DESIGN AND SIMULATION OF AUTOMATED STORAGE AND RETRIEVAL SYSTEM (ASRS) USING SOLIDWORKS

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***Abstract*—This paper presents the design and simulation of Automated Storage and Retrieval System (ASRS) using SolidWorks software. ASRS is a system usually used to ease the storage and retrieval of a lot of things at one place. SolidWorks is used to design the system due to the software being able to offer designers a way to design in three-dimensional (3D) and provide simulation of its movements using motion analysis. It is also used to analyze critical parts in the system using Simulation Xpress study.**

Keywords—ASRS, SolidWorks, motion analysis

I. INTRODUCTION

It is no longer a foreign matter that automation is integrating in humans' daily life. In fact, nowadays, people tend to search for automated ways to do their jobs or routine. Sometimes the term automation is used interchangeably with robotics. This is due to the work and researches of automation that may include robotics element and vice versa. According to Kenneth Yigael Goldberg, the difference in robotics and automation are in terms of quality control [1]. While researches in robotics tend to be more of the way to imitate movements of life-forms such as walking, jumping, running, surgical tasks and many more, researches in automation tend to focus on increasing the reliability, productivity and efficiency of any systems or robotic movements. For example, the quality of a system can be increased with new techniques, analysis models etc. In some cases when robotics is involved, such as a walking robot, researches of automation on it is meant to make the robot walk more efficiently, more cost productive and more reliable.

Nowadays, the need to digitize a design even in automation researches is getting more and more relevant. This is not only to ease the designer to 'see' their design in real life before actually making them, but to also show others, especially the clients, the design and be able to improve the design with different inputs. To achieve this, there are many 3D computer aided design software available such as AutoCAD, SolidWorks, FreeCAD, Catia, SolidEdge and many more. SolidWorks software is chosen mainly because SolidWorks is widely known and used by all layers of designers be it from suppliers, competitors and users, have a short learning curve and offers the integration of analytical tools and design automation that helps stimulate physical behavior such as kinematics, dynamics, stress, and deflection.

Although ASRS has already existed since the 1950s [2], there are still room for automation in the system. There are two primary versions of ASRS, one being fixed aisle and the other is carousels/Vertical Lift Module (VLM). These two versions mentioned differs from each other in the way the loads are stored and retrieved. Loads are usually products or materials that has been put on a pallet or a specific storage box. The design in this project uses a fixed aisle ASRS. A fixed aisle ASRS consists of fixed storage spaces and a mean of storing and retrieving the loads in the spaces, using a vertical/horizontal lift crane or a movable shuttle [2]. There are also different types of racks for a fixed aisle ASRS, with the most use ones being single-deep and double-deep racking system. As seen in Figure 1, a single-deep rack simply means that only one load can be stored or retrieved per one slot in the rack, while double-deep rack is a rack that can store and retrieve up to two load per slot in the rack.

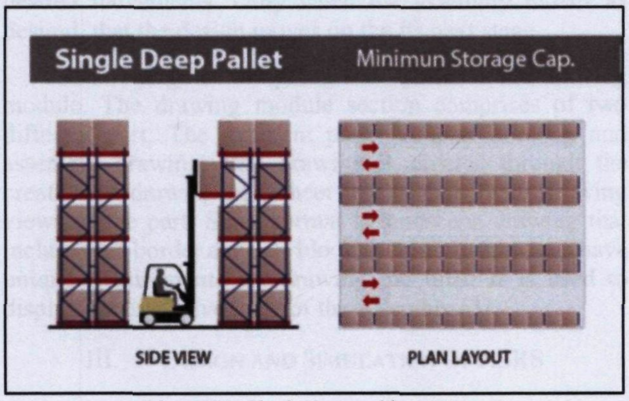


Figure 6.1: Single-deep racking system

In this paper, SolidWorks software is used to design a fixed aisle ASRS with a single-deep rack. Instead of designing a forklift that has to be controlled by human as can be seen from Figure 2, this paper focuses on automating the forklift, allowing viewer to accurately see the flow to the system without much intervention from humans. The flow of the system is simulated through motion analysis provided in the SolidWorks software.

