Capston Design

Mechanized Pedestrian for Automated Vehicle Development

M4

Marvelous
Mechanized
Mobile
Mannequin

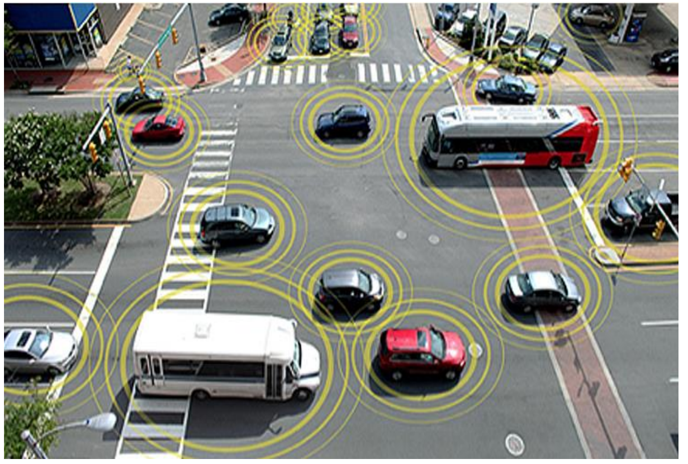
TIM the Beaver Workshop

Approaching the Design Problem

- Problem Description
- Motivation and Background
- Project Requirements
- Engineering Specifications
- Project Plan
- Specific Challenges

Problem Description

- Problem:
  - 33,561 Auto-related deaths in US 2012
  - 14% in US and 50% pedestrian fatalities in other regions
  - Automated vehicle tests needed
- Solution:
  - Mechanized pedestrian

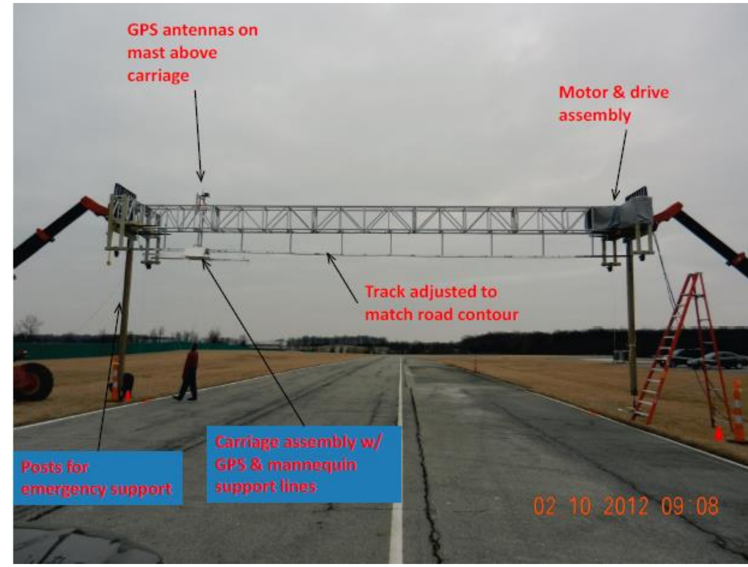


Automated Vehicle System Concept

- Sponsor:
  - Prof. Huei Peng, Dr. Jim Sayer
  - Michigan Mobility Transformation Center(MMTC)

Background and Motivation

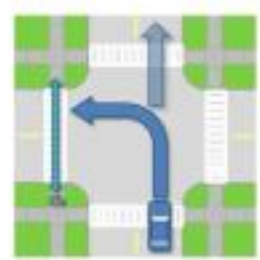
- Significant investment in autonomous vehicle research
- Test required for different scenarios
- Only stationary test equipment available



Stationary Test Mannequin Design [1]

S1

S2



S3

S4

Requirements Overview

- Human-like
- Portable (no overhead gantry)
- Different weather conditions
- Quick Reset
- Robust to light bump
- Cost efficient

Indoor Mannequin [2]

Wire Pulled Mannequin [1]

Design Driving Specifications

Requirement	Specification	Design Concern
Human-like	Travel Speed: 0 to 1 m/s	Motor power
	Step Length:30 ± 2 in.	Leg separation angle
	Size: 50^{th} percentile adult male	Weight and joint force
Quick reset	Time: < 1 min	Mechanism design
Cost efficient	Price: 1500 U.S. dollars	Part selection

Project Plan

- Confirm Project Requirements and Engineering Specifications (Sep. 11)
- Mechanism Concept Generation and Selection with Preliminary Design (Sep. 25)
- Detailed Design and Simulation (Oct. 12)
- Purchasing and Prototype Fabrication (Oct. 30)
- Control System Implementation (Nov. 7)
- Design Test and Engineering Specification Validation (Nov. 21)

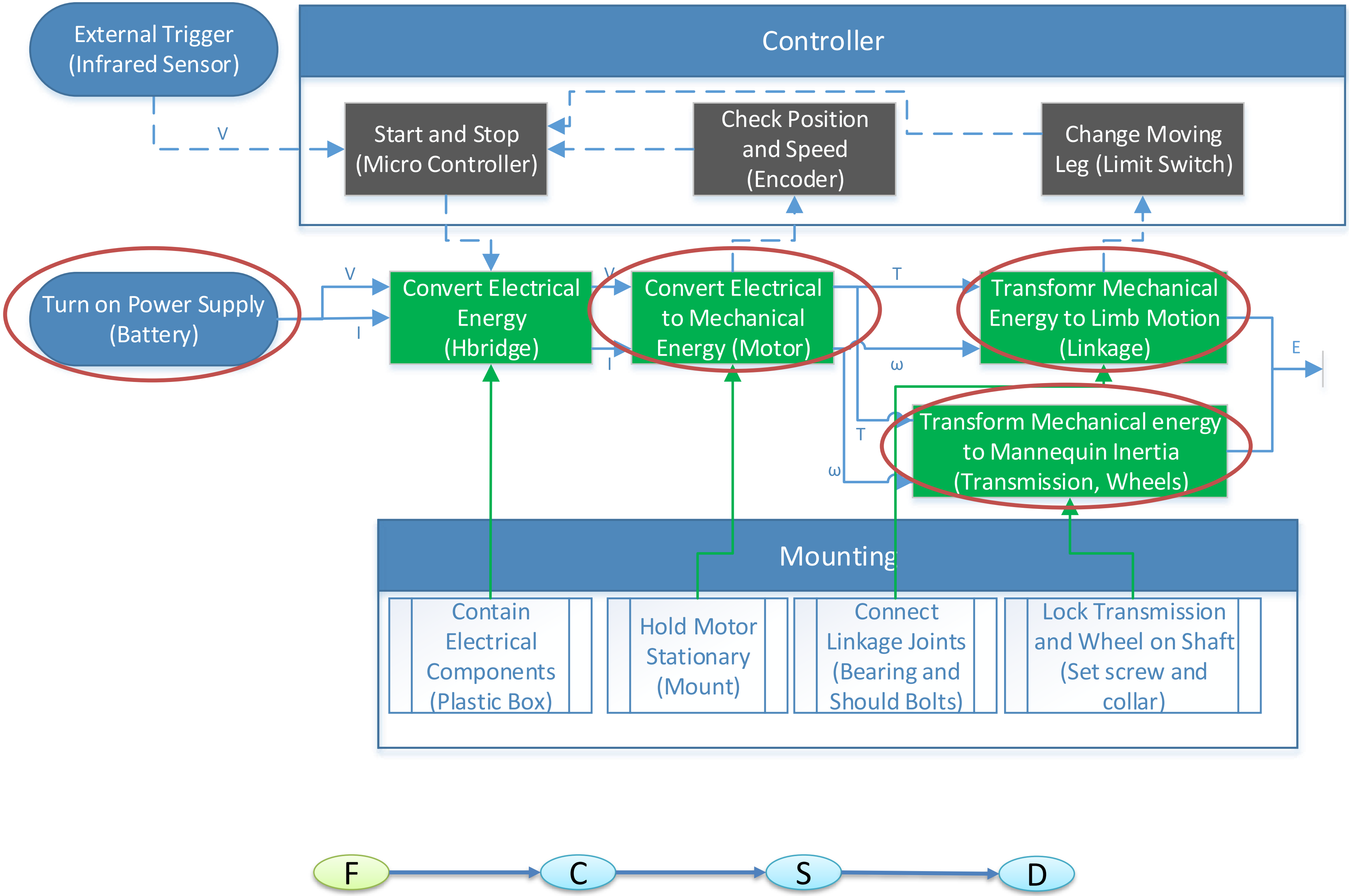
Specific Challenges

- Rain resistance realization for electrical system
- Mechanical pedestrian structure balancing without over hand gantry and pulling wires
- Mimic of pedestrian motion with very few actuators and limited degree of freedom
- Simple mechanism structure for reset

