Bio-inspired Robot

Hong Wei Tan
MMAE 232
Illinois Institute of Techonology
Chicago, Illinois, United States of America
htan8@hawk.iit.edu

***Abstract*—This report describes the process of designing and fabricating a biologically inspired robot that can autonomously climb up a 90 inches vertical pegged wall. The robot is controlled by the use of servos and an Arduino board that are able to be easily disassembled. The biologically-inspired robot is inspired by an inch-worm is modeled using *Autodesk Inventor* and fabricated with 1/4" Medium-Density Fibreboard (MDF). After modelling the design, changes are implemented in order to assure a successful robot was fabricated. In the final testing, the robot climbs successfully climbed up a vertical pegged wall in 3 minutes and 15 seconds.**

I. Introduction

For the third project in MMAE 232, students were required to design a biologically-inspired robot that can autonomously climb up a vertical pegged wall (see Fig.1). The robot was controlled by the use of servos and an Arduino Board. Our initial design was inspired by an inch-worm and similar features of the inch-worm were incorporated into the mechanics of the robot. The robot managed to climb up the vertical wall in the final testing in 3 minutes and 15 seconds.

A. Functional Requirements

The requirements were:

- Autonomously climbs up a vertical pegged wall.
- Robot has to be biologically-inspired.
- Has the ability to be disassembled. All servos and electronics must be able to be disassembled. No glue can be applied on servos, servo horns, or electronics. Tape cannot be used to hold down servos or moving parts.

II. Concept Generation and Evaluation

The first step in the robot's design process was to identify animals with both a simple and stable gait and incorporate it into a the basic sketch of a robot. Two ideas were generated and each was analyzed by creating (1) A hildebrand gait plot, (2) A convex contact polygon, and (3) a free body diagram representing the varying force(s) and torque(s) acting on the robot. These three analyses allowed us to understand the gait that was being incorporated into our design and how that gait will affect the overall stability of the robot. Based on the results of the various analyses, a design will be chosen for modelling. Of the two sketches pictured in Figure 2 & 3, the three segments inch-worm was chosen.

Fig. 1. Final Bio-Inspired Robot Prototype

III. Analysis

The motion of the robot was inspired by the locomotion of an inch-worm, which was consisted of a repetitive cycle of elongation and contraction. The robot was consisted of 3 segments, 2 arms on the top segment and the other 2 arms on the bottom segment. A gait plot was drafted to visualize the motion of the robot (see Fig. 4). The motion of the robot was initialized by lifting two arms on the top. Next, the pinion in the middle segment rotated in an anti-clockwise direction to elongate the segments of the body. The motion of the robot was followed by the putting down both of the top arms, lifting up both of the bottom arms and the pinion rotated in a clockwise direction to contract the body of the robot. Finally, the bottom two arms was put down on the peg, which was the last step of the motion cycle. It was designed in a way that there were always at least two points of contact with the pegs as the robot pulled or pushed itself along (see Fig. 7)

A static torque analysis determined if the robot could hold its own weight while resting on the pegged wall. A free-body diagram for the torque acting on the servo was shown in Figure 6. The following calculations showed the the torque analysis from the legs onto the servos. The servo could produce 350Nmm of torque. The total mass of the robot, which was consisted of an Arduino, three servos, two 9-v batteries and the body, weighed 736.5g.

