

Tru-Vee Disk Inductive Sensing Project

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Abstract: The planting units that John Deere builds have the task of creating furrows on the field, depositing dosified seeds and covering them with fertile soil for them to germinate and develop into plants. The main component for this process is the row unit, which contains special disks in “V” form called Tru-Vee. These disks dig furrows, and they tend to wear with use, as well as getting stuck on pebbles or dirt, preventing their optimal performance. This project developed a solution that can determine the wear that a disk has, as well as processing if the disk is moving. Using CAD design to determine the appropriate location to place the selected sensors, as well as developing an algorithm implemented through NI LABVIEW, with communication through an Arduino card, a solution was obtained providing a correct read of the variation in voltages translated as distance, along with an algorithm that determines disk movement, using only one sensor. The engineers at the company were satisfied with the obtained results at this instance of the project and will use the experimental results to further develop the solution with more robust components and improved implementation, as the solution requires few components and changes an existing mechanical part of the unit.

Keywords; Inductive sensor, drilled guard, CAD, row unit

1. Introduction

The different planting machines that John Deere offers carry out the task of optimizing the seeding, care and harvest of different crops. The main planters that are sold to the United States consist of different mechanisms that let farmers do their tasks. The main mechanism is the row unit, consisting of gage wheels that regulate the depth of the furrow, the tru-vee disks that dig furrows, the deposit mechanism for the seed, and any additional mechanisms available. The Tru-Vee disks are sharpened disks that spin with pure force from the rest of the unit, carving the furrows and letting an opening to deposit seeds. These furrows need to be spaced out correctly, as well as having only one seed deposited, to prevent waste of resources. The precision on furrow spacing and seed deposit rate is vital for productivity and efficiency, so the purpose of this project revolves around determining if the disk’s blade has worn out to a point it doesn’t create appropriate furrows, as well as detecting angular movement from the disk, to make sure that the seeds are being deposited in different furrows, and they don’t compete between each other for resources.

Different approaches have been made to determine if the two variables of interest, angular movement and distance, have changes. Gao, W. et al propose a new contactless inductive sensor for measurements of absolute angular displacement [1], Jae-Jeong, J. and Joon, M. created an inductive sensor spinning around the induction sensor coils to measure rotational movement [2], and Kumar Jha, A. et al. presented a new sensor used for detection and measurement of angular rotation and proximity, with an intended use for additive manufacturing, and consisting of a rotor and stator, and analyzing measurements through a vector network analyzer [3].

The materials and methods used to formulate a solution will be covered in the next section, in addition to the components used for the implemented system with justification of the elements chosen, a graphic describing the steps of the process to arrive to a solution and its implementation. After that, the results obtained will be covered, detailing the mechanical design of the solution, the sensor used and its role, the results of different tests performed on real machinery from John Deere, and the algorithm logic implemented through programming to successfully make all the parts of the system work. Finally, conclusions are drawn from the data and the reliability of the system, with additional recommendations and considerations to have for further development and research.

2. Materials and Methods

The implemented system consists of the following materials:

- Drilled Guard to hold the sensor
- Proximity Inductive Analog Sensor
- ARDUINO MEGA board
- NI LabView VI Program
- Standard cables
- Alligator clips
- USB 1.0 cable

The selection for controller used was chosen due to its ease of use, almost universal communication with different programs and IDEs, and its cheap price, since it didn't require additional spending from the company. The software LabView was used due to its options for developments of interactive HMIs to show the user relevant data and allow for control, and the possibility of communication with different controllers using Serial port. Alligator clips were required to connect the sensor to the board, as it included a special harness input, while cables connected everything, and the communication between the Arduino and LabVIEW was obtained through a USB 1.0 cable, which also aided in powering the inductive sensor.

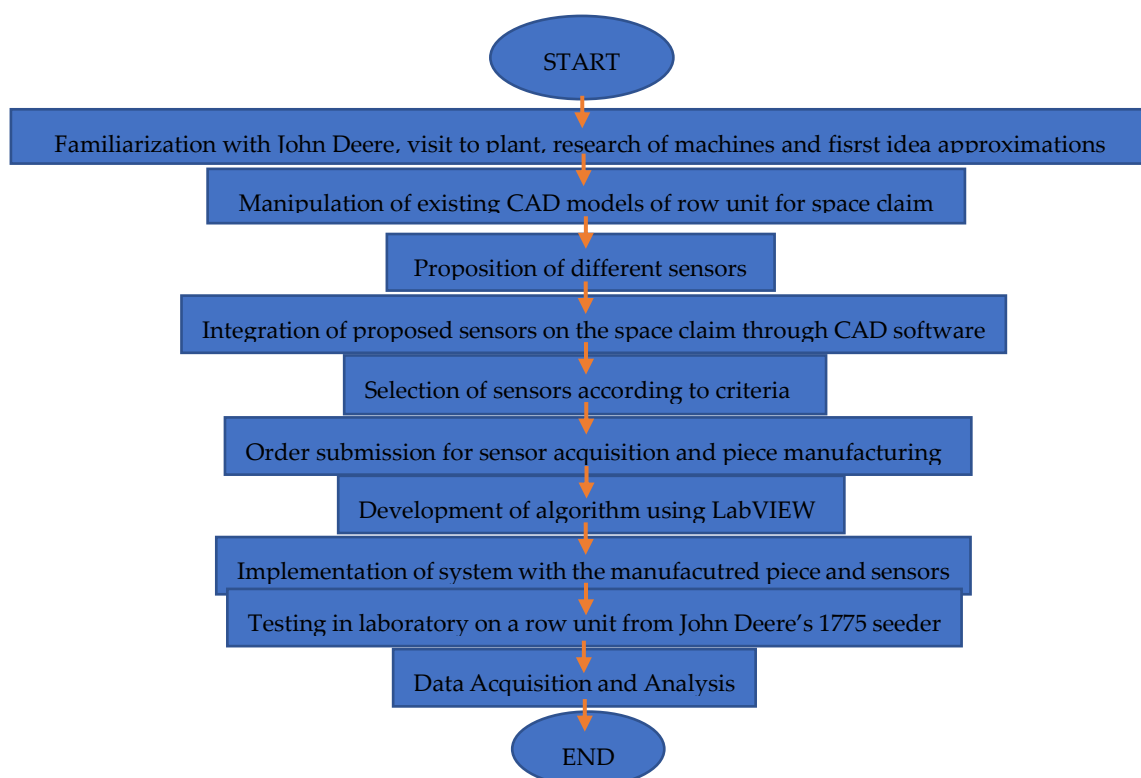


Figure 1. Flow diagram detailing the series of steps taken to solve the sensing issue. Each step required active communication with engineers Óscar and Ángel for feedback, access to files and overall discussion and report of activities and results according to deadlines.

3. Results

The development of the project started with the familiarization with the business, which meant a visit to the plant located in Santa Catarina, Nuevo León, and research of the machines available for planting that John Deere offers for farmers.

After having access to the company's resources, the next step involved the analysis of the model of a row unit, and of the seeder units, to determine where would be the best position or space to implement the solution. This step was the most difficult aspect of the project, and the one that took the most time, because the spaces and distances available were millimetric and of odd geometries.

Next, with the identification of the space, different sensors were proposed, mainly of inductive nature due to the harsh conditions of the environment and space. The sensors were integrated in different configurations using their CAD models, until a favorable position and place were identified, and the appropriate sensors were chosen.

An existing piece was modified to accommodate one of the selected sensors, and reviewing was conducted to finally decide to submit order for the acquisition of the sensors and the manufacturing of the modified piece using casting and soldering of a hub, which allowed to screw in the analog sensor.

