via wired connection.
2- A PC program monitors the light sensors and sends commands to the blinds controller based on the mode and user demands
3- The PC (when it is on) maintains two-way wireless communication with the blinds controller.
4- The blinds control unit has two-way communication ability, and can function independently.
5- A motor is custom fitted for our set of blinds, and turns the exact correct amount.
6- A light sensor is carefully positioned and calibrated to read only outside sunlight.
7- An remote control can be used to “manually” turn the shades.
8- The blinds can also be actuated by physical holding a key.
9- The device will be battery powered, possibly with wired recharging capability.
10- The on-window central control device operates the window

Figure 1. Schematic of proposed window treatment solution

Demonstrated Features

The features of the Smart Window have been chosen to successfully meet consumer needs. These features can be understood by studying each sub-system. These systems include the PC application, the in-room controls, the on-window controller, and the window treatment driver.

PC Application

The first sub-system is the central PC application. The user will communicate with the Smart Window system through this software application. This application will have the following minimum features:

- Window treatments shall continue to operate while the application is not running
- The application can set each window to one of two *modes*:
  - Manual Mode: treatments controllable from the PC or in-room controls
  - Green Mode: treatments automatically close if a significant light flux is present
- The application shall report the mode and state of all windows
- The application will have a safe mode, which instantly closes all windows until the user exits safe mode. Following exit, windows return to their previous state.
- The application should, at minimum, be able to wirelessly communicate with an on-window controller 25m from the base station (indoors).
- The application should have a simple graphical user interface (GUI)

In-Room Controls

In addition to the computer program, the user can communicate with the on-window controller through the in-room controls. These controls, consisting of on-window buttons and a remote control, should have the following minimum features:

- Wireless remote control must work for all windows in the house depending on proximity
- In-room controls must be capable of setting the *state* of the window treatments while the window is in manual mode
- When the window is in safe or green mode, touching an in-room control should convert the window to manual mode and perform the desired operation
- The remote control must run on batteries for at least a month

On-Window Controller

The in-room and software controls will each communicate with the on-window control unit. This unit, which will instruct the window treatment driver, must have the following minimum features:

- Operate either on rechargeable batteries or on non-rechargeable batteries that last for a minimum of a month
- Receive instructions from the in-room and software controllers
- Receive current window light flux information from a window-mounted light sensor
- The light sensor must ignore indoor and transient outdoor light
- Store and transmit the mode and state of the window to the PC software application
- Drive the window treatment reliably into one of three states: open, half-open, closed
- Occupy minimum space on the window or wall near the window

Window Treatment Driver

The on-window controller directs the driver capable of controlling the treatments. This actuator should:

- Reliably set the window blinds to an open, half-open, and closed state
- Receive instructions from the on-window controller
- Operate either on rechargeable batteries or on non-rechargeable batteries that last for a minimum of a month
- Have minimal spatial and noise impact on the environment

Module #	Module Name	Expectations	Difficulties
1	PC interface	Allows the computer to send and receive signals	Must work with most computers
2	PC program	Makes decisions on when to open and close windows and interacts with user	Window modules must still operate when PC is off
3	PC wireless device	Can send/receive signals with the window modules	Must reach across large homes reliably
4	Window wireless device	Can send/receive signals with the PC wireless module	Must stay very low power if window unit battery operated
5	Blinds motor	Must reliably turn the blinds the correct amount each way	Should be low power
6	Light sensor	Must reliably read sun measurements	Cannot be fooled by lightning, car lights, indoor lighting, etc
7	Remote Control	Interprets open/close commands from a remote control device	Should not interfere with TV/ DVD channels, etc
8	Open/Close buttons	Can reliably open and close the blinds, even if other systems fail	Must work with all other forms of control
9	Battery power	Can recharge from wall outlet once per month, otherwise store energy	Must be fairly light, but have significant capacity

Table 1. Summary of system requirements

Available Technologies

The success of the Smart Windows project depends on the availability of certain required technologies. Using ease of procurement, cost, and functionality as the criteria, several options for these critical technologies have been identified. The availability of these technologies shows clear promise for the success of the Smart Window design.

The main technology that Smart Windows rely on is wireless communication. The most important form of wireless communication is the connection between the PC-based control application and the on-window control units. This connection needs to be capable of passing data in both directions at an indoor distance of at least 25m. Since only window treatment mode and status is being passed, the system will only communicate relatively small data sizes. The wireless connection should be low power in order to save battery in the on-window unit. Based on these constraints, the most promising technology for this application is radio frequency (RF) media.

While several communications protocols are available for RF communication, the communications protocol that best fits the design is ZigBee. ZigBee is designed for low-power applications with a low data rate. ZigBee can support a multitude of nodes in its mesh network and requires a central hub. We intend to use a PC as our central hub. The ZigBee has an approximate range of 70 meters. Zigbee devices are readily available with the budget of this project. Should increased range become necessary, affordable routers are available to increase the range by about 30 meters.

