Drillbotics UND Design Submittal Package

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ABSTRACT

Drillbotics is an international design competition and is put on by the Society of Petroleum Engineers to further the development of autonomous controlled drilling rigs in the oil and gas industry. The UND design team embodies multiple students from different engineering backgrounds to co-operate and specialize in certain areas of the design process. The mechanical engineering group focused on the mechanical and dynamic design of the drilling rig, and control systems design. The electrical engineering group focused on sensor selection, circuit design, and control systems design. The petroleum engineering group focused on drilling fluid skid design, and system processes. A mixture of different analysis models consisting of analytical solutions as well as finite element models, Matlab simulations and programs, and Multisim circuit simulations. All calculations and simulations allude to an overall successful design. The process of completing the design gave all members of the team not only technical experience, but also collaborative experience on working on a multidisciplinary team to accomplish a large difficult project. The project is also designed to fall below the maximum budget of $10,000 with an expected expense of fabrication to be $7,000.

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INTRODUCTION

Drillbotics is an international design competition and is put on by the Society of Petroleum Engineers (SPE). The mission of this competition is to develop technology for completely autonomous drilling. The goal is to eventually have full scale drilling rigs that can complete the drilling process automatically with no human interaction that are being used in industry. SPE is helping develop the technology by putting on a competition for universities to design and fabricate small scale drilling rigs that can drill through multi-layer unknown rock formation samples that are supplied by SPE. Since the goal is to develop technology, the SPE introduces competition guidelines that challenge the designs such as but not limited to: limiting drill string material and size, drill bit type and specs, and stabilizer/centralizer limitations. The rock formation samples are provided by SPE and are designed to be challenging to drill as they may contain angled formations, washout zones, and more. Knowledge of the rock formations prior to drilling is unknown. After the competing teams are selected by SPE, they enter the build phase where the designed rig is fabricated and tested. At the end of the design phase, SPE representatives travel to the selected schools to test the drilling rigs where we are to drill through the rock formation samples supplied by SPE. The winner is selected by whoever can drill the deepest in the shortest amount of time.

The UND drillbotics design team is a multi-disciplinary team of engineering students in the fields of mechanical engineering, electrical engineering, and petroleum engineering. Each of the disciplines provide a necessary set of analysis and design skills required for such a large, broad project. The mechanical engineers were mainly focused in the mechanical design and mechanical system dynamics of the drilling rig, and control systems design. The electrical engineers were focused on sensor selection, control systems design, and electrical systems design. The petroleum engineers were focused on design and analysis of the drilling fluid skid. The follow sections in this design package report will go through and describe each of the critical systems and components as well as the design process for each system.

DRILL STRING MODELING AND ANALYSIS

Obtaining an accurate model and analysis of the drill string loading is the one of the most crucial parts of the design. Since all teams are required to use a specific drill string size and material, the UND design team decided to maximize the loading drill string to obtain a maximum ROP. Due to the small scale of the drilling rig, a compressive force must be applied to the drill bit to be competitive. The required aluminum drill string along with all the extra components of the composite drill sub, drill bit, and swivel assembly give the total length from platform to bit to be significantly large. Due to the slenderness of the drill string, buckling is a large concern when applying a compressive load. Using a Euler's buckling model, the critical load of the drill string was found to be about 25N. The selected model was a fixed-pinned system, the connection to the drilling rig is considered a fixed connection and the connection to the rock is considered a pinned reaction since the force of friction while drilling would help keep the system in a single location. A fixed-free end system was also modeled with a critical load being about 20N. Both of the analytical models were verified by utilizing finite element buckling analysis, which yielded similar results. The 20-25N compressive force was thought to be too low to be competitive. In response, the UND design team came up with a creative solution that falls within the technical rules of the drillbotics guidelines. The UND design team added a lateral support rigidly connected to the drilling platform which interfaces with the drill string as close to the critical mode deformation location as possible. The modeling of such a system became an issue, due to the spontaneous nature of buckling failure and the lack of stress-strain relationships for the failure mode. The Euler's analytical model becomes statically indeterminant when such a support is used. To accurately model the system, finite element buckling analysis was conducted and results are shown in figure 1 below.

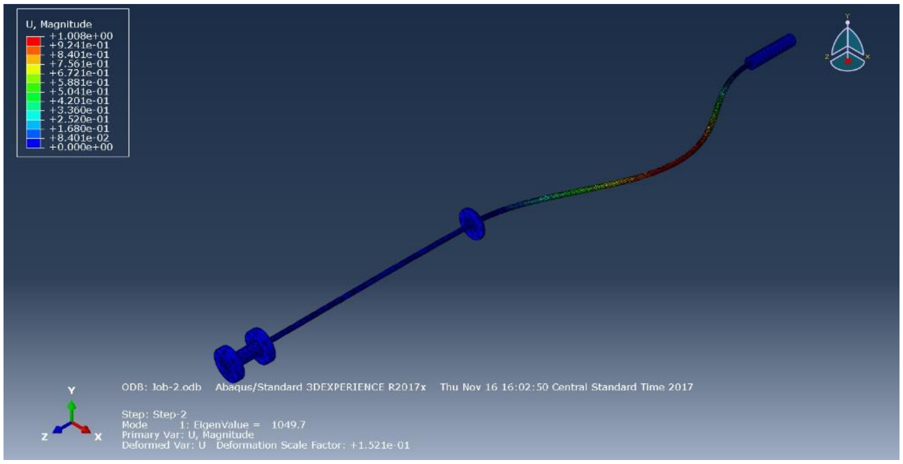

Figure 1: Finite Element Buckling Analysis of Drill String System.

The max critical load determined from the finite element model was found to be 700N with a 1.5 safety factor from unknown effects of tool joints. The new WOB was determined to be significantly high enough to yield competitive results. However, the drill string is not only subjected to a single compressive loading, but a combination of compressive force and axial torque yielding combined normal and shear stress. To obtain a maximum allowable torque for the system, two failure methods were evaluated consisting of maximum principal stress theory as well as maximum shear theory. A Mohr's circle with both models is shown below in figure 2.