The time period before the sensors arrived at Mexico was used to develop the algorithm using LabVIEW and considering two sensors, decision that for the final implementation was scrapped, as an algorithm was developed that used the readings of the Analog Sensor to conduct both variables, removing the need for an additional, digital inductive sensor.

Finally, the system was implemented on an existing row unit, and data was obtained through testing on a laboratory, using different measurements and conditions.

3.1. Mechanic Design

The space claim of the machine due to the multiple accessories, devices and hardware played a crucial role on determining the location of the disk's sensor. Promising positions were found on two different spots of the row unit. The first suitable place was between both truvee disks, and another one at the back of the disk where a metal guard could be crafter to meet our requirements, since it would be close to the range of an inductive sensor for measuring the disk's edge, as well as the sensor could be implemented on various configurations of the row unit.

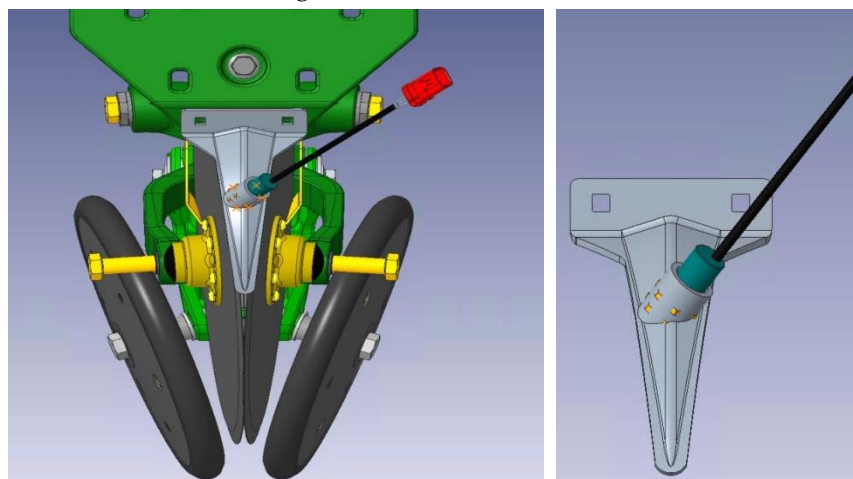


Figure 2. View of the row unit, with a sensor placed on the metal guard. This option was the final decision for the implementation of the solution. The sensor is introduced through a hub that is soldered to the guard after a perforation on the guard. The hub has an inclination that allows the sensor to directly point to the sharp edge of the disk, to properly measure the wear of the disk. Further drawings, including a drawing for another sensor and other views are present on **Appendix A** and **Appendix B**.

Description	Part Number	Quantity
Inductive Sensor JD	AFH215154B	1
Shield double disk	A48879	2
Bush	No Part Number	2

Table 1. Build of Materials for the selected prototype solution part.

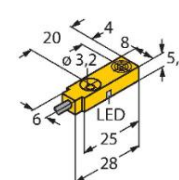
3.2. Sensor Selection

Originally, two sensors were selected to perform one of the tasks separately. However, as the project advanced, an algorithm that will be explained on a further section rendered the use of one of the sensors as obsolete. The sensors selected were inductive, as the disks are metallic and there were few margins of error of the sensors detecting a different metal. Other options would have had worse performances due to requiring additional material, or due to the conditions of wet soil making readings harder to obtain.

The sensors chosen for the task were John Deere's AFH215154 inductive analog sensor with a sensing range of 8 mm, originally for the measurement of distance with the purpose of determining the disk's wear, and TURCK's NI3.5-Q5.5-AP6X digital inductive sensor [4]. The electrical diagram used is shown on **Appendix C**.



(a)



(b)

Figure 3. Inductive sensors selected for the solution implementation, chosen due to the materials sensed being metals and the working conditions. (a) shows John Deere's analog industrial sensor, and (b) shows TURCK's digital industrial sensor, which was not used on the final implementation of the solution.

3.3. Algorithms

Two algorithms were developed to determine if the disk is spinning, being based on the variation of certain data available. One algorithm was supposed to be used with the digital sensor, being placed in front of the rivets that hold the disk together to determine variation between 1's and 0's. This algorithm is available as **Appendix D** for further research.

The other algorithm uses a feature that we didn't consider at the start: even new Tru-Vee disks have some irregularities on their structure and circumference, and the readings vary as the disk spins regardless of the velocity of the spin. That variation was used and, depending on a threshold that can be input by the user, aided to determine if the disk was moving, comparing data stored into arrays of different reading samples and comparing the maximum and minimum points. If the values are similar according to the threshold, then it can be assumed that the disk is static. The algorithms were coded into NI LabVIEW and are part of the main program, which is included as **Appendix E**.

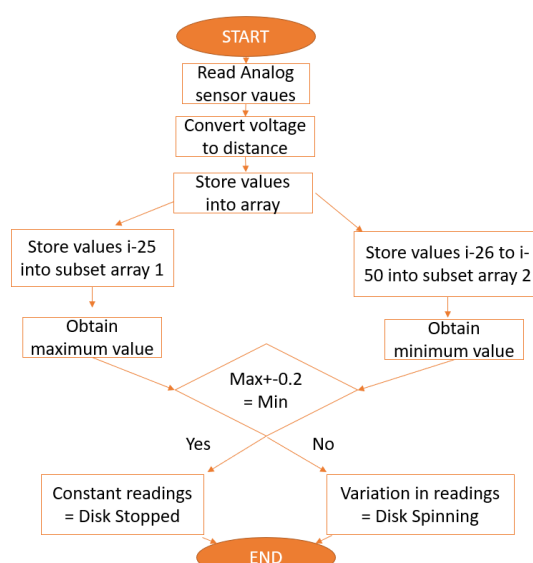


Figure 4. Flowchart for the algorithm using the analog inductive sensor to determine if the disk is moving properly or if it is stopped, which would be caused by an external factor on the field.

3.4. Instrumentation and Testing

Tests were conducted with the system implemented into a detached row unit on John Deere's laboratory facilities, in order to fully determine the correlation between voltage sensed and distance after installing the sensor into the mounted drilled guard designed with CAD. Measurements of distance were conducted with feeler gauges. The sensor was mounted and connected to the Arduino board, to obtain the read of the analog voltage value at certain distance and at certain angular position of the disk. The disk's irregularities provided a range of values of approximately 0.5 V (which was used for the algorithm to determine if the disk is rotating) with a constant sensor position, and with an eye test, it was easy to identify the areas with highest and lowest voltage values. The relation showed on the graphs was of a linear relation of the values, with very high R square values of correlation, carrying the tests with both a new disk and a worn disk, with different sensor positions.

