Solar Tracking Structure Design

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Team 07

Concept Generation and Selection

Document

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Contents

1. Introduction

The solar tracking system project is about designing and building a solar tracking system for solar panels as part of NAU renewable energy test facilities. The current solar panels are stationary, which is an inefficient way to collect solar energy during the day time. In order to maximize the power the solar panels produce, a solar tracking system is necessary. The conventional tracking systems are bulky, expensive and are usually unreliable. This needs presented by Dr. Tom Acker require the team to design a light-weight yet reliable solar tracking technology with a low cost. The prototype will be tested on existing fixed solar panels that are installed at NAU College of Engineering up at the shack.

2. Concept Generation

This report introduces 7 different design concepts with rough sketches. For each design, pros and cons are fully discussed in the report as well as general overviews of how the designs work. The final concept selection will be made based on the decision matrix at the end of this report. The progress of the project will also be shown at the end.

2.1. Standing Tripod Tracking system

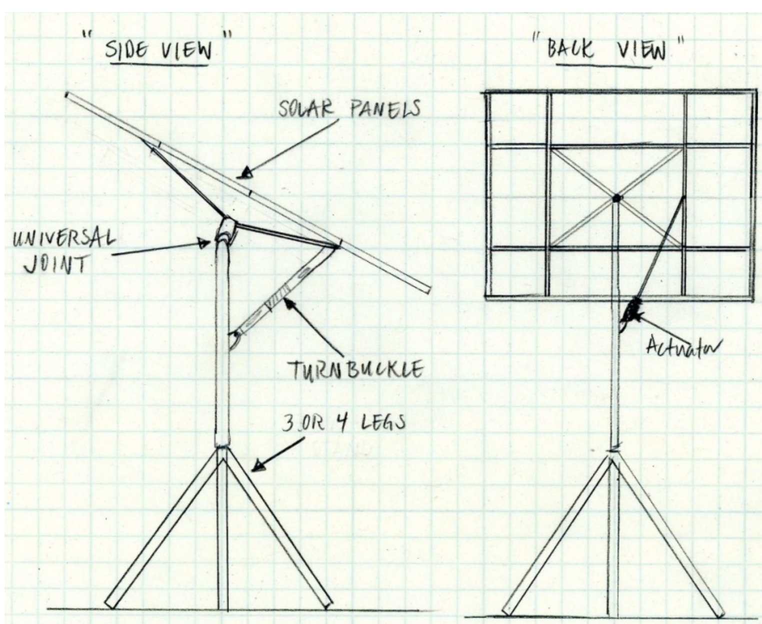

Figure 1. Standing Tripod tracker

Each team member formulated their own solar tracking design. All the designs are unique and have their own advantages and disadvantages. The main focus of this design is intended to be very simple and portable. The method of tracking on this design could either be used with a timer or multiple sensors mounted to the system.

The design of the tracking device is that the four solar panels are mounted into a tray-like device. With the panels all mounted together, it will track the sun as a whole throughout the day. This setup, will hopefully keep the panels from shading each other in the morning and evening hours. This design should be able to hold up to inclement weather, such as snow and wind. Since this design has not been through the testing phase, there is a lot of uncertainty about the survivability aspect. The panels would be both automatically and manually set for the best efficiency. The angles that the panels are to be set are not known at this point. The panels are to be set in the north-south direction using a turnbuckle. The turnbuckle would be tightened to aim it to the south and loosened to aim it to the north. For the east-west setting, it would be connected to an actuator that would automatically set the angle for the best efficiency. The apparatus that will house all four panels would be made of low carbon steel. The tray-like device would be comprised of 4 angle bars welded or bolted together to form a square. This material is chosen to use because it is readily available and rather inexpensive.

The tray-like apparatus will be mounted to a pipe then onto a universal joint. The universal joint could be from a vehicle’s driveline. The universal joint is to be used because it would not only allow east-west movement, but it will allow north-south movement as well. In addition, this part was chosen because it is readily available and inexpensive as well.

The base of this design is to either have three or four legs that will expand out into a tripod-like system. The purpose of the tripod-like system is for stability on level ground so that the tracking device will stay upright. The only thing with the solar panels being elevated, there is a potential that it could be unsafe due to the fact that it will not be very stable in inclement weather. To resolve this problem, the tripod could be designed with a wider span. One drawback that this could bring is that it could affect the portability of the design.

Advantages:

- Inexpensive
- North-south and east-west movement
- Portable

Disadvantages:

- Needs external power source
- Unsafe due to elevated design
- Can with stand inclement weather up to a certain point
- Manual setting on north-south axis