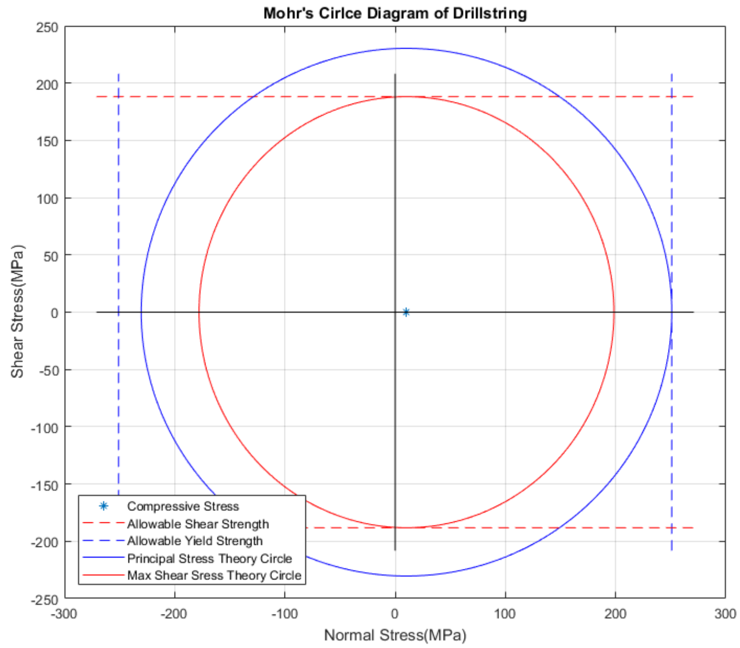

Figure 2: Mohr's Circle for Max Principal Stress and Max Shear

The compressive stress from the critical compressive buckling load is shown on the mohr's circle with a "*" on the normal stress axis with a value of 20.56 MPa. A set of red dashed horizontal lines are drawn to represent the max shear strength of the material with a safety factor of 1.1 and a value of 188.18 MPa. Similarly, a set of blue dashed vertical lines are drawn to represent the max principal stress with a safety factor of 1.1 and a value of 250.91 MPa. Two circles are drawn with the center starting at the applied compressive stress. The red circle is drawn to represent the maximum shear theory with the circle centered at the applied stress point and tangent to the shear strength line. The blue circle is drawn to represent the maximum principal stress theory with circle centered at the applied stress point and tangent to the closest principal stress line. It can be seen from figure 2 that the drill string will fail from max shear theory rather than max principal stress theory because the applied compressive stress is significantly low comparted to the material strength. Calculating the max allowable shear stress from the figure into max allowable torque yields approximately 22Nm with a 1.75 safety factor due to unknown effects from tool joints.

FUNCTIONALITY OF THE DRILLING RIG

The entire drilling rig assembly is made up in two main independent systems being the drilling rig and the fluid skid, with semi-independent sub-systems. The goals for the entire design was to design a safe system that is made up of independent components that can be easily changed without requiring a re-design of the entire system, while keeping high manufacturability, and high performance and quality. Each of the independent systems, sub-systems, and components will be discussed in their corresponding sections while the current section describes how multiple sub-systems and components make up the drilling rig system.

The drilling rig and fluid skid were designed to be independent systems so that the current and future UND teams can focus on optimizing smaller and more detailed portions of the system without requiring a massive re-design of the entire system. The both the drilling rig and fluid skid are shown together in figure 3.

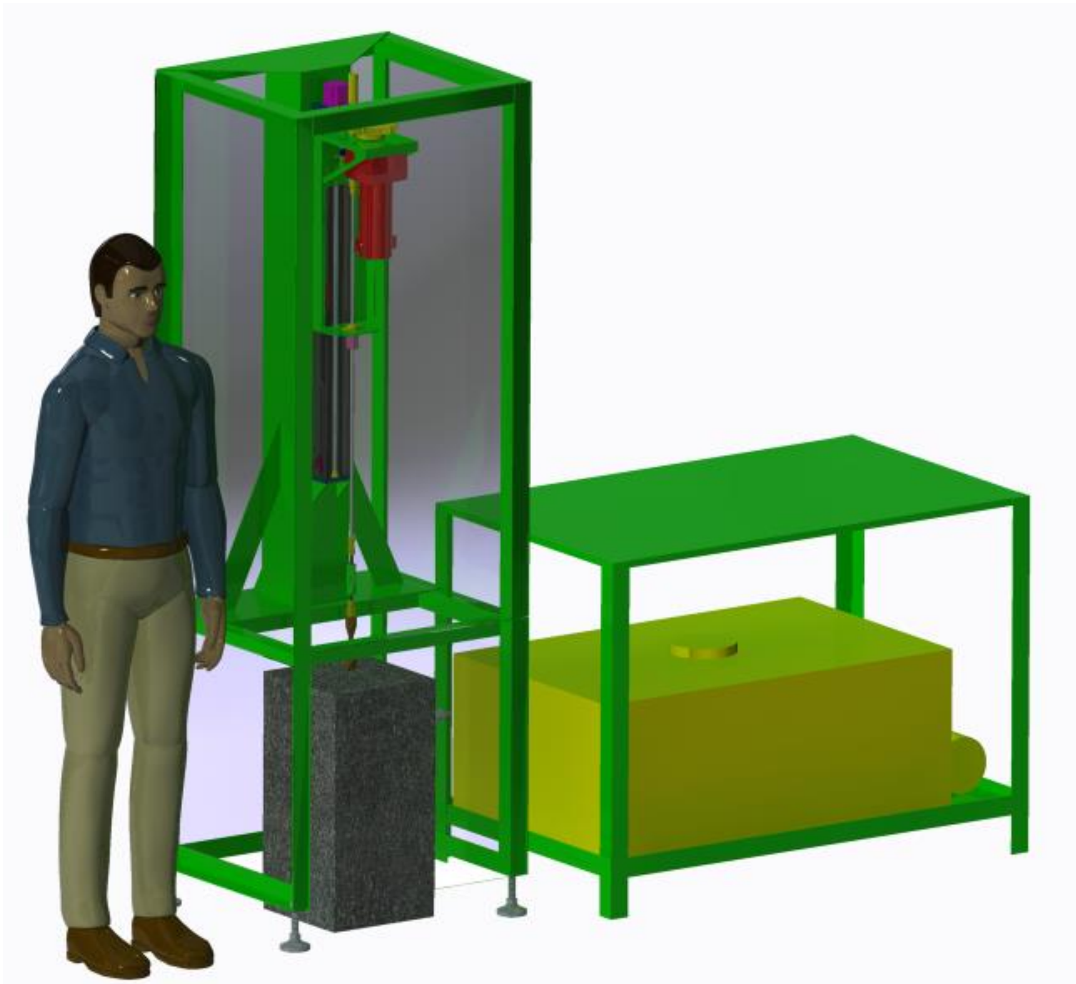

Figure 3: 3D Render of Drilling Rig (Left) and Fluid Skid (Right)

The drilling rig houses the rock sample in an enclosed chamber that sits on the ground. The rig frame extends above the rock sample, where a power screw linear actuator is mounted. The linear actuator moves the drilling platform assembly, shown in figure 5, in a vertical motion, while preventing any lateral movement, twisting, or bending. The drilling platform mounts two components; the swivel assembly shown in figure 7, and the drive motor. The drive motor turns the swivel assembly and drill string through a gear reduction transmission. All raw materials can easily and accurately be processed in the UND fabrication shop. Angle steel was utilized because of the flanges make welding and mounting components easy. Plate steel was utilized because the variety of shapes and geometries that material can be cut, bent, and welded into. Large tube steel was utilized for the high stiffness and mountablility. These materials are used to build most of the rig and fluid skid for easy manufacturing. The total rig weighs around 200 pounds and contains rubber feet to help minimize vibrations.