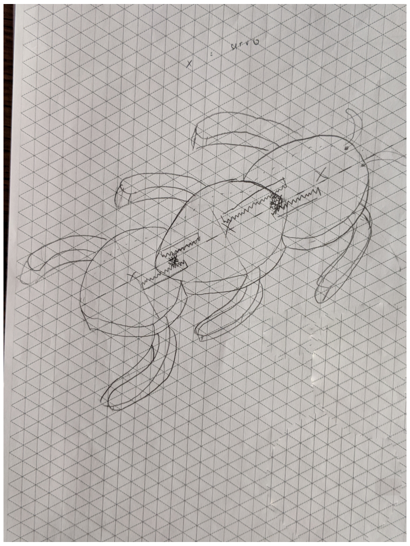


Fig. 2. Design Concept 1: Inch-worm

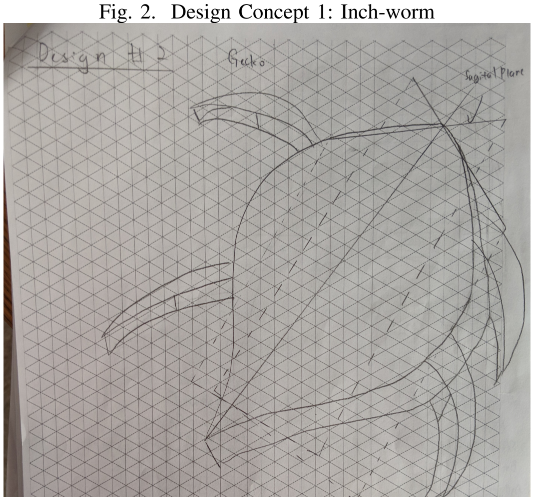


Fig. 3. Design Concept 2: Gecko

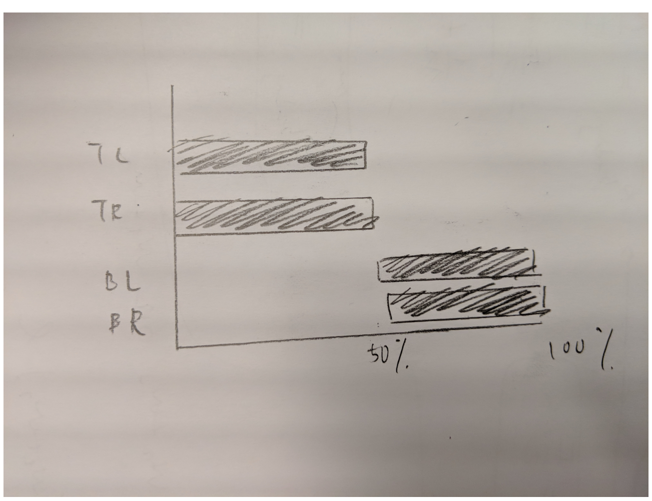


Fig. 4. Gait Plot for the Inch-worm Prototype

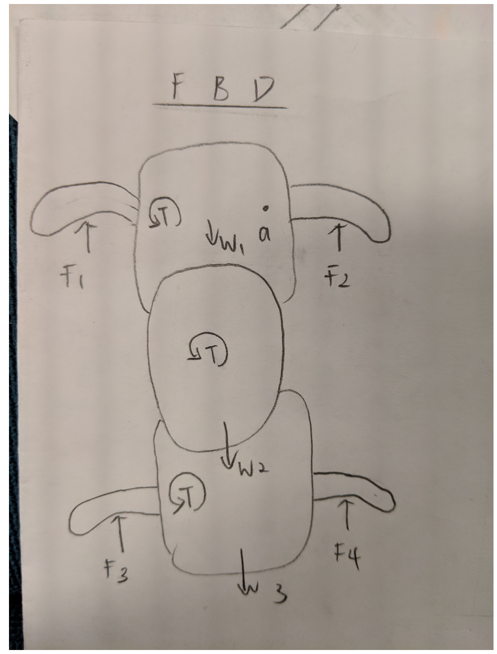


Fig. 5. Free Body Diagram

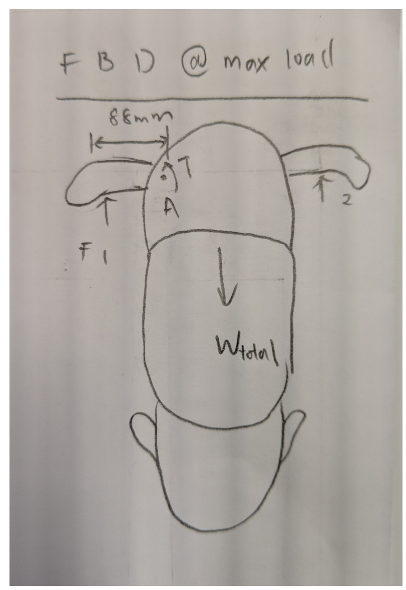


Fig. 6. Free Body Diagram with maximum load

The maximum reaction force acting on each arm in the y-direction are given:

$$F_1 = F_2, F_3 = F_4 \tag{1}$$

$$\sum F_y = 2(F_1) = mg \tag{2}$$

$$F_y = \frac{mg}{2} \tag{3}$$

From equation 3, reaction force acting on each arm in the y-direction is $3.613N$. The maximum moment applied is

