Illinois Institute of Technology
School of Applied Technology
Brazil Scientific Mobility Program

Door Opening Warning Sensor

498UG Research Immersion Team

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Final Project report, Summer Research Program at Illinois Institute of Technology, program provided and sponsored by the Brazilian government in partnership with Institute of International Education.

Door Opening Warning Sensor

Prof. Jeremy Hajek

Report regarding project research developed by five Brazilian students during the period of June 5 to July 26.

Summary

Introduction

Unfortunately, the media always emphasizes how safety matters are taken for granted in the industry. It is not different when it comes to common areas or constructions, such as houses, shopping centers and even university buildings.

Service doors, swinging or revolving, play a major role in domestic and industry accidents. According to the U.S. Department of Labor's Bureau of Labor Statistics, 17,800 non-fatal workplace door accidents were reported in 2003. Even though the safety regulations are becoming stricter, from 2003 to nowadays, many accidents regarding service doors still occurred.

It is known how fast Illinois Institute of Technology projects are growing and consequently, the amount of people walking around campus and inside the buildings are increasing as well. These facts draw attention to safety matters inside the facilities in order to provide a harmless and efficient work environment.

The Wishnick Hall, built in 1945, is place of many events, seminars and presentations, containing five classrooms and one auditorium. Throughout the years, the community noticed that both doors, which give access to the auditorium, are not necessarily safe.

Both service doors are made of wood and are consequently heavy. The major issue is how fast they open, due to an opening system. Consequently, many people have been injured when walking outside the auditorium by the door.

The Door Opening Warning Sensor seeks to solve this human factor issue by proposing and implementing a warning sensor inside the auditory, using a solar panel as its energy source. The device would detect people inside and warn people outside, enhancing the safety matter at Wishnick Hall.

Figure 1 – Wishnick Hall at Illinois Institute of Technology campus.

Objectives

As the project title tells itself, the main objective is to propose a solution to the safety matter at the auditorium of Wishnick Hall Auditorium. As explained in the introduction section, when it comes to provide a harmless working environment, efforts should not be measured.

The idea is to design and execute the further implementation of a warning sensor for both auditory doors. Using a presence sensor, the device, as it detects a person approaching the door, would emit a signal in order to warn people outside. The warning, searching for maximum human factor efficiency, will be visual and audible as well.

Additionally, in order to achieve the community needs for environmentally friendly systems, the whole warning device will be powered by solar panel. The project also includes, as an objective, a study of how the glass, specifically the one used in the mentioned building, influences the solar panel efficiency is providing the necessary energy to the warning device.

Materials list

Table 1.0 – Material list, all taken from the Smart Technology & Embedded Systems Lab.

Item	Quantity	Value per Item	Total Value per Item	Description
Solar panel	1	$29.00	$29.00	Medium 6V 2W Solar panel - 2.0 Watt
Controller	1	$24.95	$24.95	Arduino Micro with Headers - 5V 16MHz - (ATmega32u4 - assembled)
Charger	1	$17.50	$17.50	USB / DC / Solar Lithium Ion/Polymer charger
Tiny breadboard	1	$4	$4	
Half-size breadboard	1	$5.00	$5.00	
Battery	1	$9.95	$9.95	Lithium Ion Polymer Battery - 3.7v 1200mAh
Ultrasonic Distance Sensor	1	$29.99	$29.99	Parallax 28015 - Rev C
RGB Led ring	3	$9.95	$29.85	NeoPixel Ring - 16 x 5050 RGB LED with Integrated Drivers
Piezo Buzzer	3	$1.50	$4.50	Piezo Buzzer - PS1240
		Total	$154.74	

Table 2.0 – Material list, all taken from IDEA Shop, at IIT Campus.

Item	Quantity	Value
Used boxes	2	$0.00
Black paint spray	-	$0.00
General wires	-	$0.00
General tapes	-	$0.00
Flat cable	-	$0.00
Screws	3	$0.00

Solar Panel Experiment

Seeking to attend the global tendencies of renewable energy systems, the warning sensor uses a solar panel, which model was specified in the Material List section of this report. Due to logistics reasons and attempting to reduce the usage of extended wires along the construction, the solar panel shall be installed inside the building.