DESIGN AND ANALYSIS OF THE DRILLING RIG FRAME

The drilling rig frame was designed to be easily fabricated, while still being able to have all required functionality. Multiple styles of rig designs were considered, but the final design selected was a rig that is enclosed in an angle steel frame, with a single main structural pillar in the center. The single pillar design allows easy addition of the safety enclosure panels, which mount on the exterior flanges of the angle steel. This safety enclosure prevents any human interaction with the moving parts of the rig during the drilling process. The single pillar design is favorable over a multi-pillar design because of the difficult nature of aligning multiple pillars together on parallel linear actuators/slides. A multi-pillar design would reduce bending stress in the pillar and drilling platform. However, the UND design team preferred the more forgiving tolerances associated with the single pillar design. To minimize the induced bending stress, the drill string was placed as close to the pillar as possible, to lower the moment arm of the WOB. Angle steel beams and plate steel was added to specific areas of the rig to increase strength and stiffness.

Rather than conducting analytical stress calculations using simplified models, the UND design team opted to use a realistic finite element stress analysis model for analyzing the drilling rig frame. The model and element mesh under stress can be seen in figure 4.

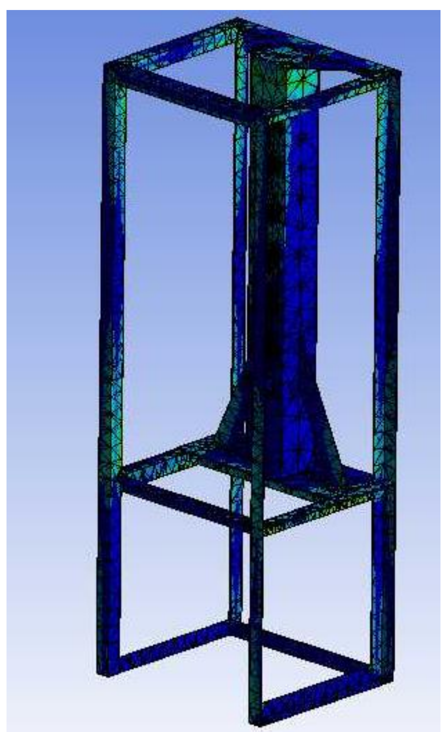

Figure 4: Finite Element Analysis of the Drilling Rig Frame

The loadings applied to the model are the type of loadings expected from the functionality of the rig. The loadings consist of a force load from the WOB, a bending moment from the moment arm of the WOB, and a torque from the drive motor. All values given to the loadings are twice as much as we are expecting for a few different reasons. One of the reasons being that the drilling rig frame is designed more for strain resistance rather than stress. Another reason is that the UND design wants to be able to utilize the rig frame for many years, so the team opted to design for loadings that might be higher in future competitions. The values for the loadings are 1400 N for the WOB, 179.8 Nm for the bending moment, and 40 Nm for the torque. The maximum stress from the given loadings was found to be 11.27 MPa, located at the angle steel below the main square pillar. Compared to the material strength of 250 MPa, these loadings yield a safety factor of 22.2. The large safety factor is desirable because of the design goals for the drilling rig frame.

DESIGN AND ANALYSIS OF DRILLING PLATFORM ASSEMBLY

The drilling platform was designed to mount onto the power screw linear actuator, and hold the drilling swivel assembly and the drive motor. A more detailed 3D render of the drilling platform and all mounted components can be seen in figure 5, as well as figure 6.

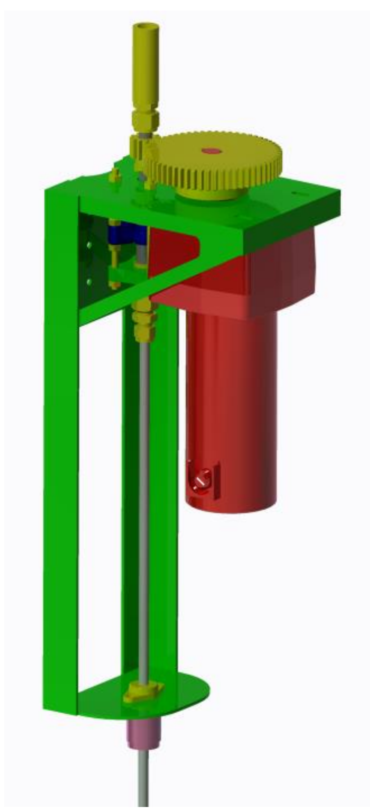

Figure 5: Detailed Platform View

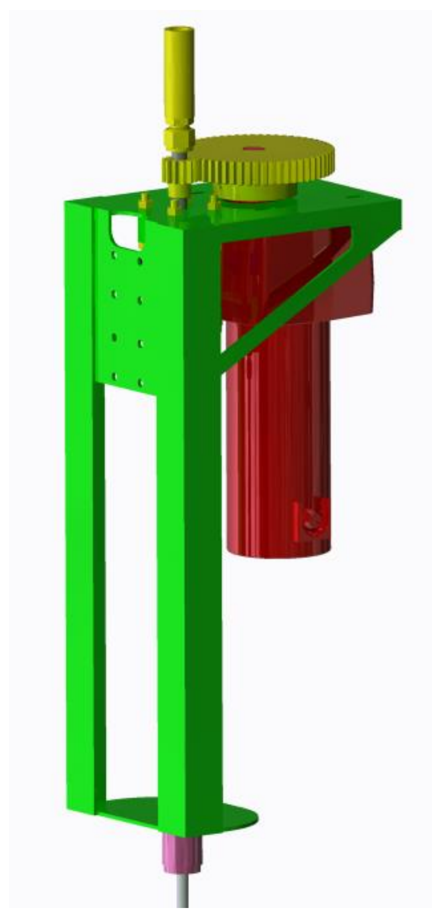

Figure 6: Detailed Platform View

The main mounting surface of the drilling platform is cut with a CNC milling machine, for highest possible tolerances. Mounting holes for the drilling swivel assembly are bored with a loose fit tolerance to give some minor adjustability. Slots are machined in for adjustable mounting of the drive motor. This adjustability allows for multiple gear ratios, and proper gear meshing. The platform assembly also acts as a stabilizer to reduce buckling of the drill string, and increase the WOB. As mentioned in the drilling rig design section, the drill string was designed to mount as close to the linear actuator as possible, minimizing the moment arm of the WOB. On the bottom side of the stabilizer is a mounted an electrical slip ring. This device allows wires to connect from the rotating sensors embedded in the drill sub, to stationary electrical systems mounted on the top of the fluid skid.

Similar to the drilling rig frame, rather than conducting analytical stress calculations using simplified models, the UND design team opted to use a realistic finite element stress analysis model to analyze the drilling platform. The model and element mesh can be seen in figure 7.