2.2. The half-cylinder design

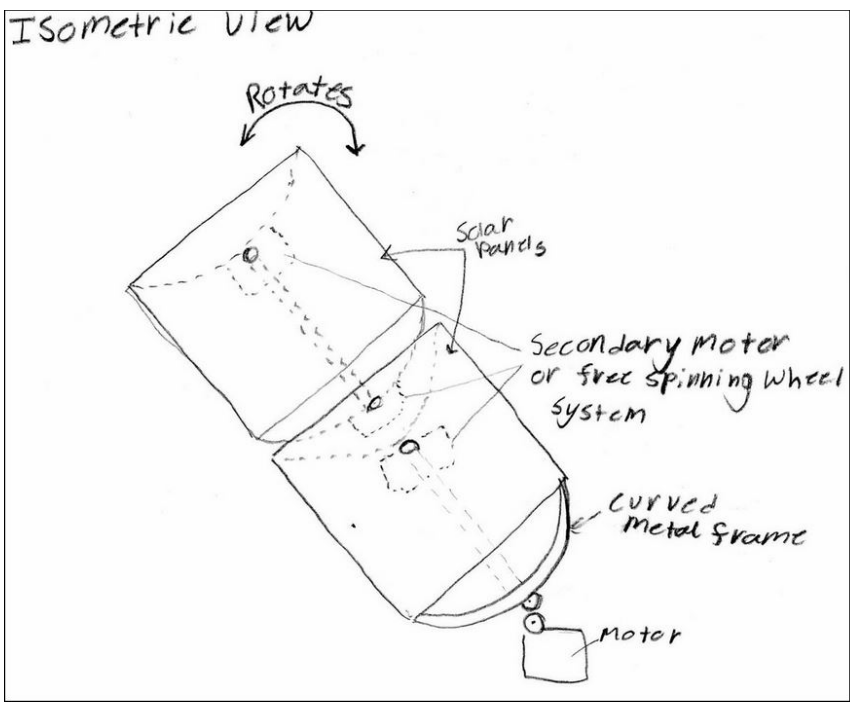

Figure 2. Half-cylinder design

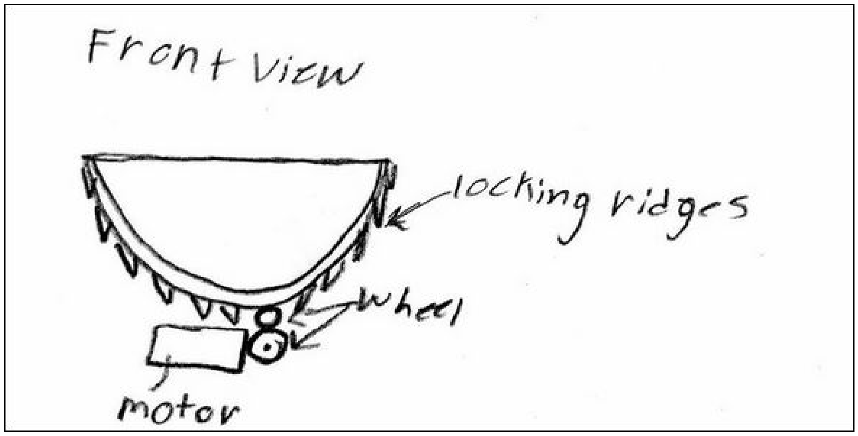

Figure 3. Wheel-assembly

The half-cylinder design is set to turn on a motor at a specific time thus rotating a specially designed wheel as seen in Figure 2. The wheel will spin a certain amount thus turning the half cylinder frame. The wheel will lock into preset grooves along the frame as seen in Figure 3. The frame will be made out of a material that can be bent easily and is should be relatively cheap. The solar panels will be mounted to the half-circular frame that has wedges cut into it to allow for a controlled movement of the half cylinder. The design calls for one powerful motor that rotates a specialized wheel seen below in Figure 4. The wheel will be attached to a drive shaft rotating the solar panels all at once. The design scored low marks in the decision matrix because of these key disadvantages.

Figure 4: Specialized Wheel

Advantages:

- This design has a unique design
- Can have multiple solar panels connected

Disadvantages:

- A difficult to manufacture frame
- It would require a powerful motor
- It would require a costly specialized wheel
- The design would be costly

2.3. The low-tech water clock design

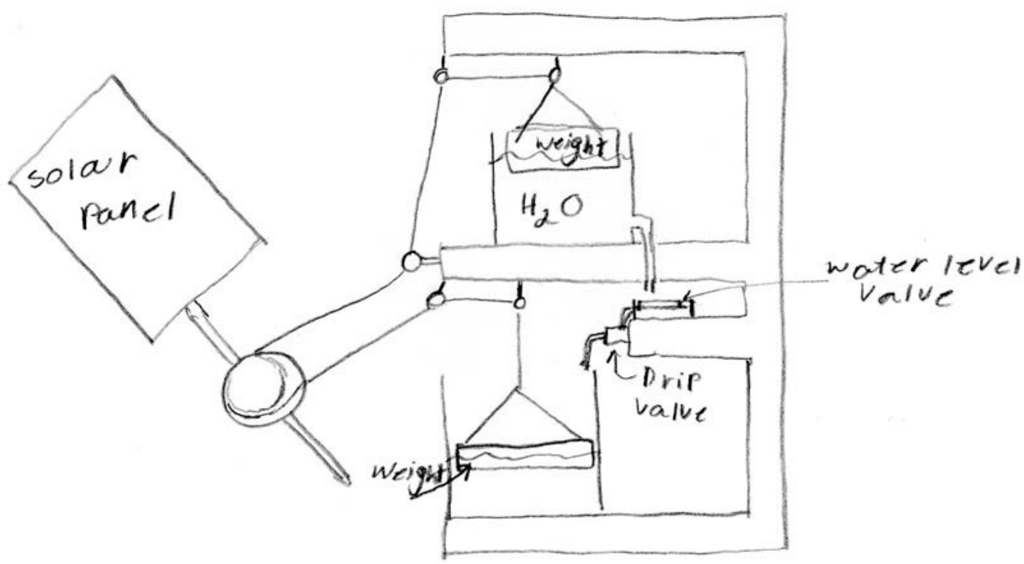

Figure 5: Low-tech water clock design

The design calls for the solar panel to be tilted so that it can be rotated via a cable and a round disk as seen in Figure x2. Weights that have buoyancy will be tied to cables and lowered until they float in water. The water will drain from the top tank into the bottom tank. This will cause the solar panel to rotate and follow the sun as it rises and sets each day. The tanks would need to be emptied and refilled the following day. This design could be modified with to use a motor thus eliminating the need for someone to add water to regularly.