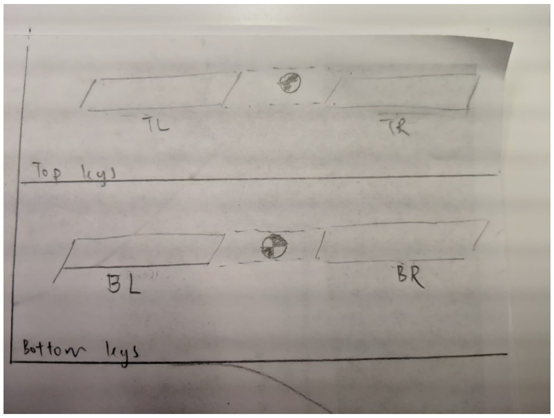


Fig. 7. Convex Convoy Polygon

determined by muliplying the length of the arm r with the reaction force F_y on each arm (see equation 4)

$$\sum M_a = r \times F_y \tag{4}$$

The moment about A from the arm was obtained to be $318Nmm$. The amount of torque applied from the servo was proven to be sufficient for the robot to be statically stable as $M_A < 350Nmm$.

A. *Torque Analysis on Rack and Pinion*

The mechanism that contributed to the locomotion of an inch-worm was by using a rack and pinion mechanism in the robot. The pinion played an important role as it was responsible for the pulling and pushing action for the robot during elongation and contraction of the robot. A quasi-static force equilibrium is performed on the pinion to determine if the torque from the servo will be sufficient.

During the elongation of the robot, the pinion received a downward force from the weight of the front segment W_1 and a upward force from the weight of the front and the middle segment $W_1 + W_3$ (see Fig.) The total torque required can be determined by multiplying the pitch diameter of the pinion with the total force exerted on the pinion (see equation 5).

$$TotalTorque, T_t = r(2W_1 + W_2) \tag{5}$$

During the contraction of the robot, the pinion received a downward force from the weight of the bottom segment W_3 and a upward force from the weight of the middle and the bottom segment $W_2 + W_3$ (see Fig) The total torque required can be determined from equation 6.

$$TotalTorque, T_t = r(2W_3 + W_2) \tag{6}$$

The total torque during the elongation will me used to measure the sufficiency of the torque from the servo as the weight of the top segment, W_1 has heavier weight due to the attachment of the Arduino board and battery. Given pitch diameter of the pinion, $r = 2.35mm$, the required torque is $197.66Nmm$. The torque exerted from the servo is proven to sufficient as $T_t < 350Nmm$.

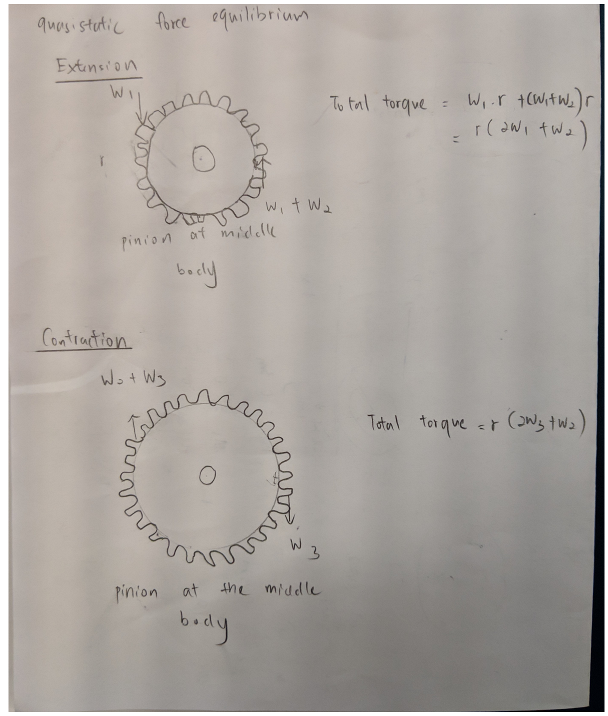


Fig. 8. Quasi-static Force Equilibrium on the pinion during elongation and contraction

EXPERIMENTAL RESULT

During the final test day, the robot was equipped with fully-charged 9-volts battery to ensure the servos could perform at their full capability. After fastening the mechanical components of the robot, the robot was tried out on the pegged wall. The robot managed to climb up all the way to the 90 inches point in 3 minutes and 15 seconds.