Although ZigBee is an excellent match with the Smart Windows system requirements, other communications protocols are available. For example, a new technology called IP Over Power or Ethernet Over Power runs Ethernet signals over household electrical power distribution lines. An IP Over Power kit comes with two adapters; one is plugged into one electrical socket and the second adapter into a different socket. The Ethernet signals are transmitted through the power line along with the standard electric power. Using this Internet connection, we could transfer data to and from the on-window units. Additionally, this connection could be used to power the on-window systems. However, one kit's retail value is $220, making it difficult to pursue on the Smart Windows budget.

For IP Over Power is to be utilized, the system will have to pass data packets over the Internet. Another option for passing data over the Internet is Wi-Fi. Wi-Fi is an RF wireless protocol that allows a device to wirelessly connect to the Internet, as broadcast by a central wireless router. Wi-Fi gives the added complexity of passing signals over the Internet, but could be used to complete the project.

Yet another option for wireless communication is the Texas Instruments RF solution SimpliciTI. This RF protocol is designed as a simpler version of ZigBee intended for networks with less than 100 nodes and requiring long battery life. Since the standard Smart Windows system will be small enough to support SimpliciTI, the long battery life could be advantageous.

The final wireless solution of relevance to the Smart Window system is infrared (IR) communication. Infrared communication uses infrared light from readily available photodiodes to establish a link to a photoreceiver. IR communication is best suited for short-range applications since IR signals do not pass through walls. This makes IR well suited for remote controls, an application in which it has found widespread use. Therefore, IR is an ideal technology for the in-room remote control device of the Smart Window. Options are readily available to construct a custom IR remote or simply use a universal one readily available on the market. Due to low cost and ease of use, a premade model seems most prudent.

Taking all of these wireless protocols into account, there are many options for the Smart Window communication system. Based on the system requirements, the most promising course is to use ZigBee RF communication to connect the PC application to the on-window units and a pre-designed RF communication system to connect the remote control to the on-window units.

In addition to wireless protocol, a technology must be chosen for the microcontrollers in the on-window control units. This unit will store information about the window, make decisions about status changes, and enact these changes. A simple search of several electronics distributors reveals that there are an abundance of microcontrollers available within the project budget. Further decisions as to microcontroller technology can be made once more is know about memory and speed requirements.

The most important function of the microcontroller is to drive a change in state of the window treatment. Therefore, a technology is needed which can reliable set the window treatment state and keep track of this state. The driver device chosen to operate the window treatment depends on the specific window treatment. Since a Smart Window set will include both the window treatment and a matching actuator, a specific window treatment technology must be chosen. One option to be considered is working with the company Solar Shades, operated out of Innovation Park at the University of Notre Dame. Solar Shades makes windows that use polarization to darken windows instead of traditional blinds. Solar Shades is looking to partner with an outside design group to develop a control system for their blinds, which are currently operated manually.

Due to ongoing discussions, the availability of a partnership with Solar Shades is still uncertain. Of course, any other commercially available window treatment can be made to work with the Smart Window system. Options to be considered include horizontal blinds, vertical blinds, and roller shades. Horizontal blinds offer the easiest and most widespread use while roller shades offer the best energy saving properties, according to the Department of Energy.

The device driving the mechanical motion of the window treatment will depend on the window treatment technology. However, several options exist. Simple low-voltage motors are readily available and cost-effective. However, they would require a second device such as a rotation sensor to measure and control the motor's rotation. A second option is a stepper motor. This device divides a full rotation into a large number of steps. The motor's position can thus be precisely controlled and measured without the use of a second device. A drawback is that stepper motors exhibit more vibration than other motor types, since the discrete steps of the motor snap the rotor from one position to another. A stepper motor seems the most promising solution for the Smart Window design.

In order for the on-window control unit to determine the light flux through the window, a light sensor will be needed. These devices are readily available from many companies, including TAOS, within the project budget. They range from simple npn-transistor-based devices to complicated digital designs capable of I^2C serial communication. Based on our needs, these serial-communication-ready light-to-digital converters best meet the project requirements within the project budget.

The final technology that needs to be considered in the design of the Smart Window is power delivery. A simple solution is to tap directly into the house's power line. However, doing this for every window in a house would quickly use up all of the available power outlets. Therefore, batteries are a more viable power source. 9V batteries, for example, are readily available and easy to replace. However, depending on the power use of the motor, the battery life may not be acceptable in our system; a device that needs multiple battery replacement every two weeks has serious drawbacks. A better solution is to use rechargeable batteries. The most promising rechargeable battery is the lithium-ion battery. These feature high energy-to-weight ratios, lack of memory effect, and slow self-discharge when not in use. Lithium-ion batteries are already common in portable consumer products. Unfortunately, they have a relatively poor cycle with the capacity of the cell decreasing upon every recharge. These batteries also have a high internal resistance, decreasing their maximum current. If rechargeable batteries are used, a recharging circuit capable of drawing power from the power grid will have to be developed.