Advantages:

- Does not require power
- The design can be modified to use power
- Innovative

Disadvantages:

- Requires constant maintenance
- Would require a liquid that would not freeze in the winter time
- Only works for one solar panel

2.4. Solar Panel Array

Instead of making individual tracking systems for each solar panel, having a single tracking system which can adjust all the solar panels in the system simultaneously can efficiently reduce the cost and efficiency of the design. This design is called a solar tracker array, which is shown in Figure 6. There are many different ways to connect and adjust panels in solar tracking arrays. The sketch shows a design using rack and pinion to pivot the solar panels. A rack and pinion is a type of linear actuator that comprises a pair of gears which convert rotational motion into linear motion. A circular gear called "the pinion" engages teeth on a linear "gear" bar called "the rack"; rotational motion applied to the pinion causes the rack to move, thereby translating the rotational motion of the pinion into the linear motion of the rack. [1] In the design, a solar panel is attached on an axis, which can rotate on the frame. All the axes are connected through the rack and pinion, which translates the motor's rotational motion to the axes' rotational motion. Since all solar panels in the system have the same motion, only one sensor and motor are needed to pivot all solar panels.

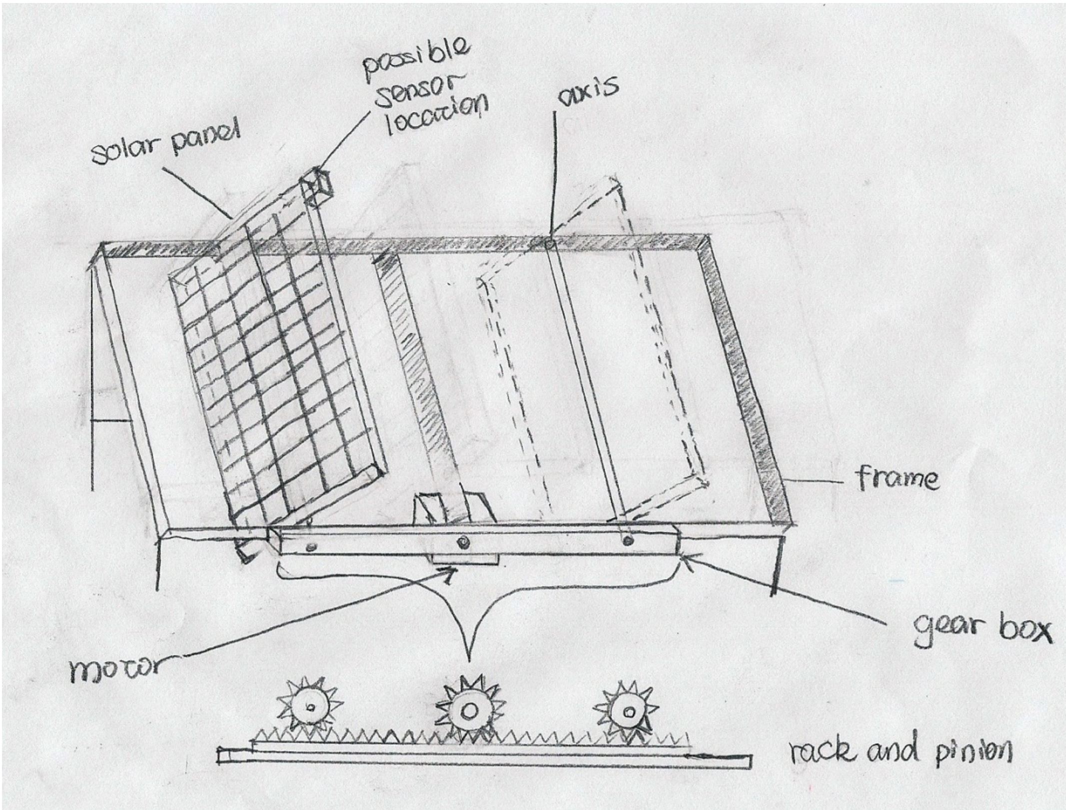

Figure 6: Solar Panel Array

This design is setup for East-West rotation of the solar panel. North-South orientation needs to be preset on the frame based on where the system will be located. For places such as Flagstaff, North-South rotation is not necessary compared to the cost of adding another degree of freedom to the system.

<u>Advantages:</u>

- This design has been done before with different connections between solar panels, which means there is plenty of information around.
- Based on the way all solar panels are connected, this can have really simple structure.
- Only one sensor and motor are needed to pivot all solar panels, which can reduce the cost.

Disadvantages:

- Large amounts of torque are needed since the single motor has to rotate all the solar panels in the system. The more solar panel in the system, the more torque that will be needed to rotate them.
- This system also needs a large working space to avoid solar panels shading each other once they are being rotated.
- There is a potential for high maintenance because of the rack and pinion gear system.
- External power source is needed to power the motor.

