Automation of a Solar Panel Cleaner on Mars

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Introduction

There are a multitude of rovers and science probes on Mars and most of them are powered by solar panels. There are many problems with this. One of them is that the solar panel will be covered up with dust as time passes. Dust storms only make this worse. The sand on the solar panels reduces the number of photons that can hit the solar cells and this decreases the amount of energy that the solar panels convert. Mars is also further away from the sun. The further away from the Sun the solar panels are, the less efficient the panels become. The increase in power from the solar panels will improve the quality of life and capabilities of future colonies and rovers on Mars.

The engineer aims to fix this issue by upgrading a vacuum cleaner that will remove the dust and/or sand from the solar panel, thus allowing more photons to hit the solar cells. The vacuum cleaner is moved back and forth three times to remove as much dust as possible. It is moved by a pulley system, with the spools being powered by a Spike Prime Lego set. This set has a control block (the main power source) which is connected to two motors that drive the spools. The pulley is set at the opposite of the solar panel and pulls one of the threads coming from the pulley.

Continuation

This project is a continuation of a project that the engineer did in 2022. This original project was a primitive design but proved that it was possible and also showed that it had potential . The previous design had only one motor so it could only go one way. It was manually operated so that made it less reliable. This new version is more focused at improving the amount removed and automation.

Engineering Goal

The engineering goal was to improve the design from 50% to 75% efficiency, as this would lower the power consumption of the machine by 50%. Incorporating a color sensor that detects when the solar panel is covered with enough dust and sand would half the number of times the machine has to be run.

Background Research

When humans eventually go to Mars, there will be rovers and spacecraft going to Mars. These crafts will most likely be powered by solar energy. Sand and dust covering solar panels make them produce less electricity. Lack of electricity can cause failure of heating systems, science equipment, and oxygen supply. This may make Mars travel even harder than it is by making equipment fail or destroy itself. The solar panels on two Mars rovers (Spirit and Opportunity) became filled with sand and dust. As a result, the solar panels could not produce enough electricity so they had to shut down the heating. This caused the systems to fail in Mars's freezing temperatures, according to these two NASA articles NASA (2008) And NASA(N/A).

Water is not used in this design because water is heavy, thus making it hard to get to Mars. Water is also better used for human consumption where it can be recycled, like in the Apollo missions. Water can also freeze if not heated, and heating takes electricity. Nasa has used another way to clean solar panels, but these methods only work in very specific locations and circumstances. The tilted winter strategy is the current strategy used by NASA. This method relies on winds and the rover to be a specific way, but it is unable to be done on command, is a natural occurrence, and is not toggleable as stated by NASA (2017). There is another method that uses a small excavator, as stated in the article by NASA/JPL-Caltech(2021).

The engineer believes humans will be using something other than MMRTG (Multi-mission Radioisotope thermoelectric generator). These are generators that use the heat emitted by the plutonium and thermoelectric generators to convert that heat into electricity. Because they are dangerous and have never been used on a US space mission as its main power source. It was used, however, on some of the later Apollo missions as stated by NASA(2013) as a power source on some science modules. These RTGs (RTG is another name for MMRTG and vice versa) ran for another eight years after being left there by the Apollo mission.

An MMRTG also emits a lot of heat as stated by UCLA(2023) making it difficult, if not impossible to have them inside a closed environment like a Mars habitation module or space station. Temperature is what they use to generate electric power. Radiation is also a problem with MMRTGs as they use the isotope Pu-238 as their heat source, as stated in Jiang's (2013) paper. MMRTGs are also a lot more difficult to maintain than solar panels. They are also extremely expensive. MMRGTs cost approximately 130 million dollars, which accounts for 20% of the cost of a non-manned spacecraft's spending on nuclear power. The fuel used for MMRTGs is also rare and not very common as in Lal's (2018) article. The Mars colonies will most likely be powered by a combination of solar and nuclear.

Pictures of the Mars rover Opportunity show that the solar panel has been covered in orange Mars dust. To solve this problem in this year's design the engineer has decided to try to implement a color sensor. This color sensor might be able to detect the specific color of orange and the current shade of orange so that the machine can also work both automatically and manually. The automation is useful because it reduces the workload of the astronauts and the manual mode means it can still be operated in case of a failure of the color detecting system. The two new brushes on the side are going to be used to funnel and move the sand to the middle where the vacuum cleaner is.

The addition of a box covering the gear mechanism is because Mars dust is very likely to get stuck in gears and electronic parts as stated by Hille (2015). Because the dust particles and sand are very small, 4 to 30 times smaller than on Earth as stated by this article by Nasa(2023). The small size makes it hard to keep the sand out of the sensitive equipment. To simulate the Martian sand, we used regolith. Regolith can be hazardous so we had to use gloves and masks when working with it.

Another problem on Mars is to avoid the machine being damaged by the extreme cold temperature during the Martian nights. Making the machine concealed means that the machine does not get as damaged as if it were outside and gets frozen and damaged by wind and dust.