To produce energy with a photovoltaic panel we need to mount the panel directed to the sun. The process is simple, when the photons (particles of sunlight) hits the panel a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely.

This project demand requires a study of how the glass, which separates the outside area from the inside are of the building, affects the solar panel efficiency. Said that, a one-day experiment was performed in order to measure the glass attenuation regarding the solar radiation.

Starting at 8 am to 8 pm, running a step the experiment approximately each 3 hours, the electric current and voltage were measured in a specific location inside and outside the building.

The solar panel and multimeter, which models are specified in the Material List as well, were used in order to collect the data shown in table 1 and 2 below. It is notable how the average electric current and voltage varies within time of day and by the glass parameters.

Table 3.0 – Collected data, solar panel installed outside the building.

Experiment #	Time of day	Voltage (V)	Electric current (mA)	Standard Deviation
1	8:20	5.75	7.48	1.22
2	11:15	5.93	9.46	0.43
3	14:07	6.35	23.52	1.49
4	17:05	5.53	4.37	0.13
5	18:30	5.46	3.24	0.15

Table 4.0 – Collected data, solar panel installed inside the building.

Experiment #	Time of day	Voltage	Average	Standard Deviation
1	8:24	6.29	17.18	2.36
2	11:00	6.22	18.23	0.29
3	14:35	6.83	79.22	6.66
4	16:58	5.96	13.52	0.89
5	18:22	5.86	8.17	0.35

Analyzing the plotted charts, the expectations, based on the papers and studies analyzed previous to the experiment, were accomplished. Right below, the electric current data is shown for both cases of solar panel installation.

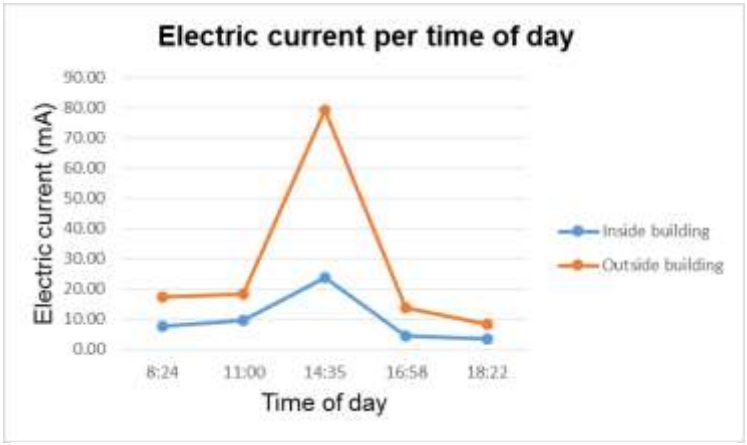

Figure 2 – Comparison of electric current, provided by the solar panel, inside and outside the building.

On the other hand, figure 3 shows how the voltage varies among time of day and compare its values when the solar panel is located inside or outside the building.

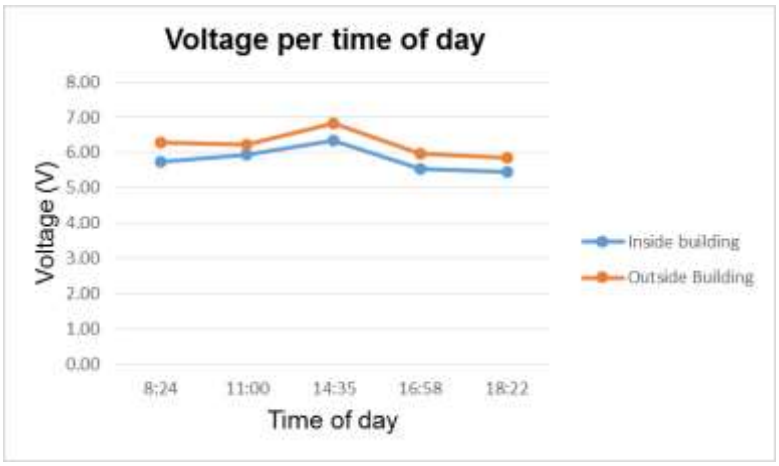

Figure 3 – Comparison of voltage, provided by the solar panel, inside and outside the building.