Preliminary Design

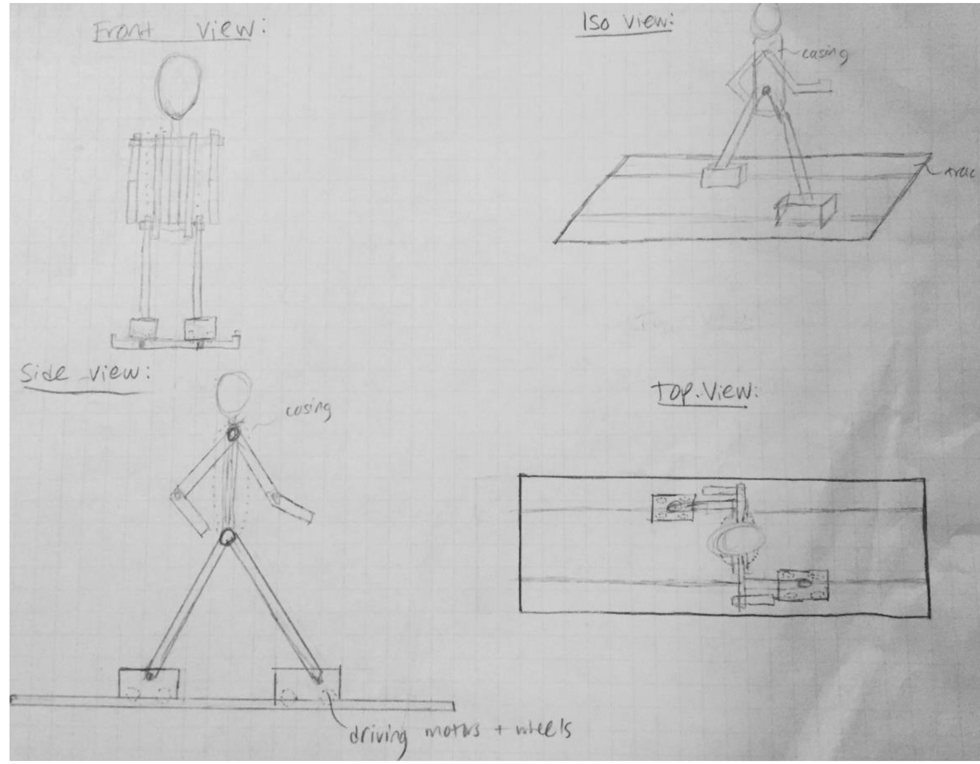
- Functional Decomposition
- Concept Generation
- Design Selection
- Prototype Model

Functional Decomposition



Concept Generation

- Linear Actuator
- Swinging Arm
- Constrained on Track
- Self-lock Brake
- Battery Powered

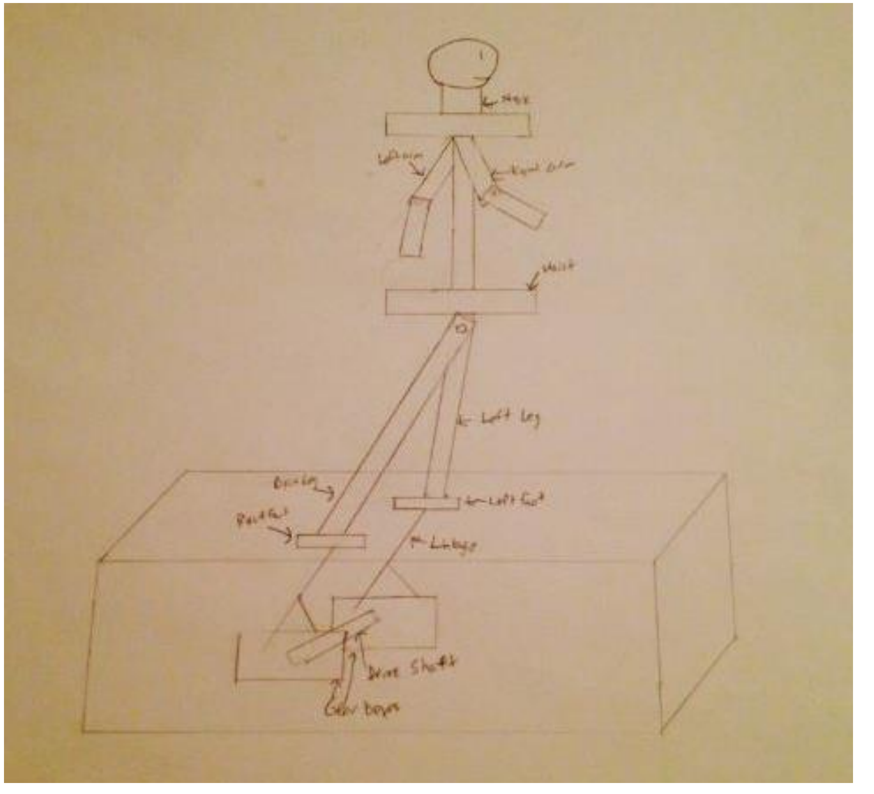


Concept Design 1

F → C → S → D

Concept Generation

- Linkage in Cart
- Linkage for Arm
- Aluminum Wheel
- Self-lock Brake
- Spring Loaded or Battery