2.5. Angled Solar Tracking system

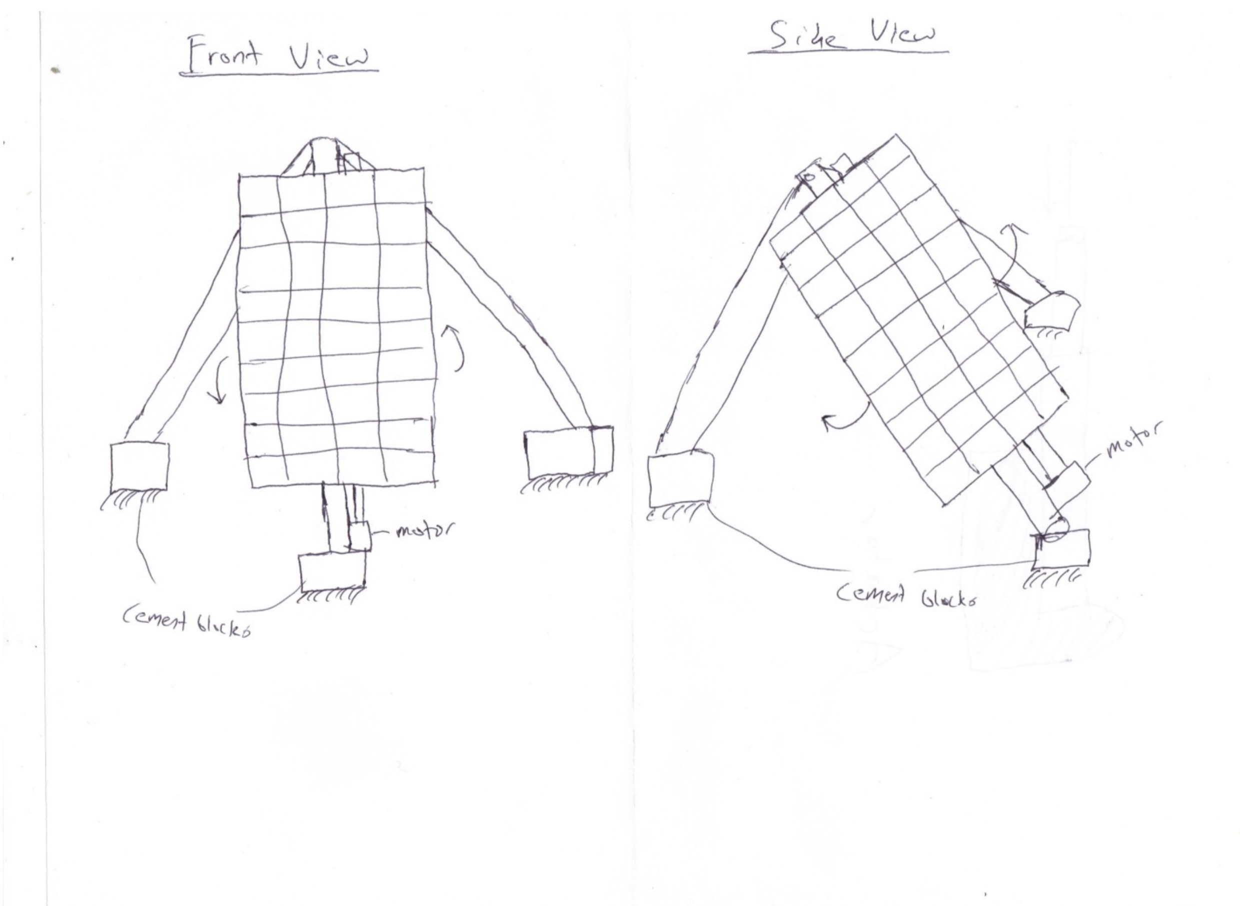

Figure 7: Angled tracker design

The general concept of this design is to have the solar panel at an angle that is capable of allowing the solar panel to track the sun in an east-west direction through the sky. The angle has yet to be determined for the most efficient way to absorb energy and effectively track the sun. However, the solar panel being angled only requires a simple tripod design to support the solar panel itself. The poles of the tripod can either be semi-permanent, held down by sand bags or other weights, or permanent with the poles being cemented into the ground or cement blocks above the ground for each support. The solar panel itself is laid down on top of the long pole in the middle which is connected to another pole which rotates the panel through the use of actuators or a motor of some type.

Advantages:

- This design has been done before with different variations in design such as two supports instead of three, which shows that the design works.
- Simple design
- Relative low cost depending on the materials used for the supports and motor/actuator systems.
- Only moving parts are the motor/actuator systems along with the pole that the solar panel sits on.
- Could be designed as either an active or passive tracking system.

Disadvantages:

- This design is not new so it would be unlikely that we could market the design outside of NAU.
- Requires external power to power the motor/actuator system depending on what we choose.
- Only works for one solar panel.
- Takes up space that would require the other solar panels to be spaced further apart from each other which might be a problem with the amount of space up at the shack.