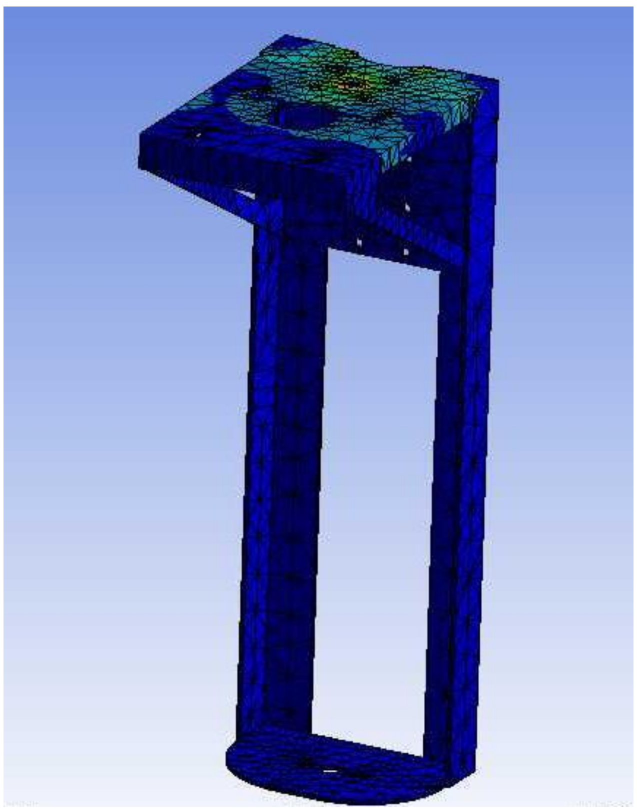

Figure 7: Finite Element Stress Analysis of Drilling Platform

The loadings applied to the model are the type of loadings expected from the functionality of the rig. The loadings consist of a force load from the WOB, and a torque from the drive motor. Values given to the loadings are twice as much as we are expecting for a few different reasons. One of the reasons being that the drilling platform is designed more for strain resistance rather than stress. Another reason is that the UND design team wants to be able to utilize the drilling platform for many years, and the team opted to design for loadings that might be higher in future competitions. The values for the loadings are 1400 N for the WOB and 40Nm for the torque. The maximum stress from the given loadings was found to be 212.65 MPa, located at the top plate steel. When compared to the material strength of 250 MPa, these loadings yield a safety factor of 1.23. This safety factor is significantly smaller than the drill rig frame, but it is still within an acceptable value for use.

DESIGN OF SWIVEL ASSEMBLY

The swivel assembly which connects to the drilling platform is made up of many components, some custom designed and fabricated parts as well as many purchasable parts, all which help accomplish a certain required task. The real challenge in completing the design of this sub-system is compiling all the custom parts with the purchased parts to yield a useable system. An exploded side view and an assembled isometric view are shown below in figure 8 and figure 9, respectively.

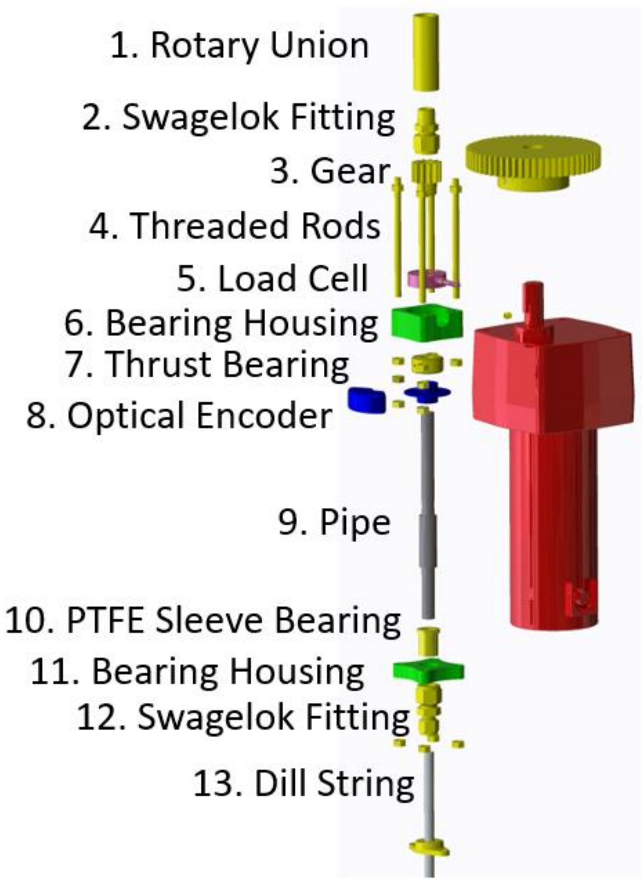

Figure 8: Exploded Swivel System

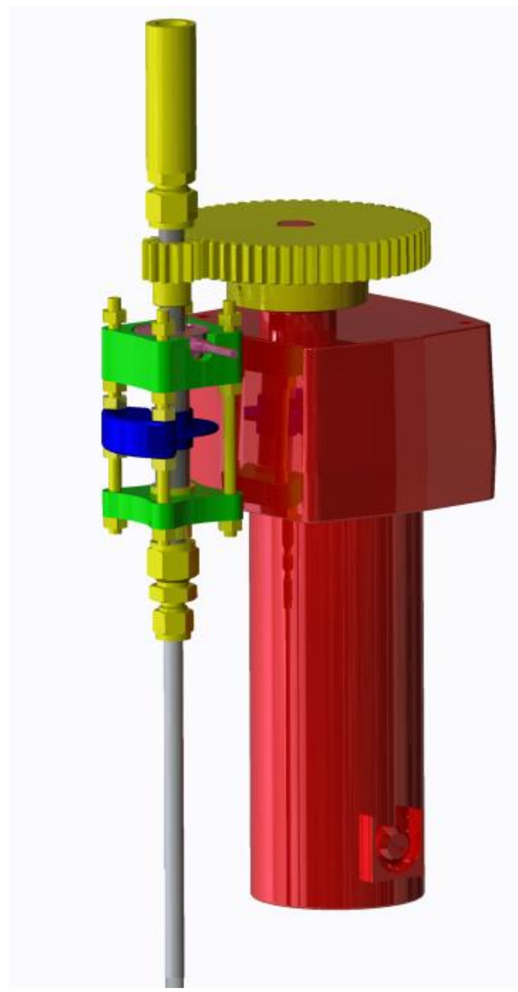

Figure 9: Assembly Swivel System

Many constraints were applied for the swivel system design each of which will be discussed. The major constraints consist of: allowing the connection from the rotating drill string to a stationary fluid system; allowing the measurement of WOB and RPM; allowing the mounting of drill string such that it can be compressed and lifted; allowing the disassembly and re-assembly of the system without the need of new parts each time; allowing the system to be once contained unit which can be removed from the drilling platform without the requirement of removal of each individual part.