We used Lego because it is very durable and this is only a proof-of-concept. The lego also has fewer hazards involved like not having a chance of cutting off your fingers like with wood while using power tools. This is because of its friendliness and ease of use due to the fact that it's easy to connect. If something breaks in the mechanism, the engineer can just change it with another part. The new design also makes it easy to upgrade and improve the machine by switching out modules or changing the code of the machine. The last improvement was the change in testing material from normal sand to a Mars sand simulant; it is around twice as light and it also contains different elements according to The Martian Garden. (2023). Some of these elements can be used for making equipment on Mars like containers and tools.

Pulley system

The reason the engineer has chosen the retraction and pulling method is that it is the most compact. This method is light on the engines, requiring less power compared to if the engine had to make the entire mechanism move. The alternate method of mounting the entire assembly and making that move is much heavier because it has to move the rechargeable batteries, the motors, the gearing, and the control unit. By contrast, the retraction and pulling method only has to move the vacuum head and is thus more stable compared to the heavy and bulky method where the entire thing has to be. The upgraded version should be more efficient because the machine can pick up 78% of the sand compared to 50% of the old version. The machine also uses half of the energy compared to the old version because the old version has to run twice. The leftover energy may be used for more experiments or heating. The design choice of making the pulling mechanism retraction and extension is so that not only can it go one way. The old version could only go one way so when it had gone all the way up it had to use gravity to move down. This can cause issues when the solar panels move so that they face the sun. The programming makes it potentially able to go for multiple rounds when it decides to activate or is manually activated.

Spike Prime

The spike prime is a Lego robot that is used in this project; it includes a power brick, 3 motors, and a couple of sensors.

Parts of the machinery

The machine consists of four major parts. These are the two motor assemblies, the power brick, and the pulley system. There is one big motor and one small one. They are attached with a spool through an axle and the spool has thread wrapped around it. This thread is spooled up and unspooled depending on the way that the vacuum cleaner head needs to be pulled. The motor assemblies also have small rings that the thread leads to to guide the thread. The pulley is attached to a yellow plate which is attached to the base plate. The power brick is what powers the machine. The power brick is powered by a battery pack and is connected through Bluetooth or a wire which is how the code is uploaded to the power brick. The code is the default one used in the Spike Prime software. The program code consists of two functions. One of them moves it towards the pulley and one moves it away. This is then set in a loop that runs it 3 times.

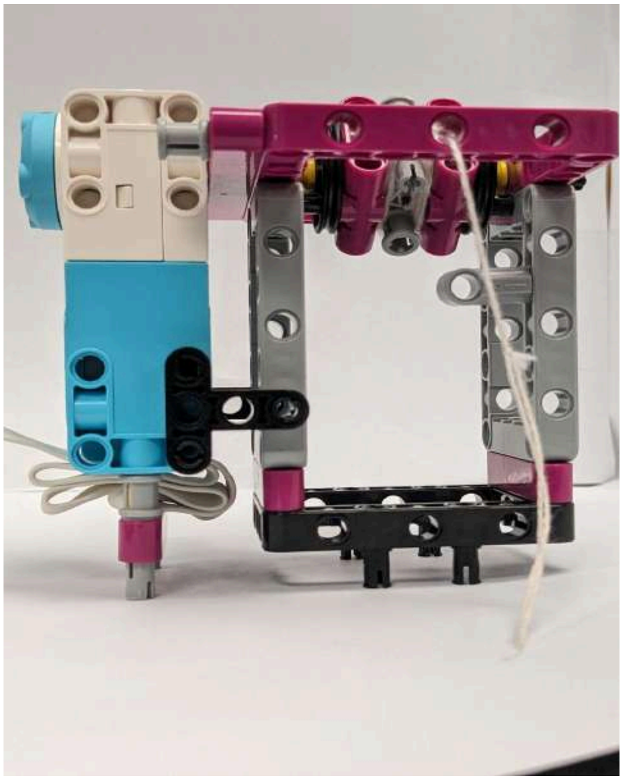


Figure 1.1

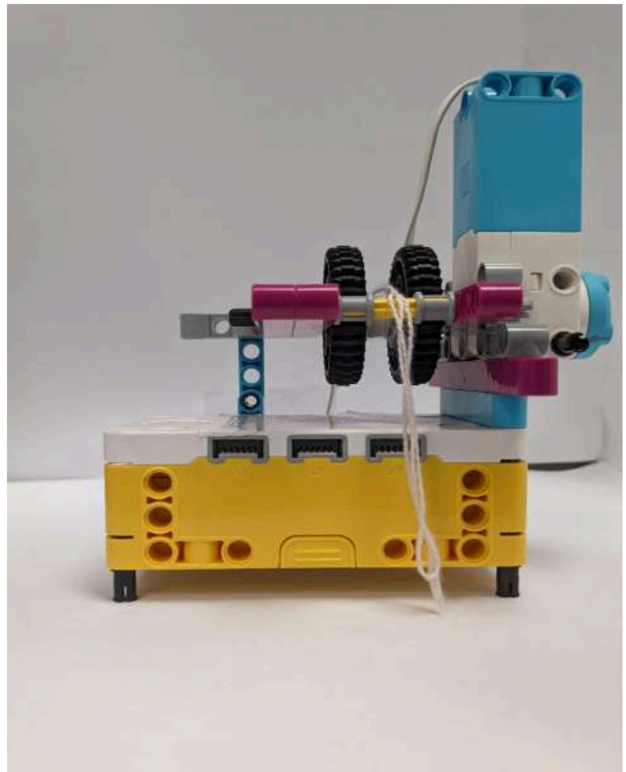


Figure 1.2

Figure 1.1 shows the big motor and its spool.