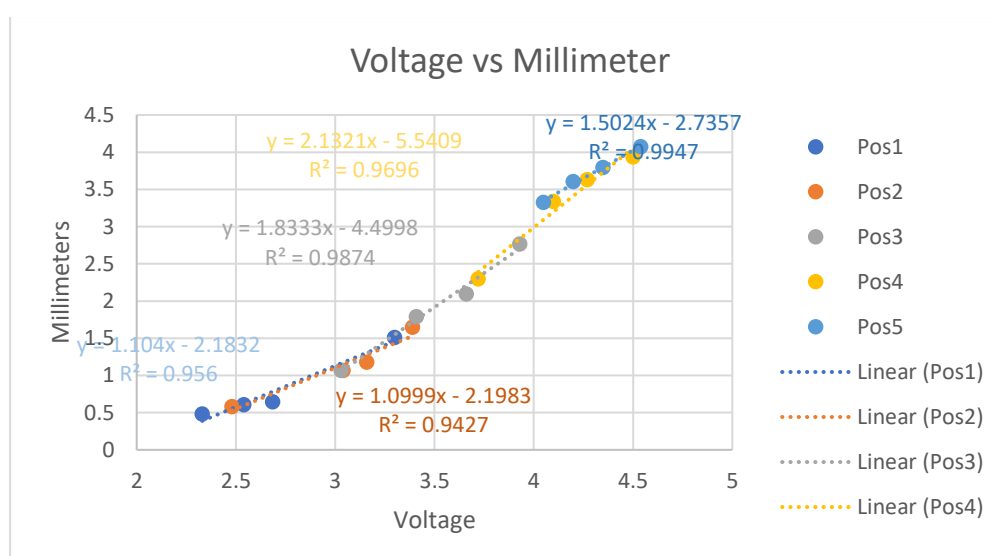


Figure 5. Graph exposing the behavior and relation of different voltage measurements read with the Arduino Software, as the voltage goes from 0 to 5V, and the distances measured with the sensor on mounted position. Different positions were used, each with different readings as the disk is rotated for variation, and to expose the irregular circumference of the blade of the disk. Additional graphs are attached on Appendix F.

The graphs expose the linear relation between voltage and distance in millimeters that the sensor has, and this data could be used to formulate an equation for the data conversion on this configuration. However, values can change because of the principle of the inductive sensor, as values differ according to how close to the center of the sensor the metallic material is, and the thickness of the material. Considering the angle that the sensor has to the disk's edges, and the thickness of the material, it is understandable that the minimum voltage value possible read was around 2V, instead of the normal 0V that a sensor would have on its minimum value.

4. Conclusions

The data was evaluated and presented to Engineer Óscar, who accepted the results as positive and showed satisfaction with the project's results. The engineering was transferred to the company, sending videos and pictures of the tests, the code on LabVIEW, the electrical diagram and the data obtained. The results of the system were successful, and this system will be considered for further testing on more realistic environments, which will require more advanced technology, a different microcontroller, and a more robust installation of the hardware.

The availability of measuring both variables of interest with only one sensor showed to be one of the biggest advantages of this implementation, since it cuts costs and leaves additional space free for the resolution of different issues. Another advantage relies on the mechanic design of the solution, which uses an existing part of the row unit, the guard, and modifies it to a drilled guard to support the analog sensor. The implementation using the hardware and software selected also opens the chance of using more industry-oriented components of different variety, since the code is not complex and is explained through flux diagrams. It is recommended to transfer the tests next into an actual field to determine the disk's performance, with different communications from the field to the processing unit.

5. Patents

Author Contributions: The conceptualization of the ideas was thought by D.N. and A.C. The methodology was D.N. and A.C. responsibility. Both authors conducted investigative activities on different areas. The creation of the Mechanic Design is credited to D.N. The algorithms were developed by A.C. The validation and testing of data was A.C.'s responsibility, while both A.C. and D.N. did the testing of the values of the analog sensor on the laboratory. Logistical and communicative roles were assigned to D.N.

Appendix A

This appendix section contains different drawings of the manufactured drilled guard piece that was used in the final version of the project. A link to a Google Drive Folder with the CAD is present at the last appendix, with the drawings present on the folder “CAD”

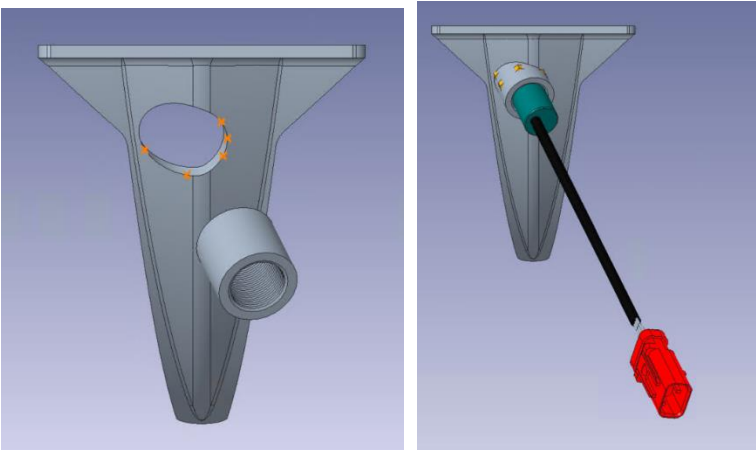


Figure A1. Frontal view of the drilled guard, with the external hub and an angled hole, as well as an assembly with the sensor installed.

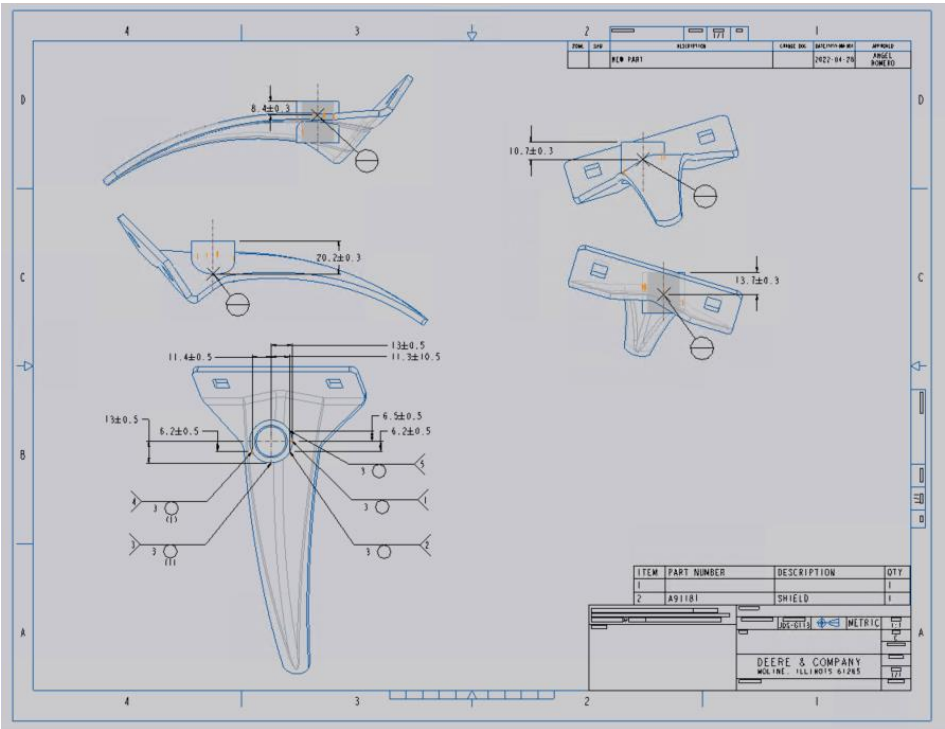


Figure A2. Drawing of the guard used with indications for manufacturing and labels.

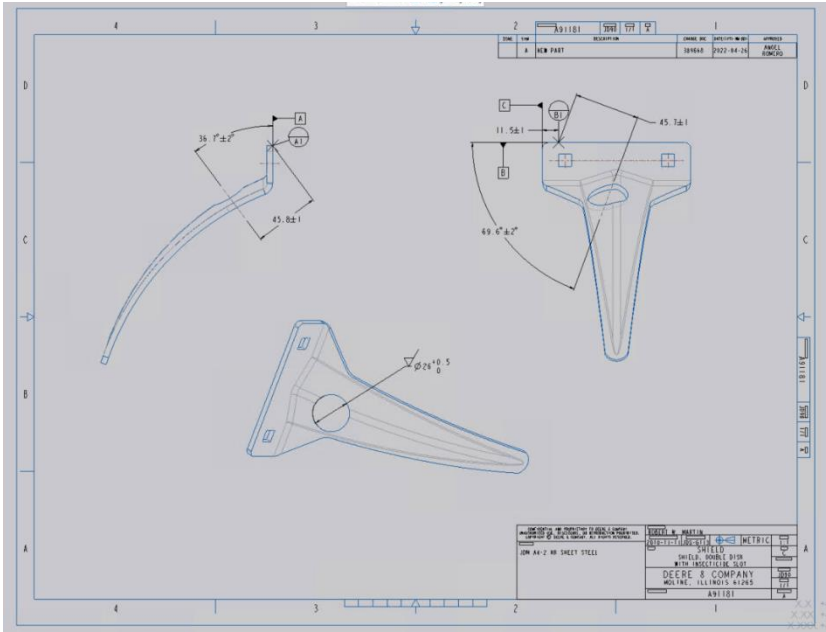


Figure A3. Drawing of the guard used with indications for manufacturing and labels.