The heart of this sub-system consists of the custom fabricated pipe, item #9 in figure 8. The part is made from a raw 3/8" sch. 80 stainless steel pipe. This size pipe was chosen so that the part can be turned down to a ½" hollow tube on the ends, while keeping the 0.675" pipe diameter in the middle. The ends are turned down with a lathe to allow connection of standard bearings (items #7 and #10) and Swagelok tube fittings (items #2 and #12) as well as given the part a shoulder to contact the thrust bearings for compression and lifting of the drill string. Alternatively, a standard round stock was considered for fabrication of the part, but it would be difficult to accurately turn down the interior of the part using boring bars on a lathe just because of the length. Being able to utilize a part that has an existing interior diameter was favorable, thus the standard pipe was sized and selected. The material was chosen to be stainless steel as it has a higher material strength compared to aluminum, but it more chemically resistant compared to carbon steel. The chemical resistance was favored for the freedom of using different drill fluids without the need to re-design or re-fabricate the pipe for the current and future UND teams.

On each end of the pipe, item #9 in figure 8, a Swaglok tube fitting is mounted as tool joints for connecting to the aluminum drill string as well as connecting to a standard rotary union. The Swagelok fittings are preferred as they allow the pipe and drill string to be thread less, which means there is less stress concentration and allows higher loading. The Swaglok fittings that are selected contain special PTFE ferrules so that the pipe in the swivel assembly does not get deformed on the ends. If the pipe were to be deformed, full disassembly would not be possible as other parts have to slide off the same ends.

Connecting on the upper Swaglok tube fitting on the swivel assembly in figure 8 is a standard rotary union, item #1. This standard rotary union is a key component of the swivel system, in that it allows the rotating drill string to connect to a stationary fluid delivery system. Luckily the UND design was able to find a standard, purchasable part that connects using standard pipe threads to the Swaglok tube fitting. The rotary union was sized to the proper RPM as well as fluid flow rate and pressure.

Within the swivel system assembly, the WOB measurement is made from a purchasable load cell, item #5 in figure 8. The load cell is an analog sensor which is discussed more in the controls and circuits design sections. The load cell is a pass through or donut type, which allows the pipe in the swivel system to pass through to connect to other components while being able to yield a measurement with a concentric interface. The load cell has a specific interface for loading, which was verified with the loading interface of the thrust bearing, item #7. The thrust bearing is required to allow the rotating pipe to interface with the stationary load cell, without scaring the loading interface of the load cell. Both the load cell and thrust bearing are contained in a custom fabricated aluminum mount, item #6. This aluminum mount allows the thrust bearing to move axially from the strain of the load cell without significant friction by utilizing a UHMW sleeve that interfaces between the thrust bearing and the mount. However, the mount does not allow any lateral motion of the drill pipe as the mount is fixed to the drilling platform by means of threaded rods shown as item #4. On the opposite side of the shoulder of the drill pipe is the other bearing and corresponding mount which also prevents lateral motion as well as preventing the drill string from falling out of the assembly while in tension during lifting processes. The bottom bearing is a simple PTFE linear bearing with a thick shoulder which is different from the top bearing, a roller thrust bearing. This difference is due to the fact that the drilling process is conducted while in compression, thus the bottom bearing has minor compressive loading and is not as critical as the upper bearing which is also in compression when the drill string is compression. The mount for the PTFE bearing also connects to the same threaded rods as the upper bearing mount. When the bottom mount is attached, the load cell is pre-loaded depending on tightening torque applied to the threaded rods.

The other critical measurement accomplished in the swivel assembly is the RPM measurement. This measurement is obtained by utilizing a custom made and designed 3D printed infrared optical encoder, item #8 in figure 8. The encoder is designed and printed by the UND design team has been tested for signal quality and system identification to determine the transfer function of the control systems which are further discussed in the circuits and controls design sections.

The last important component of the swivel system is the set screw mounted spur gear, item #3 in figure 8. The spur gear allows torque to be applied to the swivel system while being able to change out different motors without the need of a significant re-design. The placement of the spur gear was chosen in the shown location in figure 9 because no electrical wires or fluid lines come close the area. The concern was that electrical wires could accidently get sucked into the gears and rip out critical electronics during the drilling process.

The drive motor which connects through the spur gear transmission received a large amount of attention. A DC motor was the desirable motor type for the simplicity of circuits and controls, as well as well-defined torque curves. The challenge in the selection was determining the most ideal torque curve that could be applied to the system. The UND design team was able to simplify the process by using the calculated max torque of the drill string from the drill string analysis discussion which was 22Nm, as well as an ideal drilling RPM which was determined to be around 100 RPM. Over 30 different motors were evaluated with power ranging from 1/17 HP to ½ HP each requiring their own specific gear ratio to fit geometrically in the system. Each of the torque-RPM curves were plotted using Matlab and the curve that best fit the system with the required gear ratio was selected. The end torque-RPM curve is shown below in figure 10.

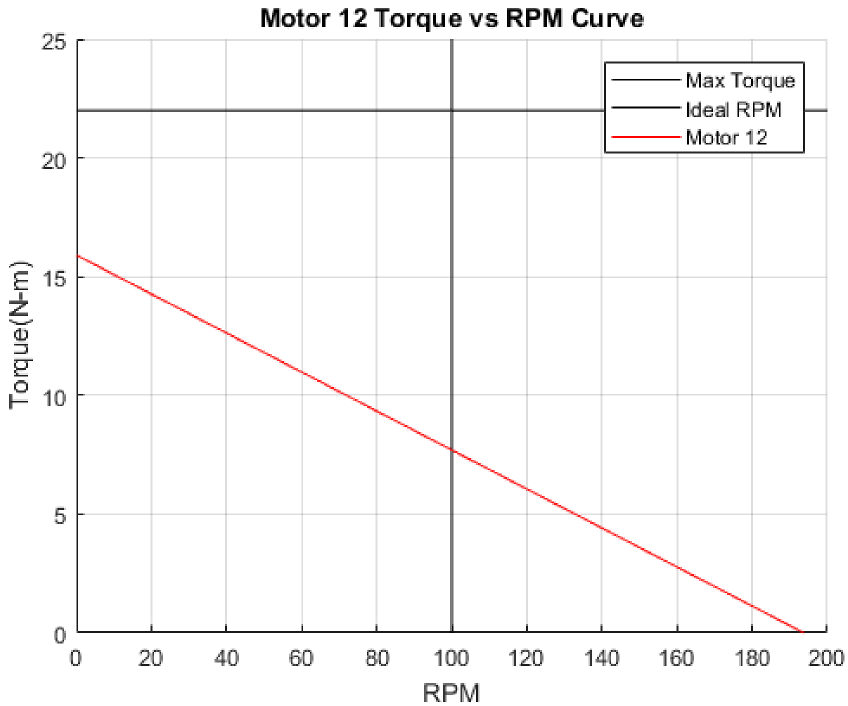

Figure 10: Drive Motor Torque-RPM Curve

This specific motor and gear ratio was selected because the stall torque at maximum voltage was the closest to the max allowable torque to the drill string without going over. This allows us to be sure that the drilling rig will not twist off the drill string due to unforeseen drilling conditions. As discussed in the platform design discussion, the motor and gear ratio can be easily changed without a re-design from the adjustability in the platform mounting.

