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Engineering a Low-Cost, Non-Invasive Corrosion Monitoring System

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Corrosion is one of the most costly global expenditures. In recent years, a multitude of Non-Destructive Testing (NDT) methods to detect early corrosion in rebar have been developed. However, there are several issues that prevent their wide-scale application. Thus, the goal of this project is to create an accurate, low-cost corrosion monitoring system by using the voltage via an electrical current from a solar cell using an engineering design process. The final device was programmed by an Arduino Uno to export data to a Google Sheets cell. In all the trials, as the cross-sectional cut of the rebar samples increased, the voltage output in the rebar samples decreased, and statistical significance was later shown. In addition, the transfer time of the voltage readings to a Google Sheets cell was seen to be relatively quick. This system costs roughly $61, making it 51% more economical compared to other Arduino-based monitoring systems.

Keywords: corrosion, electrical current, solar cells, non-invasive, monitoring system, Arduino

Introduction

One of the most costly global expenditures is corrosion costs, totaling approximately $2.5 trillion every year [1]. This value encompasses, but is not limited to, corrosion repair and prevention. Additionally, thousands of lives have been lost due to corrosion-related incidents [2]. Over time, although these numbers have only risen, efforts to reduce them have been made. In the United States, infrastructure spending over the past decade has shifted toward maintenance spending, opposed to capital spending [3]. This reallocation of spending has led to many benefits, including reduced infrastructure damage and reduced management costs [4]. However, current efforts have not shown significant progress, as the American Society of Civil Engineers ranked overall infrastructure a D+ in a comprehensive report in 2017 [5].

Corrosion

Corrosion is a unique occurrence in metals that develops over various periods of time. Existing in various forms, corrosion consists of a redox reaction at the surface of the material. Upon oxidation, ions and electrons are created that are later used in the reduction reaction. Seen in Figure 1 is an illustration that highlights the electrochemical process at an atomic level.

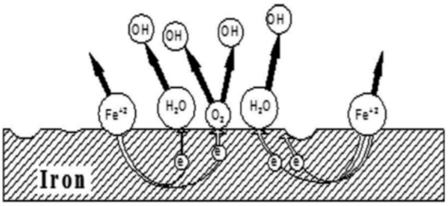

Figure 1: Electrochemical Process of Corrosion [6]

As a result, rust starts to form over the surface of the metal. Multiple studies have shown that once corrosion has occurred, the product continues to amass, reaching a larger volume than the actual metal itself [7] [8]. Essentially, this allows for corrosion-inducing agents to further penetrate the steel, rapidly accelerating the process. Consequently, stress builds up in the rebar, creating cracks and spalling that causes serious infrastructure deterioration [9]. The combination of the loss of tensile strength and fracture toughness in the rebar within concrete has been identified by structural engineers as one of the leading causes of infrastructure failure [10]. In effect, the costs to repair the infrastructure skyrocket. Societal consequences also exist, because the safety and health of the public is put at risk [11] [12].

Non-Destructive Testing (NDT)

In recent years, non-destructive testing (NDT) has widely proven to have potential for civil engineers. NDT is a field of engineering analysis technique that enables inspection methods to predict corrosion without causing damage to the structure, allowing for the structure to maintain its integrity [13]. These methods have become more abundant over recent decades. A review of NDT methods conducted by Zaki et al., researchers at the Department of Civil Engineering at University of Malaya, in 2015 found that these methods are critical to providing the necessary detection and monitoring for the evaluation of the condition of reinforcing steel structures [14].

Furthermore, NDT methods provide many crucial benefits. Due to the ability for rapid data collection through several methods, early detection of corrosion is feasible. In effect, costs associated with corrosion damage significantly decrease. When discussing the impacts of early corrosion detection, Anita Augustyniak, PhD in Material Science at the University of New Hampshire, stated, “further material damage would be prevented by providing maintenance on an as-needed basis when it is relatively inexpensive” [15]. Additionally, Larry Summers, former Secretary of the Treasury writes, “not only does prolonged corrosion make the bridge weaker, but it makes fixes much more expensive.” [4].

Although NDT methods provide promising insight on corrosion detection, there are several key limitations preventing their application on a much wider scale. Multiple reports have shown that commercially available NDT equipment is beyond the reach of many researchers due to the cost, with the cheapest NDT equipment averaging around $1000 per unit [16]. Furthermore, the costs of equipment in widely-used NDT methods have not seen a significant reduction in prices over time [17].