From the experiment, it is proved that the window's glass really influenced the energy production by the solar panel. This effect happened because the glass used on windows nowadays receives special treatment to improve their ultraviolet and infrared reflections. This glass is known as Low-emissivity Glass, and according to the U.S. Department of Energy it has the capability to decrease up to 70% the heat provided by the sun.

That being said, it is confirm that when it comes to solar panels, more light means more energy. As expected, experimental results showed that the solar panel, while installed inside the building, achieved approximately 35% of capability to produce energy compared to the installation outside the building.

Solar Panel

An experiment, which objective was to verify if the solar panel provides enough power to the sensor system, was performed in the laboratory. A power source with variable voltage setup was used in order to simulate the solar panel. A voltage of 6 V was settled in the variable power source, based on the average voltage provided by the solar panel.

After soldering the capacitor on the Solar LiPoly Charger v2.0, which receives the tension from the power source and distribute it to the battery and sensor system, the power source was linked to the laboratory electrical system. Using a multimeter, it was verified that 6.2 V and 4.24 were distributed to the sensor system and battery, respectively.

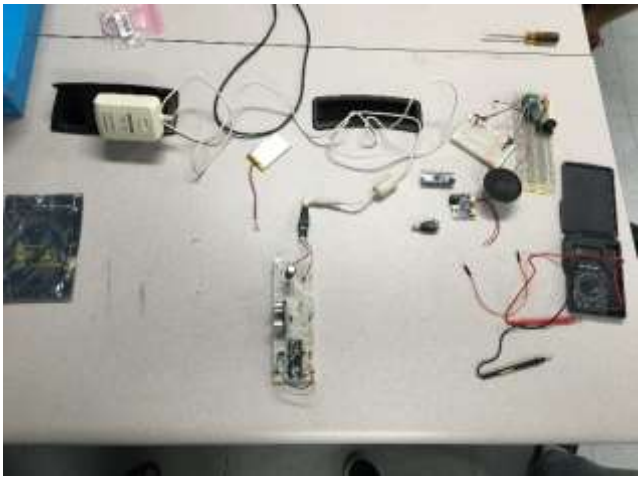

Figure 4 – Experimental apparatus and disposition.

At first, even though the whole system was attached to the electrical system, the sensor experienced an unstable period. The buzzer identified this stage, sonorously indicating that the sensor was detecting someone even thought there was anyone on its range. After a while, approximately 5 minutes later, the system started to work as expected. The most reasonable explanation for that fact is the battery, which faced an unstable charging period and consequently, the whole system was compromised for that period.

Conclusively, based on this presented test and the last one, which verified that the solar panel is capable of providing, in average, 6 V to the system, one solar panel is enough to electrically feed the whole warning system.

Algorithm

1. Code progression through the project

One of the most important requirements of this project is to be responsive. The latency between the distance between the sensor and the person needs to reflect as fast as possible in the alarm. This yields in two main constraints code-wise: The distance sampling needs to happen quite often and the decision of activating or deactivating the alarm needs also.

In our first iteration, we used a simple threshold for activating the alarm (i.e., if the distance is smaller than X, activate the alarm, deactivate otherwise) and a direct sensor sampling (i.e., the detected distance is considered to be absolute truth and taken without noise). This first version met the constraints but not the requirements. The code executed really fast and the alarm activated/deactivated immediately, but this was far from what we needed. Not because it wasn't fast enough, but because there were noise. Lots of noise. If someone stood still in a specific distance, the alarm would activate and deactivate several times per second.

Our approach was to use the libraries available to us made by the manufactures of our components and hysteresis in the threshold. Those libraries exposed to us several methods for noise handling. At this point, our code was somewhat usable enough to start calibrating to get the specific values for our test case. This values are the maximum distance to trigger the alarm, size of the hysteresis, amount of noise reduction needed, etc.