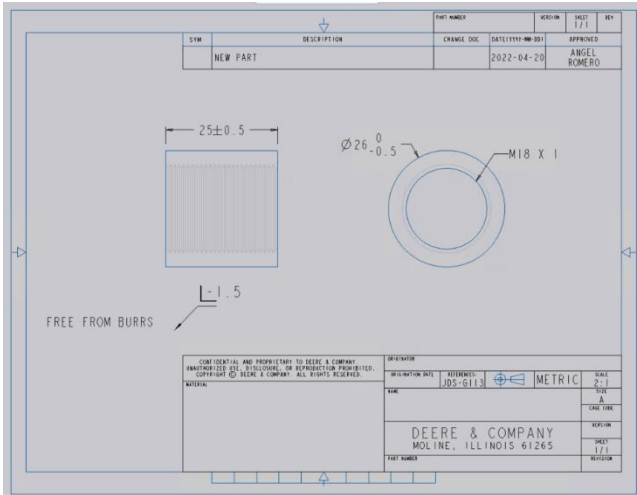


Figure A4. Drawing of the hub used with indications for manufacturing and labels.

Appendix B

This appendix section contains different drawings of a proposed case for the second sensor that the original implementation intended, which was discarded from the final version of the project.

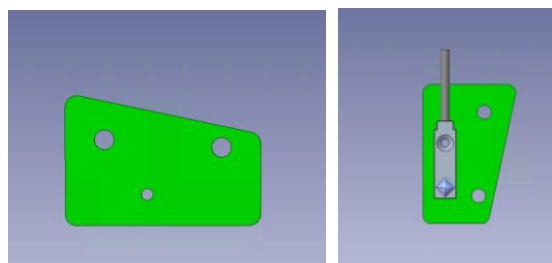


Figure A5. Model of the proposed case, with the sensor mounted on the right picture.



Figure A6. Location of the proposed second sensor that was discarded. The sensor would have different rivets in front of it at a distance of around 2mm.

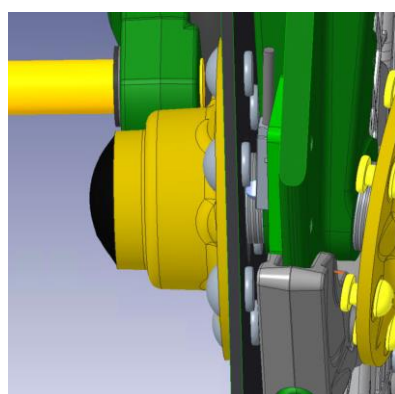


Figure A7. Side view of the proposed second sensor, displaying the small gap that would be taken advantage of for its use.

Description	Part Number	Quantity
NI3.5.Q5.5_AP6X Inductive Sensor	No part number	1
Screws 5M	No part number	2
Plate	No Part Number	1

Table A1. Bill of materials of this assembly.

Appendix C

Electrical Diagram

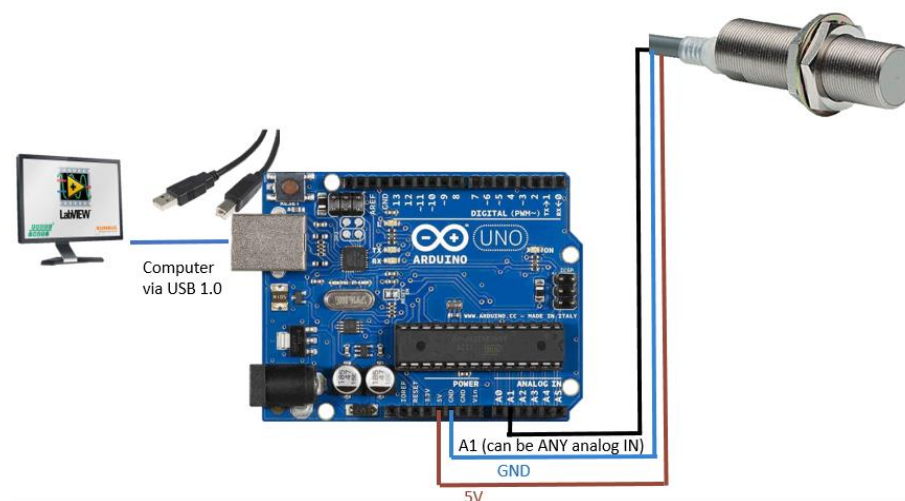


Figure A3. Electrical diagram of the solution implemented, only requiring the connection of the analog sensor to the ARDUINO card, and the connection of the card to a computer with the installed software. The sensor is powered by the card, since it works on a range from 4.7 to 6 V.

Appendix D

Algorithm for Disk Movement Using Digital TURCK Sensor:

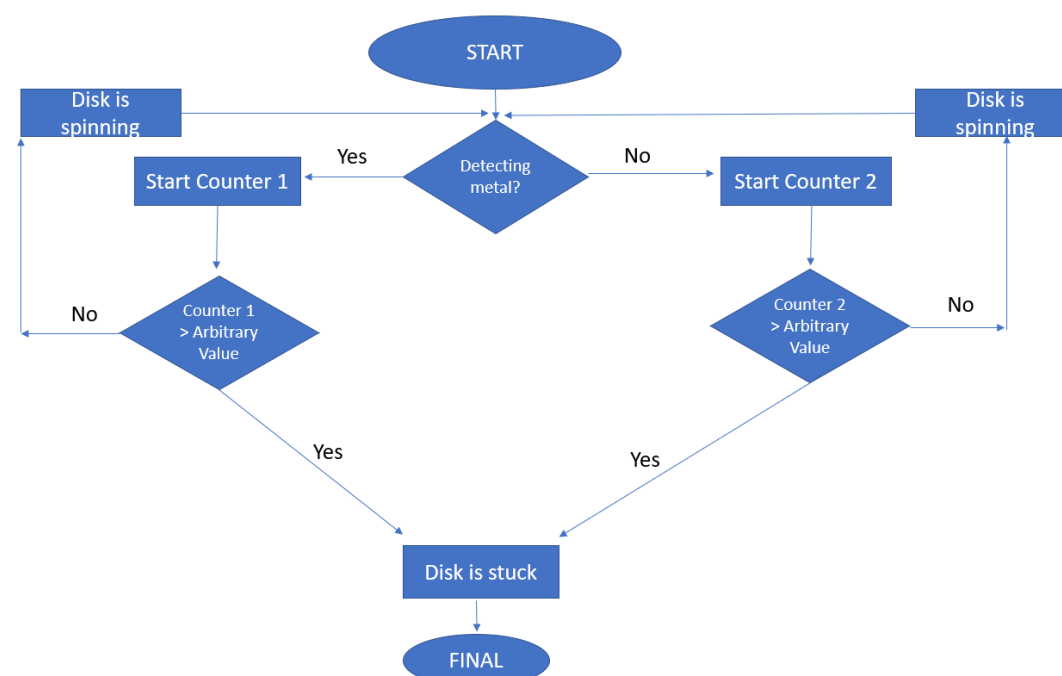
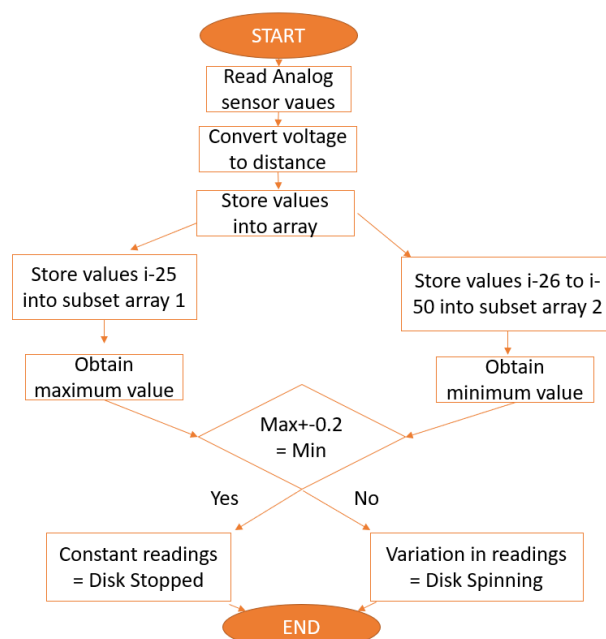