However, in the methods that are relatively accessible to researchers, accuracy can often be mediocre. The half-cell potential (HCP) method, the most widely regarded accessible NDT method in the field, generally requires the addition of other methods, rendering the lone technique as unreliable [18]. In addition, Lukas Sadowski, a university professor at the faculty of civil engineering at Wrocław University of Science Technology in Poland, writes, “half-cell potential values merely provide information about the probability of corrosion and not about the rate of corrosion” [19]. Essentially, the corrosion occurring within a structure is indeterminate rather than quantifiable via the HCP method. As a result, many predictions about future deterioration within the structure are flawed. Despite this method allowing for large-scale data acquisition and establishing fundamental corrosion trends between, these drawbacks have led researchers to question the reliability of the technique.

Research has accelerated methods to account for the absence of accurate methods. Ground Penetrating Radar, commonly known as GPR, has progressed the field by accommodating for the spread of more advanced NDT technologies. Through the propagation of different radio frequencies via electromagnetic waves, reflected waves are sent back to a receiving antenna to be recorded and converted into a voltage wave [20]. Istiaque Hasan and Nur Yazdani, professors of civil engineering at the University of Texas at

Arlington, found that within testing, GPR is one of the few methods able to identify localized damage within rebar [21]. For many applicable methods in the literature, rebar is assumed to undergo uniform corrosion. An important facet of GPR is its proficiency to highlight specifically where corrosion has occurred. Figure 2 illustrates an example of the results of a GPR scan.

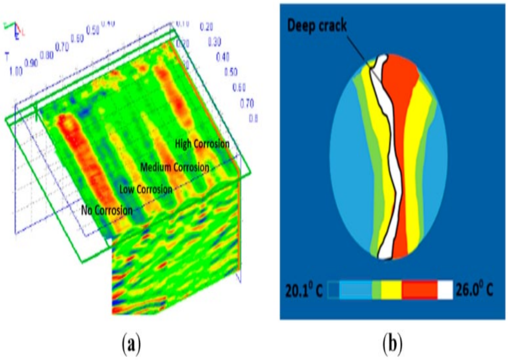

Figure 2: Ground Penetrating Radar [22]

Although this method is capable of identifying localized corrosion, the results scanned are often too difficult to interpret for those without expertise in the field, making them highly susceptible to human error [23]. Moreover, current GPR technology only allows the wide-scale application of GPR containing a qualitative assessment of the results. Ahmad Zaki, PhD in civil engineering from the University of Malaya and one of the most prominent NDT researchers, et. al published a study using GPR that collected quantitative results using wave peaks [24]. The researchers conclude that quantitative assessment of corrosion damage was possible using GPR, addressing a critical gap within the literature surrounding GPR technology. However, since the publication of this study in 2018, GPR equipment still remains very costly. Despite the results in this study, researchers are unable to obtain access to the newest technologies.

Project Goals

Based on the current literature, the end goal of this project is to create an accurate, low-cost corrosion monitoring system by using solar cells. Solar cells are devices that utilize light energy, primarily from the Sun, and convert it into electricity [25]. Since solar technologies are constantly under innovative research and development (R&D) [26], the end product could be enhanced by researchers in the future. Furthermore, no literature exists concerning the use of solar cells to detect early corrosion. Given that solar cells only require light energy to operate, the end system could enable hands-off corrosion monitoring, therefore allowing resource allocation to be more efficient. This research aimed to investigate the question: Can voltage readings from solar cells be utilized to detect early corrosion in rebar, and if so, how can a non-invasive system continuously monitor these readings? By creating this system, the significant gap in the literature to create a low-cost, accurate corrosion detection methodology could be addressed.

Methodology

In order to achieve the project's goals successfully, this study has two fundamentally different components to the embedded system: the hardware and software. For the hardware, an engineering design process was utilized in order to construct the monitoring system correctly. As explained by Seyyed Khandani, PhD and professor of engineering at Diablo Valley College, the engineering design process is an iterative process that involves defining a problem, generating a solution, and testing and implementing that solution [27]. Due to the design process' flexibility, it allows the researcher to backtrack and enhance the device to meet the goals that were originally set for the product. Given its flexibility, it made this methodology ideal for the construction of this monitoring system. Refer to the project goals section to see the goals for this study.