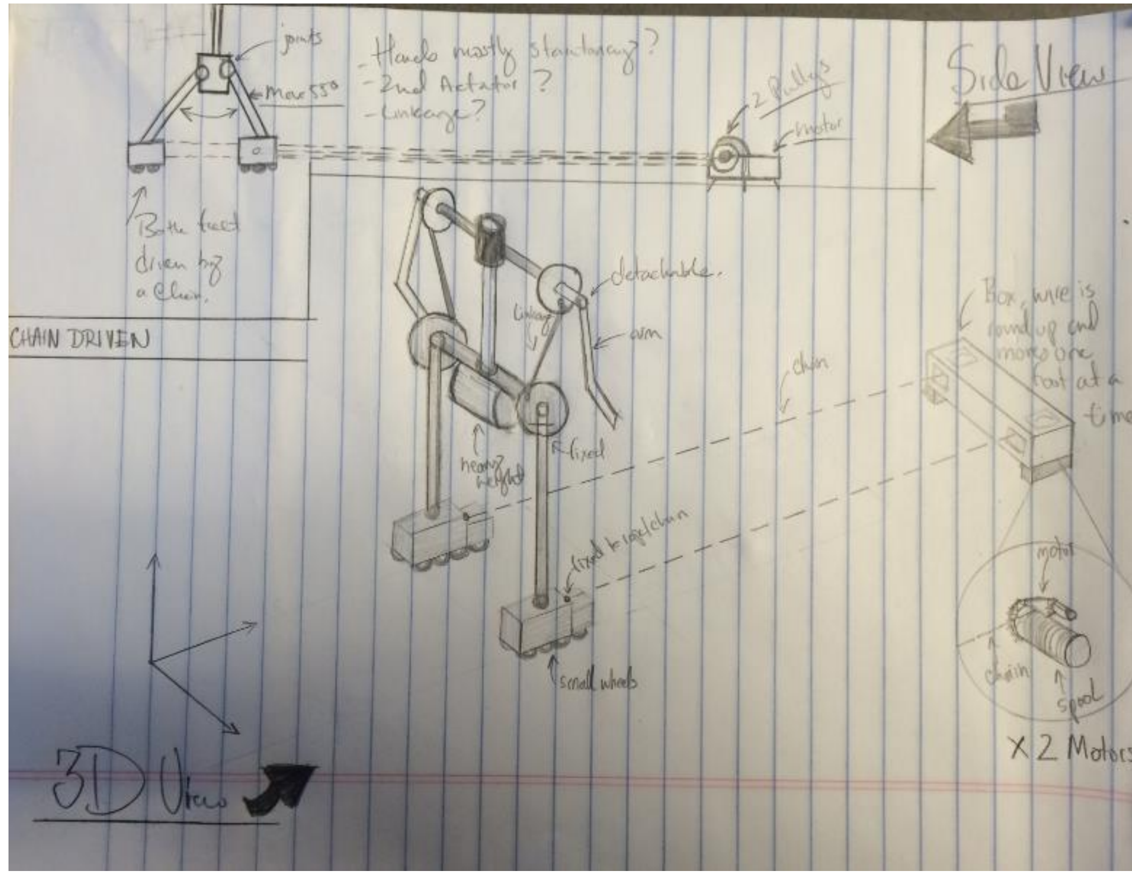


Concept Design 2

F → C → S → D

Concept Generation

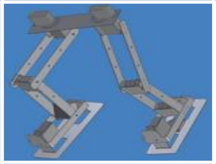
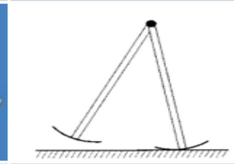
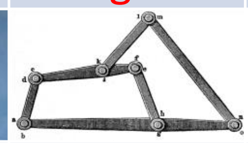
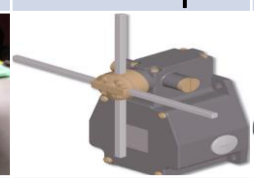
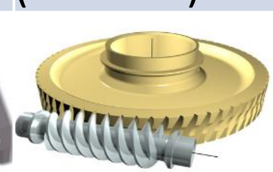
- Windlass Drive
- Linkage for Arm
- Aluminum Wheel
- Hard Stop Brake
- Plugged



Concept Design 3

F → C → S → D

Morphological Analysis

System Function	1	2	3	4	5	6
Leg Motion	All Joints	Motor at Waist	Motors In Feet	Linkage in Cart	Windlass Pulled	Linear Actuator
						
Arm Motion	All Joints	Linkage	Free Swing			
						
Brake	Magnetic Clutch	Friction Induced	Hard Stops	Worm Gear (self lock)		
						
Ground Roller	Track	Ball Screw	Aluminum Wheel	Wheel with Rubber Tires		
						

F → C → S → D

Morphological Analysis

AsiaUS Business Connection   workshop TIM THE BEAVER

System Function	1	2	3	4
Power Source	Batteries	Passive	Plugged	Spring Loaded
				
Cover	Plastic Model	Artificial Skin	Clothes	
				
Filler	Foam	Styrofoam	Cotton	
				
Structure Material	Aluminum	Steel	Carbon Fiber	PVC
Torso Balance	Isosceles & Slider	Gravity Balanced	Motor Driven	

F → C → S → D

Sample Selection of Leg Motion Mechanism

Design Criteria	Weight: Scale(1-3)	All Joints	Motor at Waist	Motors In Feet	Linkage in Cart	Windlass Pulled	Track
Human-like	3	+++	++	++	0	+	+
Detection Interference	3	++	+	++	---	-	--
Affordability	2	---	++	+	-	+++	+
Setup Time	2	++	+++	+++	+	---	---
Portability	2	0	++	+++	+	+++	+++
Stability	2	--	-	+	++	+++	+++
Robustness	1	---	--	-	-	++	+
Maintenance	1	---	0	++	0	+	+
	Plus(+)	19	23	30	8	23	19
	Minus(-)	-16	-4	-1	-4	-9	-12
	TOTALS	**-3**	**19**	**<u>29</u>**	-12	14	7

Rating Scale [- - -, - -, -, 0, +, ++, +++]

Selected Design Model

- Motors in Feet
- Linkage for Arm
- Friction Induced Brake
- Wheels with Rubber Tires
- Battery Powered
- Clothes Cover
- Styrofoam Filler
- Aluminum Structure
- Isosceles & Slider

