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Design of Ladder Climbing Assisting Device with Simple Mechanism and Safety Equipment

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Abstract: Falling accident that caused by falling from height are happen occurly in Malaysia. Ladder climbing assisting device had been invented to reduce this type of accident. Many ladder climbing assisting device sold in the market have a big size and the mechanism of the device can be said is very complecated. This cause the maintenance job become hard and decrease the lifespan of the device. This project focuse on making a ladder climbing assisting device that have simple mechanism and in small size. In order to achieve the project objective, several research had been done by searching the related patent and existing machine. Engineering process had been applied in this project which included three phases that are conceptual design, embodiment design, and detail design. All the concept product specification are find out by using morphological chart and weight matrix evaluation. The 3D geometry layout of the final product are drawn by SolidWorks software. Finally, a final ladder climbing assisting device with simple mechanism had been design out. The machine only use 2 set of gear to complete all the mechanism. It simplified the maintenance job and increase the lifespan of the machine. In term of size, the final product have a dimension of 716mm x 307mm x 226mm with expected weight 15.82 kg. The device not only can lift people but object. In addition, a ladder stabilizer also been design out together with the machine. The ladder stabilizer help to increase the stability of the ladder.

Keywords: Ladder Climbing Assisting Device, Ladder Stabilizer

1. Introduction

Accident falls from ladders have caused many serious injuries cases and deaths in the construction industry, even just only at relatively low heights. Basically, the ladder injuries might depend on the following factors. The first factor is the height, many ladder accidents involve falls from extreme heights place which can cause death. The second factors are the inclement weather. If the worker is doing the work when the big wind is howling and the rain fall heavily, the chances for the worker to fall from the ladder will become more easily and cause a serious injury. From DOSH website in year 2013 to 2018, there are 145 cases of fatal accident collected are happen in construction site. Table 1 displays that there have 63 cases or 43.40% accident happen caused by the falling from heights.[1]

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Table 1: Frequency of cases by types of accidents

No	Type of accident	Case Number	Percentage (%)
1	Falling from heights	63	43.4
2	Struck by falling object	31	21.4
3	Struck by moving object or vehicles	18	12.4
4	Caught in between	11	7.6
5	Fall into opening or drowning	8	5.5
6	Electrocution	7	4.8
7	Environmental factors	4	2.8
8	Fire or Explosion	2	1.4
9	Exposure to, or contact with harmful substances	1	0.7
	Total	**145**	**100.0**

The inventions of ladder climbing assisting device help to reduce the injuries cases. Ladder climbing assisting device is a device who give fall protection and climbing assistance for the worker that using permanent fixed ladders and help to reduce fatigue of the workers due to the device can take over some of the weight of the worker. The device also makes ascent and descent become more safer and eliminate the compatibility issues with ladder safety system. With the help of the device, there is no need to attach one more fall protection system on the fixed ladder. The device was widely use in the industry area such as the Oil, Gas, and Chemical Refinery Industry, Water Tower Industry, Wind Turbine Industry etc for maintenance job [2].

The research shows that many accidents happen in construction are due to falling from heights. Many industries not that often to do the maintenance of ladder climbing assisting machine due to its complicated mechanism. After they doing the maintenance job, they cannot arrange back the machine. So, an invention of ladder climbing assisting machine with a simple mechanism shall be introduced. The main objective of this project is to design a ladder climbing assisting machine which have a simple mechanism and safety equipment**.**

2. Literature Review

Literature review was important in the evaluation of relevant literature on related topics which give the information on the design structure, mechanism, and specifications of the machine and give help on designing the ladder climbing assisting device. The literature review will get the information through the patent research and the article research and finding through the online website.

2.1 Patent Search

Several patent regarding ladder climbing assisting device are reviewed and compare to develop the design concept. Table 2 shows the list of patent that used in the project.

Table 2: List of patent reviewed

No	Patent Name	Patent Number
1	Ladder Climbing Booster	CN105936482B
2	Climbing Assisting Machine	CN102536107A
3	Climbing Assisting Equipment	TW201414523A

2.2 Benchmarking

Benchmarking is important for a designer to compare the existing product specification and develop the design concept. Table 3 shows the comparison of 3 different existing product specification

Table 3: Comparison of available product

Product	**H-Lift**	**E-Lift**	**Limpet L2**
Figure			
Manufacture	Hailo Wind System		Limpet Technology
Weight	20 kg	11.5 kg	54 kg
User Weight	60 -120 kg	50 -130 kg	40 – 140 kg
Climb Assist Options	Up to 40 Kg	80% assist	90% assist, up to 140 kg
Operating Temperature	-10 ℃ - 45 ℃	0 ℃ bis 50 ℃ (-10 ℃if battery > 0 ℃)	-40 ℃ to 45 ℃
Speed	25 – 30 m/min	24 m/min	1.1m/s
Advantages	- Enormous cost reductions - Simple installation - Very low maintenance requirements - Huge time savings	- High-cost reductions - Long service life - Low maintenance requirements - Huge time savings	- Quick installation - Provide recording and monitoring function - IP rating up to 66 compared with other only 44