Figure 1.2 shows the power brick (Yellow brick) and the small motor with its spool

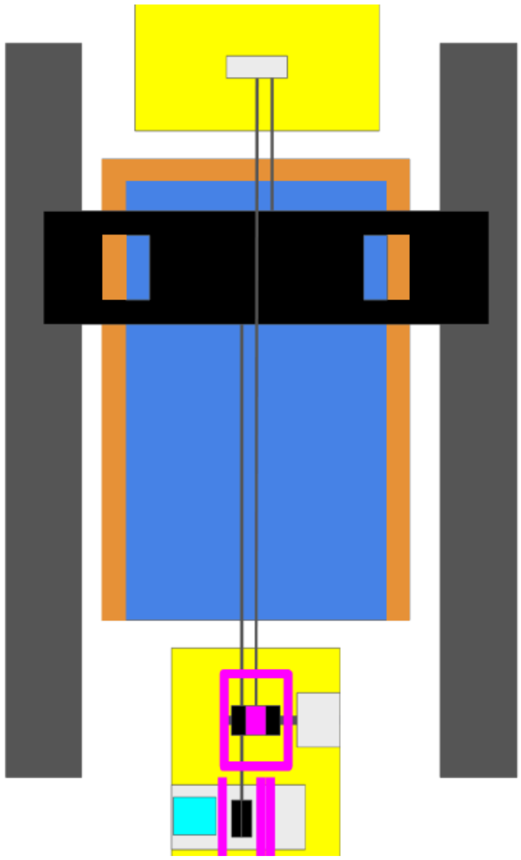


Figure 1.3

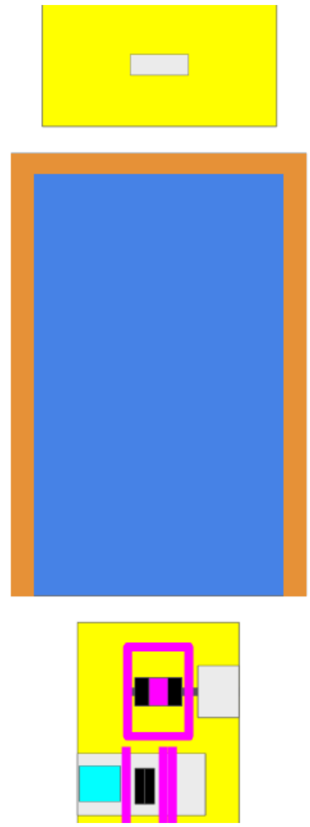


Figure 1.4

Figure 1.3 shows a top view of the machine

Gray is the rails

Dark Blue is the solar panel

The yellow plates are what allow the legos to attach to the base plate

Black is the vacuum head

Figure 1.4 shows a top view of the machine without the rails and the vacuum head

Bottom colors is the yellow square is fig 1.2 and the other one is fig 1.1

The different colors at the bottom in the yellow square are the motor assemblies.

Vacuum cleaner

The vacuum cleaner is supposed to be used to pick up sawdust and other similarly sized particles and was repurposed to pick up sand and dust in this project. The vacuum cleaner is placed on the white base plate while the vacuum cleaner head is placed in a base that has four wheels that allow it to move in the rails which are parallel to the solar panel.

Data Collection Procedures

The data was collected by recording how much sand was removed from the solar panel. The starting amount was 200g of regolith that was placed on the solar panel and spread out. Then run the code to start the machine. After the machine is done running, then remove the sand that was around the solar panel and not directly on it. Then measure the remaining sand. Log this data. Here is a more detailed version.

- Take everything that is used in testing: the machine, regolith, safety equipment safety goggles, P95 Mask and safety gloves, and a computer outside.
- Put 200 grams of regolith/ simulant on the panel and spread it out when that is done press the button to run it or you can wait for it to go itself with the color sensor.
- Allow the program to run its course.
- Take the sand that is not on the solar panel and put it in the vacuum cleaner
- Measure the amount of sand in the vacuum cleaner
- Log the results in a table
- Repeat steps 1 - 5 five times

Procedures

These are the basic versions of the procedures for assembling the machine and coding the machine's motors.