Furthermore, the same techniques apply to the software portion of this research. The purpose of the software in the device is to allow for user-friendly access and collection of the data. Many of the decisions regarding the software were based on shortcomings with current monitoring systems within the literature. Given that this portion only involved programming the device, a laptop with the Arduino Integrated Development Environment (IDE) installed were the only materials required for this.

Rebar Sample Preparation

The first step in the creation of the monitoring system was to emulate the damage caused by corrosion within the rebar samples. For this experiment, a 4 to 18 mm hydraulic electric rebar cutter was used to reduce the rebar samples to ¼ , ½ , and ¾ of their cross-sectional depth. Additionally, a rebar sample with no cut served as a control. This process was modeled after a study done by researchers at the University of Kerman, in which an accurate assessment method found that decreasing moment capacity, a direct result of corrosion, is linearly proportional to corrosion [28]. Next, in order to establish a reliable electrical current throughout the rebar samples, stainless steel screws were attached to the ends of the rebar [29]. See Appendix A for a picture of the rebar samples.

Solar Application

For this experiment, an ALLPOWERS 5v solar cell was utilized to send a current through the rebar samples. Due to the scope of this research, the ALLPOWERS 5v solar cell allows for a consistent electrical current to be sent through the steel rebar samples without damaging the voltage regulator of the Arduino UNO. According to Ankem Susheel and S. Selvendran, researchers at the Department of Electronics and Communication Engineering at the CVR College of Engineering in India, because the Arduino UNO is a sensitive device, damage to the system through high heat or voltage can hinder the circuit [30]. Given that this solar cell cannot easily attain these high metrics, it was used as the source of power for the electrical current throughout this study. In addition, this solar cell model costs $13 dollars. Since equipment cost is a key drawback of current methods, the low cost of this solar cell made it ideal for the device.

Furthermore, alligator clips, which are used to create a temporary electrical connection, were attached to stainless steel screws on the ends of the rebar samples in order to establish this current. The solar cell used in this experiment was soldered to expose the conducting copper, and the other ends of the alligator clips were attached to the positive and negative terminals of the solar cell.

After the electrical current had been established to the rebar and pins on the Arduino UNO, the code to receive these voltage readings was developed. The pins on the Arduino UNO were programmed to sense the electrical current from the solar cell. It was coded to read the voltage from the electrical current, converting and outputting that value to volts. The code was continually modified once additional code serving different functions was developed. For this code specifically, it can be found in lines 1-13 of the full code in Appendix C.

Cloud Architecture

The final step in the creation of the monitoring system was the implementation of a program to non-invasively monitor these voltage readings on a spreadsheet, rather than the serial monitor on the IDE. The purpose of this step was to allow users of the product to gather information from remote locations. Essentially, in order to monitor the system, cloud architecture enables great abstraction for users that are not in situ [31]. This phase of the development of the monitoring system was modeled after a previous photovoltaic system from Ibrahim Affali, researcher at the Department of Electrical Engineering at Memorial University of Newfoundland, and Tariq Iqbal, professor of electrical engineering at Memorial University [32] . In Affali's design, the results were sent to a Microsoft Excel spreadsheet. By sending the data collected throughout this experiment to a Google Sheets cell, the data could be shared between users.

For the hardware setup of the system during this step, jumper wires, which are used to connect two points on a circuit, were used to transfer the current from the solar cell going through the alligator clips to two separate pins on the Arduino - the negative terminal of the solar cell to the GND pin and the positive terminal of the solar cell to a 5v analog pin. A finalized picture of the monitoring system can be seen in Appendix B.

Next, the code to transfer these voltage readings to a cell on Google Sheets was developed. The device was coded to allow the user to access the Google account of the user by inputting his/her username, password, and the name of the spreadsheet that they are writing to. These were accessed by allowing for the device to import packages from different classes over the Google cloud network. It is important to note that this input is case sensitive, meaning that all characters had to match the Google information in order for the device to respond correctly. For the spreadsheet, it was coded to create rows that would allow the voltage readings from the serial monitor to be placed in a cell. In addition, the time and date were also recorded, thus allowing the device and users to track any frequencies over time. See Appendix C for the full program. The program was approximately 70 lines of code.

Results and Discussion

When the system was built, 5 trials were run on the different rebar samples to test whether or not differences in voltage could be seen after varying levels of corrosion had occurred. After the electrical current had been applied, measurements on each trial were taken at 10 minutes, 30 minutes, and 1 hour. In all 5 trials for each rebar sample, approximately 5 volts and 1 amps was applied to each rebar sample in order to ensure that no damage was done to the regulator of the Arduino UNO.