Prototype Model

Solidworks Model

F → C → S → D

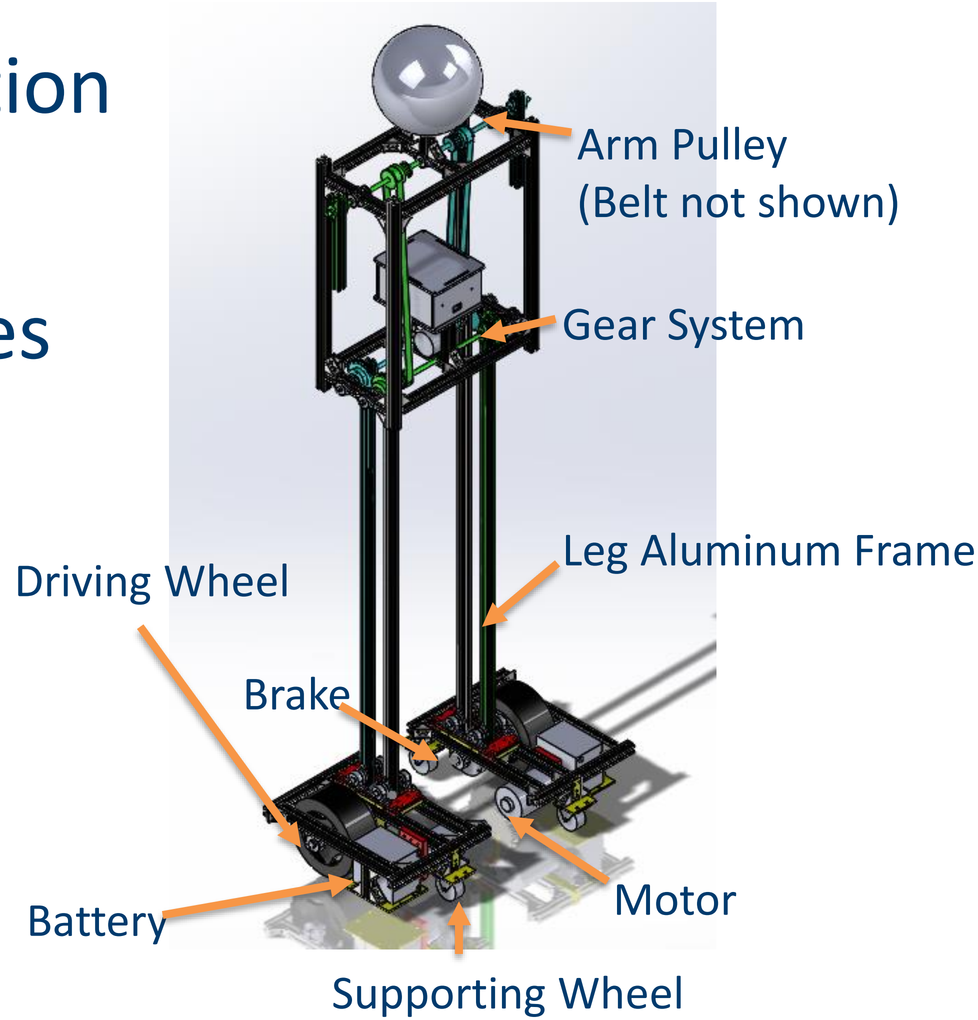
Detailed Design

- CAD Modeling
- Mechanical Analysis
- Actuator Selection

Selected Design Model

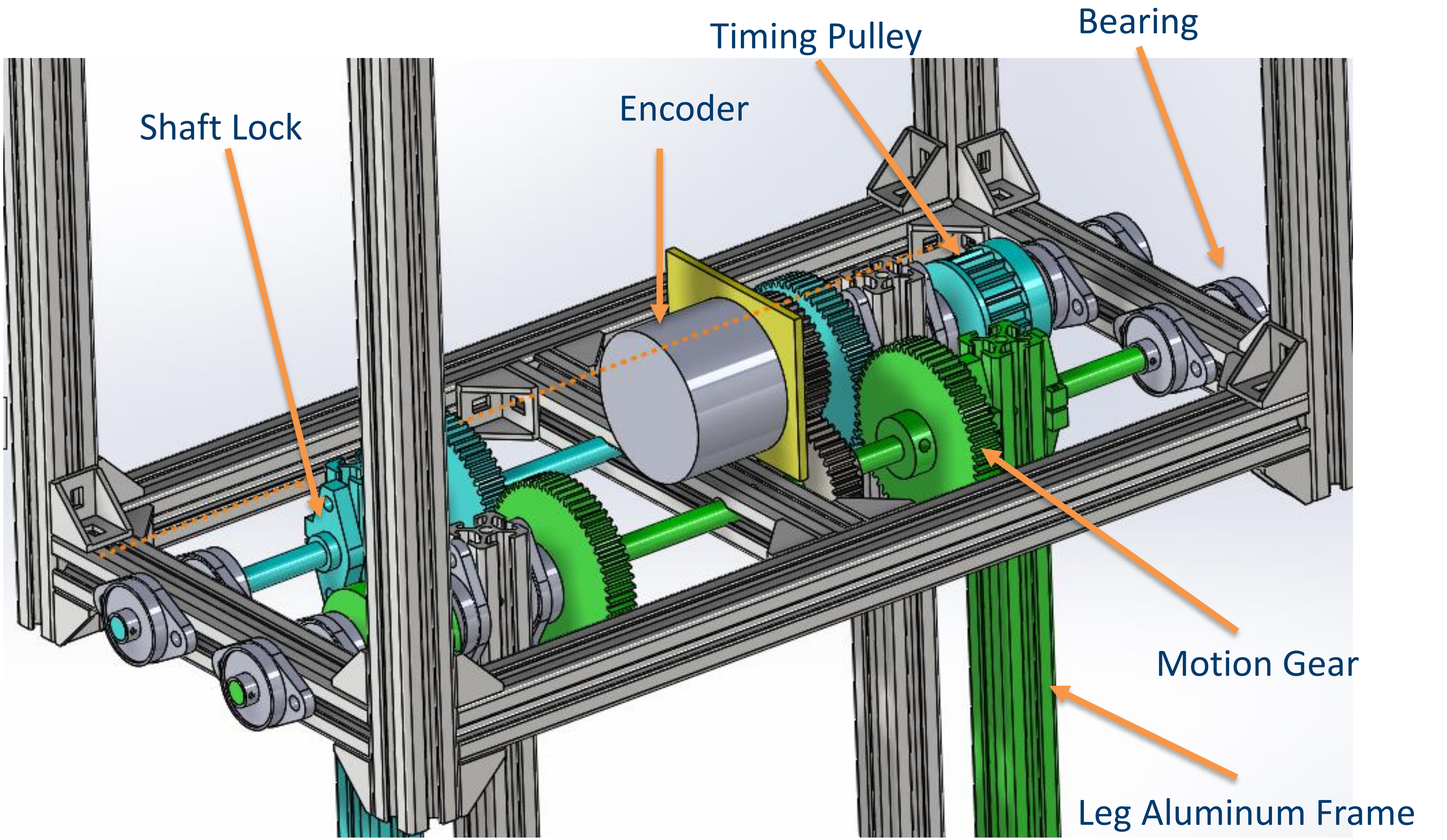
- Motors in Feet
- Timing Belt for Arm Motion
- Friction Induced Brake
- Wheels with Rubber Tires
- Battery Powered
- Aluminum Structure

Motion Simulation

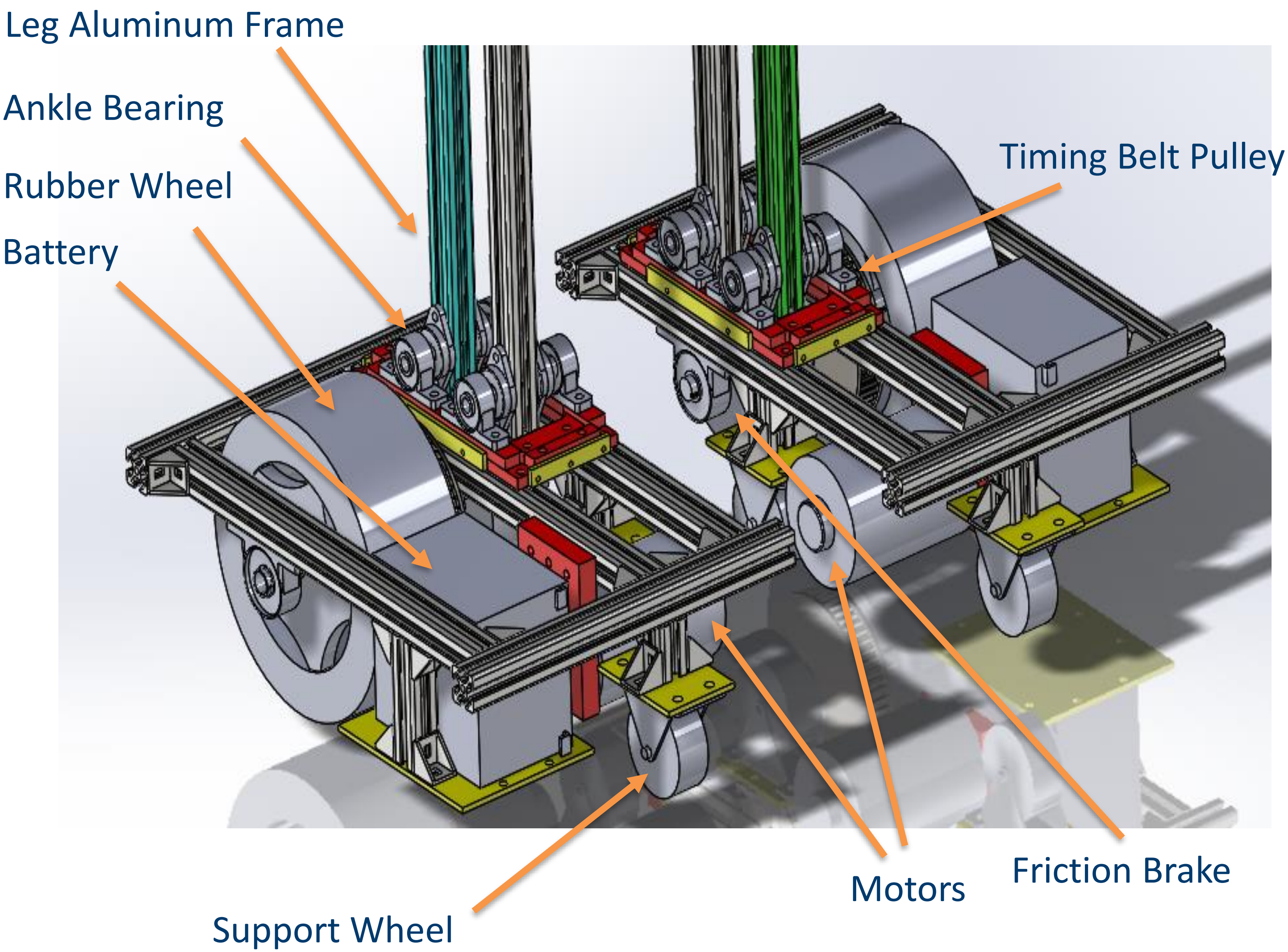


Solidworks Model

Torso Structure



Feet Structure



Motor Power Analysis

- ## Analytic Result

$$f_L = f_R = \frac{1}{2} mg \tan\theta$$

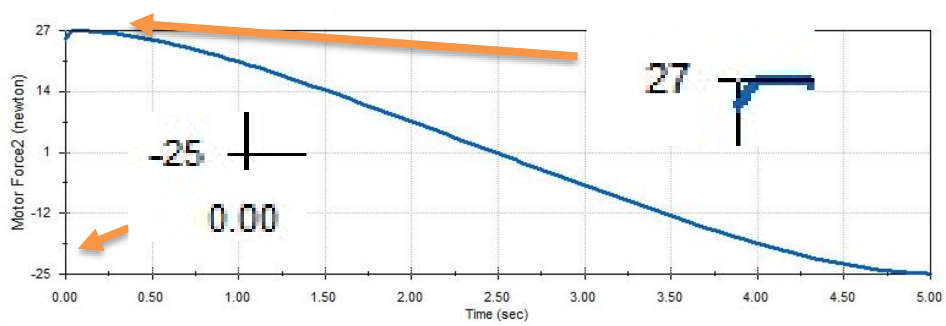
$$f_S \approx 0 \rightarrow f_D = f_L = \frac{1}{2} mg \tan\theta$$