DESIGN OF THE COMPOSITE DRILL SUB

The design of the drill sub was centered around embedding the sensors to be able to get accurate readings inside the drilling hole. This led to creating designs that could house these sensors and with stand the different loads applied to this important piece. Three designs were narrowed down that included a 100% carbon fiber drill sub, a metal rod with a 3d plastic sleeve, that would house the sensors, covered by thin sheets of carbon fiber, and a 100% steel sub.

The 100% carbon fiber sub was preferred because it was a unique way to solve the problem and would be extremely light weight. The problems with this is the ability to create this carbon fiber piece and the difficulty of threading such a small part. There are a lot of unknowns about this that seemed to create a lot of problems like how would a part like this perform under torque and force that is expected. The answers to these questions required a lot of testing and research so this idea was not chosen. The goal is to use this idea in the future when later generations have the ability to put it the required testing to make it possible.

The 100% metal sub was the simplest out of the three ideas. The only thing need to do was to machine a part with the required thread size and just attach the sensors to the inside of the metal tubing. This idea was not chosen because it did not show enough innovation compared to our other design. This idea was kept as an alternative design as a simple backup plan.

The design that was chosen was to a combination of all of the designs. To have the needed mechanical properties to withstand the torque and the force applied, round tubbing would be used and threaded with properties that can withstand the expected loads. A 3d printed sleeve was designed to create a housing to place the sensors in the right positions see Figure 11.

Figure 11: 3D Printed Drill Sub Sleeve

Over the housing part carbon fiber weave will be there to protect the sensors from any outside threats. This designed proved to meet our design goals of creating to making a part that can withstand the expected loads in a new and innovative way.

This sub will be made of one steel round tub, plastic, and carbon fiber weave. it will house six accelerometers to measure chance in direction in the different axes. It will also have two thermistors that will measure approximate temperature on the bit. Each of these sensors have redundancies that are there just in case one of the sensors break. Each of these sensors are positioned in the housing with ample room for wiring.

DESIGN AND ANALYSIS OF THE DRILLING FLUID SKID

A fluid system was designed to remove cuttings from the wellbore while drilling. In addition to removing the cuttings, keeping the bore clean and the bit lubricated are essential in maximizing the efficiency of the rig. The UND team designed a fluid system that will keep the bit free of cuttings and transport the cuttings so that mud logging may be performed during operation. With environmental and human safety in mind, the design team chose tap water over mineral oil or a mud-based oil. Initial calculations, with drilling maintained for two hours, put the cost of using alternate fluids well above several hundred dollars. Based on scale, water is sufficient as there is no need to account for extreme pressures, temperatures, and weight on bit associated with drilling at thousands of feet. The UND design team opted for a closed fluid system. This type of system allows for the recycling of the fluid, which keeps costs down, and minimizes rig floor space. However, to account for any fluid loss while drilling, the fluid reservoir is connected to a local water supply. An on-demand makeup valve is used in the tank, ensuring that the reservoir level does not drop below the minimum for continuous operation. Below is the schematic of the fluid system, Figure 12.

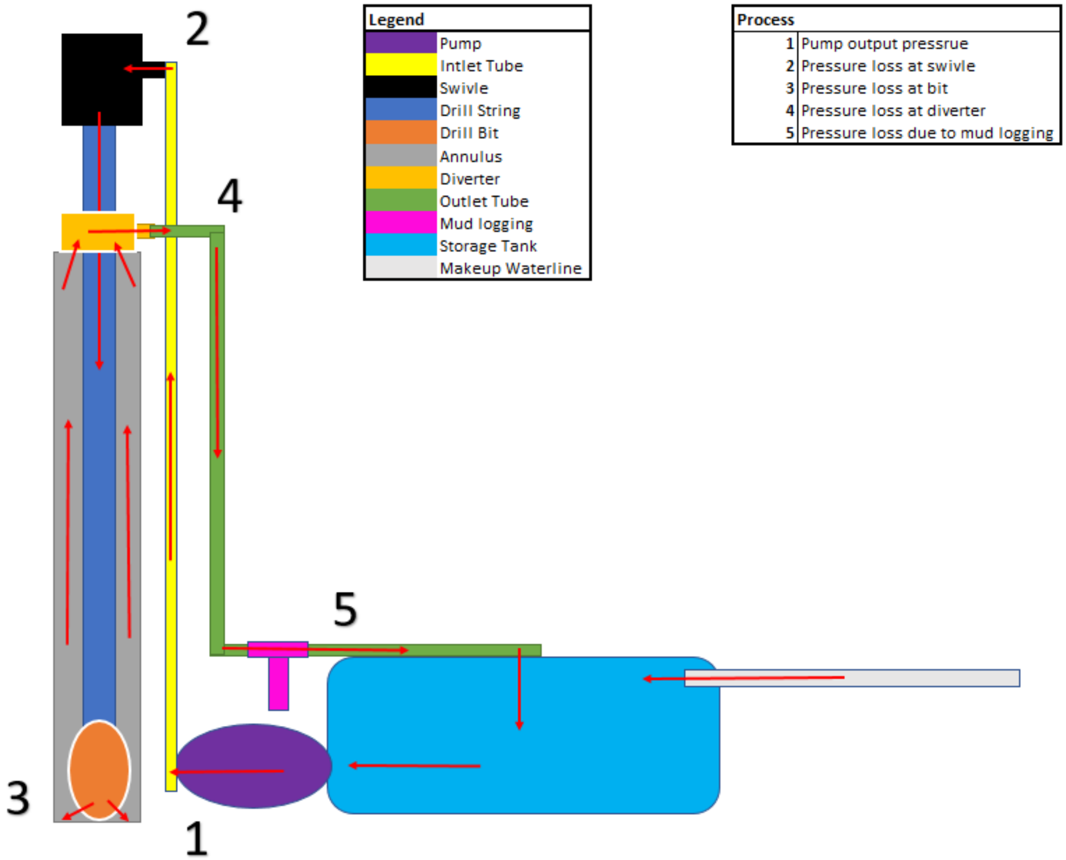

Figure 12: Schematic Representation of the Fluid System with Nomenclature

The design team has identified 5 points of interest that contribute to the pressure loss throughout the system. The fluid system team attempted to utilize industry-standard models for fluid flow and pressures. It was very quickly realized that these models, however good in full-scale use, do not scale down to values easily used for Drillbotics purposes. The team decided the best applicable model is the Hazen-Williams equation for turbulent flow of cold water. The Darcy-Weisbach friction factors for plastic and aluminum were calculated both separately and combined, as used in the final design. It should be noted that at the Drillbotics scale, using either 100% aluminum or 100% plastic in the calculations did not result in an appreciably large difference in flow rate or pressure change. The following pressures and volumes were calculated in Table 1.