In all 5 trials for each rebar sample, there were no issues regarding the transferring of voltage readings to a spreadsheet cell, as indicated from visual observations from a multimeter. Therefore, this signifies that there were no major errors regarding the schematic design of the monitoring system nor the code used to monitor the voltage readings. In order to see trends between the data more precisely, the data is represented in millivolts (mV).

Time	Voltage (mV)	Current (A)
10 minutes	148.0	.996
30 minutes	147.7	.996
1 hour	148.4	.996
Average	148.0	.996

Table 1: Control Rebar Sample

Table 1 shows the voltage output of the control rebar sample as while the current was set to a constant 0.996 Amperes. On average, 148.0 mV was sent through the rebar sample. A major trend that can be seen is that over time, the voltage readings fluctuated, indicating that the electrical current being sent through was not numerically constant.

Time	Voltage (mV)	Current (A)
10 minutes	132.6	.996
30 minutes	128.4	.996
1 hour	133.1	.996
Average	131.4	.996

Table 2: ¼ Rebar Sample

As seen above in Table 2, one major observation that can be noted is that in comparison to the values found when there was no cut in Table 1, Table 2 shows values of voltage that are proportionately less than that of the rebar at full size without any cross-sectional cuts. At the voltage readings at 10, 30, and 60 minutes for Table 2, each of the values were lower than those in Table 1. In addition, the average voltage for the ¼ cut rebar sample was 12% less than the control.

Time	Voltage (mV)	Current (A)
10 minutes	88.3	.996
30 minutes	93.4	.996
1 hour	89.2	.996
Average	90.3	.996

Table 3: ½ Rebar Sample

In the results shown in Table 3 with a ½ cross-sectional cut, the rebar trend continues to persist of declining voltage as cross-section cut increases. The voltage values had a much more significant reduction from ¼ cut to ½ cut compared to the control. Compared to the control, the average voltage in the ½ cut rebar sample was 39% less. When compared to the ¼ cut, the average voltage was 32% less in the ½ cut rebar sample.

Time	Voltage (mV)	Current (A)
10 minutes	55.6	.996
30 minutes	38.7	.995
1 hour	42.9	.996
Average	47.64	.996

Table 4: ¾ Rebar Sample

The table above shows the results for the ¾ cut rebar sample. This sample showed to have a significant impact on the value of the voltage being passed through in comparison to no cross-sectional cut. In comparison to the control, the average voltage for this rebar sample was more than 100 mV less, or 64%.

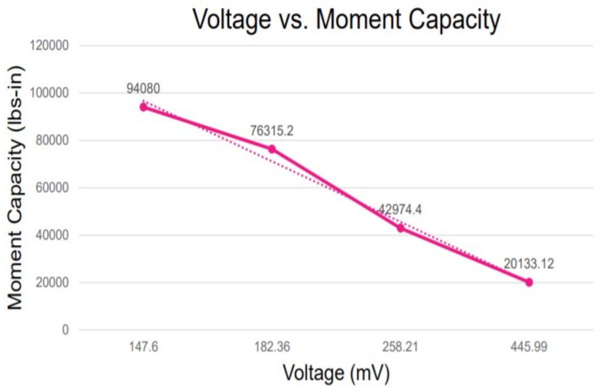

Figure 3 – Voltage vs Moment Capacity

As seen in Figure 3, when the electrical current was sent through the different rebar samples using a solar cell, the moment capacity of the sample decreased as the voltage increased. Based on the trend line seen on the graph, the value between voltage and moment stayed approximately at a 1 to -1 ratio. This meant that if the corrosion had led to a section of 1/10th the rebar, the moment capacity would also decrease by 1/10th which is equivalent to 90% the total load it could once hold. These findings are critical to the application of the device at a larger scale, as the voltage readings are relatively proportional with the moment capacity of the rebar. Furthermore, the results shown below reinforce the findings of other studies, with respect to the different instruments used [33] [34].