Figure A4. Algorithm that uses the digital inductive sensor to identify if the disk is spinning. The sensor is installed in front of four rivets that hold the disk into the machine. As the disk moves, the signal should vary from 0 to 1 with some frequency, as if it was a PWM signal. Each time a signal is set to 1 or 0 a counter is started, and an arbitrary value is set as threshold for that counter. If the value of the counter surpassed the value, then the conclusion that the disk is stuck can be inferred, as the movement required to start the other counter is very small.

Algorithm for Disk Movement Using John Deere's Analog Sensor:

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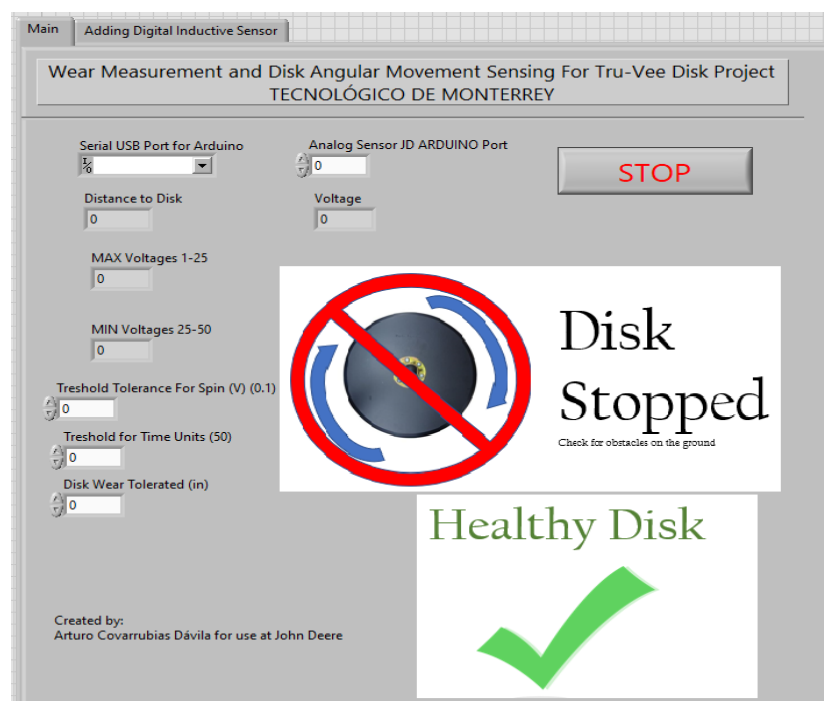
Appendix E

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LabVIEW HMI developed to expose the sensor's data, and control the inputs and communication between the computer and the ARDUINO Card:

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Figure A6. HMI interface using LabVIEW, with controls for user input of communication, analog sensor pin, threshold to determine the voltage tolerance for the disk spin algorithm, the threshold for time limit to compare and conclude that the disk is stopped, and the disk wear tolerated on inches.

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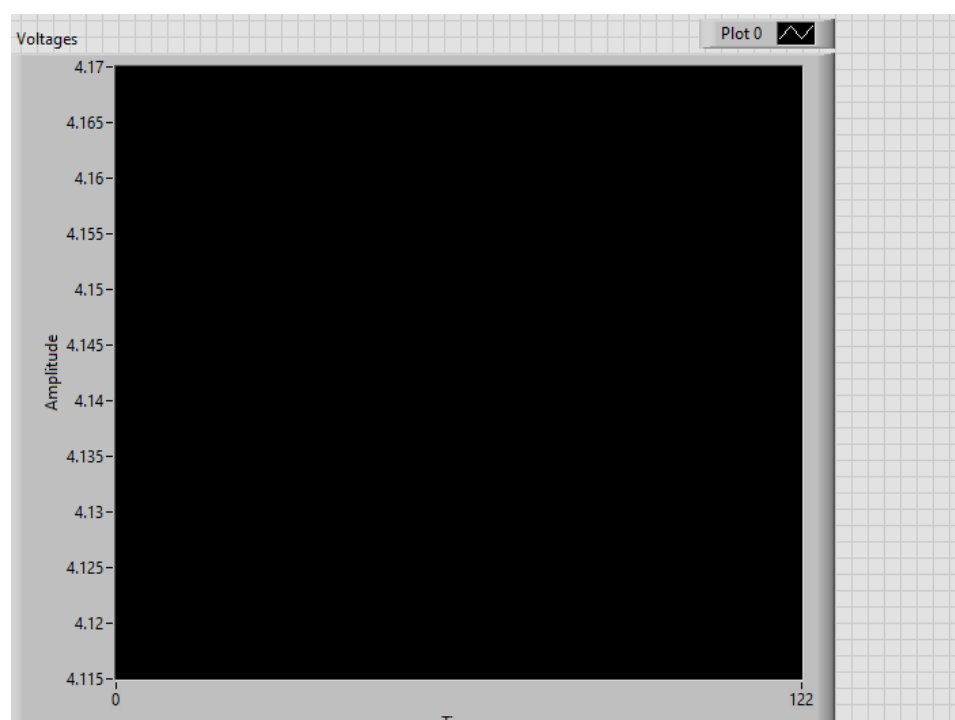


Figure A7. Graph for the display of the voltage variation in the signal of the analog inductive sensor.

LabVIEW Block Diagram:

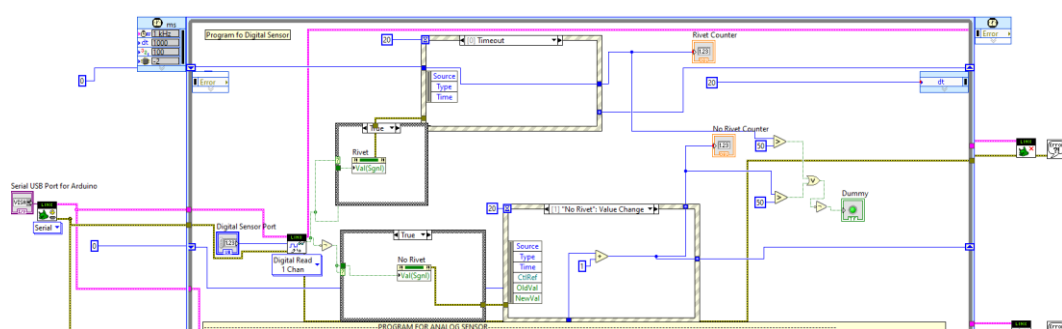


Figure A8. Block diagram of the first algorithm implemented with the digital sensor for disk spin. Uses local variables and counters with shift registers to compare the values, and if one surpasses the value of 50, then the disk is interpreted as stopped.