$$P = f_D \cdot v \cdot SF = \frac{1}{2} SF \cdot mgv \tan\theta$$

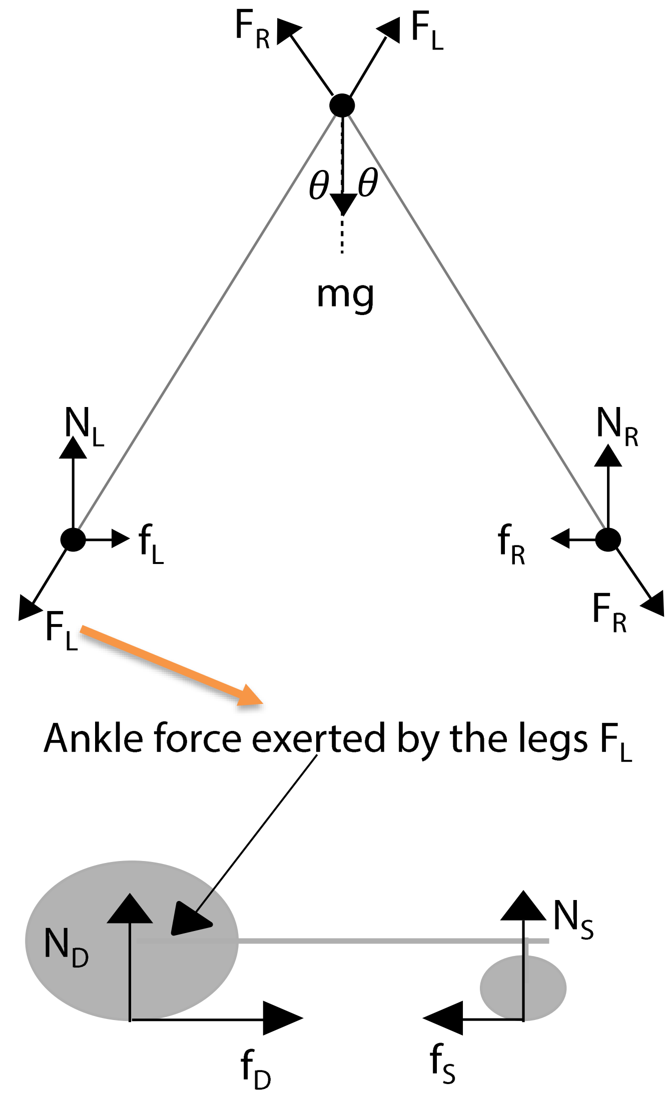
- ## Estimated Value

$m \approx 10\ kg$ $\quad v = 1\ m/s$ $\quad SF = 2$

$\theta \approx 30°$ $\quad g = 9.8\ m/s^2$ $\quad P \approx 120$ W



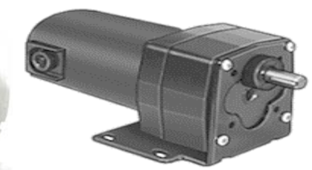
Force (N) Versus Time (s) Solidworks Simulation



Free Body Diagram

Motor Selection

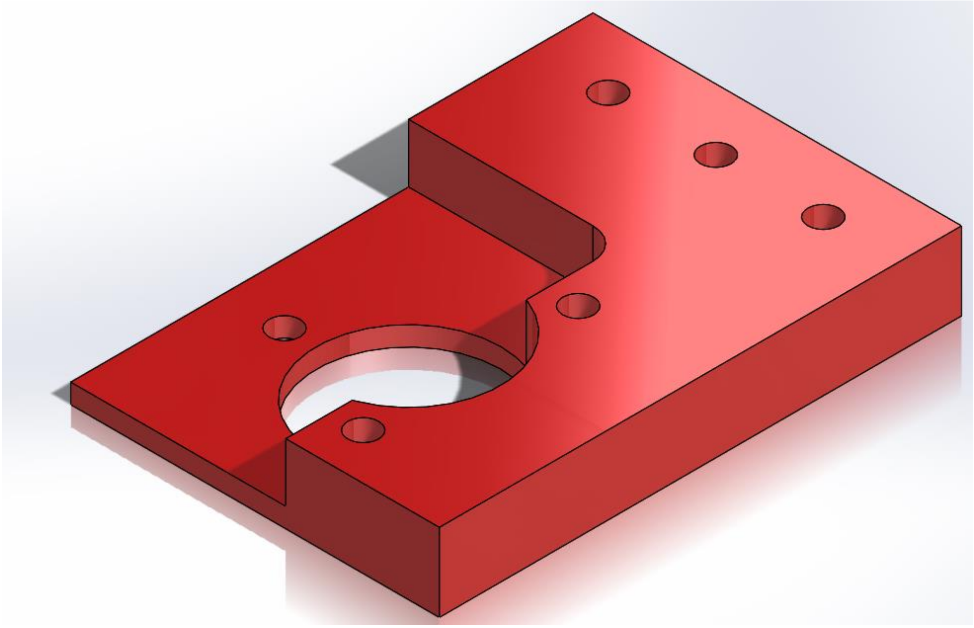
- Motor Power Estimation from Simulation: 120 W
  - Torque: 2.5 Nm (Through Transmission)
  - Speed: 570 RPM (Through Transmission)

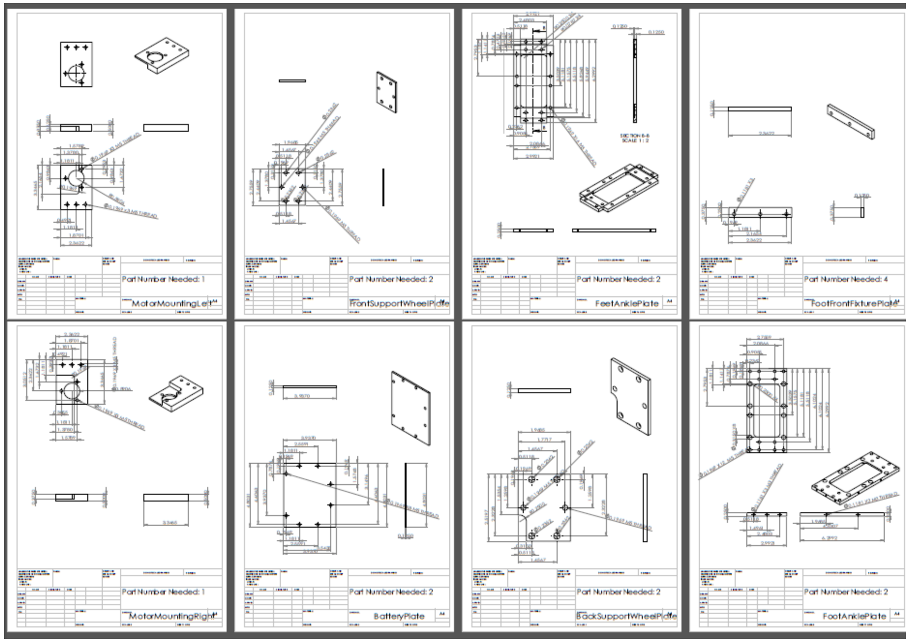
	Electric Bicycle	Electric Scooter	Robots	Assembly Line	Extreme Condition
Motor Picture					
Size (in)	4*4*3	2.5*2.5*4	1.2*1.2*2	3.3*3.3*12.6	1.77*1.77*3
Power (W)	350	135	60	186.4	150
Max Speed (RPM)	2750	2500	500	500	5650-6090
Voltage (V)	24	24	12	90	12-24
Cost ($ each)	63	59.99	24.95	469.27	699.88
Quantity	2	2	8	2	2