2.6. Nitinol Solar tracking system

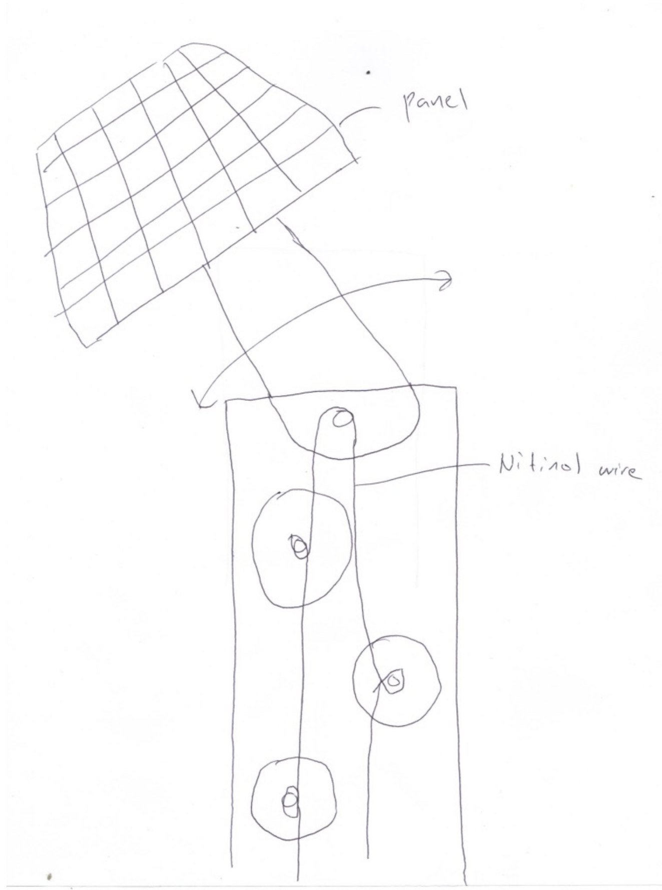

Figure 8: Side view Nitinol tracker

To understand how this design works it helps to know what Nitinol is and what some of its engineering characteristics are. Nitinol, which stands for nickel-titanium (NiTi), was discovered at the Naval Ordnance Laboratory in the 1950s. Nitinol is considered to be one of the more common types of SMAs (Shape Memory Alloys) which exhibit two important characteristics known as the "*shape memory effect*" and the "*pseudoelastic effect*". The "*shape memory effect*" is a property by which very large mechanical strains can be recovered above a critical temperature. The "*pseudoelastic effect*" is a property by which the material exhibits a very large strain upon loading that is fully recovered fully when the material is unloaded. [1]

Within the context of this design to achieve the shape memory effect current is passed through the lengths of the Nitinol wire to move the pulleys that would then pull the solar panel in an east-west tracking pattern. As the current passes through the Nitinol it heats up causing the "*shape memory effect*" to occur which contracts the wires and pulls the pulleys thus pulling the solar panel one way or another. After the current is shut off the wire will return to its original shape and thereby return the solar panel as well to its original position.

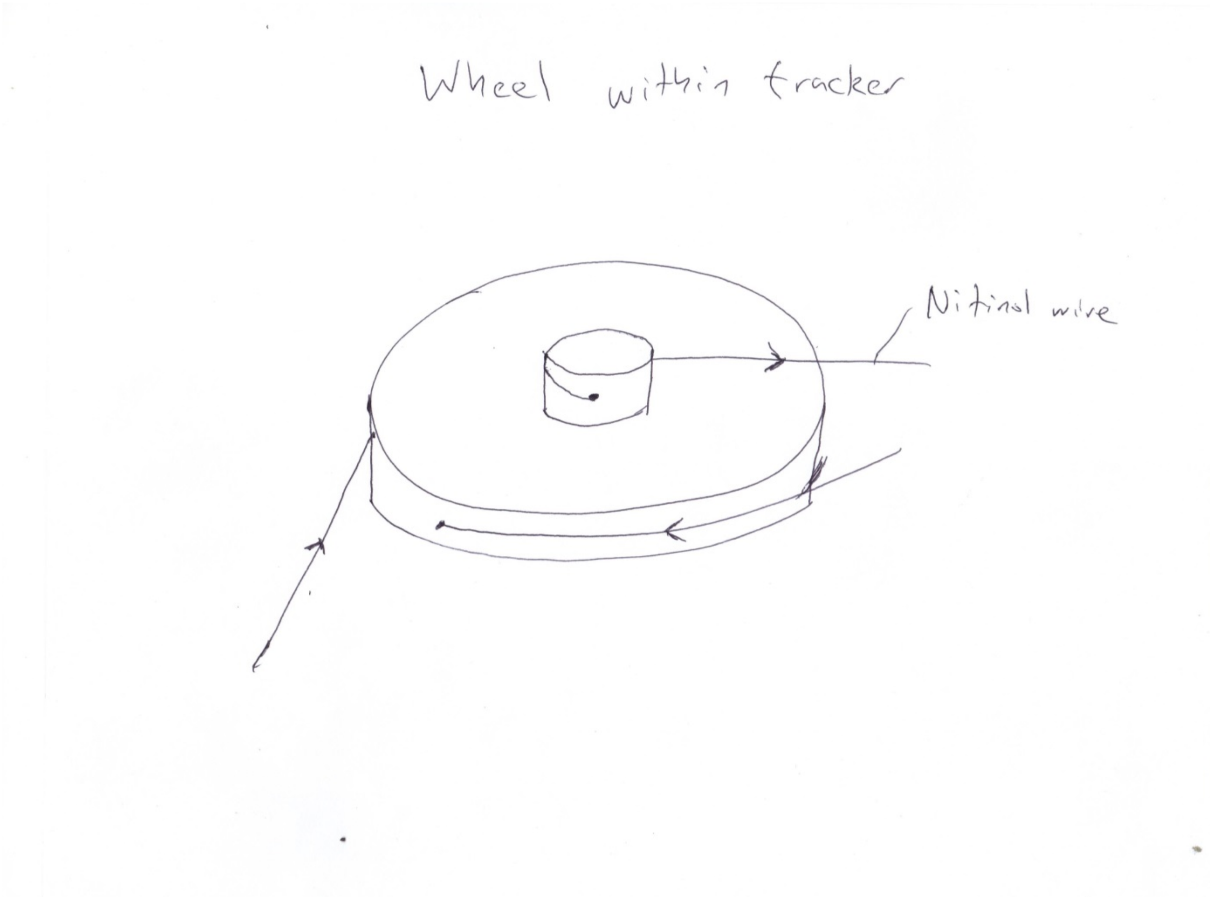

Figure 9: Nitinol tracker wheel close up

To better understand how the Nitinol wire moves the solar panel and wheels we drew this sketch of one of the wheels. The wires are connected to the wheels sides and top so that when the wire under goes the "*shape memory effect*" the wires will contract and pull the wheel in one way or another as the figure above shows.