Table 1: Fluid Pressure and Flow Rates

	Minimum	Nominal	Maximum
Water pressure in psi	43	47	53
Flow rate in US gallons per minute	3.0	3.3	4.0

In the event of water return loss, ie: the drill string penetrates a void in the rock sample, the maximum rates may be exceeded until water return has been restored. After exiting the return diverter, the water and cuttings will pass through the mud logging apparatus.

SYSTEM SENSOR SELECTION AND DESIGN

Sensors are an integral part of the control and operation of the drill. As downhole sensors are required by the guidelines, they will be used in tandem with surface mounted sensors to manage the drill. The plan is to combine a mixture of controlling sensors that will measure vital components to the drilling operation as well as data for collection similar to industrial LWD operations.

Originally, the proposal called for a range of LWD type of data. It was planned to incorporate a downhole gamma ray sensor as well as a sonic sensor. However, it was determined that there was not an appropriately sized gamma ray detector that could feasibly be placed in the drill sub at this scale. A similar situation was determined with the sonic sensor, as well as an issue of line of sight and transmission of data. With these two types of sensors determined unusable, a third option was proposed, Spontaneous Potential. Again, this was determined to be infeasible when calculations returned the likelihood of a too small sample size to have any sort of meaningful data. Following this reveal, the final feasible measurement that could be taken was temperature. Using mud-logging was another possible solution. In this method, a Geiger counter would be attached to the fluid skid and examines the debris as it passed through the fluid system. The final selection of sensors and their placement in the system is shown in table 2.

Table 2: Sensor Overview

Sensor	Measurement/Function	Location
Load Cell	WoB	Swivel Assembly
IR Phototransistor	RPM	Swivel Assembly
Accelerometer	Acceleration in Normal, Tangential, Z directions	Embedded in Drill Sub
Thermistor	Temperature (LWD)	Embedded in Drill Sub
Flow Sensor	Flow Rate	Fluid Skid
Geiger Counter	Gamma Ray (Mud-Logging)	Fluid Skid

A load cell was chosen as the preferred tool of choice to measure the WOB. A pass-through (donut) design was selected to allow the drill pipe to pass through while still receiving data, Figure 13. This sensor is mounted in a custom-made assembly onto the swivel assembly. As a vital sensor for the function of the drill, it will be connected directly to the Arduino control system.

Figure 13: Futek Load Cell

To be able to determine the RPM of the drill bit an optical encoder was required and the desirable mounting place for the optical encoder is in the swivel assembly. To fit within the special geometry allowed by the swivel assembly, the UND design team had to design its own optical encoder. The optical encoder is made of two basic components, the stationary caliper and a rotating rotor which can be seen in figure 14 in blue.

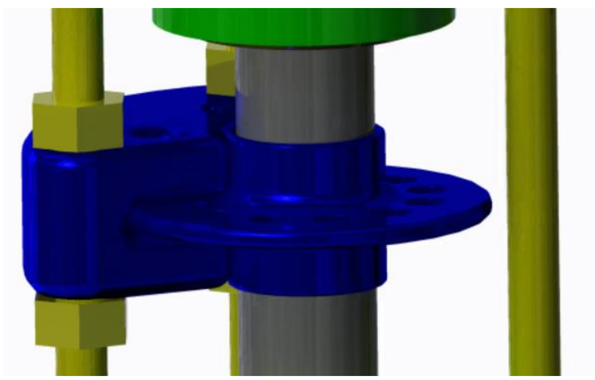

Figure 14: 3D Printed Optical Encoder

The caliper has holes for mounting constantly powered infrared LEDs as well as mounting infrared phototransistors. The rotor also as holes which are designed to allow light to pass through at certain points. The rotor is printed with 12 holes, for a faster reading of RPM compared to a single hole design. The optical encoder has already been printed and tested at UND with promising results.

The accelerometers are the first downhole sensors that were envisioned. These one-axis components will be used as a mandatory component to sense problems developing in the bottom of the bore. With six total to be embedded within the drill sub, 4 will be mounted tangentially at 90 degree offsets and 2 will be mounted axially. These accelerometers will help detect bit hop, stick-slip and whirl down at the drill bit.

Figure 15: Accelerometer and Breakout Board

A goal of the UND design team coming into this project was to have some sensors that can deliver some sort of data from the drill sub similar to LWD. One of the solutions that presented itself was to measure temperature. As a purely informational measurement, temperature will not affect the drill's operation. The information will be run to a display nearby the drill and show the data there. An NTC-type thermistor was chosen, Figure 16, due to the durability over the PTC-type thermistor and its size compared to the K-type thermocouple.

Figure 16: NTC-Thermistor

A fluid flow sensor is needed to measure and adjust the fluid system of the drill rig. This allows a look inside of how the fluid system is handling the debris from the downhole and the pressure. This component will fill a role as a vital control sensor. Figure 17.

Figure 17: Flow Meter

Having a Geiger counter is the design teams solution to having a lack of LWD sensors in the downhole assembly. It will be attached to fluid skid on the return side of the fluid system. As the debris is carried away, a reading will be given from the gamma in the waste. This is a form of mudlogging and will be treated as a simple data producing sensor.

With embedding sensors comes a slew of questions into the feasibility, and the how-to, of making them work. Originally, Bluetooth transmission of data was considered, this was determined to be unfeasible due to power and size issues. The proposed solution instead, was to wire the sensors up and down the drill string. This will be accomplished by placing an electrical slip ring at the swivel assembly. This will allow the wires to be run off the drill rig without tangling or causing it to wrap around the drill string. A common power wire and common ground will be strung into the drill sub and branch off accordingly. Each sensor will have its own output wire as the electrical slip ring contains enough slots for 12 separate wires. Figure 18 shows which sensors are used for controls and which sensors are used for data logging as well as noting their origin.