3. Project Flow

3.1 Flow Chart

A good method used in the design process is an important element in design and fabricate a product. Engineering design process is a series of steps that need to come out a possible solution based on the problem given. The process included the process flow chart which include the main three design process which are conceptual design, embodiment design and detail design. This engineering design process make engineer product design work become more efficient. Figure 1 shows the main component included in the design process which introduced by George E. Dieter. The three main phase of the design process are conceptual design (Phase I), embodiment design (Phase II) and detail design (Phase III)[3]. There have four stages under conceptual design (Phase I) which are define problem, gather information, concept generation and evaluation of concepts. Three stages are under embodiment design (Phase II) which are product architecture, configuration design and parametric design while detail design (Phase III) only consists one stage [4].

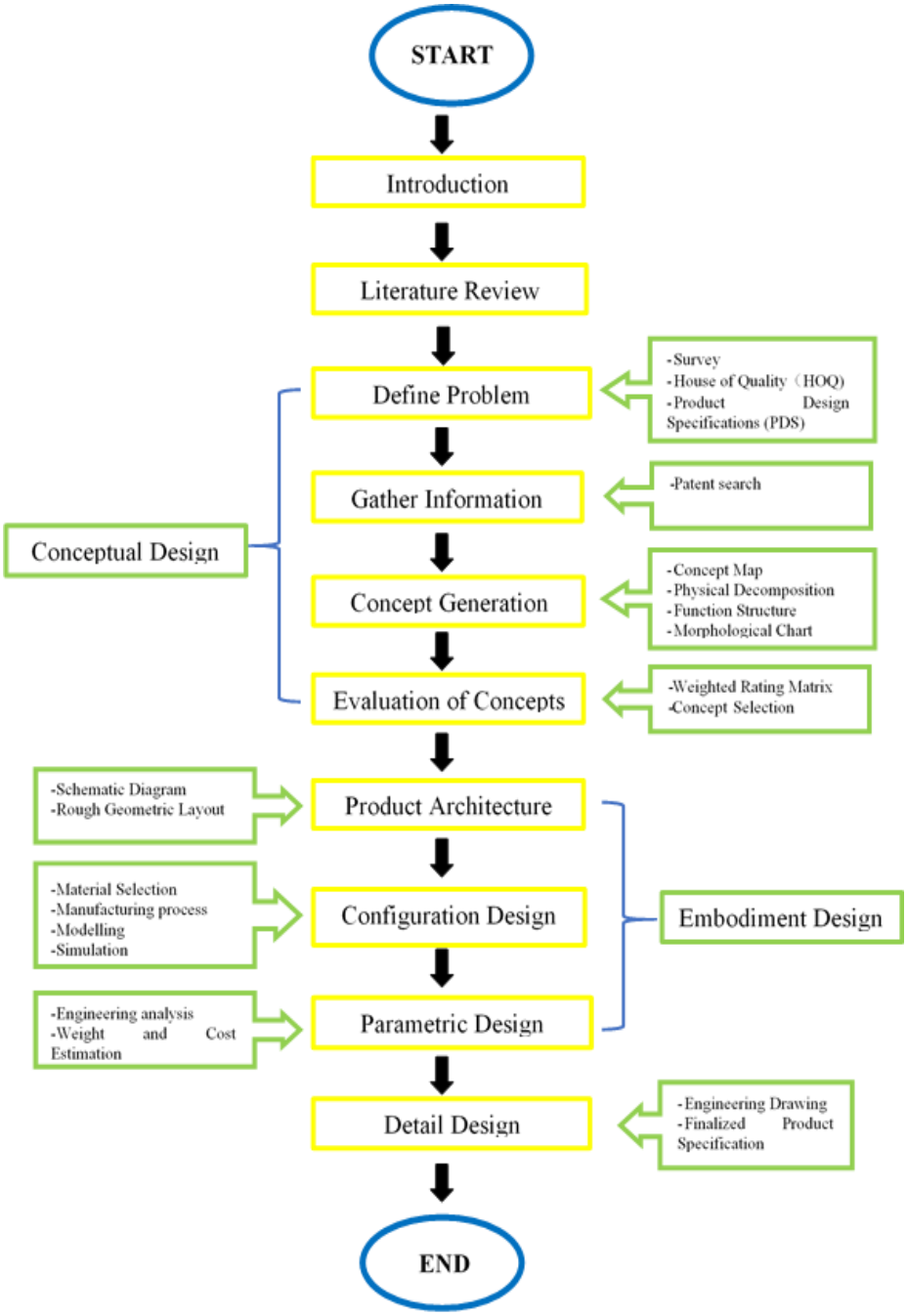


Figure 1: Project flow chart

3.2 Objective Tree

Figure 2 shows the product objective tree for ladder climbing assisting device assembly. The requirements such as function, design, price, safety, and sustainability listed followed by sub-criteria.