Advantages:

- Simple design in that the only moving parts are the wheels that move the solar panel.
- If the design were successful could be marketed to other customers besides NAU.
- The housing structure of the Nitinol pulley system could be setup horizontally or vertically to save space
- A system of this design could be used to move all four solar panels

Disadvantages:

- Design has not been used before sow we don't know how effective the design would be.
- The amount of Nitinol required would be large to ensure it could pull the pulleys and the solar panels.
- Due the large amount of Nitinol wire required the price would be high.
- Nitinol as well as other smart materials are still being heavily researched since not all of their characteristics have been explored. There are still many unknowns of how to use these materials effectively in design.

2.7. Hydraulic Ball Joint

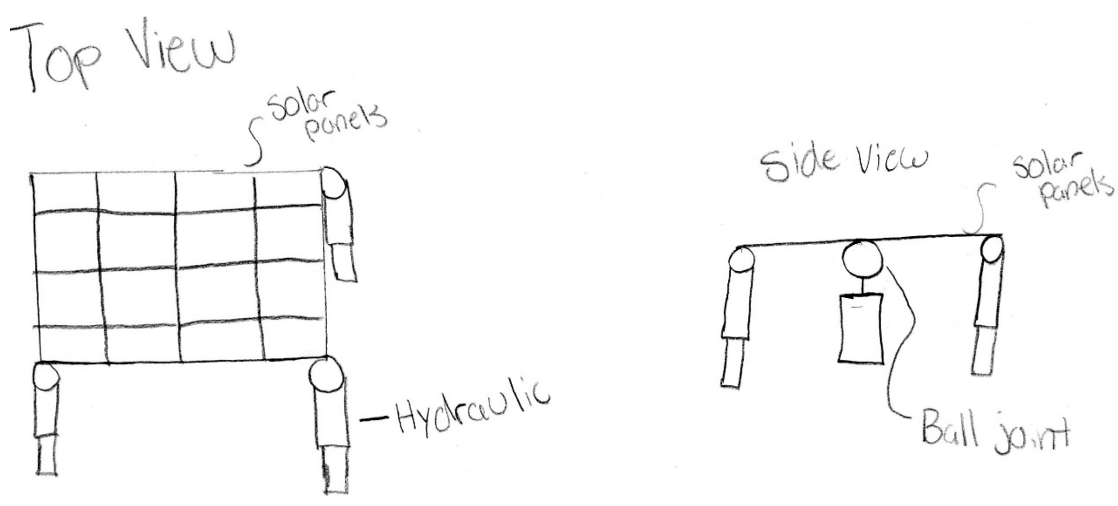

Figure 10: Hydraulic tracker design

The hydraulic design uses hydraulics to move the solar panels and a ball joint to hold the weight. With hydraulics on each corner this allows for dual axial tracking, which tracks the sun north and south over the year and east to west during the day. The design could be passive or active tracking depending on the hydraulics. Passive hydraulics would have a low boiling point fluid in the hydraulics and would be heated up with solar rays. The active hydraulics would be magneto rheological hydraulics. This hydraulics could use a magnetostrictive fluid when coupled with a magnetic field they become useful in controlling motion.[1] This system would be controlled with an electric pulse. The passive does not use any power from the solar panels but won't be as accurate as the active tracking. The reason being it takes it takes time to heat up the fluid and with cloud coverage it could throw off the tracking for the day. The active tracking takes some energy but increases the efficiency of the tracking. The reliability of the ball joint design is unknown and team does not have the time or money to build a prototype or test that is the main reason why the team did not pick this design.

Advantages:

- With the hydraulic design there are no gears or motor needed.
- The design could use either passive or active components.

Disadvantages:

- The design would need a huge ball and joint support.
- The uses of smart materials can be costly.
- The design is an untested.

3. Concept Selection and Decision Matrices

To decide between the 7 concepts that our team generated we decided to come up with 7 categories to judge our designs with 7 categories:

- Reliability
  - Does the design work consistently?
  - How often does it break down?

- Cost
  - The price of the design all together.
- Safety
  - Does the design present a danger to anyone in operation or when it fails?
- Maintenance
  - When the tracking system breaks down how much does it cost to repair?
  - How many man hours and parts are needed to repair the tracking system?
- Survivability
  - Can the tracking system operate effectively in the weather of Flagstaff and other potential market areas?
  - For Flagstaff pacifically, can the tracking system remove snow?
- Efficiency
  - How much energy does the tracking system allow the solar panels to absorb?
  - How much energy is required to move the system?
- Light weight
  - How heavy is the design?
  - The lighter the design the easier it will be to install and move the design if necessary.

As well as coming up with these 7 categories to judge our designs we weighted each category from 1 to 7, 7 being the most important and 1 being the least important.

Lightweight (1): lightweight was assigned the value of one because it was a self-imposed objective by the group and not an actual requirement of the client. Also the only benefit that being lightweight gives is that it is easy to move around and install if necessary.

Survivability (2): We gave survivability a 2 because most solar tracking systems available today are capable of being implanted in the flagstaff area. However survivability is more important than being light weight because of the added secondary objective by our client and team that the tracking system be able to remove snow from the solar panels.