Manufacturing

- Engineering Drawing
- Bill of Material and Fabrication
- Assembly

Engineering Drawing





3D CAD Model Isometric View

2D Engineering Drawing

AsiaUS Business Connection

Workshop TIM THE BEAVER

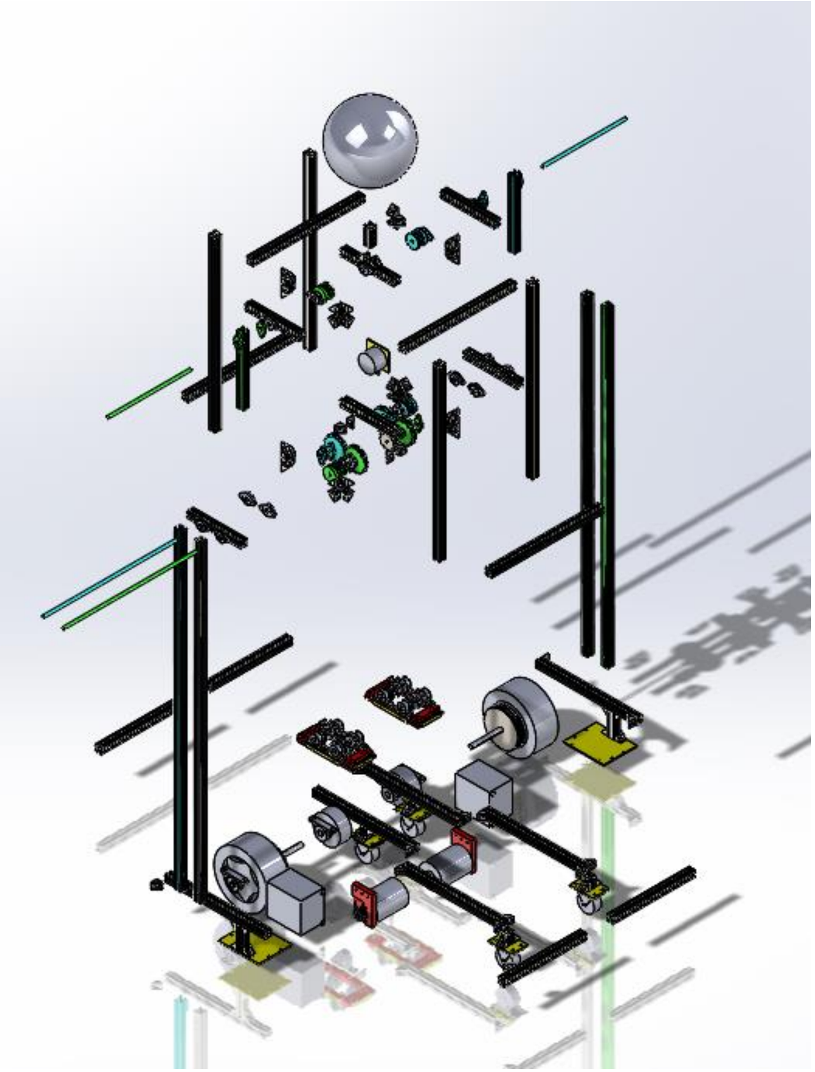
Engineering Drawing

US$ to China Yuan		6.1							
Total	1289.9								
Order ID	Order To	Shipping	Application	Sub System	Vender	Link	Price	Number I	Part Cost
0	200	200	Shipping from C	All					
1	92.82	7.39	Driving roller	Carts	HPI-RAC	170mm	45.95	1	45.95
			Roller Fixture	Carts	HPI-RAC	24mm hu	5.245	2	10.49
			Roller Fixture Nu	Carts	HPI-RAC	24mm nu	3.4975	4	13.99
2	16.92	0	Supporting Rolle	Carts	Local Sto	#N/A	4.2294	4	16.918
3	96.67	5.47	T-sloted Alumin	Structure	MiSUMi	KHFS5-2	22.8	4	91.2
4	259.28	12.36	Motor	Carts	Monster S	24 V 150	59.99	2	119.98
			Driver Circuit	Carts	Monster S	24V 18A	20.99	2	41.98
			Timing Belt		Monster S	515-5m/	16.49	2	32.98
			Battery		Monster S	12V 5Ah	15.995	2	31.99
			Battery Charger		Monster S	24V 1Am	19.99	1	19.99
5	61.738	1.6393	Arduino Xbee	Control	Taobao	2mW 120	24.59	2	49.18
			Arduino Xbee Adpater		Taobao	Arduino \	5.459	2	10.918
6	79.754	0	Aluminum Fixtur	Structure	Taobao	20*20	79.754	1	79.754
7	15.082	1.9672	PS Remote Con	Control	Taobao	Aduino	13.115	1	13.115
8	3.9344	0	12mm Wheel Sh	Fixture	Taobao	12*1000	3.9344	1	3.9344
9	22.977	5.7377	60 Teeth Gear	Torso Motion	Taobao	1M 60 T 8	2.0984	6	12.59
			40 Teeth Gear	Torso Motion	Taobao	1M 40T 8	1.6066	2	3.2131
			15 Teeth Gear	Torso Motion	Taobao	1M 15T 8r	0.718	2	1.4361
10	8.6721	0	Model Mark Up	Model	Taobao	miscellar	8.6721	1	8.6721
11	52.557	1.3115	Circuit Compone	Control	Taobao	miscellar	51.246	1	51.246
12	6.8197	1.3115	Connection Wire	Control	Taobao	1meter	0.918	6	5.5082
13	21.292	1.6393	Infrared Sensor	Control	Taobao	8 mm refl	4.9131	4	19.652
14	14.295	1.3115	Plexiglass	Fixture	Taobao	200*300	1.9508	4	7.8033
			Plexiglass	Fixture	Taobao	200*300	1.2951	4	5.1803
15	20.656	3.2787	Absolute Encod	Control	Taobao	1024	8.6885	2	17.377
16	8.1311	0.9836	Bumper Rubber	Filler	Taobao	2 m	2.0984	2	4.1967
			Bumper Rubber	Filler	Taobao	500×500	2.9508	1	2.9508
17	7.623	0.8197	Plug	Control	Taobao	miscellar	6.8033	1	6.8033
18	75.738	1.9672	Brake Driver	Control	Taobao	20A 24V	10.656	2	21.311
			Motor Driver	Control	Taobao	240w 24'	26.23	2	52.459
19	64.426	2.1311	Brake	Carts	Taobao	12mm	31.148	2	62.295
20	50.669	7.0492	5m 60 teeth pull	Carts	Taobao	5M 60 Te	8.1148	2	16.23
			5m 540 teeth be	Carts	Taobao	5M 540 T	1.5984	2	3.1967
			5m 1050 teeth b	Torso Motion	Taobao	5M 1050	2.0656	2	4.1311
			5m 20 teeth pull	Torso Motion	Taobao	5m 20 Te	2.9508	2	5.9016
			5m 16 teeth pulle	Torso Motion	Taobao	5m 16 Te	3.0984	2	6.1967
21	76.293	0.9836	8mm pillow bear	Fixture	Taobao	8mm pillo	0.6164	12	7.3967
			8mm flange bea	Fixture	Taobao	8mm flan	0.5885	40	23.541
			12mm pillow bea	Fixture	Taobao	12mm pill	1.1197	12	13.436
			shaft lock	Fixture	Taobao	8mm bor	1.3115	12	15.738
			8mm hard shaft	Fixture	Taobao	8*1000m	4.918	4	19.672
22	26.951	0.9836	permanent mag	Fixture	Taobao	50*20*10	3.2459	8	25.967
23	6.5574	2.1311	Foam	Filler	Taobao	1000*110	1.4754	4	5.9016