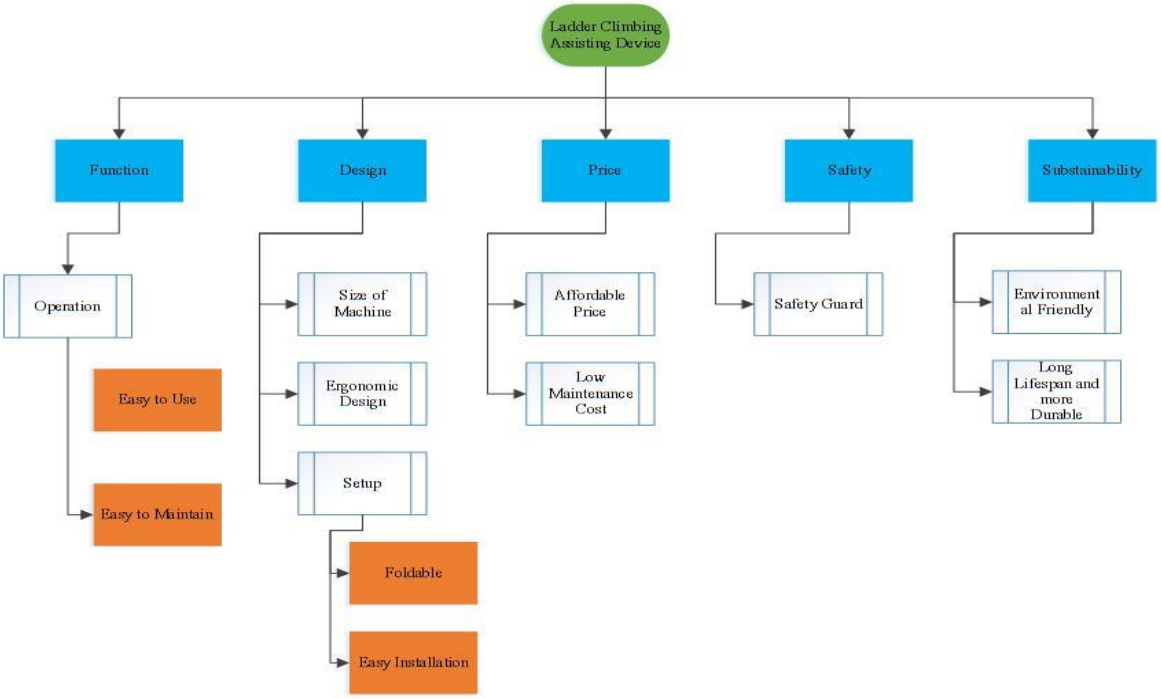


Figure 2: Clarifying Objectives Tree of ladder climbing assisting device

3.3 Product Design Specification

Product design specification play an important role for designer as a reference for their final product design which gather the information obtain form the survey and HOQ. Table 4 shows the detail of product design specification for the ladder climbing assisting device.

Table 4: Engineering Design Specification

Ladder Climbing Assisting Device
Function
Device that can help to reduce falling accident when a worker was climbing to a high place.
Customer Requirement
1. The device should be easy to use. 2. The design should be safe to use for operator. 3. The design should be easy to install. 4. The device should be in low price. 5. The device should be environment friendly.
Design Requirement
1. The device should be fully covered. 2. The device should be small in size. 3. The device should be easy to maintain.

3.4 Full Product Assembly

Morphological chart was generated to explore different combinations of the ladder climbing assisting device in order to fulfill the same required functionality. The best combination was selected through weight rating matrix method for the concept on design the product specification. 3 product sketching are done based on the concept evaluated. Figure 4 show the 3 different product sketching.