Maintenance (3): Received a 3 because simple maintenance was one of the objectives stated by our client that he would like us to consider in our design. However it is only a three because high maintenance is acceptable if the tracking system improves upon the efficiency, reliability, and cost of current designs which are weighted more heavily in our decision matrix.

Safety (4): We gave safety a 4 because anything that engineers design should be considered safe to operate around people or during maintenance. Safety is important as well due to the fact that Dr. Acker wants the systems to be used for his renewable energy classes to demonstrate ideas from the class in real life. However these systems are not as important safety wise as say bridge so that is why it received a 4 instead of a higher score.

Efficiency (5): Efficiency received 5 out of 7 because current solar tracking system designs are pretty efficient and significantly increasing the efficiency of the solar panel is beyond the scope of this project. However the solar tracking should be more efficient than the current stationary rack system that the solar panels are sitting on now or there would be no point to designing the solar tracking systems.

Cost (6): Cost was the second most important factor in our design matrix because the cost of current solar tracking systems is too expensive for Dr. Acker to purchase for the school. We also want our design to be competitive if the design were to be marketed.

Reliability (7): Reliability is the most important category in our decision matrix because current solar tracking systems are unreliable in that they break down often and require replacement and maintenance. Current solar tracking systems are also unreliable in that their ability to be a consistent energy source. Dr. Acker also emphasized to our team that this was the biggest reason he gave this project to our capstone group.

For both of our decision matrices we went with a simple system of grading each design according the each category with 1, 0,-1, 1 being good or achieving the necessary goal, 0 being neutral and -1 for not achieving the goal. We decided to go with this system for our decision matrices because of advice we received from Dr. Nelson. Basically the 1 to 10 scale normally used in most decision matrices however Dr. Nelson said that this method is often used by engineers who have lots of knowledge or experience in design.

However, us as students do not have a large amount of experience in design and we do not have a lot of experience in solar energy. It is easier for us to decide if a design fully meets or doesn't meet the goal compared to saying it received 5 out of 10.

Table 1: Concept decision matrix

	Safety	**Cost**	**Light weight**	**Efficiency**	**Maintenance**	**Reliability**	**Survivability**	
Weighted Importance	4	6	1	5	3	7	2	**Total**
Designs								
Half Cylinder	0	-1	-1	1	0	0	1	0
angled tracker	1	1	0	1	1	1	1	27
Solar array	1	1	0	1	0	1	1	24
ball joint	1	0	1	1	1	1	1	22
Nitinol tracker	1	-1	1	0	1	1	1	11
Water low tech	0	1	-1	0	-1	0	1	4
Standing tripod	0	1	1	1	1	1	0	22

With the results from the decision matrix we have decided to move forward with three designs. The three designs being the angled tracker, solar array, and ball joint systems. We are going to move forward with the three designs because they all came relatively close to each other with scores of 27, 24, and 22 respectively. So as the team moves ahead we will put two members onto each design for engineering analysis of each design to see which of the three is best and possibly propose all three designs to our client Dr. Acker.

Passive and Active Tracking Selection:

There are three factors to decide between active or passive tracking. The factors are:

- Cost
    - The price advantage of the type of tracking

- Efficiency
    - The ratio of energy gained for tracking over the energy loss because of tracking
- Reliable
    - The maintenance of the design

Each factor was also given a multiplier weight by the ranking of importance. The value of the multipliers on the passive and active tracking is different than the design matrix because this matrix is about finding which type of tracking is better not better design.

Cost (1): Cost was rated the lowest at one because the cost can really depend on the design but passive has a built in advantage in cost so it need to be included on the decision.

Reliable (2): The weighted value of reliability was a two because once again depends on the design but active has a clear advantage in withstanding weather conditions

Efficiency (3): Efficiency was rated the highest value with three because active tracking is overall more efficient than passive tracking

Table 2: Passive vs. active systems

	Cost	**Efficiency**	**Reliable**	
Weighted Importance	1	3	2	**Total**
Active	-1	1	1	4
Passive	0	0	1	2

Passive:

Passive tracking uses methods that do not require the conversion of energy to electricity in order to track the sun. The most common is a low boiling point fluid hydraulic. This is a non-precision technique but does not require any additional power from the solar panels. The reliability of the hydraulics in the weather is subpar. These reasons are why passive tracking is less common than active tracking.

Active:

Active tracking uses motors and gears to track the sun. There are many more designs and tested designs with active tracking. The additional small load on the solar panels adds a tremendous amount of efficiency in tracking these are the reason why active tracking is more common.

Dual and Single Axial:

The two types of axial rotation are north south and east west. North south tracks with the change of the season and the height of the sun. East west tracks the sun from sunrise to sunset from day to day. A single axial design can have only one or the other type of rotation. A dual axial rotates both north south and east west. Since the height position of the sun does not have a large range in Flagstaff the value of energy of single axial produce in a year is $727.09 and dual axial is $776.56 with a difference of $49.47. To design a tracking system that can do both north-south and east-west is waste of time and money. [3]

4. Projection Plan

The team has closely followed the timeline that was created in the beginning of semester. Still, there were a few changes and delayed in the Gantt chart. The research and design tasks work should have been done by Oct, 23rd, in actuality, our team finished and finalized all the design concepts on Oct, 25th. The design concept selection task was added to the original Gantt. The design concept selection task was added to the original Gantt which was missing. Due to this reason, the Numerical modeling task will be delayed at least three days and start on Monday, Oct, 28th. The original Gantt chart and undated one are shown in Figure-11 and Figure-12 below:

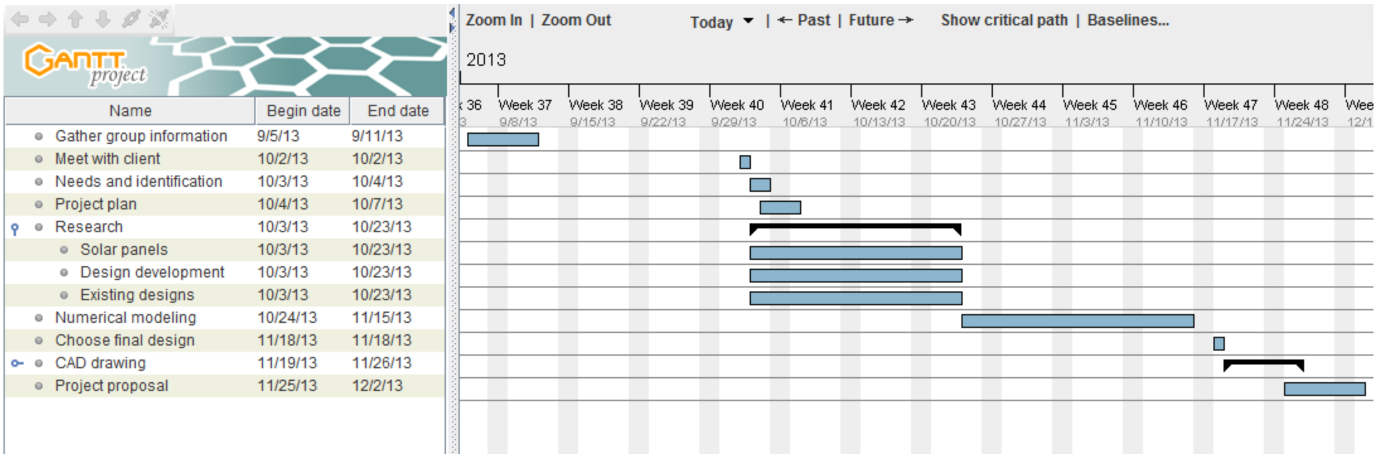

Figure 11: Original Gantt chart

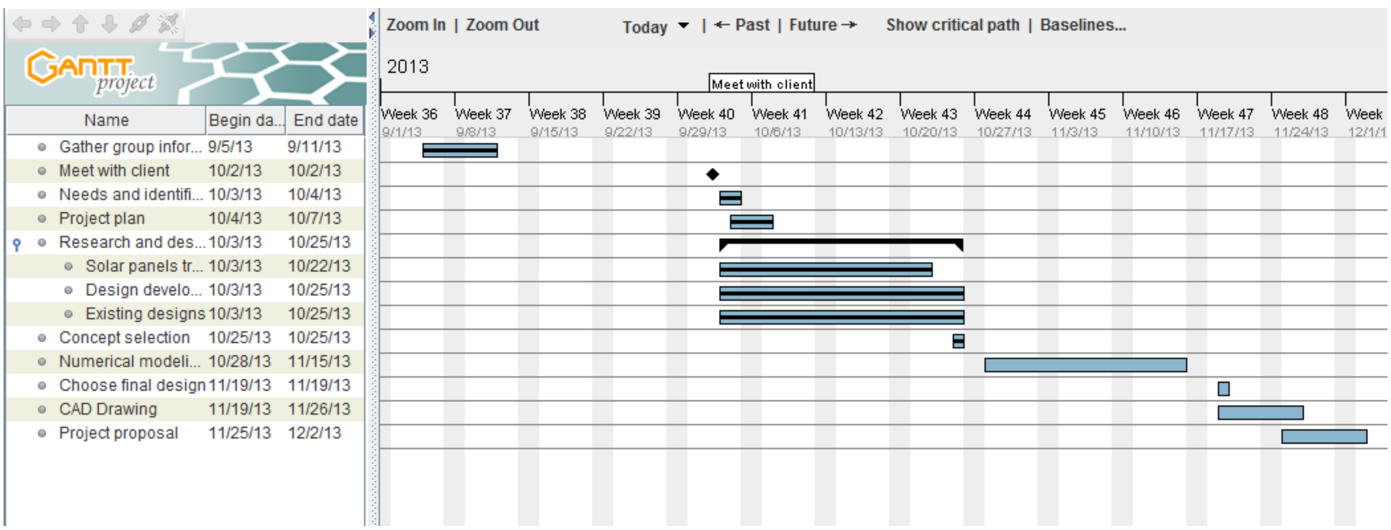

Figure 12: Updated Gantt chart

5. Conclusion:

For this report our group came up with seven different concepts for the general design of the solar tracking system that our client Dr. Acker wants. A majority of these concepts could have used passive or active tracking systems. To decide which design concepts were the best our group created a decision matrix made only for the tracking systems and we came up with three final designs that we will move forward with in the future. These include the angled tracker, ball joint, and solar array. However, we decided to make a separate decision matrix to decide between active and passive tracking methods and came to the conclusion that active would be the better choice of the two. Our group also updated our current progress and moved some dates around in our Gantt chart.

6. References:

1. Budynas G., Richard, Nisbett J., Keith, 2011, "Shigley's Mechanical Engineering Design", Ninth Edition, McGraw-Hill, New York, New York
2. Leo J., Donald, 2007, "Engineering Analysis of Smart Material Systems", John Wiley & Sons, Inc., Hoboken, New Jersey.
3. (2008). " PVWATTS: Arizona – Flagstaff." PVWATTS Calculator <http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/US/code/pvwattsv1.cgi >(Oct. 26, 2013)