As we were measuring for the first time, we noticed that we went to the other side of the scale, now having a really slow sampling code but with good decisions. After some brute-force debugging we found the issue: the libraries was executing a blocking code. To be able to

deal with the noise, the library was sampling the distance several consecutive ways, then calculating the mean, and then returning the control to the rest of the code. This was consuming a lot of the time that could be used to calculate whether or not to activate the alarm.

In the third code iteration, we decided to sample the sensor with no noise at all and write our own non-blocking noise reduction code. We also added a control state to know the direction of the movement of the person and we already wrote this with hysteresis. After some testing to determine the intensity of the noise reduction algorithm, we had a robust, fast and efficient algorithm that could not only do what we needed to do but also do it in a small amount of time.

The next step would be to do a code cleanup to reduce the size (removing unused libraries and only importing the functions used), refactor it to separate the algorithm that decides what to do from the algorithm that turns on or off the alarm, using hardware interruptions for distance sampling and optimize the non-blocking code further to have fewer time-consuming assembly operations (e.g., instead of moving the whole queue to add a new sampled distance, just replace the older one).

2. Algorithm overview

First of all, to reduce Arduino's RAM usage, our constants are Macros defined in the header. The downside is the increased compilation time, but nothing too much to be impossible to wait.

In the setup function, our code creates and initializes the C++ objects for interfacing with the LED Ring and to sample the sensor (required by the libraries). If it's a debug build, the Serial port will also be initialized.

Our main function can be divided in three parts: data gathering, data extrapolation and behaviour control. The data gathering is for collecting and cleaning the data. The data extrapolation part is to extrapolate and "understand" what is happening in the environment. The last part is actually interfacing with our outputs, LEDs and buzzers.

In the data gathering part, our code first sample the distance once and then push it to a fixed size queue implemented using a simple vector. Then it sums up all the elements of this vector and divide it by the size of the vector, thus, reducing the noise through a low-pass filter. The result of the division is the "clean distance". This distance is compared to the last clean distance detected and this is the delta value.

In our data extrapolation part, we first use the delta value to know the direction of the person. If delta is negative, it's approaching. If delta is zero, it's stopped. If delta is positive, it's distancing. We didn't used the absolute value but instead we used hysteresis. So, to our system say that someone started approaching when it was stopped, the delta needs to be, for example, -1.5 but to be considered standing still after approaching it needs to be -0.2, instead of 0 in this two cases.

Our code also uses the cleaned distance to know if the person is in the danger zone (closer than the maximum threshold) or not and also compute for how many consecutive loop iterations it has been in this state (e.g., approaching for 40 loop iterations, stopped for 3 loop iterations, etc) up to a maximum.

In the last part, the algorithm will look to those extrapolated data turn on or off the alarm based on that. For example, if it's approaching for more than 5 consecutive loops, activate alarm, if it's stopped or distancing for more than 30 consecutive loops, deactivate the alarm. The alarm is made of buzzers and LEDs. The buzzers have their ground and their signal pins connected together since their impedance are low enough to do that without losing loudness. They are activated by a simple tone function in one pin. The LEDs use a library to ease their use but what our code needs to do is set up all the desired colors for all LEDs and then send the command to the driver through the pin. After this, the loop restarts.

Conclusion and further steps

Regarding all the previous stated objectives for the 2016 Summer Research project, it is safe to say that all the main objectives were accomplished. Even though the time could have been a compromised factor, the team managed to research, design, test and implement the prototype for the Door Opening Warning Sensor.

Each of the team members agreed that a great amount of effort was put on the project and therefore, a high level of knowledge was acquired. Each member played an important role since the sparkling initial idea until the prototype installation and testing.

Both sections, the software as well as the hardware, worked as expected in the auditorium at Wishnick Hall. The algorithm works for many different cases, turning the whole product in a versatile and functional device. Additionally, the warning device, a box which contains three LEDs and 3 buzzers, works for people with disabilities as well and can be seen by many angles. All these factors, considering performance, safety and applicability were thought and developed during the project.