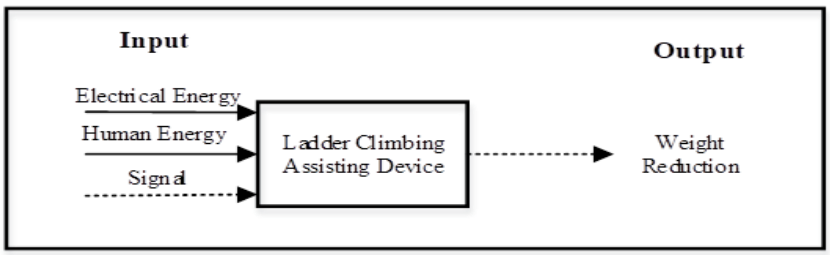


Figure 3: Black Box Function Structure for ladder climbing assisting device

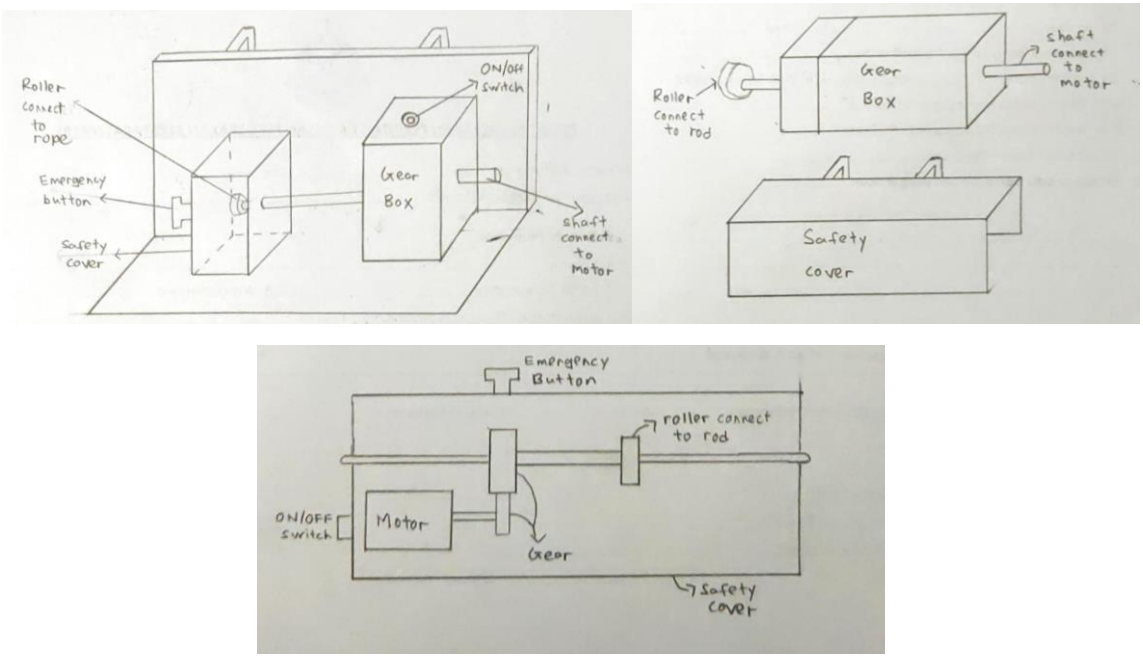


Figure 4: 3 different product Sketching

The schematic diagram was created in order to arrange and represent the required functions of physical elements in group. Figure 5 shows the schematic diagram.

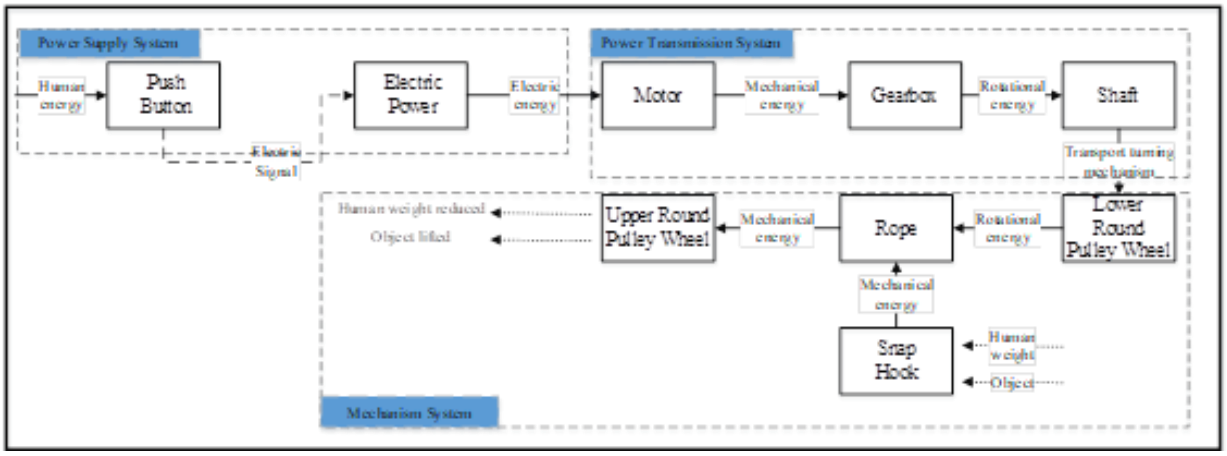
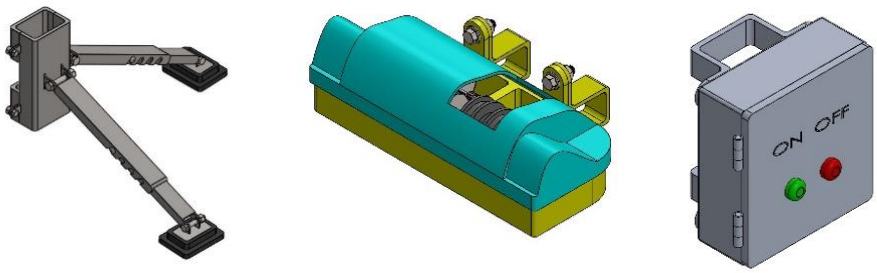