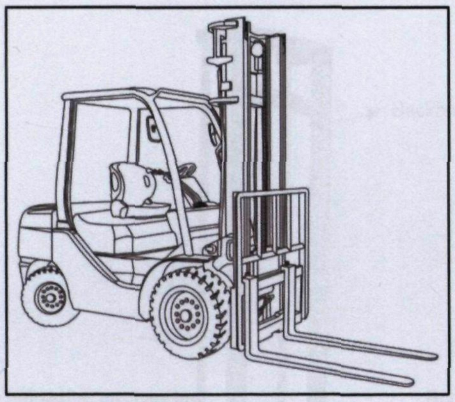


Figure 6.2: An example of a traditional forklift design which can be used to store and retrieve loads in ASRS

The main objectives of this paper are as follows:

a) To design an ASRS suitable for a warehouse.

b) To simulate and automate the function of ASRS in 3D using SolidWorks.

c) To decrease the labour cost, optimize floor space and increase reliability in handling a warehouse system.

II. METHODOLOGY

This section of the paper explains the method used in designing the ASRS using the SolidWorks software. There are four main design specifications which are manual drawings, part modules, assembly modules and lastly drawing modules.

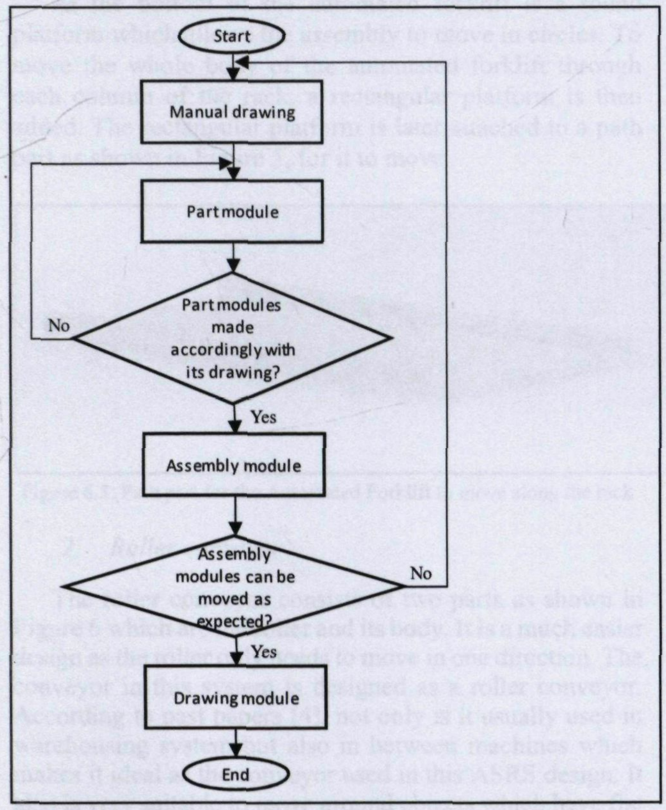


Figure 6.3: Flowchart of ASRS design

Figure 3 shows the flowchart of ASRS design flow, the first step in designing the system in SolidWorks being manually drawing out the designs. Manual drawing is the conventional mean of drawing, by using hand and paper. Since SolidWorks parts are supposed to have a complete measurement for it to be fully-defined, by using this method first, time is saved because the parts are not drawn from imagination and without measurements in SolidWorks.

Next, is the part modules drawn in SolidWorks. As said earlier, the sketches made in this section is made to be fully-defined first before going through the other stages. Although the sketches do not have to be fully defined for the design to move on to the other stages, it is a good practice to let the sketch be fully-defined. This will most help when the part modules are needed to be altered at a different time later on. If the sketches aren't fully-defined, when some drawings or extrusions of the drawings are changed, the other parts of the drawings may be damaged. To always allow different parts of the drawings be altered along with the specific altered parts at the time, a fully-defined sketch is very useful.

The assembly module comes after the part modules. In the assembly modules, the parts are put together to 'build' the design. There are different ways to put together the parts in an assembly by using mates. In mates, the parts are either coincident, parallel, locked and many more to each other. Different mating offers different result in the ways the parts then move in the assembly. Sometimes, the limitation of the designs' movement can only be seen after the parts are assembled together. This is the reason that if the movements of the assembly do not move as expected, that the design are then added with a new part, made from scratch. An existing part could also be made again from scratch to achieve the desired movements. Only when the assembly moves as desired, that the design moves on the its next stage.

The last stage of designing this system is the drawing module. The drawing module section comprises of two different part. The different parts are part drawing and assembly drawing. Part drawing is created through the creation of drawing file, sheet format and initial drawing views of the part. Sheet format is landscape drawing that includes the border and title block. Assembly drawings have unique requirements for drawing the bills. It is used to display the explosive view of the assembly [3].