Bill of Material

Fabricated Parts

Assembly

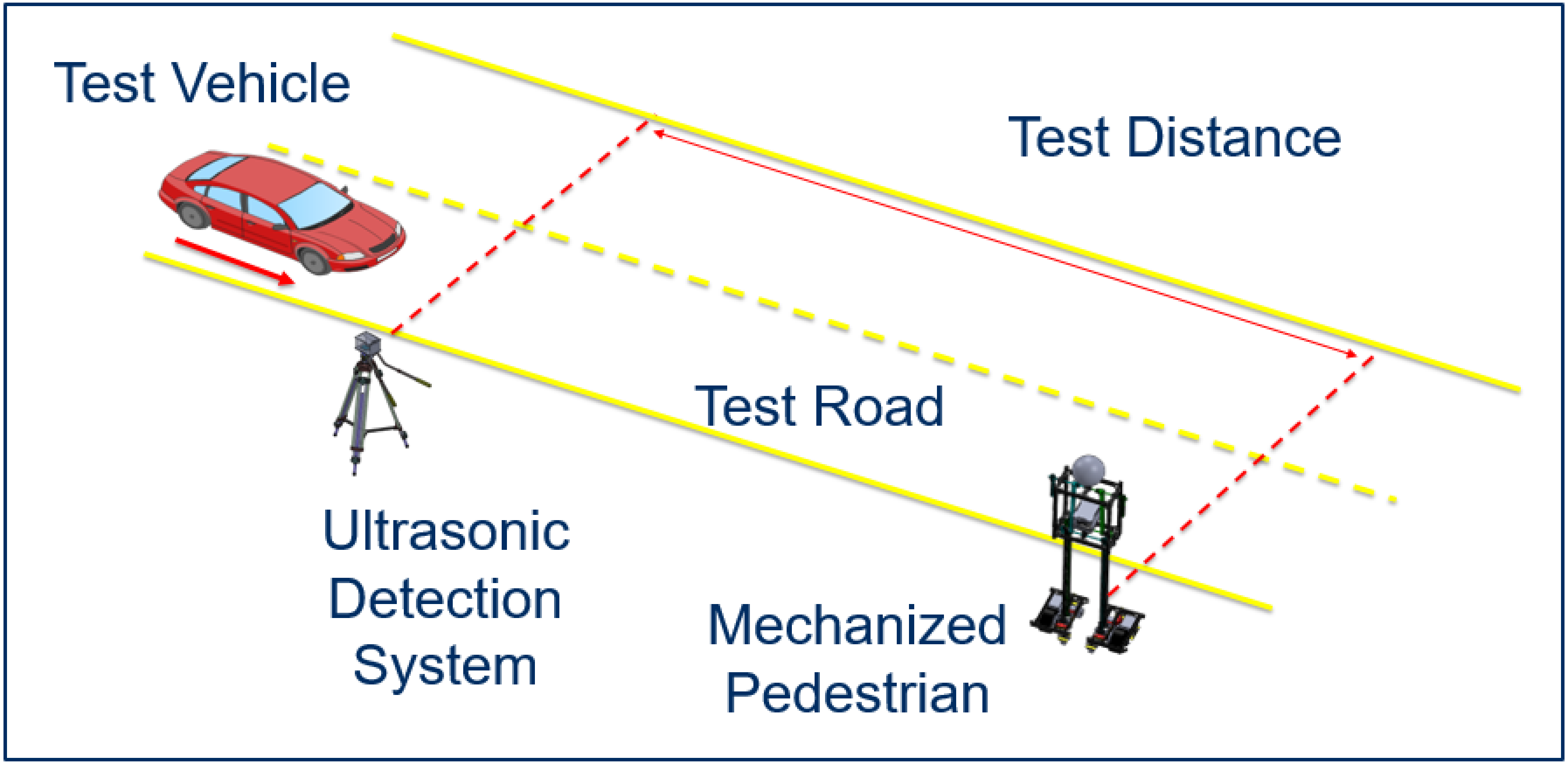


Mannequin Exploded View

Control and Electronics

- Using Scenario
- Embedded System Components
- Software Implementation

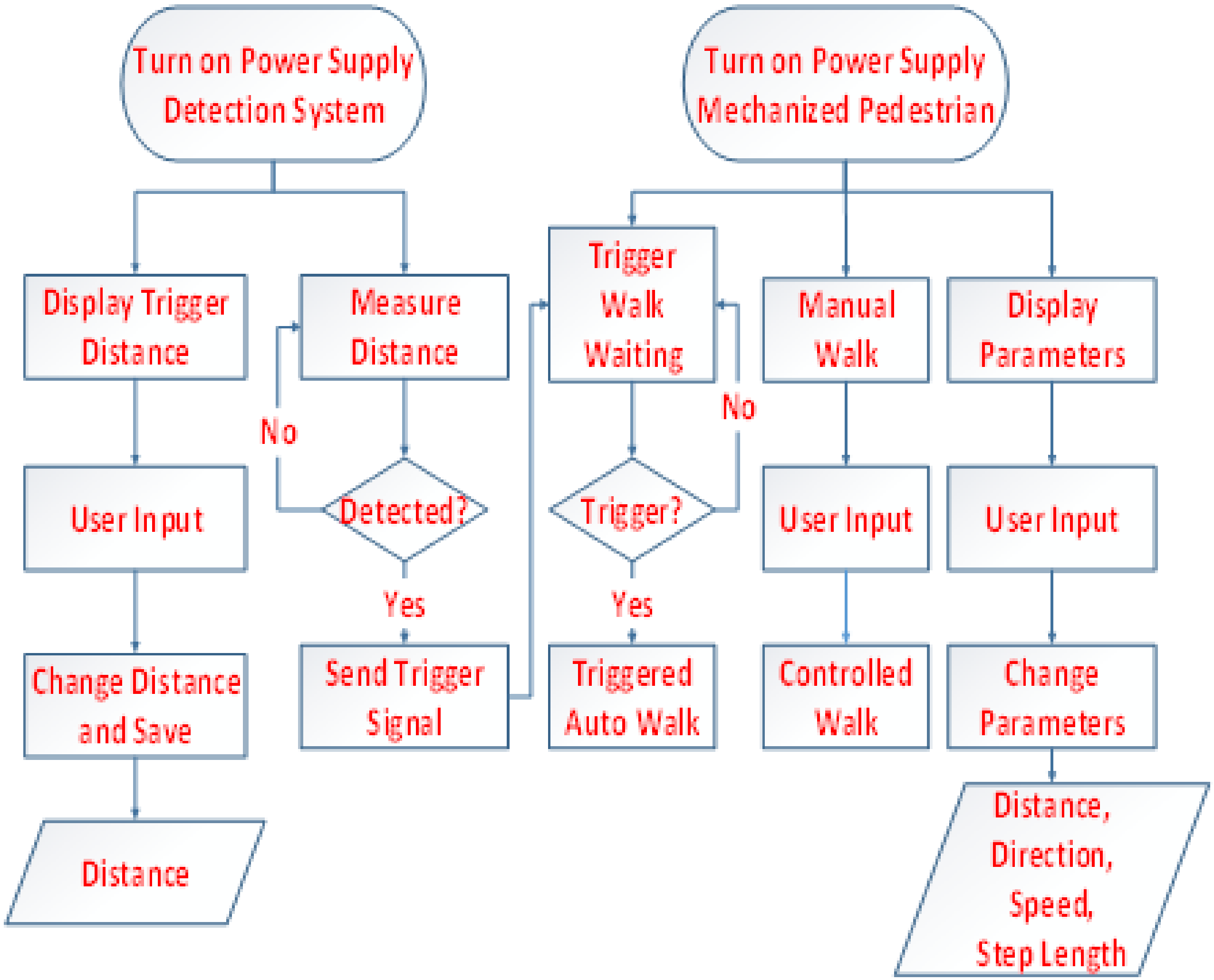
Embedded System Diagram



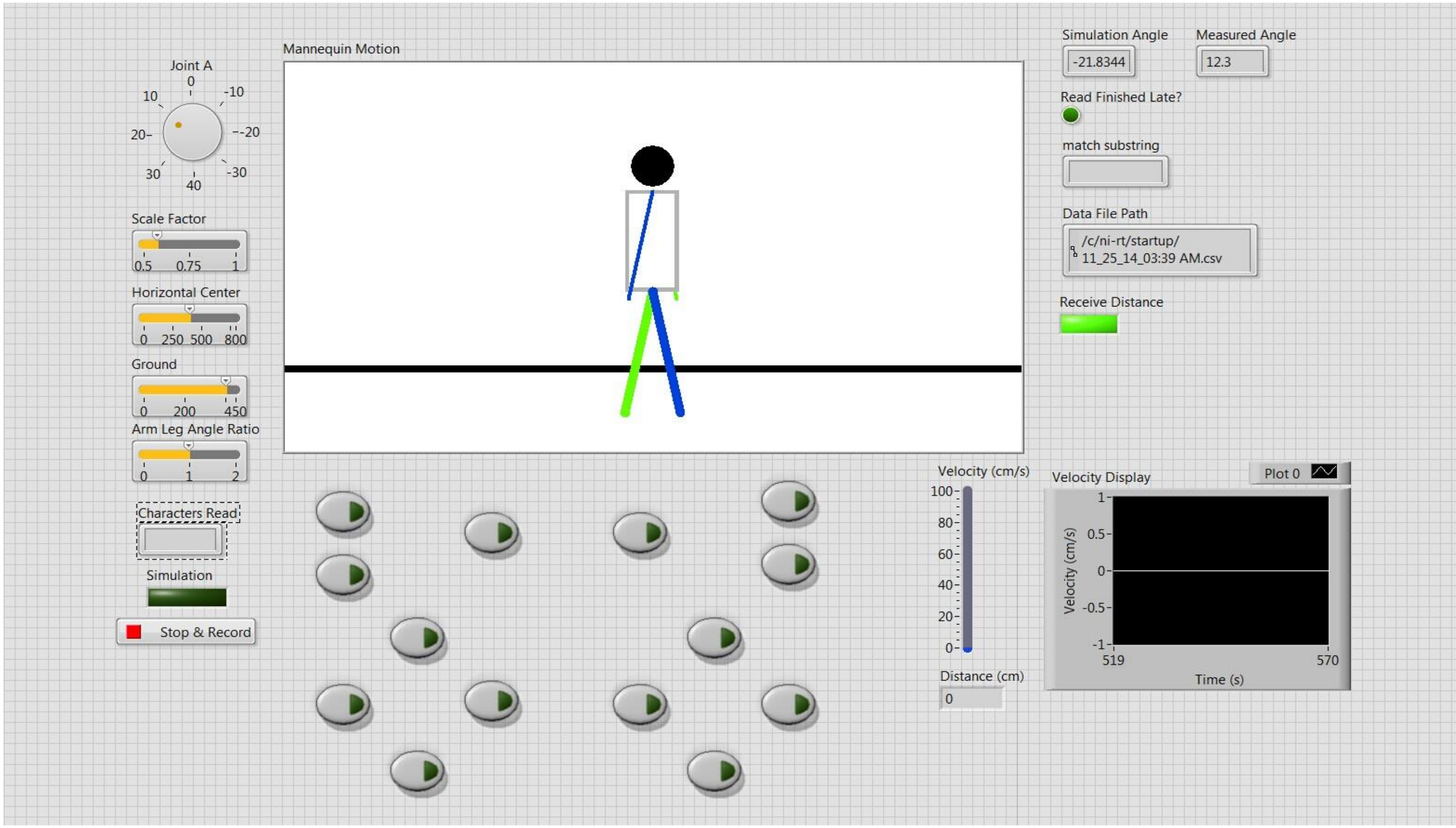
Mannequin Using Scenario

Embedded System Diagram

Software Flow Chart