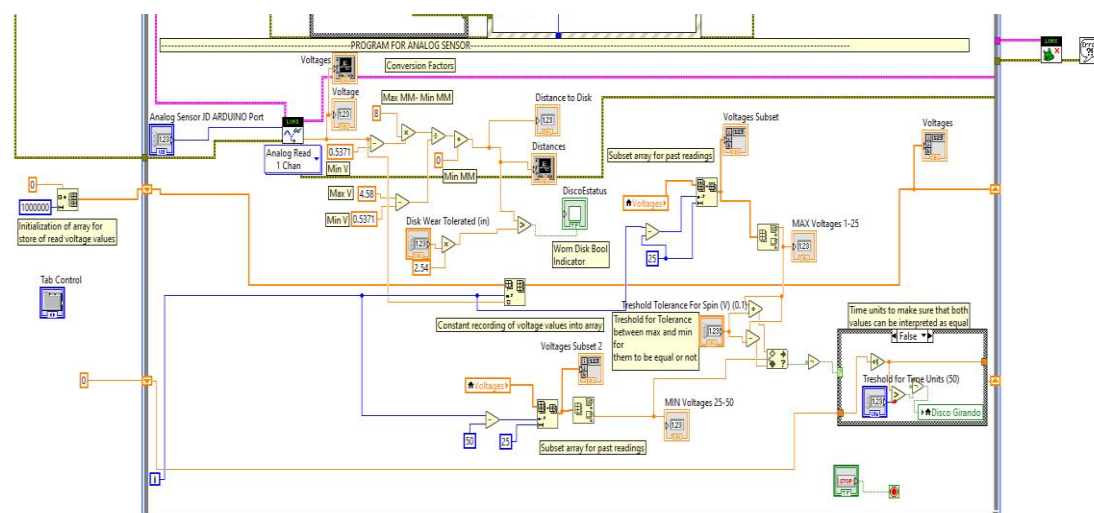


Figure A9. Block diagram of the second algorithm and the read of analog values for the analog inductive sensor. It requires an analog read of voltage, which is then displayed as an indicator and as a chart, and converted through linearization to millimeter values (which are incorrect for this configuration). The values for voltages are stored onto an array that updates every 20ms read. The array is split into two sub arrays, which record the latest to 25th latest value, and another subarray stores the 26th to 50th latest value. Then, a maximum and minimum operation is carried out to extract those values, and those values are compared using a threshold defined by the user to define equality. If the value is true, the value is inverted, and the indicator of “DISK SPINNING” or “DISK STOPPED” is manipulated. The indicator “DISK STOPPED” required certain time value to pass to justify having no false positives. This time value is specified by the user.

Appendix F

This appendix section contains the different graphs obtained from experimental data on measurements of the voltage that the analog inductive sensor sent to the arduino card, and the physical distance between the closest part of the sensor to the edge of the disk. The sensor records values on the range of 0.5 to 4.5 volts.

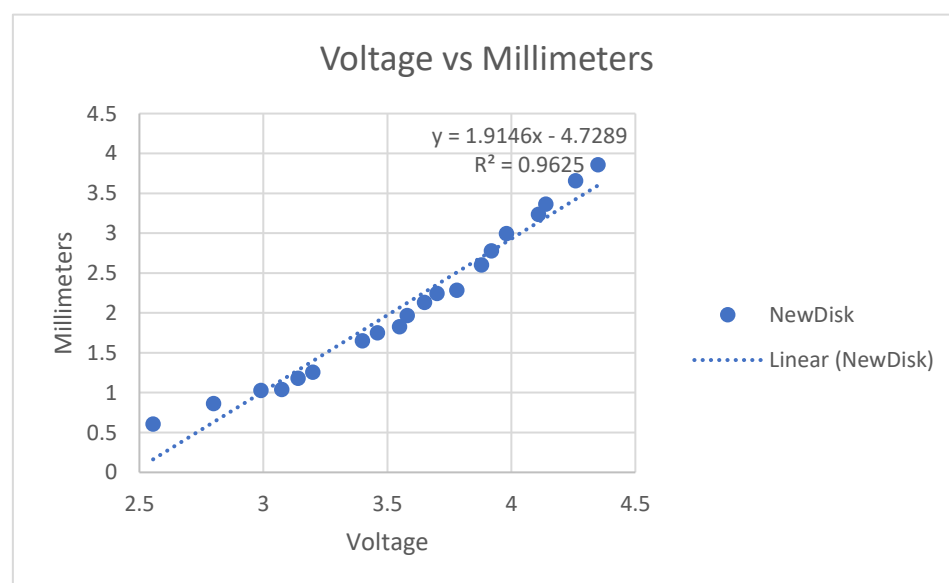


Figure A10. Graph showing all the readings done with the new disk, including different position of the sensors and different voltages. It shows a very high correlation constant, as well as a linear equation that can model the behavior recorded.

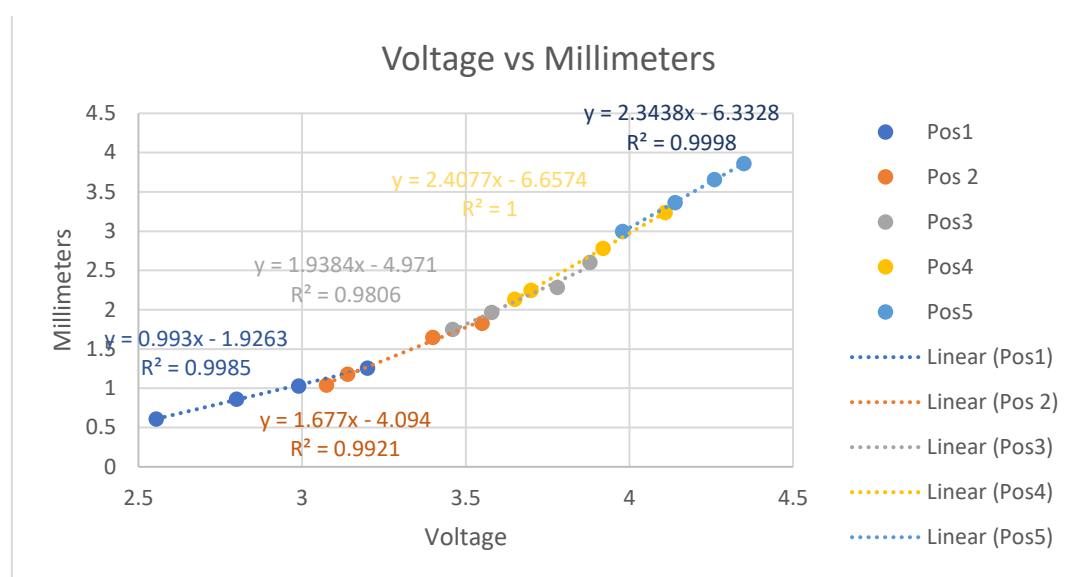


Figure A11. Graph exposing the behavior and relation of different voltage measurements read with the Arduino Software on the new disk, with different positions noted by the "Pos#" label. Each of the reading samples can be modeled with linear equations of varying constants.