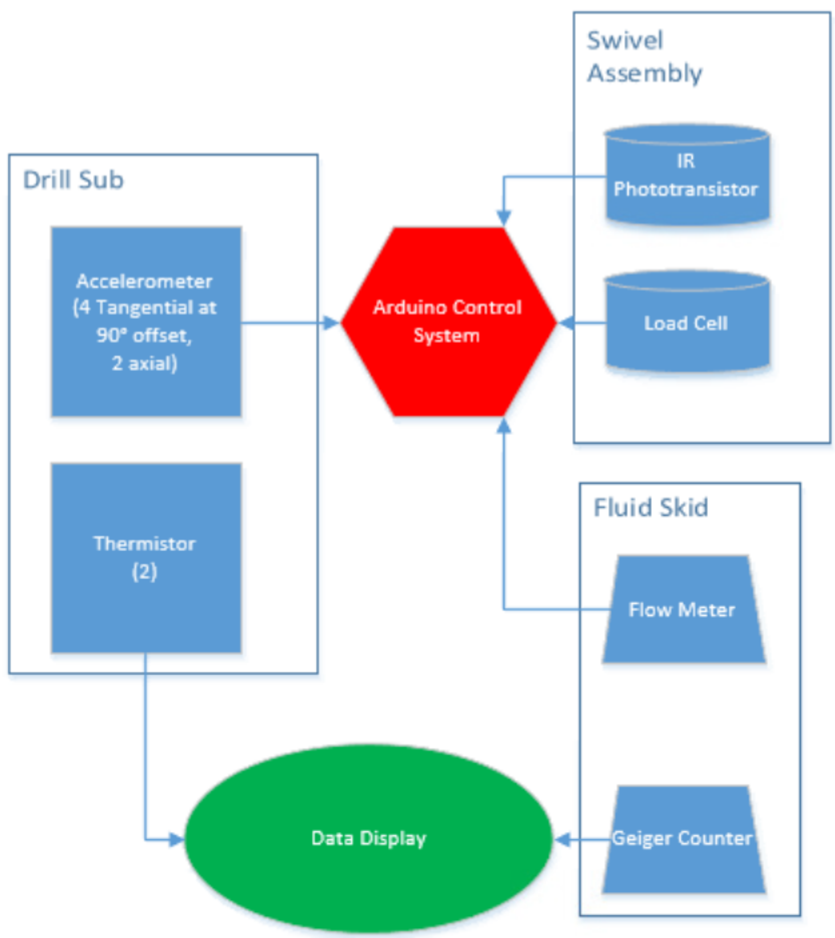

Figure 18: Visual Representation of Sensor Connections

DESIGN OF CONTROL SYSTEMS

When considering how the control systems would work for maintaining stability for the drilling rig, a few different ideas were considered but the layout in Figure 19 is what was finalized. The main aspect of this design is to have one main Arduino board that will serve as the main controller of the whole system. This main controller has logic programmed to determine the best drilling parameters of WOB, RPM, and flow rate based on feedback of the accelerometers and load cell. The main controller than outputs the desired setpoint to the independent PID control loops. In order to maximize ROP, the drilling parameters must be optimized for the specific rock formation sample and geometry. Since the formation layers and geometry are unknown, the system must be able to optimize the set points autonomously. To accomplish the autonomous optimization, the main controller continuously tracks downhole vibrations as well as WOB. This means that the system not only keeps the parameters at a certain setpoint, but it can vary the setpoint to maintain bore hole quality while maximizing ROP.

The first design of this control loop was based off a completely analog circuit by using an op-amp PID controller for the independent loops. However, this analog design did not allow for changing of the PID gains after the circuit was fabricated. Controller adjustability is crucial as it allows the UND design team to fine tune the system to obtain the most desirable dynamic response. The PID controllers are only needed for the top 2 portions of the diagram since the lower loop will be using a stepper motor. The dynamics of a stepper motor prevents the use of a PID controller as it is not actually a continuous rotational device. Future improvements to the system could be to exchange the stepper motor for a standard DC motor, and a similar PID controller could be utilized.

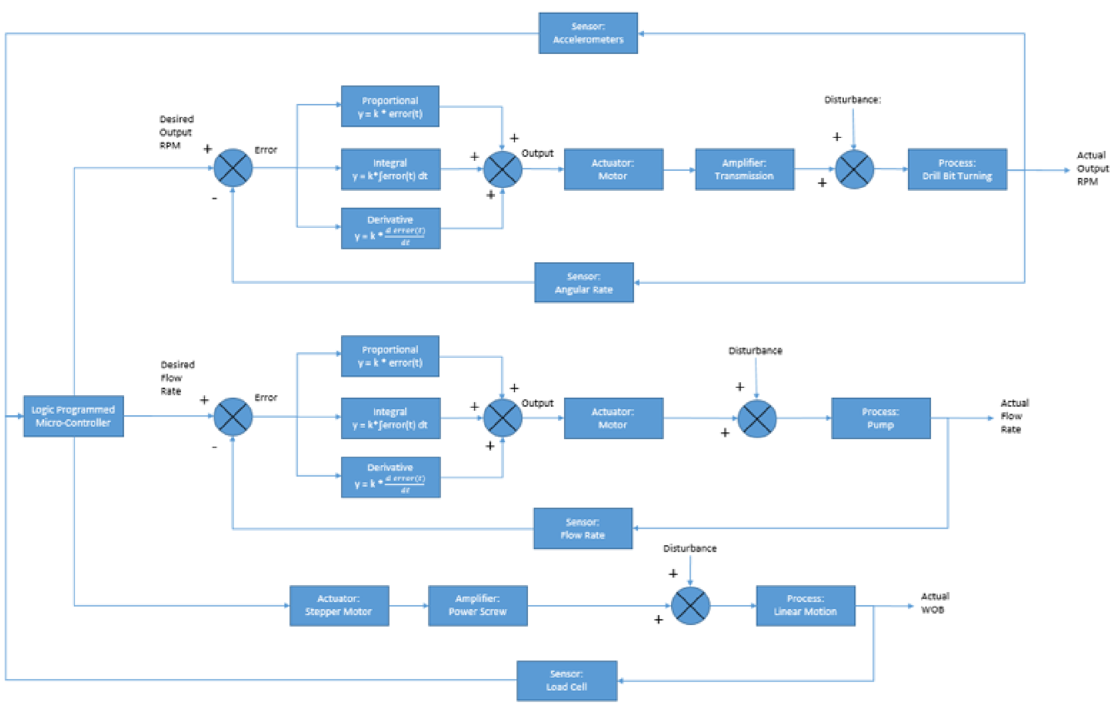

Figure 19: Control Systems Block Diagram

The PID controller gains will be selected to yield system stability as well as desirable dynamic responses. The control loops can be simulated in Matlab and the UND design team and employ design methods such as the Ruth Hurwitz stability criteria and the Root Locus method to determine the appropriate gains. However, the gains cannot be determined until the transfer functions for the physical systems can be determined by utilized system identification processes. The system ID process can only be completed after the physical system is built and data can be collected. The UND design team will use the Matlab Simulink package to determine the mathematical model of the transfer function of the system.

CONCLUSION

Over the past 5 months, the University of North Dakota Drillbotics design team successfully designed and verified an autonomous drilling rig and fluid skid. This started with brainstorming and basic designs, and quickly moved into design and analysis. The team has done 3D modeling, finite element stress analysis, Matlab simulations and calculations, and Multisim circuit simulations. The Drillbotics teams plan to set itself apart from the rest of the competition with a variety of specialty designed components and systems.

NOMENCLATURE

LWD – Logging while drilling

ROP – Rate of penetration

WOB – Weight on bit

IR – Infrared

PID – Proportional, Integral, Derivative

RPM – Revolutions per minute

UHMW – Ultra high molecular weight polyethylene

PTFE – Polytetrafluoroethylene

FEA – Finite element analysis

UND – University of North Dakota

SPE – Society of Petroleum Engineers