Source	Sum of Squares	Mean Square
Between-treatments	10789.2027	10789.2027
Within-instead	64367.5842	1399.2953
Total	75156.7869	

Figure 4 - One-Way ANOVA Statistical Test

Given that there were varying cuts within the rebar samples, specifying that there was more than one independent variable, an ANOVA statistical test was done in order to explore whether the data collected was due to random chance. In order to test the significance of the data, the one-way ANOVA statistical analysis was conducted at 95% accuracy. The statistical analysis consisted of 48 samples, 24 for the rebar sample with a ¾ cut and 24 for the control rebar sample. The mean of the ¾ size rebar sample was 104.18 mV with a standard deviation of 39.7267, while the mean of rebar the control rebar sample was 134.165mV and the standard deviation was 34.8929.

The greater standard deviation seen in the rebar sample with a ¾ cut shows larger variation in the data with slightly less accuracy than that of the control rebar sample. Because the p-value is 0.007916 which is less than the p-value of significance 0.05, the downward trend seen in the trials were significant. Moreover, given that the solar cell used during data collection was able to show this significance, the results seen above demonstrate that the voltage readings from an electrical current using a solar cell was a feasible alternative to other exorbitant NDT equipment.

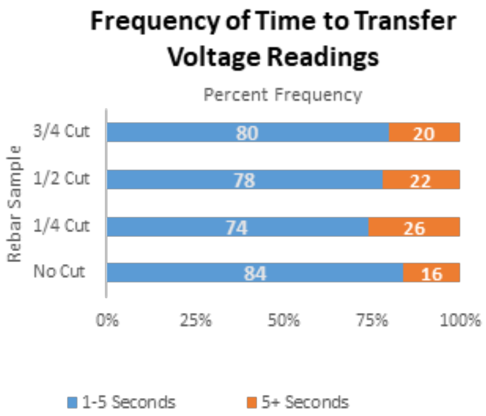

Figure 5 – Frequency of Voltage Readings Transfer

Once trials were conducted on each rebar sample, because the data in the study was transferred through a cloud network instead of an offline source, an additional trial on the frequency of time that it took the device to send voltage readings to each rebar sample was completed. Similar to previous trials, this additional trial was 10 minutes. Approximately 300 voltage readings were gathered during this test. The results can be seen above in Figure 5. As seen from the data, 79% of the voltage readings gathered from the device took between 1-5 seconds to reach a cell on Google Sheets. The longest time it took a voltage reading to reach a Google Sheets cell was 12 seconds.

One key finding in this trial was a large discrepancy between the control sample and the rebar sample with the ¾ cut. In addition, it can be seen that the frequencies varied between each rebar sample. Based on the data seen in the graph, the standard deviation of the frequencies is approximately 4.16, indicating that the frequency times were varied. Because the IDE software is usually operated offline, in the context of this research, it could be initially assumed that the frequency should stay the same for all samples; however, the results do not align with this assumption. It is important to note that the trials for this study were not all taken on the same date. Given this, a highly probable rationale is that different bandwidth speeds at the location of the research during the different trials. Because it was sent through a cloud network, the speed of the data reaching Google servers was heavily reliant on internet speeds. However, during these periods of lower internet speeds, the data would quickly send over once the internet speeds were restored to normal levels.

Integrant	Cost
Arduino UNO	$23
ALLPOWERS Solar Cell	$13
Arduino Integrated Development Environment	FREE
Multimeter	$12
Jumper Wires	$9
USB Cables	$4
TOTAL	$61

Figure 6 – Cost Table

Given the cost of all components, the final cost of the product is $61 dollars. The laptop used to program the Arduino UNO and the rebar samples used were exempt, assuming that users would have access to these materials. Compared to other monitoring systems in the literature, the cost of the product is significantly less. An Arduino-based corrosion monitoring system from the Department of Applied Science and Technology at University of Ferrara priced at approximately $162 dollars [35]. In addition, researchers from the Polytechnic University of Turin developed a logarithm-based Arduino-based system that cost around $100 [36]; however, the Arduino-platform used in their study was almost half of that cost. Upon additional review of the costs of these systems, the device constructed in this research was approximately 51% more economical.

Furthermore, this device is simpler compared to other Arduino systems. In this device, it can be concluded that corrosion predictions can be made from the voltage readings displayed; however, in other systems like the aforementioned logarithm-based system from Polytechnic University of Turin, the independent variables were very dynamic.

Conclusion

New Understanding and Significance

When compared to other systems and their limitations, this device improved on many of the aforementioned problems with them. As high equipment costs prevent many researchers from accessing these technologies, this monitoring system proved to be significantly more economical. In this study, one of the most important findings was the strong positive correlation between decreasing moment capacity and voltage. Therefore, as seen in the trials conducted on the rebar samples, along with the one-way ANOVA statistical test, this device was able to produce significantly accurate results between the different rebar samples.