III. DESIGN AND SIMULATION OF ASRS

A. *Design of the ASRS parts*

1. *Automated forklift*

There are seven different parts altogether in the automated forklift design, two of them being the same part which is the moving mechanism, only used at different axes. As shown in Figure 4, the first part is the 'backbone' base of the automated forklift. It comprises of two vertical pillars connected to each other with four smaller horizontal pillars. It also includes two poles for the Y-axis moving mechanism. The axes of directions can be seen at the bottom left corner of Figure 4.

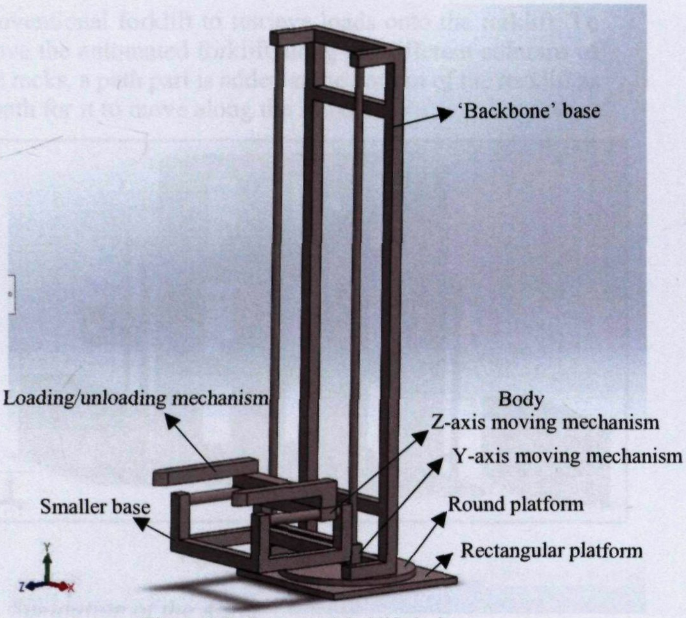


Figure 6.4: Automated forklift design

The Y-axis moving mechanism is attached to a smaller base part which a Z-axis moving mechanism and a loading and unloading mechanism of the automated forklift is attached to. This smaller base comprises of the same component of the 'backbone', but in smaller size for stability. It homes a loading/unloading mechanism, which moves in the direction of the Z-axis. The loading/unloading mechanism is designed to move forward and backward to load and unload loads on the conveyor and from the rack.

At the bottom of the automated forklift is a round platform which allows the assembly to move in circles. To move the whole body of the automated forklift through each column of the rack, a rectangular platform is then added. The rectangular platform is later attached to a path part as shown in Figure 5, for it to move.

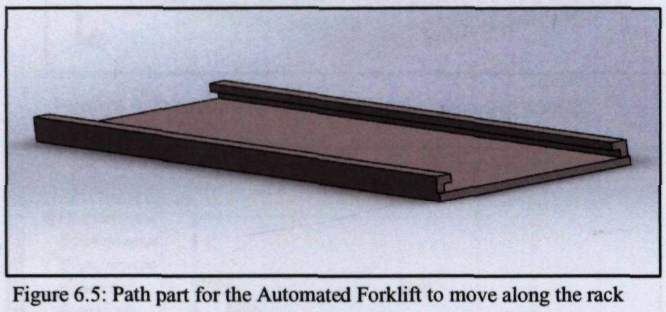


Figure 6.5: Path part for the Automated Forklift to move along the rack

2. *Roller conveyor*

The roller conveyor consists of two parts as shown in Figure 6 which are the roller and its body. It is a much easier design as the roller only needs to move in one direction. The conveyor in this system is designed as a roller conveyor. According to past papers [4], not only is it usually used in warehousing system but also in between machines which makes it ideal as the conveyor used in this ASRS design. It also is very suitable to move around objects which have flat rigid surfaces, a load in which most ASRS have/used. With a roller conveyor, the space consumption for which the load is set to move can be restricted thus can maximize the space of the warehouse in which the ASRS is applied.