Figure 5: Schematic diagram of ladder climbing assisting device

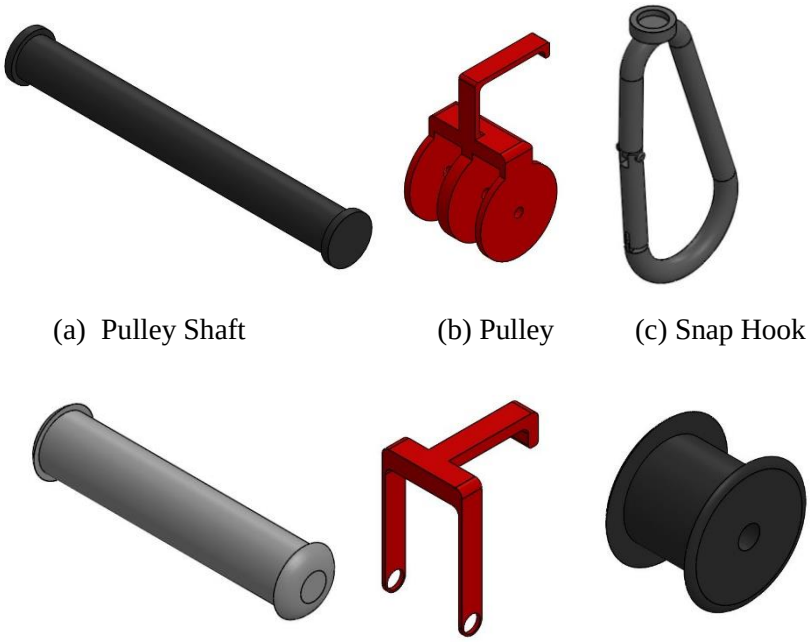
There are 3 main components included in this project. The 3D geometric layout of the 3 main part was created through SolidWorks and exported as shown in Figure 6.



(a) Ladder Stabilizer (b) Climbing Device (c) Power Box

Figure 6: 3D geometric layout.

Beside the 3 main part, there have another 6 other component that also needed for the complete ladder climbing device to work. Figure 7 show the 3D geometric layout of other 6 other component.



(a) Pulley Shaft (b) Pulley (c) Snap Hook

(d) Rope Wheel Holder Shaft (e) Rope Wheel Holder (f) Rope Wheel

Figure 7: 3D geometric layout

3.5 Simulation

Simulation was done in the device housing and the round pulley wheel of the climbing device. Device housing was conducting the static test while the round pulley wheel was undergoing drop test and thermal test. Figure 8 shows the simulation of these component.