Several electrochemical NDT methods in the literature have successfully used an electric current from a variety of sources within their monitoring systems [37] [38]; however, this device is the first to use the electrical current from a solar cell as an accurate means to detect corrosion within rebar. This is significant for several reasons. As previously mentioned, because solar technologies are constantly under R&D, this system can be enhanced in the future to address any limitations that current solar technologies, specifically solar cells, may contain. Furthermore, constant supervision of the equipment within the monitoring system is not necessary because solar cells only require light energy to operate. Although the cost of monitoring systems is an issue, the costs to have a person continually operate this system and repair it could also become a problem, as seen in other monitoring systems [39]. By allowing for noninterference of the equipment via a solar cell, costs relating to equipment repair can potentially decrease.

In addition, this corrosion monitoring device is the first to use Google Sheets as a means to store data. By allowing for the transfer of data through Google servers, this further reiterates the device's capability to enable hands-off monitoring. In the specific context of corrosion monitoring, this is critical. By allowing researchers to monitor corrosion levels at different locations, the allocation of resources, such as labor and money, can be used more efficiently. As a result, overall corrosion costs and damage can be further mitigated. This directly related to the initial project goals for this research.

The problems regarding corrosion management have persisted for decades, and multiple solutions have been proposed to mitigate the impacts by detecting corrosion early on. For example, the United States Department of Transportation and Tracy Gordon, an economist at the Urban-Brookings Tax Policy Center, suggest that the scope should be moved to local officials [4]. However, the issues regarding the high costs and ambiguous exactness of corrosion detection are still present in current technologies. This device assists to fill that gap in the current literature regarding these technologies.

Limitations

Although this low-cost monitoring system successfully gathered data that could give insight on corrosion levels within reinforcing steel, there are several limitations of the device that were not addressed during this study. The two main limitations of this study were the corrosion modeling in the rebar and the dependency on internet speeds.

As stated in the rebar sample preparation section, in order to emulate corrosion, slits were made into the center of the rebar. The reasons for this are twofold. First, given the time frame for this research, attempting to create these conditions using corrosive liquid would likely not be efficient. In addition, importing corroded rebar is an option, but price would likely become an issue Although this was grounded and modeled from other researchers, it is not an exact representation of the real world. The same patterns seen in the data collected in this study would likely be seen; however, conclusions cannot be made that solidify the device's capability in real world situations.

Furthermore, another key limitation was the dependency on internet speeds. Although the device is able to send the voltage readings over various speeds, the bandwidth of the user has a large impact on the time it takes for data to reach them. For example, if the voltage readings are sent from an area of higher internet speeds to one of significantly lower speeds, this potentially could drastically hinder coordination to address the problem. Regardless, the device shows promising solutions to civil engineers attempting to rapidly gather information on the amount of corrosion that has occurred within a structure.

Future Directions

There are a multitude of paths that researchers could take to look further into the field. Based on the limitations, the future directions for this research focus on enhancing the system in order to further achieve the goals that were set originally. First, coordination with local governments to implement the device on different structures would allow insight on the scope to which the monitoring system is feasible. In order to accomplish this, modifications would likely have to be made to the solar cell used in the monitoring system due to the physical nature of current infrastructure. Furthermore, while the program that was developed in the monitoring system was concluded to enable researchers to obtain data at various locations, the frequency of receiving that data is highly reliant on internet speeds because it was sent through Google servers. The incorporation of a phone application component to notify users if a problem occurs could mitigate the issue regarding the various internet speeds of users. By allowing for large amounts of data to reach users these speeds, actions by local transportation officials could be taken at a much faster rate, further reducing costs and damage, and increasing public safety.