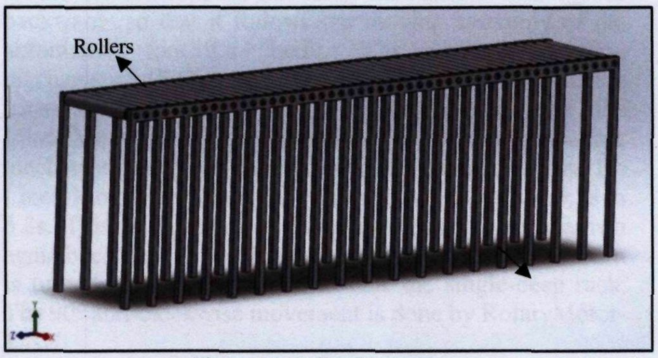


Figure 6.6: Roller Conveyor

3. *Single-deep rack*

Figure 7 shows a single-deep rack part designed for the ASRS. A single-deep rack is chosen because it allows easier access to the loads stored in it. This is because a single-deep rack does not have to remove interfering loads to be given access to the desired loads like a double-deep rack system. This reduces the time of retrieval of the loads when compared with a double-deep rack system [5].

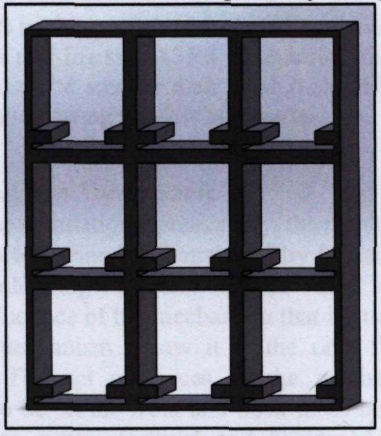


Figure 6.7: Single-deep rack part design for the ASRS

B. *Assembly of all the design parts in the ASRS*

There are only several important assemblies that makes up the ASRS design shown in Figure 8. The first one is the automated forklift, then the conveyor and lastly the single-deep rack. The idea of this storage and retrieval system is to allow it to be automated so the conventional forklift design must be changed for it to meet the automation requirement of the design objective. The basic movement of a forklift which is to lift a load vertically up and down is imitated so that the load is able to be stored and retrieved at different slots in a rack. An addition to the automated forklift's movements are the ability of the forklift to move forward and backward via the loading/unloading mechanism to retrieve loads whether it be on the conveyor or in the slot of the racks.

In SolidWorks terms, the automated forklift is able to move up and down the Y-axis, allowing it to achieve different height of slots in the racks. It can also move forward and backward along the Z-axis, which automates the movements of a human operator controlling a conventional forklift to retrieve loads onto the forklift. To move the automated forklift along the different columns of the racks, a path part is added at the bottom of the forklift as a path for it to move along the Z-axis.

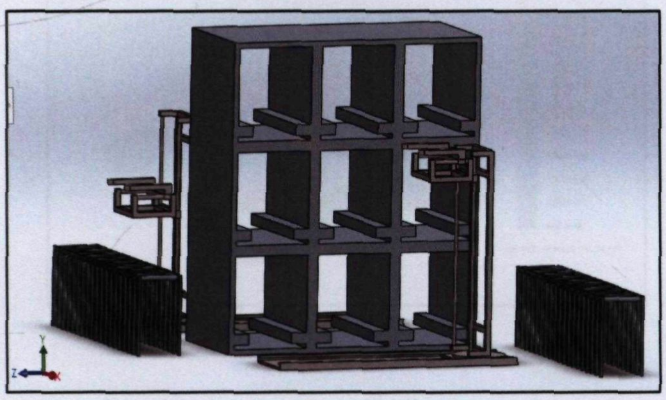


Figure 6.8: ASRS design

C. *Simulation of the ASRS*

The simulation of the ASRS shows the movements of the automated forklift in storing loads into the single-deep rack. Figure 9 shows the direction of movements in which the automated forklift could take. In Figure 10, the timeline of the movements of the automated forklift is shown.