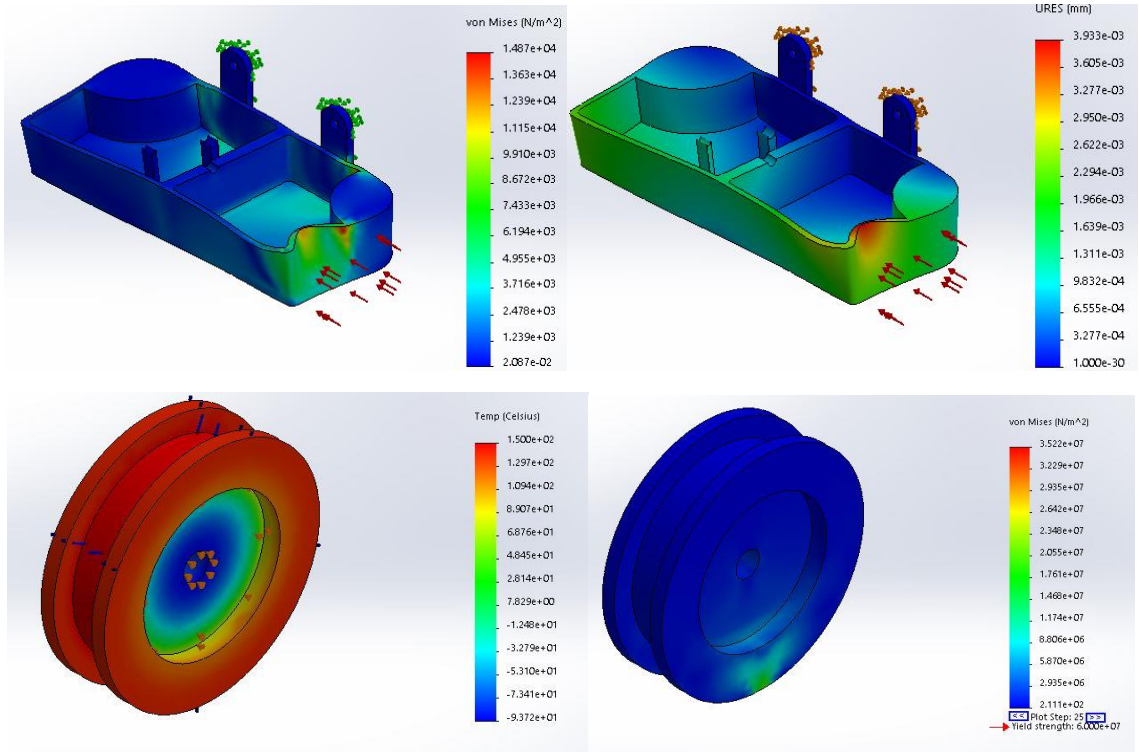


Figure 8: Simulation of the component

3.6 Engineering Analysis

Engineering analysis is important in parametric design for the component and standard part that needed calculation to obtain theirs parameter.

i. Motor Selection

The role of motor in this ladder climbing assisting device is to transmit power to the pulley wheel. The he specification of real machine speed is between 0.4 m/s until 1.1m/s and the weight reduced by the device is between 40 kg to 140 kg. Based on the specification, the optimum speed and the optimum speed weight expected to be reduced for the device are set in 0.5 m/s and 50 kg.

$$\omega = \frac{2v}{d} \quad Eq.1$$
$$= \frac{2(0.5)}{0.2}$$
$$= 5\,rad/s$$

$$T = rF \quad Eq.3$$
$$= (0.1)(125)$$
$$= 12.5\ \text{Nm}$$

Speed of climbing assisting device, n_{req}

$$= \frac{60(\omega)}{2\pi}$$
$$= \frac{60(5)}{2\pi}$$
$$= 47.75\ \text{rpm}$$

Power requirement, P_{req}

$$= T\omega$$
$$= 12.5(5)$$
$$= 62.5\ \text{W}$$
$$= 0.0625\ \text{kW}$$

$$F = mr\omega^2 \quad Eq.2$$
$$= (50)(0.1)(5)^2$$
$$= 125\ \text{N}$$

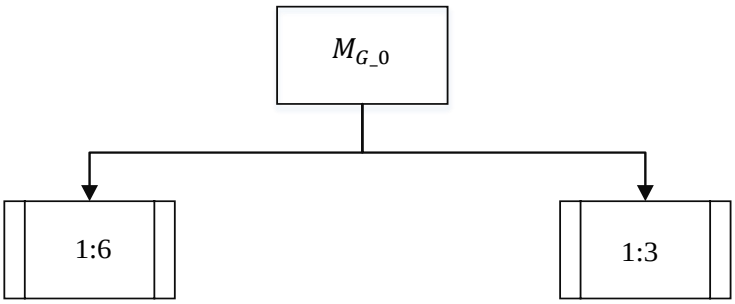
Based on the power required, the motor selected is AC motor with power, P = 0.093 kW[5]

ii. Overall Gear Ratio Selection

Gearbox is used to reduce the motor speed and increase the torque. Gear is used to transmit rotary motion and power from one shaft to another shaft. Gear ratio is the relationship between two gear. The overall gear ratio based on speed is given by:

$$\text{Gear ratio} = \frac{\text{Input speed}}{\text{Output speed}} \quad Eq.4$$
$$= \frac{870}{47.75}$$
$$= 18.22$$

The minimum gear ratio for the speed of motor to reduce to desired speed of the machine is 1: 18.22. Therefore, the most suitable gear ratio selected is 18.



iii. Gear Fundamental Analysis

In this project, 2 sets of gear is used to transmit the rotary motion and torque from motor to the sifting shaft to rotates the sifting blades. The equation used to calculate all the fundamental are shown below and the result of calculation are shown in Table 5.

$$N_p = \frac{2k}{(1+2M_G)\sin^2\phi}\left(M_G\sqrt{{M_G}^2+(1+2M_G)\sin^2\phi)}\right) \quad Eq.5$$
$$D_p = m \times N \; Eq2$$
$$T_0 = \frac{N_0}{N_i}T_i \; Eq3$$
$$n_0 = \frac{N_0}{N_i}n_i \; Eq4$$