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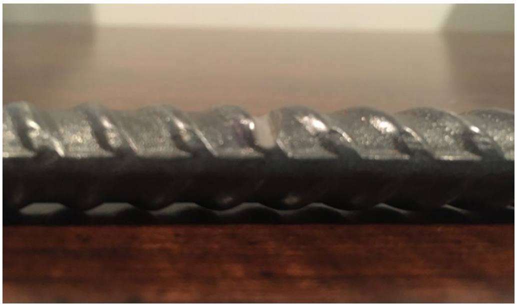
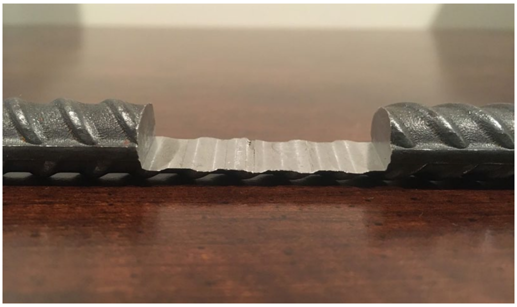
Appendix A – Rebar Cuts

Rebar Sample: No Cut (Control)

Rebar Sample: ½ Cut

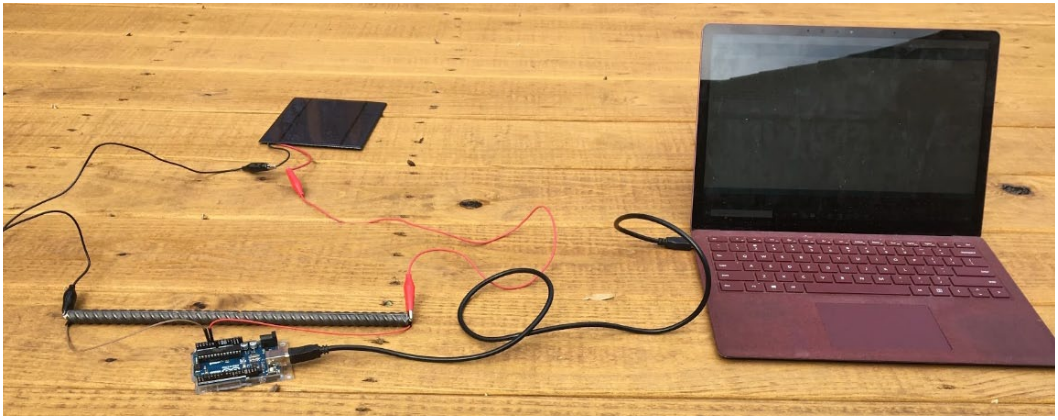


Rebar Sample: ¼ Cut



Rebar Sample: ¾ Cut

Appendix B – Final Monitoring System



Appendix C – Final Code for Monitoring System

```
  const float referenceVolts = 5.0;
  const int SolarPin = 0;
  void setup()
  {
  Serial.begin(9600);
  }
  void loop()
  {
   int val = analogRead(SolarPin);
   float volts = (val / 1023.0) * referenceVolts;
   Serial.println(volts);
   delay(500);
  }
  import com.google.gdata.client.spreadsheet.*;
  import com.google.gdata.data.*;
  import com.google.gdata.data.spreadsheet.*;
  import com.google.gdata.util.*;
  import java.net.URL;
  import processing.serial.*;
  String uname = “xxx”;
  String pwd = “xxx”;
  String spreadsheet_name = “sensorlog”;
  int spreadsheet_idx = 0;

  Serial port;

  int oldTime;

  int reportingInterval = 2000;
  void transmitData(float val) {
   String date = day() + “/” + month() + “/” + year();
   String time = hour() + “:” + minute() + “:” + second();
   try {
     ListEntry newEntry = new ListEntry();
      newEntry.getVoltageReadings().setValueLocal(“date”,
date);
      newEntry.getVoltageReadings().setValueLocal(“time”,
time);
                                  newEntry.getVoltageReadings().
setValueLocal(“reading”, Float.toString(val));
     URL listFeedUrl = worksheet.getListFeedUrl();
       ListEntry insertedRow = service.insert(listFeedUrl,
newEntry);
   } catch (Exception e) {
     println(e.getStackTrace());
      }
     }
    service = new SpreadsheetService(“test”);
    try {
      service.setUserCredentials(uname, pwd);
     URL feedURL = new URL(“http://spreadsheets.google.
com/feeds/spreadsheets/private/full/”);
        SpreadsheetFeed feed = service.getFeed(feedURL,
SpreadsheetFeed.class);
      for (SpreadsheetEntry entry: feed.getEntries()) {
       if (entry.getTitle().getPlainText().equals(spreadsheet_
name) ) {
         break;
       }
              SpreadsheetEntry se = feed.getEntries().
get(spreadsheet_idx);
      worksheet = se.getWorksheets().get(0);
       println(“Found worksheet “ + se.getTitle().getPlain-
Text());
    } catch (Exception e) {
     println(e.toString());
    }
```