Conclusively, the prototype was successfully made and tested and, from now on, as every technological/engineer project, it can be optimized. The warning devices can be changed to more user-friendly ones and regarding the sensor, it can be replaced by one with a larger range. The main power source could also be improved or changed depending the location, among other improvements and optimizations.

Hopefully, the prototype is an additional spark for the development and improvement of warning systems, always looking for durable, safe and efficient solutions for human factor problems.

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Individual impressions

9.1 Gabriel Filipe Botelho Barbosa

Even though that the Door Opening Warning System is not the first research program that I am participating in, it is the first that I was expected to develop a full fledged and working prototype by the end. The fact that I would need to interact and collaborate with colleagues from different areas of knowledge and that I would be in close contact with hardware development were major keys to make me interested.

I saw this opportunity as a way to sharpen some of my skills and to learn more about things I didn't had much knowledge nor practical experience such as multi-disciplinary group collaboration and management, prototyping, arduino programming and optimization. By the end of this research project, new ways of approaching a problem, new point of views and a new mindset are also a few of the skills that I am proudly adding to my skillset on my way home.

Having access to a lot of high-level and quality, state-of-art resources ranging from tools to components in the Smart Technology & Embedded Systems Lab and also in the Idea Shop made a huge difference. It allowed us to develop the solution in our pace, without tool/component bottlenecking, with a better quality than what is expected from a prototype.

Having such a diverse group was by itself an awesome experience, allowing us to work in what we know best and trusting that the other would do so in their areas. As I am a Computer Engineering student, I was assigned to work with hardware interfacing programming (i.e making buzzer to sound, LEDs to blink, distance sampling through the sonic rangefinder, sensor data cleaning, etc), light optimization for small-memory devices and pseudo-concurrent algorithms implementation. One more good thing about working with a

group with different backgrounds is that you learn a lot from each other, both theoretical and practical skills, from areas where you hardly would get contact with.

One thing that I would like to highlight from this experience is the freedom and lack of bureaucracy in regards to how the problem should be tackled and in getting access to all resources needed. It was quick and easy to find and use everything needed. Having such a high-paced environment to work with allowed us to have enough time to fulfill the expectations and meet the deadline with ease. I would say that it was quite similar to the hacking atmosphere found in hackathons and that is awesome.

I, together with the whole team, am happy with the end result. The final prototype worked really well and demonstrated that a large scale production of a more robust product is possible. There still is a need to analyze the viability but since the code and the hardware design is simple, I believe that it is viable to produce it in industrial scale for commercial use.

I am really thankful for being accepted in the Science Without Borders program. I would like to thank Illinois Institute of Technology for accepting me and God for giving me opportunities to grow, to learn and to be able to exceed the expectations upon me wherever I come to be.

9.2 Guilherme de Castro

Working on the Door Opening Warning Sensor project was a very good opportunity to me, even though I also think that it was challenging. When professor Hajek introduced us to the problem and to the project I was very curious about how that would work and how we would do it.

That was the first time in my life dealing with a project strongly related to hardware. At that point I had zero knowledge of how to work with sensors, Arduino and electrical circuits. After that, I started to talk and get to know my teammates better, it was very exciting because we all were from different fields. Everyone was already suggesting ideas on how to start and what we could do. My teammates are Gabriel, who studies Computer Engineering; Matheus, who studies Electrical Engineering; Rodrigo, who studies Mechanical Engineering and last, but not least we have Luiz Gustavo, who studies Automation Engineering.

I was very impressed with this group because everyone had something to share and to contribute with the project, we are a very strong and solid based team. We have people who know how to project the circuit and how to properly supply power to it, we have people to deal with sustainability since we work in an environmental friendly project powered by solar energy, they made an amazing job measuring and analyzing if only one solar panel was able to provide enough energy to maintain our system working. Furthermore, we also have people coding, doing the logic and testing the sensor. That doesn't mean we were only dealing with problems related to our majors and were in our comfort zone, we were all involved with all parts in this project.