DISCUSSION

The bio-inspired robot design process was initiated by referencing to different gait plots of the motion of different animals. An Inch-worm and a gecko were picked to become the bio-inspired robot reference because a potential was seen in them to be able to perform the functional requirement. Following by selecting one of the conceptual design, a rack and pinion gear system was selected because that gear system can effectively imitate the locomotion of an inch-worm.

The final prototype was a success mainly because the alignment of the rack and pinion was set up correctly. The surface of the sliding mechanism was sanded properly to ensure that the translation of robot will be smooth.

CONCLUSION

The final prototype successfully met all functional requirements for the project. To be successful, it is important to develop a statically stable, lightweight, and simple robot. Simplicity proved to be the key factor to the success of the robot as it utilized the minimal amount of servos to avoid synchronization error and conserve a lightweight of the robot.

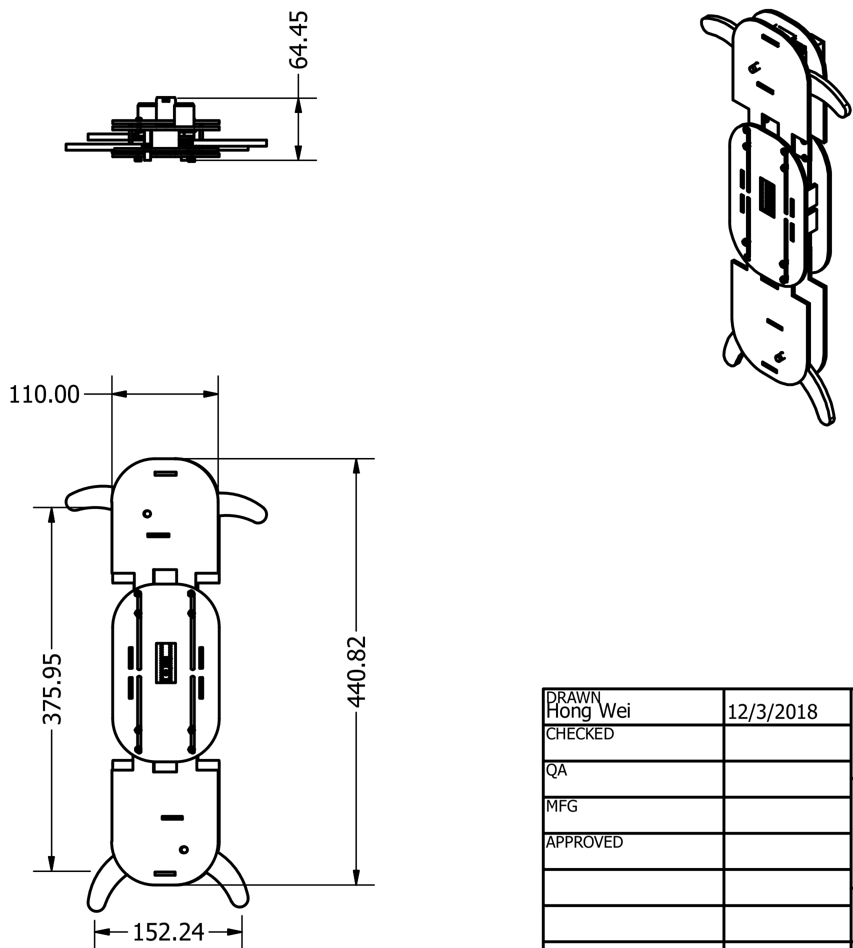
The design process was a pertinent component to the success of the robot, because it allowed us to continuously improve and develop the robot's prototype.