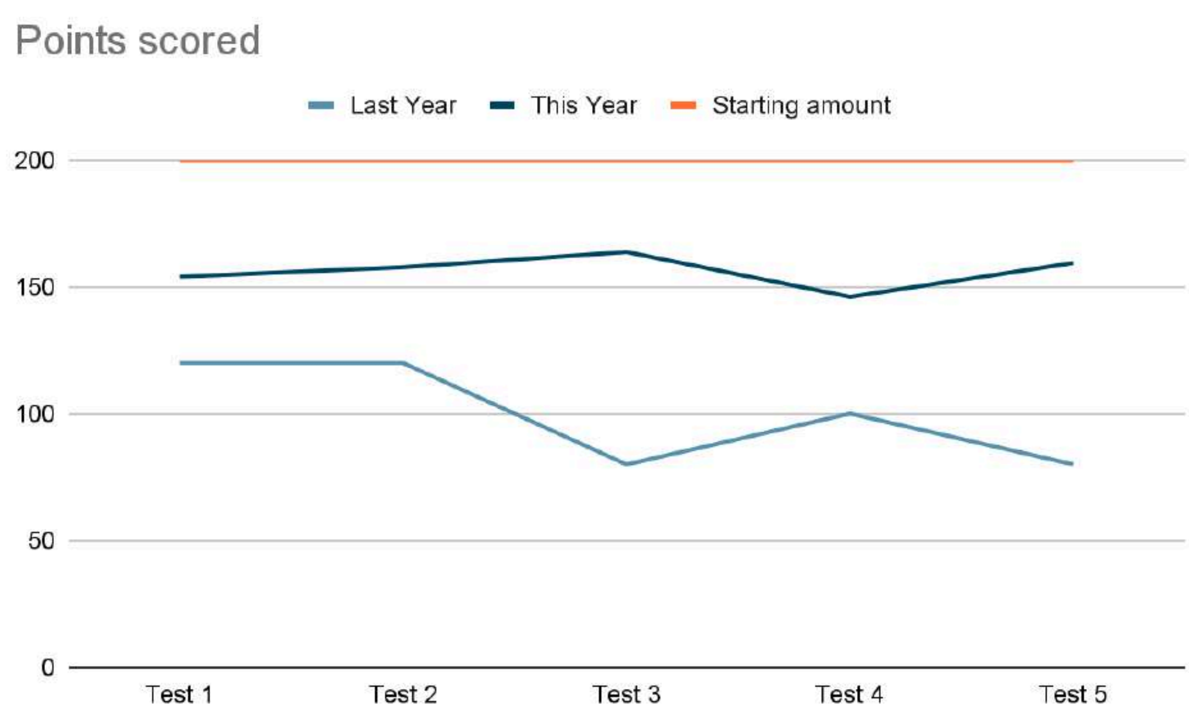
1. Assemble the new lego and place it at the other end of the sheet to the vacuum cleaner
2. Pull one string to the retracting part of the machine and put the other string to the moving-up motor wheel
3. Program the retract and push feature by making the wheel go backward or forwards
4. Code the color sensor to clean when the panel gets orange enough. For this use the color sensor, and point it at a sample of the regolith.
5. Automation: make it check in certain intervals like every 2 hours or 5 minutes and make it activate when a certain button is pressed.
6. Plug all cables and tubes into their respective locations.

Data

The data shows that the % requirement of the engineering goal was met. The average removed was 78.09% or 156.18 grams. At the most it was 163.7 grams or ~82%.

The data is very spread out and there are no common patterns. The values listed are grams removed, how many grams are left, how much was removed in %, and if it was under or over the goal.

	Test 1	Test 2	Test 3	Test 4	Test 5
grams removed	154	157.7	163.7	146.1	159.4
Grams left	46	42.3	26.3	53.9	40.6
% removed	77%	78.85%	81.85%	73.05%	79.7%
Over or under the goal	Over	Over	Over	Under	Over



Grams Removed

Upgrades and problems

This part talks about the problems, upgrades and other things the engineer would improve in future versions.

- **Fixed for this version**
    - At the start of construction, the engineer noticed that the thread was not spooling up. This was because the lego was just spooning and it had no grip on the thread. To fix this the engineer had to intertwine the thread to the Lego piece that was being moved
    - During early testing, the engineer noticed that the thread would spool the wrong way. Sometimes leading the thread to snap and have to be replaced. The engineer solved this by lowering the amount of thread that was dispensed and the amount that was retracted. The engineer also added guides that help guide the thread.

- **Planned for this version but never implemented**
    - The engineer planned on adding two brushes on each side of the vacuum cleaner head. This was because the engineer noticed that the regolith was not being removed from the edges of the solar panel. The reasoning for not including this was that it was not worth the job of having to redo the code because of time constraints. This is because the area where the sand was not being removed was not actual solar cells, it was where the border around the cells was.
    - The engineer planned on adding a color sensor. This would allow the

machine to know when the solar panel was covered in dust, thus allowing it to run automatically. The reason this was not added was because of difficulties with the sensor itself. In the coding program there was only a select number of colors you could use and the color of the regoliths was not one of them. This led the sensor to output an unknown value which made it impossible to program anything with it.

- **Planning on adding in future generations**
  - In the future, the engineer would like to add all of the improvements in the last section.
  - The engineer would like to move from Lego to more sophisticated systems and microcontrollers due to them being able to do more things and being less limited by the code blocks used for the Spike Prime.
  - The engineer would also like to 3d print some parts because that might improve the reliability and remove the limitations that using Lego has.