Engineering Content

Figure 2 shows a hierarchical summary of the engineering content involved in the Smart Window design.

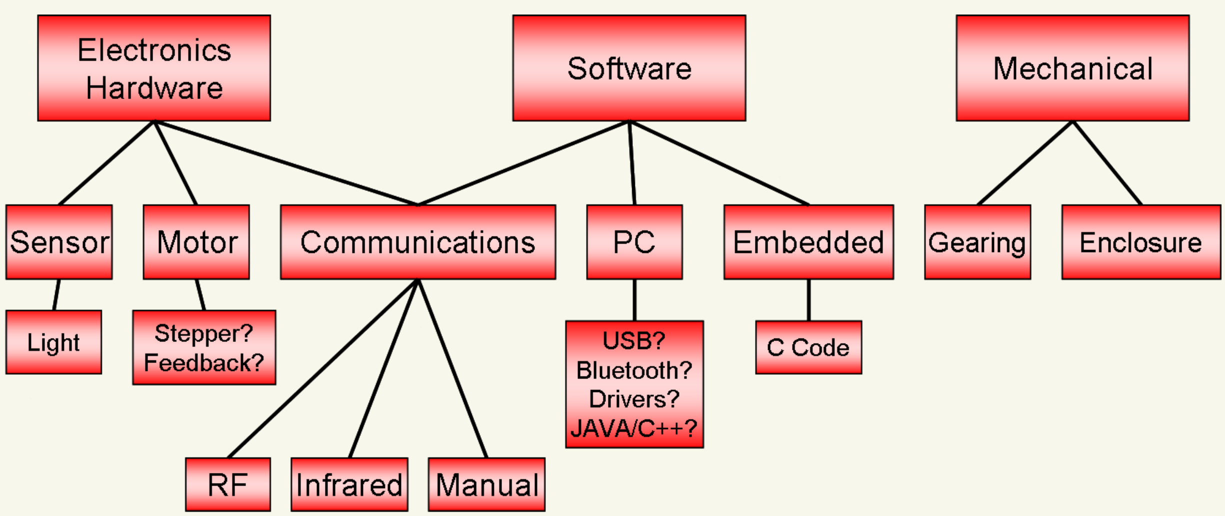


Figure 2. Engineering Content Diagram

As shown in **Figure 2**, the substantial engineering content involved in designing the Smart Window system can be broken down into three categories: electronics hardware, software, and mechanical systems.

The electronics hardware portion of the design features an embedded system receiving input from a light sensor, driving a mechanical actuator, interfacing wirelessly with a PC application and an infrared remote control, and making intelligent decisions based on current conditions. Viewed in this light, the main engineering challenge in this design in interfacing. Interfaces to be included in this project include: PC-to-wireless interface, wireless-to-microcontroller interface, light sensor-to-microcontroller interface, microcontroller-to-actuator interface, and the user-to-PC interface.

A wide variety of interfacing routines will be employed, including short-range and long-range wireless as well as wired serial interfacing. Though portions of these interfaces may be purchased as part of a development kit, the project requires a considerable amount of custom design. An embedded microcontroller will need to be set on a custom printed circuit board. A battery charging circuit will also need to be designed. Finally, the circuit operating the manual override buttons will need to be carefully designed to give the buttons functionality while the rest of the system is down.

From a software standpoint, the Smart Window will have a complex embedded system, which can monitor user options and decide on the correct window treatment state. The main loop must constantly check for an input from any one of the three input sources, and the system will have to be carefully programmed for excellent reliability. Outside of the embedded system, a PC program with a GUI will be written to control the windows remotely. Among many difficulties, the PC program will have to utilize USB or other serial drivers to interface to wireless. This wireless will have to uniquely identify each window and avoid interference from multiple-window communication. High levels of embedded C programming and C++ or JAVA desktop programming will be needed to design the system.

Finally, there is a mechanical aspect to this project. The motor must interface with the gear at the top of the window treatment seamlessly, and the entire window module must be held together safely and reliably. The state of the window treatment must be precisely controlled and known at all times to avoid incorrect status readings on the PC or overdriving the actuators.

Conclusion

For environmental as well as safety reasons, it is desirable that traditional mechanical window blinds be electronically controlled by an intelligent system. Windows treatments controlled by our proposed system will give the homeowner the freedom to get the most out of his or her window treatments. The Smart Window system has been designed to combine the flexibility, power, and usability of a PC-based interface with the practicality of embedded systems. The system can operate autonomously, making decisions about window treatment status for the homeowner. In addition to autonomous mode, the system can be controlled manually or by remote to allow maximum choice for the homeowner. With all of the technical advancements our homes have seen, it is time for innovation in window blinds.

Through this design, the Smart Windows team will implement wireless technology, motor control, sensor inputs, embedded and PC programming, and power circuitry. By combining these technical skills with other important engineering skills such as interpersonal skills, the team will ensure that the Smart Window product solves the important window-treatment-related issues faced by homeowners across the world.

SMART WINDOWS

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