Appendix

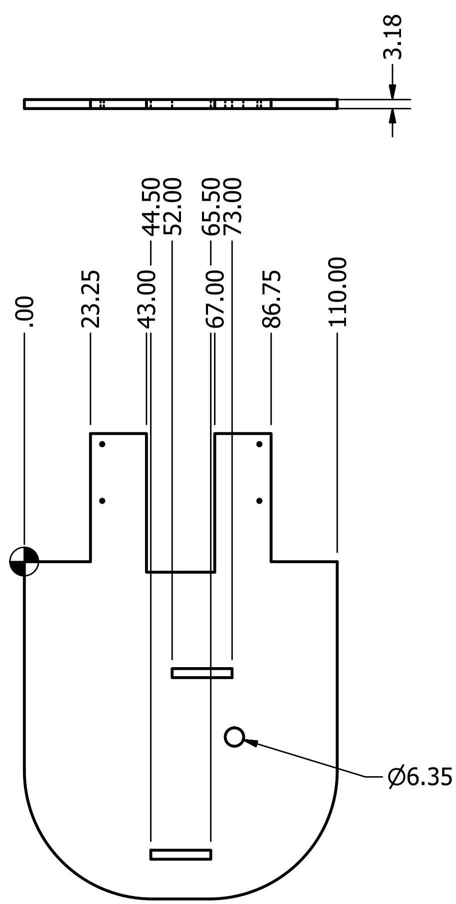
Please find the following attached.

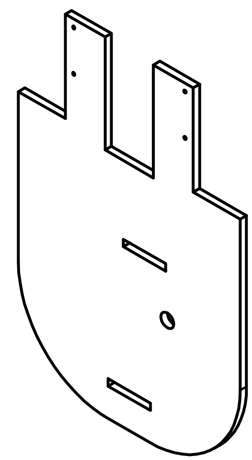
- Engineering Drawing
- Bill of Materials (BOM)

This document is created using LaTeX

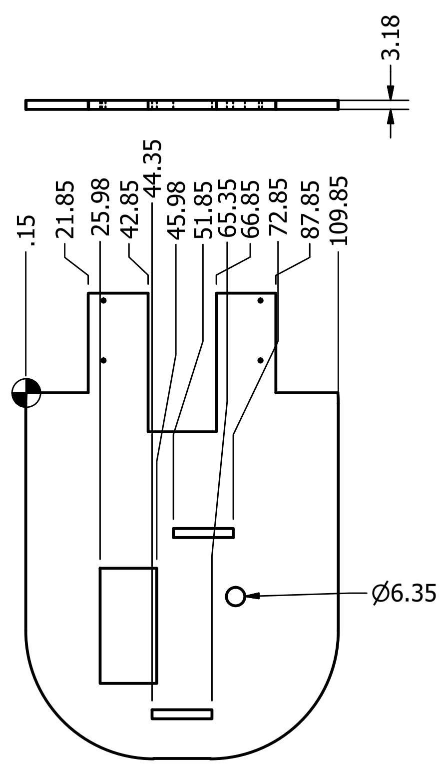


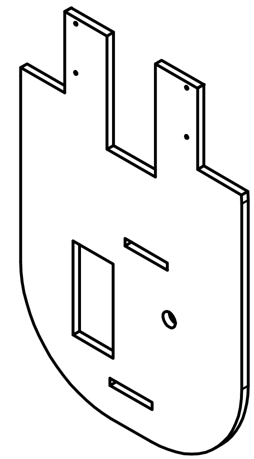
DRAWN Hong Wei	12/3/2018				
CHECKED		TITLE			
QA		Assembly			
MFG					
APPROVED					
		SIZE A4		DWG NO Assembly	REV
		SCALE 0.17 : 1		SHEET 1 OF 1	