Pictures

Pictures taken during experimentation

Fig 2.1

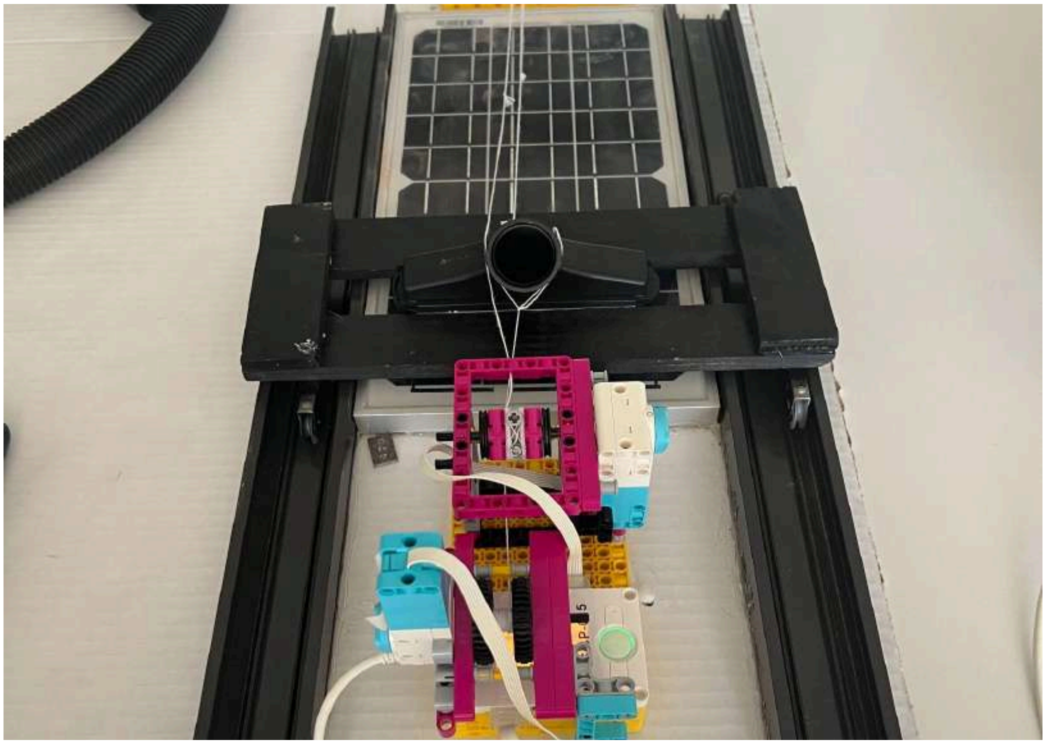


Fig 2.2

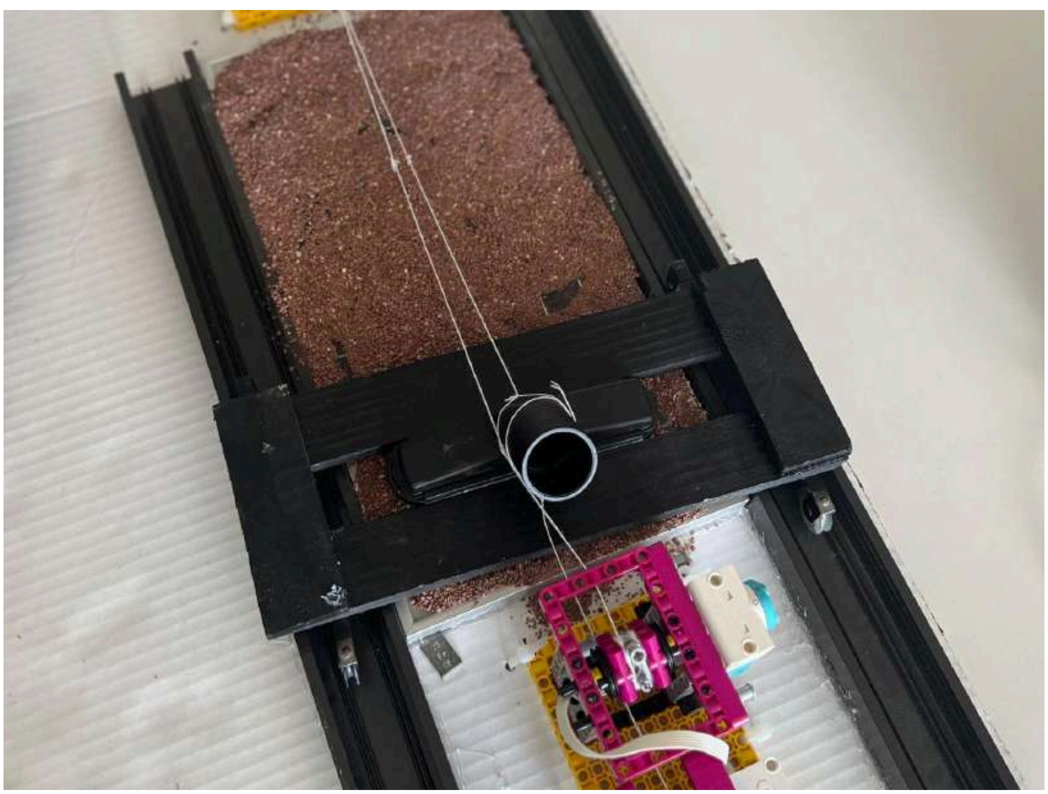


Fig 2.3

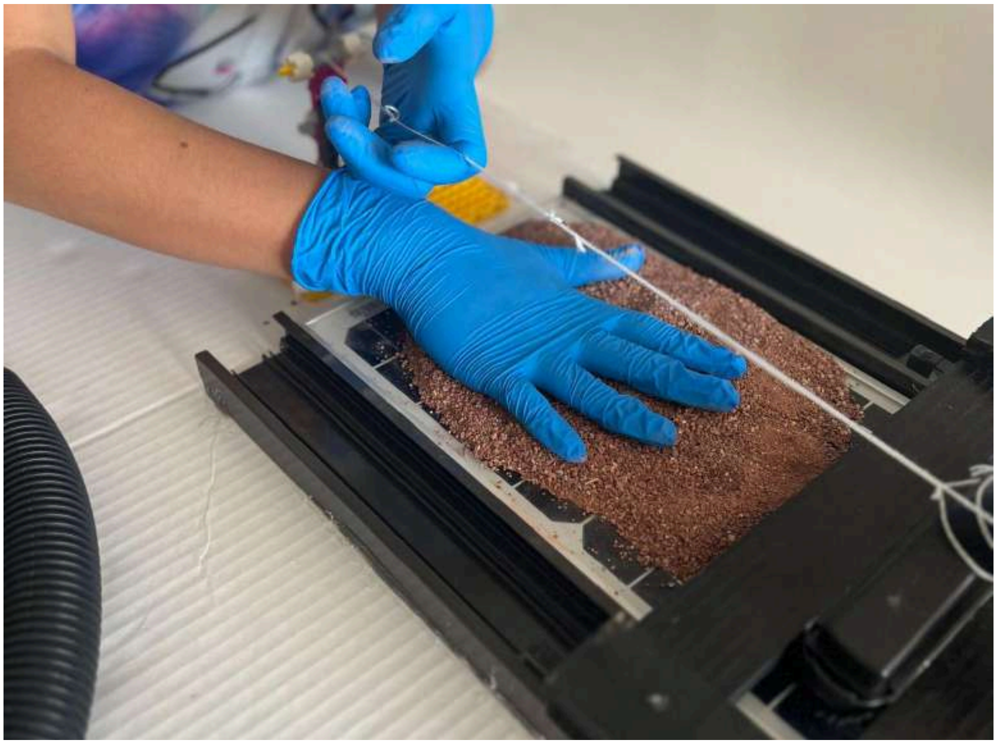


Fig 2.4

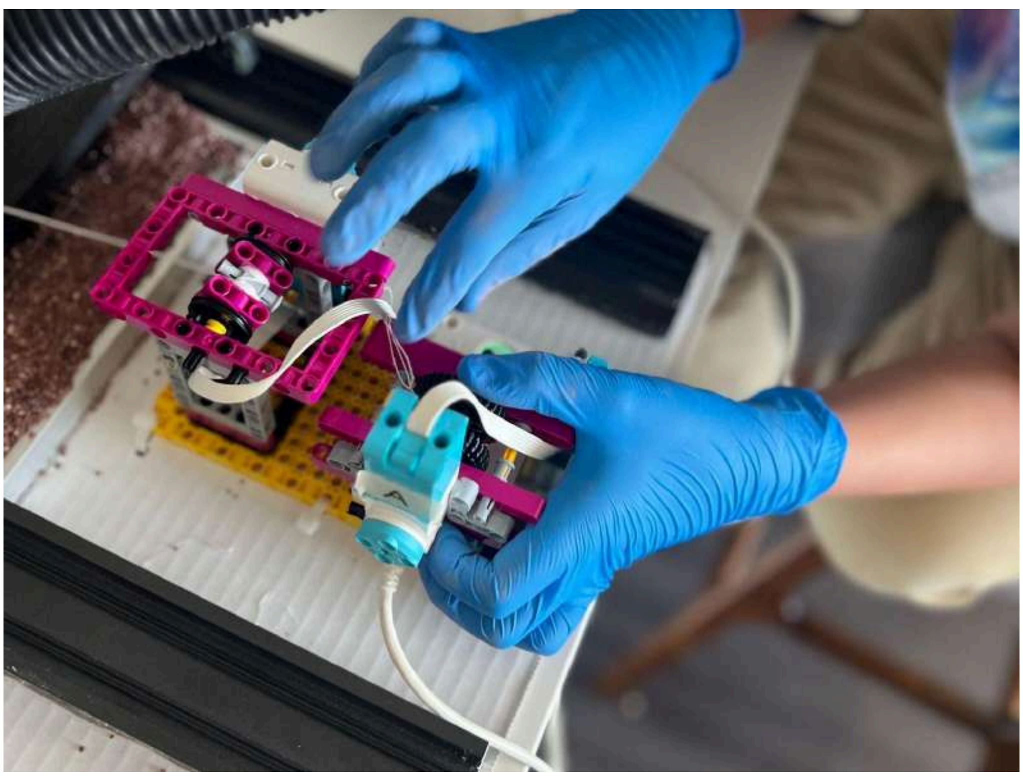


Fig 2.5

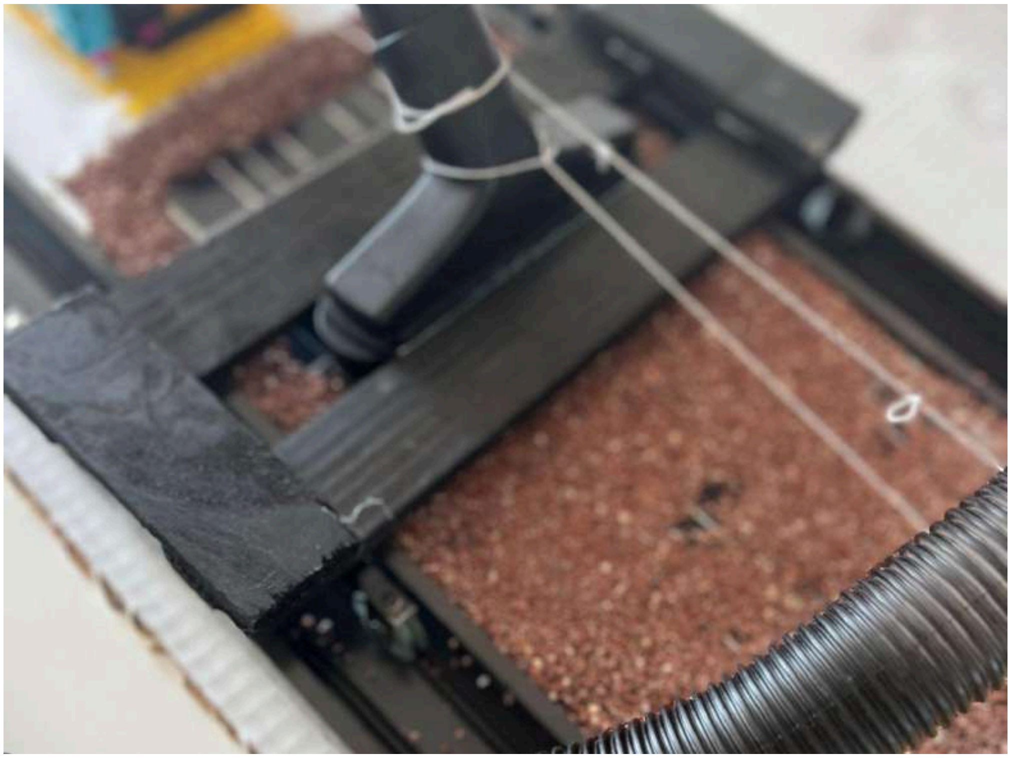


Fig 2.6

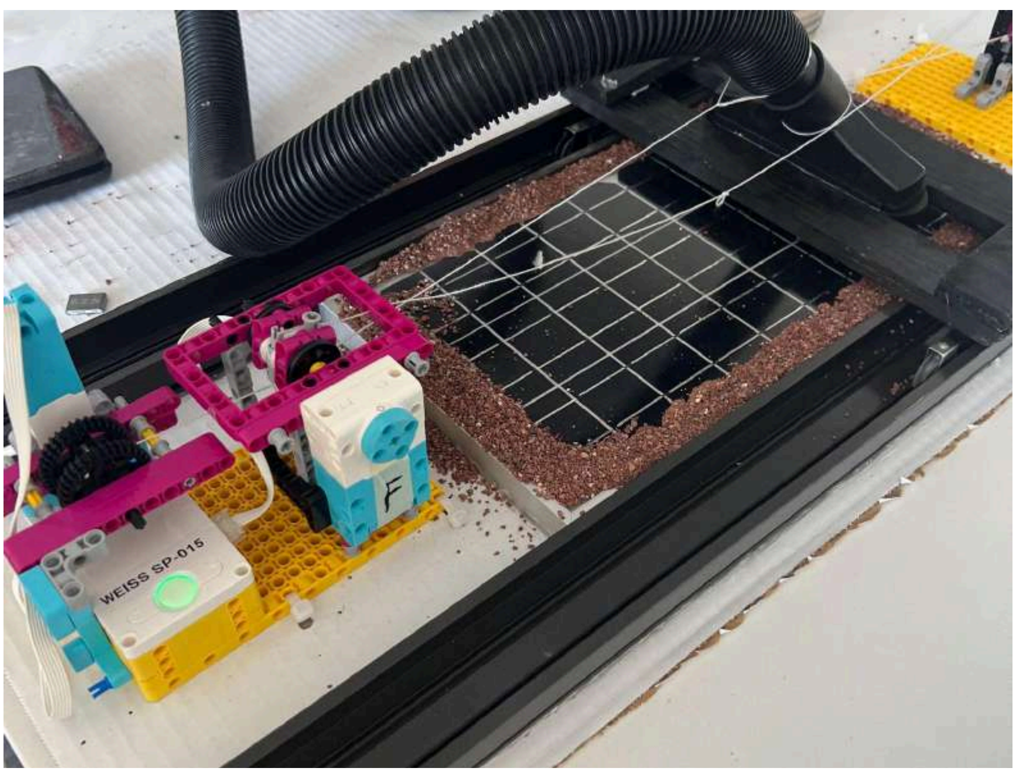
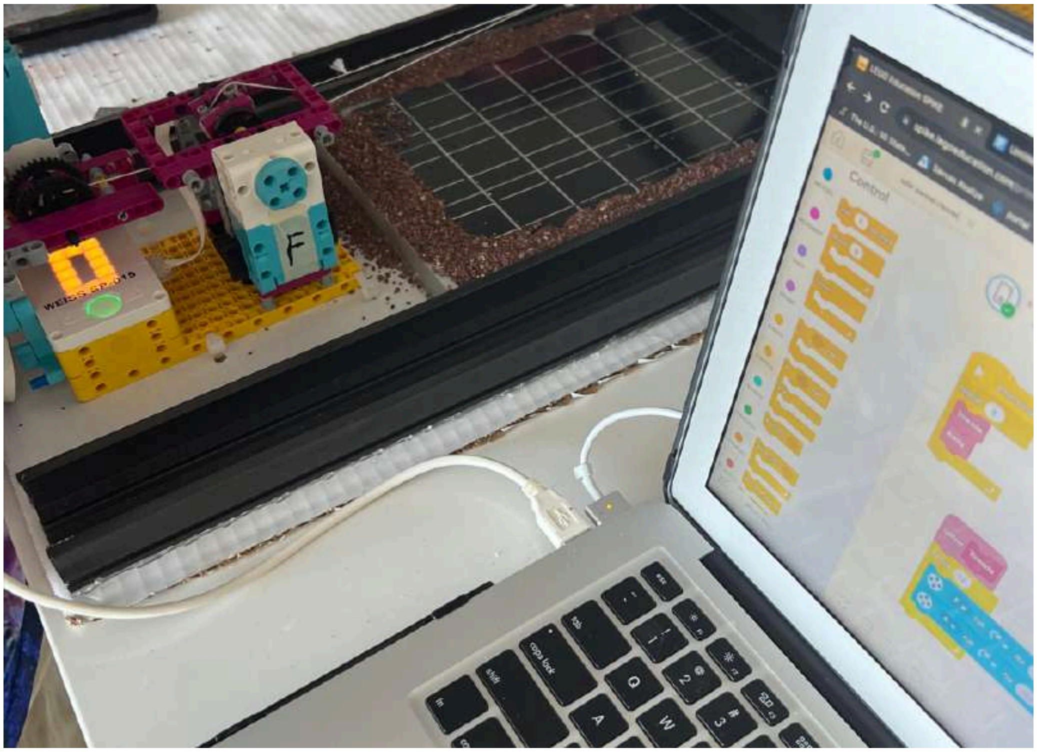


Fig 2.7



Explanation of figures:

Fig 2.1

Figure or Fig 2.1 shows the machine being idle and there being no sand on the solar panel.

Fig 2.2

This image shows the machine after the solar panel has been covered in sand.

Fig 2.3