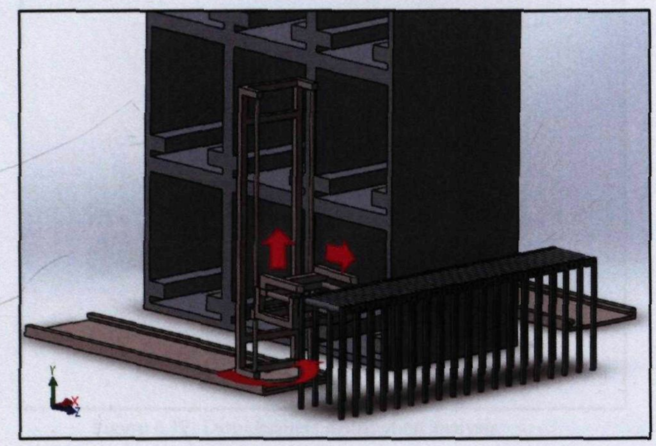


Figure 6.9: Directions of movements of the automated forklift

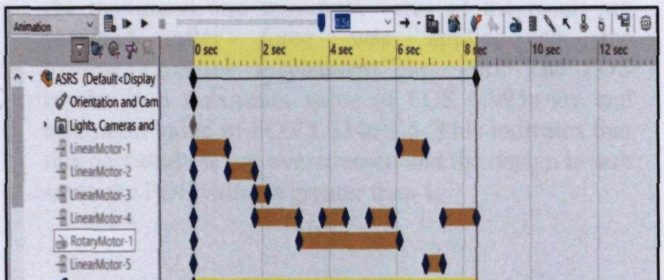


Figure 6.10: Timeline of the automated forklift movements

Firstly, the automated forklift moves its loading/unloading mechanism forward to acquire the load from the roller conveyor. This is done by LinearMotor-1 moving from 0s to 5s. Then, the smaller base is move upward to lift the load off the roller conveyor which can be seen done by LinearMotor-2 moving from 5s to 9s. The next thing the automated forklift does is moving backwards in its path to reach the designated column of the rack. The movement of the automated forklift in its path is shown by moving LinearMotor-3 from 9s to 11s.

At 9s, the loading/unloading mechanism also moves backwards so that it follows the moving assembly of the automated forklift's body. The loading/unloading mechanism's backwards movement is controlled using LinearMotor-4. It is let to move longer than the LinearMotor-3 to fully retract the loading/unloading mechanism onto the smaller base. As seen in Figure 10, LinearMotor-4 is turned on again at 3.6s to 4.4s and 5.2s to 5.8s. This is to retract the loading/unloading mechanism again because it moves forward when the automated forklift is turned 90° anti-clockwise to face the single-deep rack. The 90° anti-clockwise movement is done by RotaryMotor-1.

After the automated forklift faces the single-deep rack, LinearMotor-1 is turned on again from 6.1s to 6.9s and LinearMotor-5 which controls the downward movement of the smaller base is turned on from 6.9s to 7.4s. This is to store the load in the single-deep rack. Finally, the LinearMotor-4 is turned on again from 7.4s to 8.2s to put the loading/unloading mechanism back to its initial state.

IV. RESULT AND DISCUSSION

The ASRS in this project is designed in a smaller scale compared to a real-life size ASRS. Due to this, the value of the analysis may be smaller than what it should be if the ASRS is designed using real-life size parts.

A) *Simulation Xpress Study*

In the simulation Xpress study, the results of stress analysis are obtained and analyzed by focusing on the loading/unloading mechanism of the automated forklift. The face of the mechanism that is attached to a moving mechanism below it is the only fixed face selected. The act of forces of the mechanism are selected to be on the front and back faces because the mechanism moves forward and backward. The top surface of the mechanism is then selected to be put pressure on. The mass of the mechanism, with its material being stainless steel is 2.353kg.

In Figure 11, the stress distribution result had been analyzed and obtained. The maximum value of stress distribution is 9.399e+02N/m^2 while the minimum value of the stress distribution is 2.06e-02N/m^2. It is to test the strength of the loading/unloading mechanism when it moves with a load on it.

The maximum value stress distribution is located at the part of the mechanism where it is attached to the Z-axis moving mechanism below it. This shows that the mechanism will be stressed out from moving forward and backward with a load on it. From the analysis, the yield strength value for the loading/unloading mechanism is 1.723e+08 N/m^2. This value gives the meaning it is the maximum stress the material can withstand.