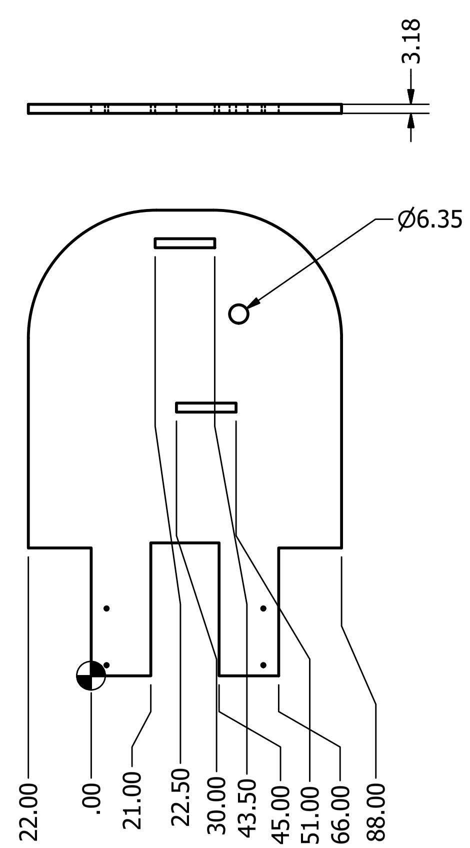


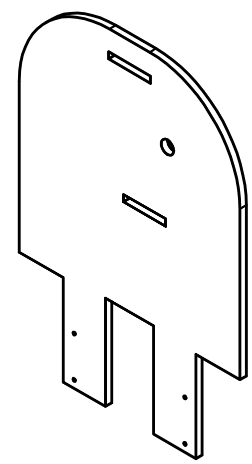
DRAWN Hong Wei	12/3/2018				
CHECKED					
QA		TITLE			
MFG		Body Bottom Top			
APPROVED					
		SIZE A4		DWG NO Body Bottom Top	REV
		SCALE 1 / 2		SHEET 1 OF 1	



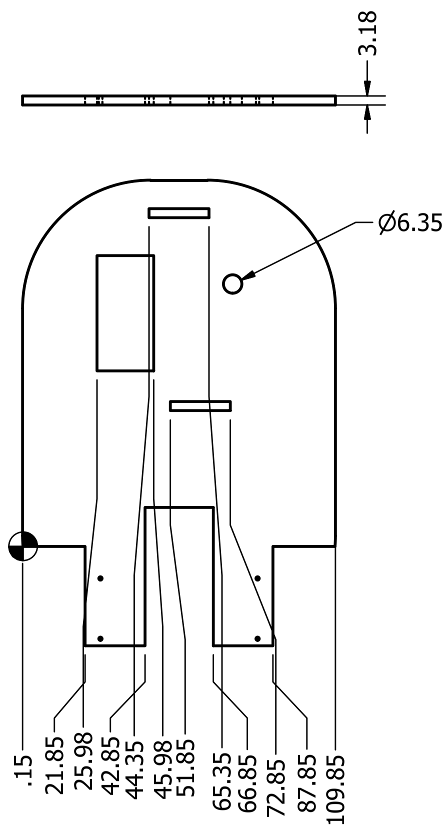


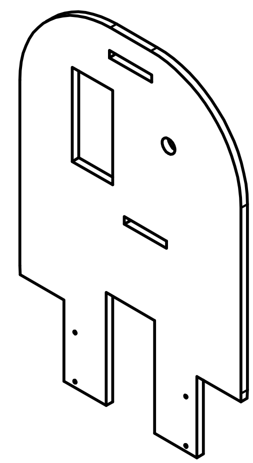
DRAWN Hong Wei	12/3/2018				
CHECKED		TITLE			
QA		Body Bottom			
MFG					
APPROVED					
		SIZE A4		DWG NO Body Bottom	REV
		SCALE 1 / 2		SHEET 1 OF 1	



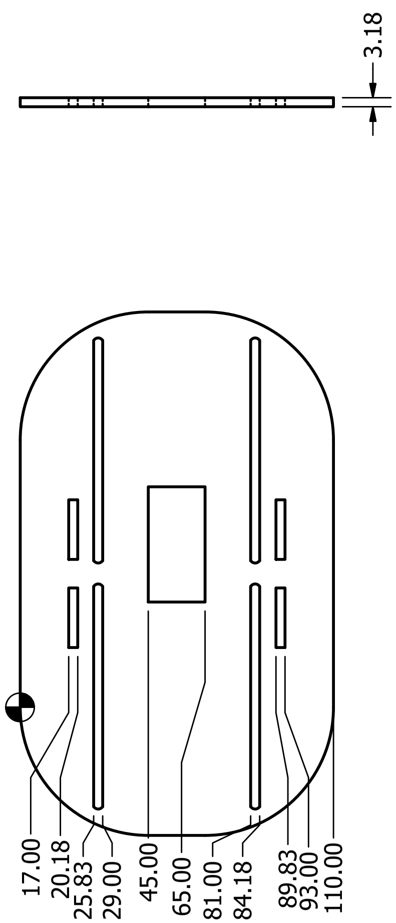


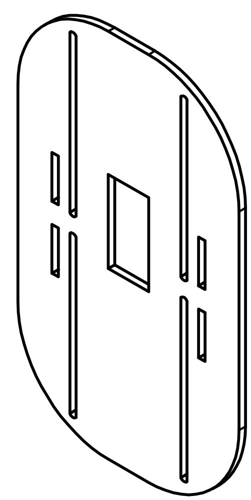
DRAWN Hong Wei	12/3/2018	
CHECKED		TITLE
QA		Body Front Top
MFG		SIZE A4
APPROVED		DWG NO Body Front Top
		REV
		SCALE 1 / 2
		SHEET 1 OF 1