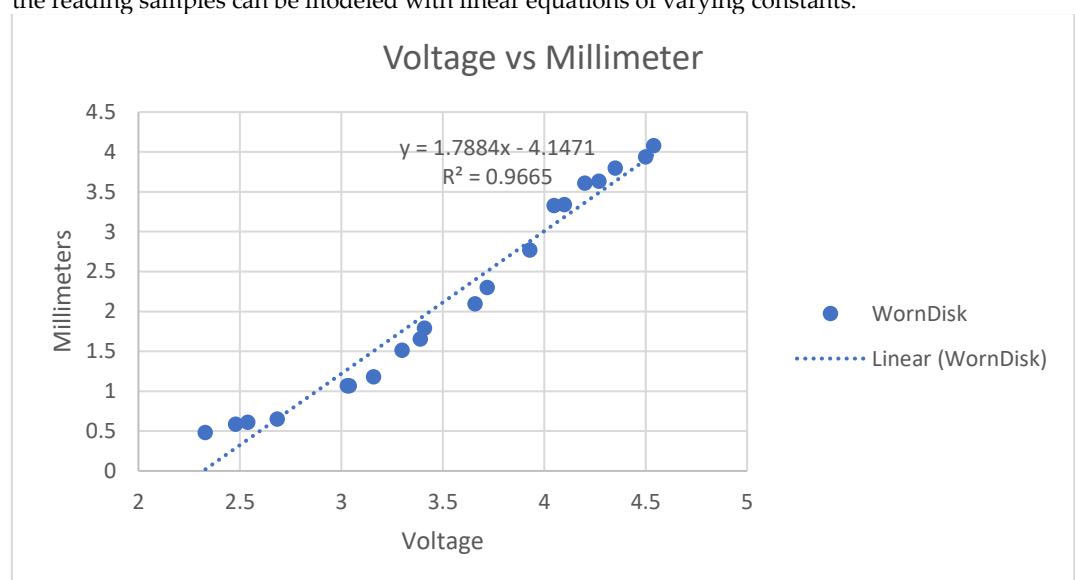


Figure A12. Graph showing the readings using the worn disk, including different position of the sensors and different voltages on the same graphic.

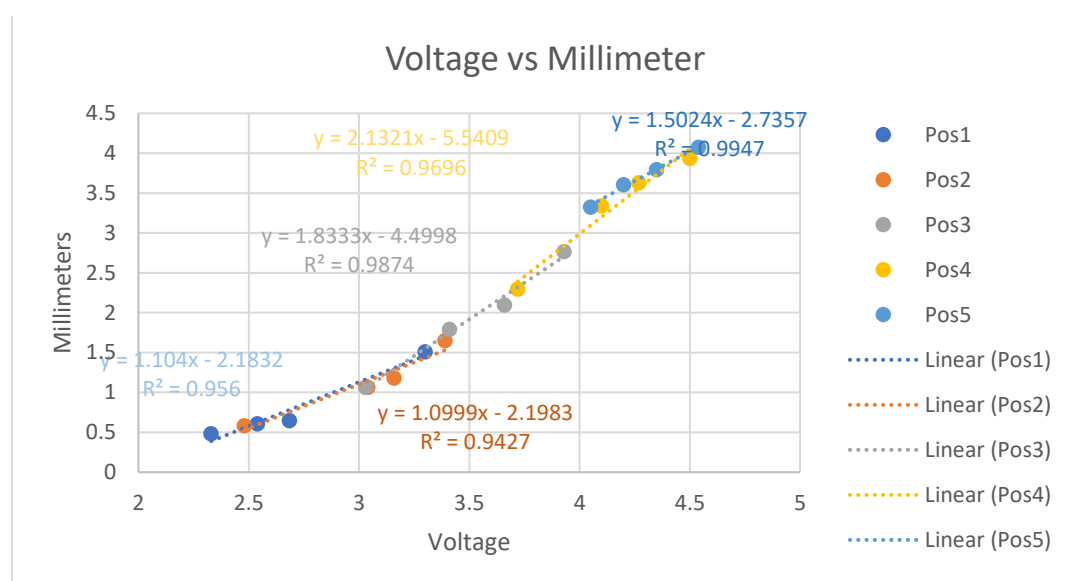


Figure A13. Graph exposing the behavior and relation of different voltage measurements read with the Arduino Software on the worn disk, with different positions noted by the "Pos#" label. The behavior is also linear, has less correlation than the new disk, but the difference is not considerable enough to stop the option of modeling the system as linear.

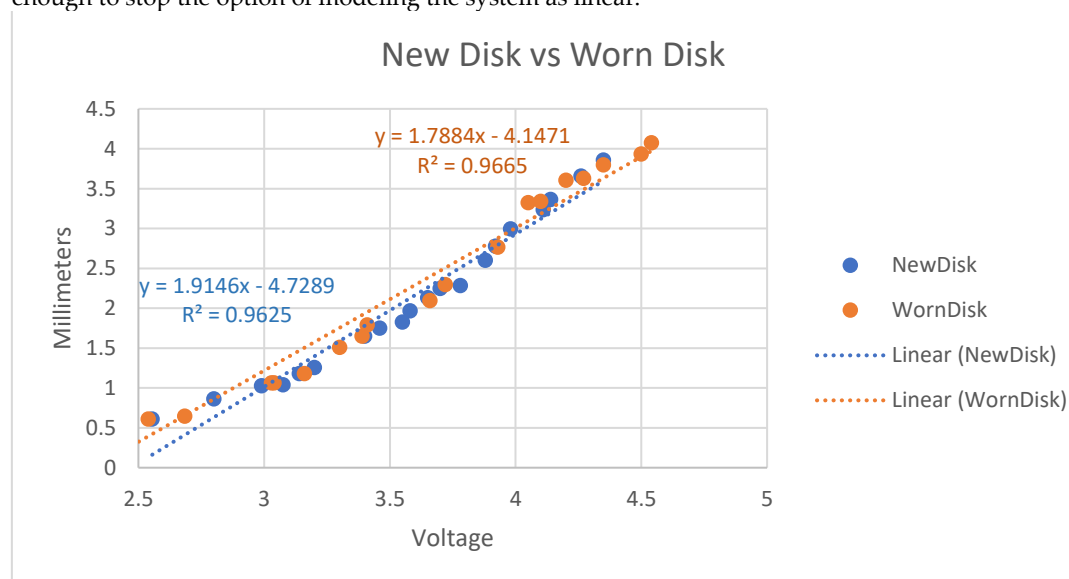


Figure A14. Graph comparing the readings of both the new disk and the worn disk, behaviors shown on previous graphs. The comparison shows that the linear behavior is still present, and it mostly is dependent on variation on the constants.

Appendix G

This appendix section will expose pictures of the tests performed at John Deere's laboratory as evidence of work.



Figure A15. Picture detailing the testing process while spinning the disk



Figure A16. Picture detailing the measuring of real distance with feeler gauges.