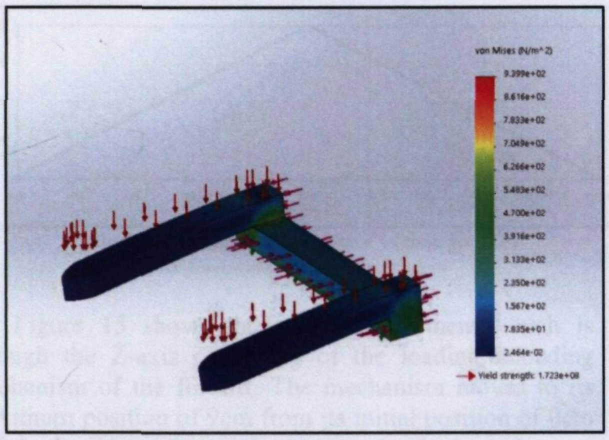


Figure 6.11: Stress distribution analysis

For the displacement distribution analysis, the result is obtained when force or stress is applied onto this loading/unloading mechanism part. Figure 12 shows the maximum and minimum resulted value. The maximum value of displacement distribution is 1.617e-06mm and the minimum value of displacement distribution is 1.000e-30mm.

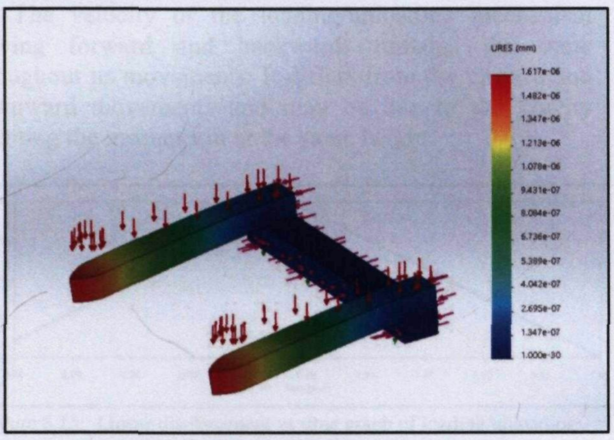
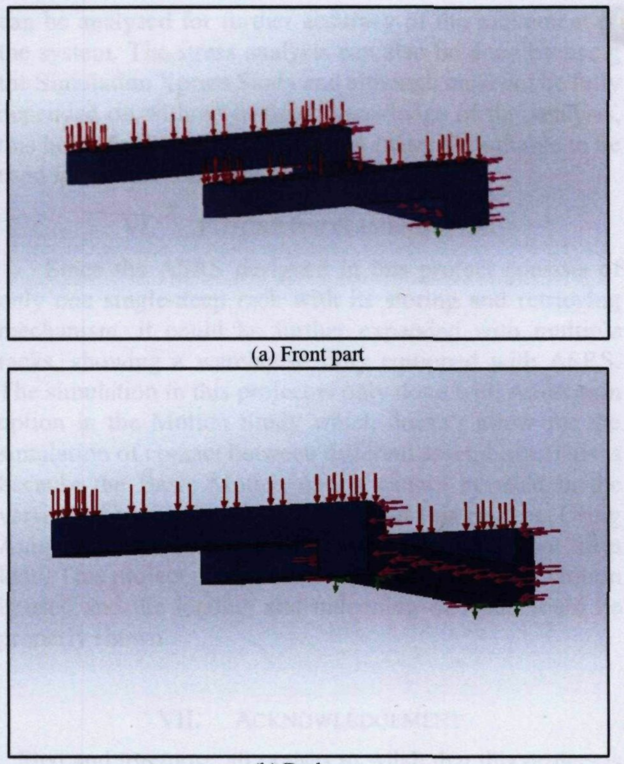


Figure 6.12: Displacement distribution analysis

Figure 13 shows Factor of Safety (FOS) analysis, the maximum and minimum value of the result are obtained after force was applied to the loading/unloading mechanism part. part. The FOS results in a maximum value of FOS 6.995e+09 and minimum value of FOS 1.834e+05. This indicates that this part study is not overstressed and the design is safe since the FOS value is greater than 1.



(a) Front part

(b) Back part

Figure 6.13: FOS analysis (a) Front part (b) Back part

B) Motion study

The motion study of the automated forklift can be analyzed through two different movements. The first movement is the linear displacement of the Y-axis moving mechanism of the automated forklift. As seen in Figure 14, the moving mechanism moves upward from 0cm to a maximum 66cm in 6.6s. It takes a much shorter time to move downwards to its initial position which is 6.4s.