User Interface

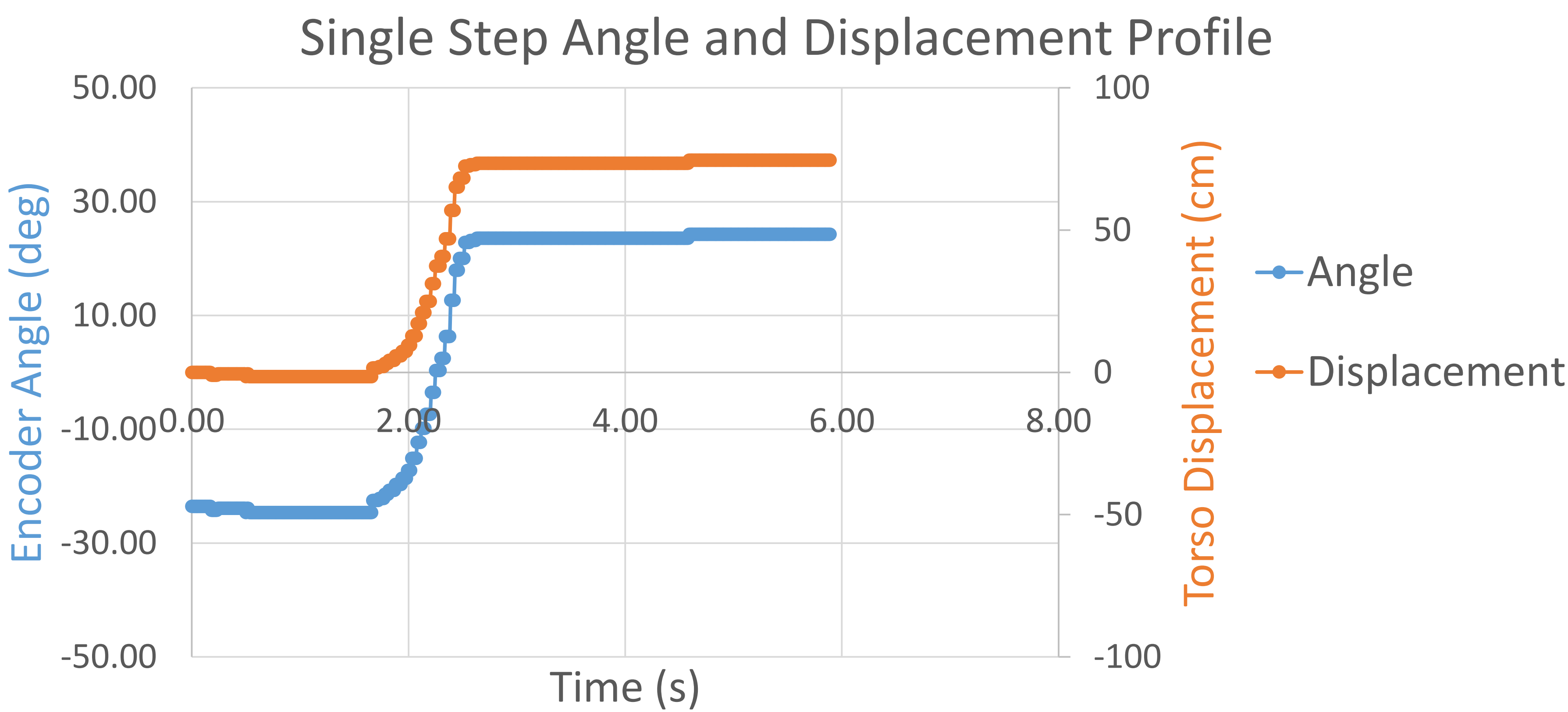


Testing and Verification

- Functional Testing
- Measurement for Specification Verification

Testing

Measurement for Specification Verification



Step Angle Versus Displacement

Design Homework

- Perform design analysis on a prosthetic hand
  - Functional decomposition
  - Benchmark solution
  - Concept generation
  - Engineering specification