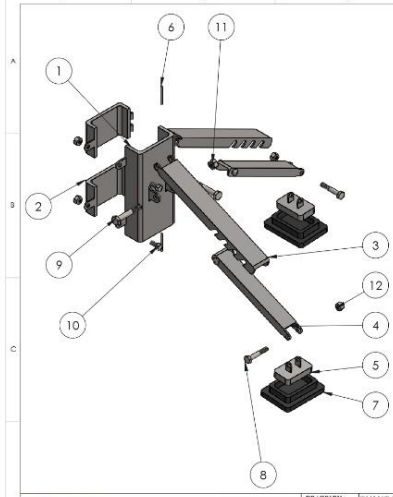
Table 5: Gear fundamental analysis

	Gear Set	Number of teeth, N_p	Pitch Diameter, D_p (mm)	Torque, T_0 (Nm)	Speed, n_0 (rpm)
1	Pinion 1	16	24	0.9807	870
	Gear 1	100	150	6.1294	13.92
2	Pinion 2	15	30	6.1294	13.92
	Gear 2	45	90	18.3882	4.64

3.7 Engineering Drawing

Engineering drawing of the ladder climbing assisting device were produced by using SolidWorks software. The detail such as the dimension and the material were also included clearly in the drawing. Figure 9 shows the exploded view of the 3 main components and the isometric view when the device is install in the ladder.

APPENDIX E



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Ladder Stabilizer (Body)	LCAD 01:01:01	1
2	Ladder Stabilizer (Connector)	LCAD 01:01:02	2
3	Ladder Stabilizer (Body Connector)	LCAD 01:01:03	2
4	Ladder Stabilizer (Leg Base Connector)	LCAD 01:01:04	2
5	Ladder Stabilizer (Leg Base)	LCAD 01:01:05	2
6	Ladder Stabilizer (Shaft)	LCAD 01:01:06	2
7	Ladder Stabilizer rubber	LCAD 01:01:07	2
8	B18.2.3.3M - Heavy hex screw, M12 x 1.75 x 70 --30S		2
9	B18.2.3.3M - Heavy hex screw, M14 x 2.0 x 90 --34S		2
10	B18.6.7M - M12 x 1.75 x 25 Indented HHMS --25S		2
11	B18.2.4.6M - Heavy hex nut, M14 x 2 --W-S		2
12	B18.2.4.6M - Heavy hex nut, M12 x 1.75 --W-S		4

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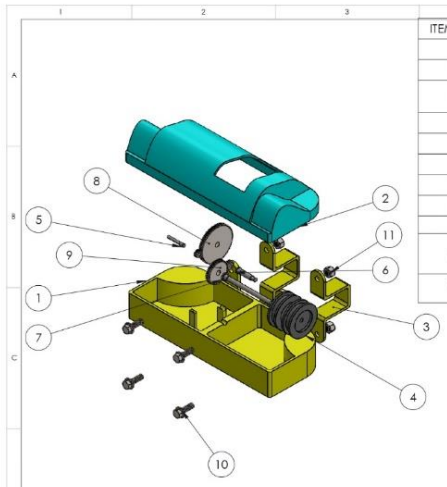
DRAWN BY: CHANG FEI NGING | MATERIAL: | QTY.: 1 | DWG TITLE: LADDER STABILIZER EXPLODED VIEW | PROJECT TITLE: LADDER CLIMBING ASSISTING DEVICE | DRAWING NO: LCAD 01:01:00(B) | SHEET 5 of 35 | SCALE 1:8 | A4 | DIMENSIONS IN mm | FABRICATOR

APPENDIX E



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Device Housing	LCAD 01:02:01	1
2	Device Housing Cover	LCAD 01:02:02	1
3	Square Bracket (Climbing Device)	LCAD 01:02:03	1
4	Round Pulley Wheel	LCAD 01:02:04	2
5	Shaft 1	LCAD 01:02:05	1
6	Shaft 2	LCAD 01:02:06	1
7	Shaft 3	LCAD 01:02:07	1
8	Gear Set 1		1
9	Gear Set 2		2
10	B18.2.3.9M - Heavy hex flange screw, M20 x 2.5 x 60 --60S		4
11	B18.2.4.6M - Heavy hex nut, M20 x 2.5 --W-S		4

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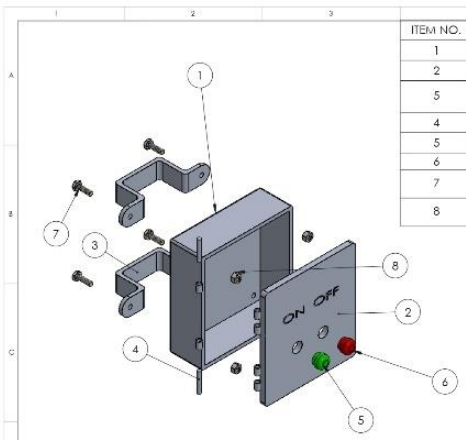
DRAWN BY: CHANG FEI NGING | MATERIAL: | QTY.: 1 | DWG TITLE: CLIMBING DEVICE EXPLODED VIEW | PROJECT TITLE: LADDER CLIMBING ASSISTING DEVICE | DRAWING NO: LCAD 01:02:00 (B) | SHEET 15 of 35 | SCALE 1:10 | A4 | DIMENSIONS IN mm | FABRICATOR

SOLIDWORKS Educational Product. For Instructional Use Only.