Figure 2.3 shows the engineer setting up the experiment by evening out the sand on the solar panel.

Fig 2.4

Figure 2.4 shows the engineer preparing the machine for operation.

Fig 2.5

Figure 2.5 shows the machine running and is on its way in the first wave.

Fig 2.6

Figure 2.6 shows the machine running and removing the sand. It also shows the border of sand that is created because of the vacuum cleaners size and power.

Fig 2.7

Figure 2.7 shows the programming of the Spike Prime robot

Videos

Here is a link to a video that shows our work with the Solar Panel Cleaner:

https://youtu.be/m9wH8wZB1Bo

Conclusion

The project was an overall success as it was a massive upgrade from the first iteration and improved the amount removed from 50% to 78%. The ability to code it also now allows it to be automated and remote-controlled. The new spools also allowed it to be more reliable and gained the ability to speed it up. The upgraded control system makes it able to move both ways, unlike the previous generation. It is also able to get more reliable data since it eliminates human error.

The data gathered shows that this machine can remove a significant amount and can be run multiple times. The data is also not consistent and it has no patterns. The average number of grams removed was 156.18 or 78.09%. The average without the two outliers, which are tests three and four, the average is 78.51% or 157.02 grams. The main issue with the machine is that it only collects the sand from a certain part of the solar panel. This is the main part of the panel as it is where the cells are located. The machine has a multitude of improvements that can be made and the more it is tested on the more improvements can be made. There are many future applications like the ones that are mentioned earlier there can also be new and better ways to get data. One of the easy ways that improve the data is by measuring the amount of energy the solar panel produces. The reason this has not been tested is because it adds a multitude of new variables.

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