The velocity of the upward and downward movement is calculated based on the graph in Figure 14. To obtain velocity,

$$\text{Upward velocity} = \frac{Distance(cm)}{Time(s)}$$

$$\text{Upward velocity} = \frac{15-0}{1.33-0}$$

$$\text{Upward velocity} = 11.28\text{cm/s}$$

$$\text{Downward velocity} = \frac{66-33}{6.6-9.975}$$

$$\text{Downward velocity} = -9.78\text{cm/s}$$

It is seen that the velocity changes when going upwards and downwards. The upward velocity is 11.28cm/s while the downward velocity is 9.78cm/s in the opposite direction. The difference in the velocity may be due to the gravity set in the Motion Analysis of the Motion Study.

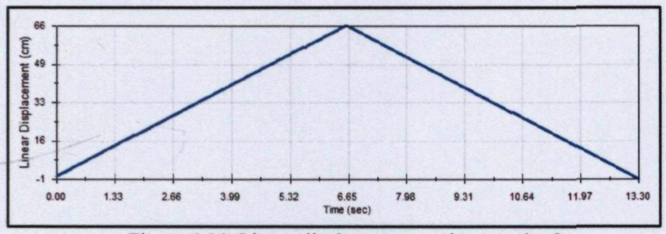


Figure 6.14: Linear displacement vs time graph of upward/downward moving mechanism

Figure 15 shows the second movement which is through the Z-axis consisting of the loading/unloading mechanism of the forklift. The mechanism moves to its maximum position of 9cm from its initial position of 0cm in 0.9s. It takes a shorter time in moving backwards to its initial position which is 0.85s.

Forward velocity = $\frac{Distance(cm)}{Time(s)}$

Forward velocity = $\frac{9-0}{0.9-0}$

Forward velocity = 10cm/s

Backward velocity = $\frac{9-(-1)}{0.9-1.9}$

Backward velocity = -10cm/s

The velocity of the loading/unloading mechanism moving forward and backwards remains the same throughout its movements. It differs from the upward and downward movements and may be due to the gravity affecting the mechanism at the same height.

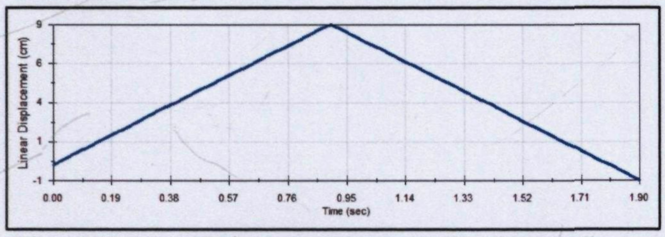


Figure 6.15: Linear displacement vs time graph of loading/unloading mechanism

V. CONCLUSION

In conclusion, the ASRS is able to be designed and simulated. It is proven that SolidWorks software is a reliable 3D CAD tool for designers to not only design, but to also simulate a system that they desire. Using SolidWorks, designers can also analyze different parts of the system. The movement can be plotted into graphs and can be analyzed for further accuracy of the movement of the system. The stress analysis can also be done by using the Simulation Xpress Study and although must not be fully depended on without in-depth knowledge of the analysis, this helps designers in determining materials suitable to be used for the parts in their design.

VI. FUTURE RECOMMENDATION

Since the ASRS designed in this project consists of only one single-deep rack with its storing and retrieving mechanism, it could be further expanded with multiple racks, showing a warehouse fully equipped with ASRS. The simulation in this project is only done with Animation option in the Motion Study which doesn't allow for the simulation of contact between different assemblies. This is because the Basic Motion option cannot be used in the version of SolidWorks used to design this project. Using Animation means that the automated forklift cannot lift a load. This project can be further improved if Basic Motion is used and the loading and unloading of loads could be properly shown.

VII. ACKNOWLEDGEMENT

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REFERENCES

[1] Kenneth Yigael Goldberg, "What Is Automation?," IEEE Transactions on Automation Science and Engineering, Vol. 9, No. 1, January 2012.

[2] K. Roodbergen and I. Vis, "A survey of literature on automated storage and retrieval system," *European Journal of Operational Research 194(2)*, pp. 343-362, 2009.

[3] [Online]. Available: http://content.inflibnet.ac.in/data-server/eacharya-documents/53e0c6cbe413016f234436fb_INFIEP_23/15/ET/23-15-ET-V1-S1__notes.pdf. [Accessed on 20 November 2019].

[4] W. M. A. B. W. M. Raziff, "Design And Simulate Of Pick And Place System Using Solidworks," 2018.

[5] S. S. Mondol, "Gravity Roller Conveyor Design," May 2017.

[6] K. R. Gue, "Very High Density Storage Systems," March 2015.