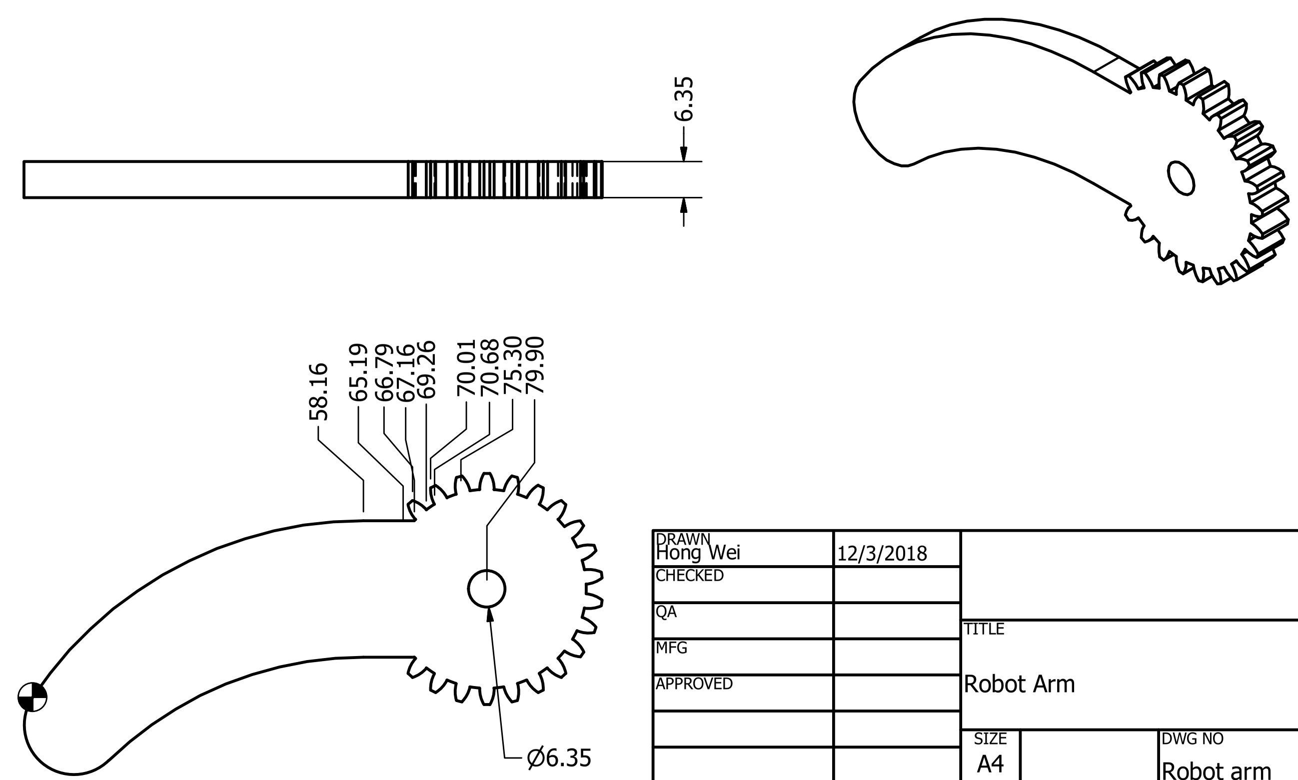


DRAWN Hong Wei	12/3/2018				
CHECKED					
QA		TITLE			
MFG		Body Front			
APPROVED					
		SIZE A4		DWG NO Body Front	REV
		SCALE 1 / 2		SHEET 1 OF 1	





DRAWN Hong Wei	12/3/2018	
CHECKED		
QA		TITLE
MFG		Body Middle
APPROVED		
		SIZE A4 · DWG NO Body Middle · REV
		SCALE 1 / 2 · SHEET 1 OF 1



DRAWN Hong Wei	12/3/2018				
CHECKED		TITLE			
QA		Robot Arm			
MFG					
APPROVED					
		SIZE A4		DWG NO Robot arm	REV
		SCALE	1 : 1		SHEET 1 OF 1