APPENDIX E



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Power Box	LCAD 01:03:01	1
2	Power Box Cover	LCAD 01:03:02	1
5	Square Bracket (Power Box)	LCAD 01:03:03	2
4	Power Box Shaft	LCAD 01:03:04	2
5	ON Switch		1
6	OFF Switch		1
7	B18.2.3.3M - Heavy hex screw, M12 x 1.75 x 40 --40S		4
8	B18.2.4.6M - Heavy hex nut, M12 x 1.75 --W-S		4

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DRAWN BY: CHANG FEI NGING | MATERIAL: | QTY.: 1 | DWG TITLE: POWER BOX FULL ASSEMBLY | PROJECT TITLE: LADDER CLIMBING ASSISTING DEVICE | DRAWING NO: LCAD 01:03:00(B) | SHEET 25 of 35 | SCALE 1:6 | A4 | DIMENSIONS IN mm | FABRICATOR

SOLIDWORKS Educational Product. For Instructional Use Only.

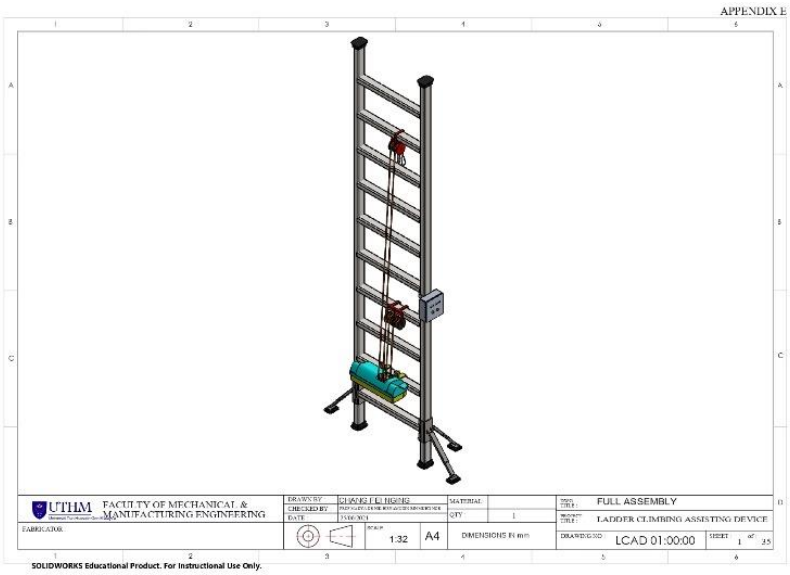

Figure 9: Assembly layout

3.8 Product Specification

The final product specification was calculated and generate after all the detail drawing and engineering analysis are done. Table 6 shows all the related specification of the product.

Table 6: Product specification

Overall Product Specification		**Description**
Product Name		Ladder climbing assisting device
Overall Weight		68.35 kg
Overall Cost		Rm 519.34
Component Specification		
Component	**Specification**	**Description**
Ladder Stabilizer	Weight	35.64 kg
	Material	Stainless Steel (AISI 304)
		Rubber
Climbing Device	Weight	15.82kg
	Dimension	716mm x 307mm x 226mm
	Material	Stainless Steel (AISI 304)
		6061 Aluminum alloy
		ABS
		Nylon 101
Power Box	Weight	9.44kg
	Material	6061 Aluminum alloy

4. Conclusion

The objective of this project is to design a simple mechanism for the ladder climbing assisting device for industries use in an acceptable price. For the mechanism of the device, the design only used 2 set of the gear to drive the device so the objective of the project is achieved. This made the maintenance job become more easy and fast and help to reduce the delay time when the machine are in damage. Besides that, a ladder stabilizer is design together with the climbing device in order to increase the safety use of the ladder during the work operation. The weight of full set of climbing device was just 68.35 kg only and the size of the device can be say is small if compare to the product sold in market. For recommendation, the cost of the climbing device can future reduce by selecting other more low cost

material. For performance part, try to made more engineering analysis that can help to improve the performance and the lifespan of the device in order to increase the user experience. Try to made more safety cover on the device to avoid accident happen when the device is on working condition.

Acknowledgement

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