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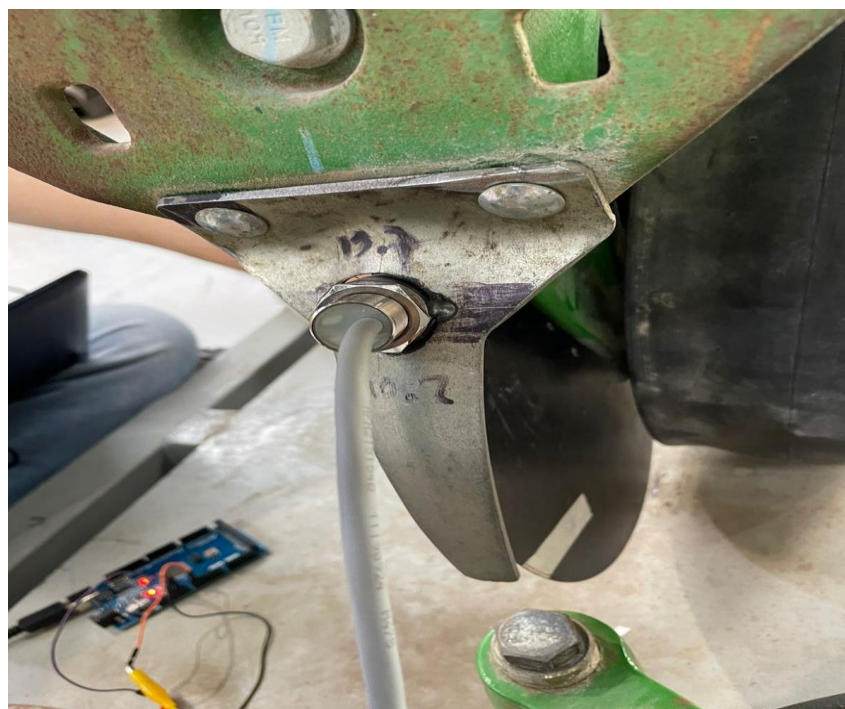


Figure A17. Picture showing a front view of the manufactured drilled guard with the sensor installed

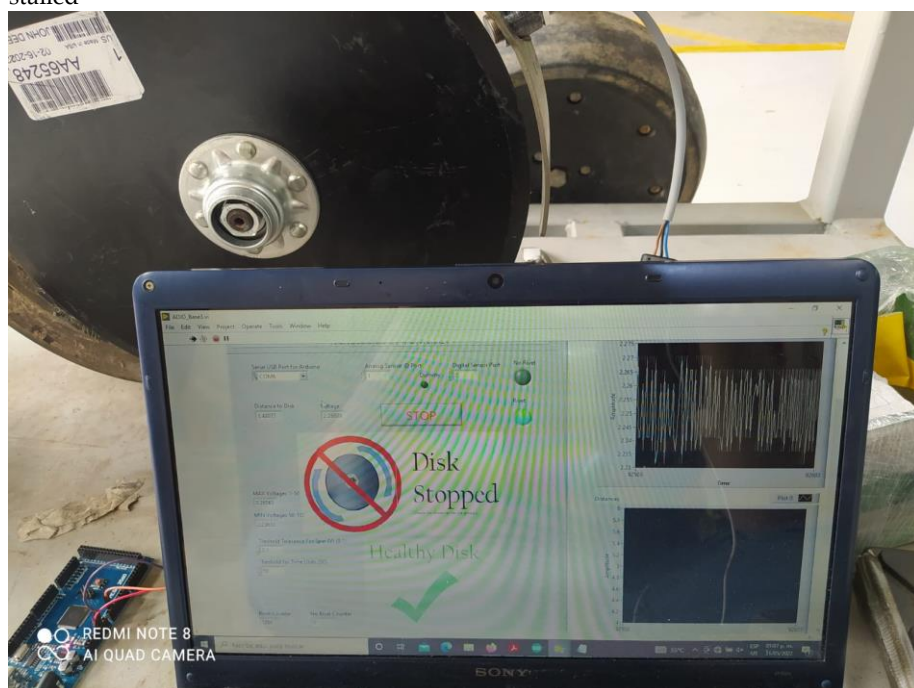


Figure A18. Picture showing the testing and communication between the sensor, the Arduino and the computer.

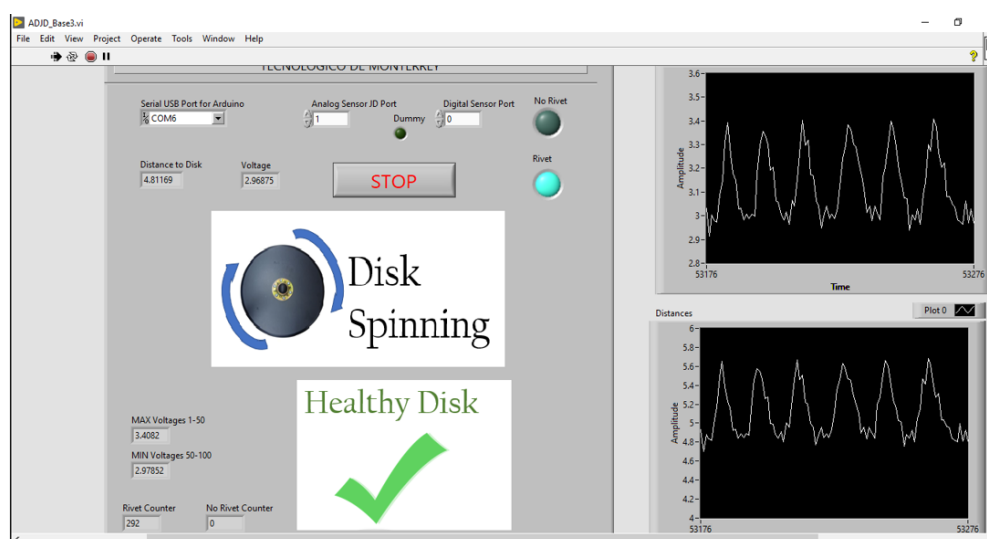


Figure A19. Picture of the HMI in the middle of operation, displaying the voltage variation as the disk is spinning, as well as the indicator.

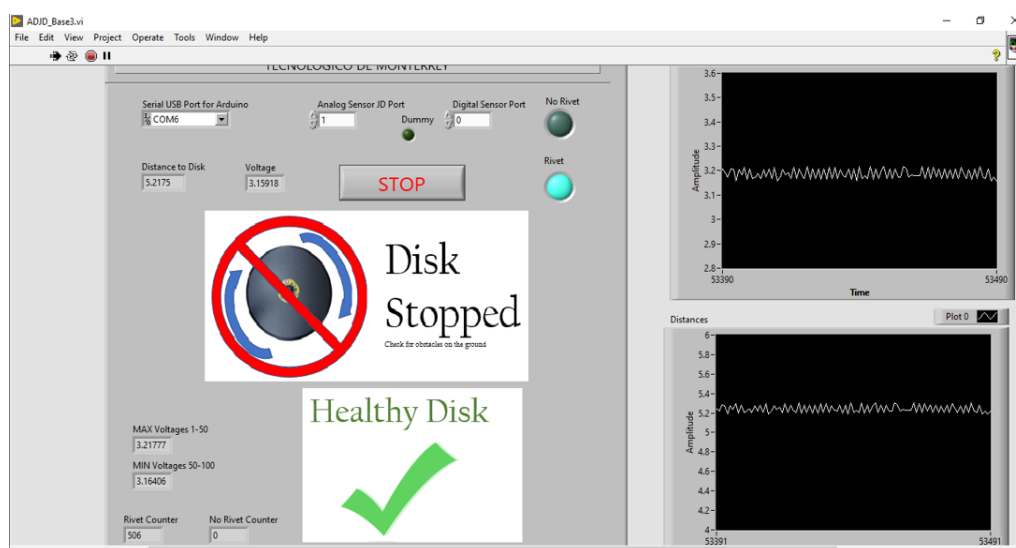


Figure A20. Picture of the HMI in the middle of operation, displaying the voltage stabilization when the disk is on a static position.

Videos can be viewed on the google drive folder of appendices, on the section “Pictures-And-Videos”.

Google drive with all appendices, including *.vi file, excel and pictures/diagrams:
<https://drive.google.com/drive/folders/1gpwOvuN8jRm3KeOZdgNTB6UPWmVDiJaq?usp=sharing>

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4. Product NI3.5-Q5.5-AP6X. TURCK. Retrieved from: <https://www.turck.us/en/product/4613601>