I learned a lot during this project, I learned how to use Arduino which was a life changing experience, before coming here I had heard about it, but never had I done anything

with it. I also learned how to use C++ for the first time, I was only used to using C# and Java. It was very difficult in the beginning and I was pretty much helping Gabriel, who had plenty experience with Arduino and C++, understand the problem and test the sensor. I improved my knowledge on that as we were working, Gabriel was very patient and taught me a lot of things while we were working on this project. I also learned how to deal with GitHub, because I had used it only once. It was a very nice experience, I learned how to deal with a very annoying bug and how to solve it. I discovered a pretty nice tool to it. We had this problem when we committed the code and me and Gabriel had changed the same part on the code, that was generating a conflict. To find and to solve this kind of problem is very difficult and takes a lot of time, so I talked to a friend and he gave me tips on how to solve that. I found a very nice tool called “vimdiff”, this saves a lot of time and is something I’ll use in another projects from now on.

At the testing and implementation phase we went to the Idea Shop and we met this really nice guy who runs the lab, his name is John**.** There we created the boxes where all our hard work fitted in. He was very attentive and gave us some advices and all the needed tools to crave, paint and build the boxes. After two days working there**,** we achieved the final prototype, and I was very impressed by it. It was way better than I thought it would be, the team did an amazing job on that.

Overall it was a great project and I’m very proud of what we did. This project has a real impact in the world and can be used to prevent accidents that can seriously injure people. We had less than two months and we delivered a 100% functional prototype. IIT facilities and professor Hajek provided all the tools and materials needed to accomplish this outstanding result. Personally, I learned a lot about different fields of study and I’m very thankful for this

opportunity to challenge myself to work in group, make connections with people I can work with in the future and to learn, be inspired and curious about things I didn't know before coming here. It was a great summer! Thanks to everyone I worked with and/or helped me somehow.

9.3 Luiz Gustavo de Marchi Brito

This summer I had an incredible opportunity of working in a Project called Door Warning Opening Sensor at the Illinois Institute of Technology. Our group consisted of 5 students, and each one of us have a different major; so we could manage almost every single problem that occurred on the development and on the tests that we made with our prototype.

We were led by Professor Jeremy Hajek; he was extremely helpful every time that we needed his assistance; also, he gave us the liberty to apply our own ideas on the project, or to change any previous specification to make improvements and a better final product, which is our main goal.

Our product can increase the security and make public places safer by warning people approaching a heavy service door from the inside of a building.

In a short period of time we produced a working and usable prototype that met and exceed the pre requisites. This is a remarkable result, because we had just 7 weeks to work on this project, and we did not have any previous material, so all progress that we made is our merit.

We divided our work timeline in steps. First, we thought about the problem, and we tried to came up with the best solution for the problem combined with an user friendly device. Then, we had to design a prototype that will be installed in public spaces, so the appearance has to be taken into consideration.

After designing the prototype we started building it, and we really got our hands dirty. We worked in a lab called Idea Shop the most part of the building stage. We had several different tools available for use on this lab, which increased our productivity and chance of succeed.

The last part of our project was testing the prototype in a real life situation, and it was taken place in the auditorium that motivate the initial idea of this product. The final result of the testing stage was outstanding.

I am really grateful for what we accomplished with this project. We improved and learned a variety of skills such as coding, Arduino kit, welding, designing, prototyping. Our entire group was linked and motived to deliver the best result possible.

Finally, I would like to thank the IIT for accept my application; to professor Hajek for being helpful and accessible all time; and to my teammates that made this summer an unique experience, working with them was a pleasure.

9.4 Matheus Braz Duque

Studying abroad had been my dream since my teenage. However, I have never imagined that some day I would not just study abroad, but also work in a research project in one of the best colleges in the US.

My first experience was meeting my research team, composed by students with different majors: Gabriel Filipe Botelho Barbosa, a Computer Engineering student, Guilherme de Castro, an Information Systems student, Luiz Gustavo de Marchi Brito, an Automation Engineering student, and Rodrigo Ferreira Abdulmassih, a Mechanical Engineering student. I really enjoyed the way the team was created because with such a variety we had different points of view about the same questions, so each one could contribute with different ideas and the team could reach higher levels of solutions.

During the development of the Door Opening Warning System research project, with prof. Jeremy Hajek, we had free access to a variety of tools and devices. It was an incredible experience, since we did not have time issues like waiting for some device to be bought or shipped and all tools were available anytime we needed. I liked the way the professor trusted in us; he made us feel free to develop without unnecessary restrictions. We had direct access to any equipment, without bureaucracy. This trust-based relationship helped the group to advance much faster.

Another important knowledge I got in my experience here is strongly related to my objective to become a professor. Research projects are common activities for a professor nowadays. Here in Illinois Institute of Technology, I could experience this activity and observe how a professor leads a research team, how the resources are shared among the teams, how to integrate students from different majors, and how to use online tools, such as

Trello and GitHub, to verify if the students are dedicating properly and how they are advancing. With these tools, a professor can easily keep up with his students and know what they are doing, even at distance. For sure it was a valuable experience for me and it is going to be useful in my career as a professor.

Finally, my campus life experience was amazing. Due to the infrastructure provided by IIT to the students who live in campus, I could enjoy my free time much more. I have made new friends here; some of them I met playing volleyball, others in the dinning… I believe it is also an important aspect to consider in a college. IIT is a complete college, because it provides the student with both academic and non academic resources, preparing him for his professional life.

I am thankful to God for the opportunity I received to experience this whole thing. For sure, my experience in IIT changed me and I will never forget it.

9.5 Rodrigo Ferreira Abdulmassih

Since the beginning of the project, I knew that the summer of 2016 would be a challenge. It was clear how much expectation the Institute of International Education (IIE) and the Illinois Institute of Technology (IIT) itself had on us. Developing a group project, on which five people that have never met before need to achieve a high level of efficiency and develop an outstanding project, sounded like an amazing opportunity.

Door Opening Warning Sensor. At first, the project title caught my curiosity and inspired me to learn more about sensors and electronics, topics that I did not have much knowledge on. Our group, formed by five Brazilian students, is very dynamic and versatile. The fact that we are very different from each other is what made our group efficient and gave us the necessary strength to face, analyze and solve problems.

The first main idea was to prevent accidents in an auditorium on IIT campus. After visiting and studying the local, our group decided that we could expand the range of our project. Obviously, the idea was to develop a solution for the suggested local. However, we decided to expand it and make the device as versatile as possible, so it could be applied in any operating door.

As we all have different skills, we could help and learn from each other during the entire project. Since the beginning, when we were brainstorming about the project steps, it was clear how each group member would help work during the project.

One fundamental factor was Professor Hajek, who gave us the necessary help and support. He amazingly balanced the equilibrium between supporting the group and at the same time, letting the group think and develop ideas by itself. The laboratory, named as Smart

Technology & Embedded Systems Lab, was an indispensable factor for the project development.

All the devices, pieces and tools were easily found in the lab. In addition to that, Professor Hajek was also very proactive for ordering/buying any device the lab did not have at the moment. The Idea Shop, a student lab, was also very helpful for manufacturing the cover boxes. All the material, including boxes, tape, painting materials, strews, and other items were provided. John, the responsible for the student lab, was also very helpful and played an important role giving tips and advice for the manufacturing process.

I consider myself very organized and analytical, skills that I applied on the management and organization of all the steps developed during the project. Additionally, the circuit cover box manufacturing process and the solar panel study was the area that I could apply the most my Mechanical Engineer skills. It was interesting how broad ours project was. We did theoretical studies, experimentations, coding, manufacturing and finally, installation and testing. All the present steps in any engineering or technological company.

Personally, I learned a lot regarding sensors, C++ programing, circuits and Arduino kit. Applying the theoretical knowledges learned in class in a real group project was an amazing experience. It is also interesting to notice the social skills all the group members developed. Of course we had our differences, but in the end, we managed it very well and developed a functional and high quality Door Opening Warning Sensor device.