

Mechanized Pedestrian for Automated Vehicle Development



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Abstract

To test the pedestrian detection subsystem for automated vehicle systems developed to reduce pedestrian fatality in auto-related accidents, the Michigan Mobility Transformation Center (MMTC) has asked us to construct a mechanized pedestrian that can closely mimic the walking and standing motion of a pedestrian. The focus of this project is to build a prototype of a portable mechanized pedestrian. The prototype is expected to mimic the profile of a pedestrian, walk at a controlled speed, be easy to reset and be cost efficient. A battery powered mannequin prototype with aluminum framing structure, motors in feet, timing belt for arm motion, friction brake, and wheels with rubber tires, was selected, analyzed, designed, and fabricated. With an additional ultrasonic remote trigger, the mannequin can be triggered when test vehicle reaches certain distance for repeated testing. Validation of the design was conducted by MyRIO and LabVIEW data acquisition system and proved to meet all requirements except speed requirement primarily due to balance issue, which is recommended to be improved by mechanical structure change.

Executive Summary

The Mechanized Pedestrian for Automated Vehicle Development project is sponsored by the University of Michigan Mobility Transformation Center (MMTC) and supervised by Prof. Huei Peng and Dr. Jim Sayer. This project aims to design and fabricate a mechanized pedestrian prototype to be used at MMTC test facility for testing of vehicle Pre-Collision Systems (PCS), which is motivated by the large number of pedestrian fatalities in automotive related accidents.

As human testing for PCS is too dangerous, mannequin test setups have been created for testing. However, many of the existing designs involve using overhead gantries and pulling cables to balance and propel the mannequins. This has the major disadvantages of not being able to test different scenarios and disturbance to PCS vision detection capability caused by the pulling cables. Thus, the portable mechanized pedestrian is proposed as a solution to this problem.

To realize the function of the mechanized pedestrian, four requirements were provided by the sponsor. The mechanized pedestrian should look like a human and closely mimic the arm and leg motion of an actual pedestrian; have no overhead gantry and be portable in a truck; be easy to set up for the next test quickly and be cost efficient. Qualitative and quantitative engineering specifications that were derived from the requirements correspondingly.

With the established requirement and specifications, three concepts, namely, mannequin on track, mannequin on cart, and mannequin pulled by windlass were generated at beginning. A morphological analysis was then conducted on ideas for each subsystems such as leg motion, arm motion, brake, ground roller, torso balance mechanism and etc. A mannequin design with motors in feet and linkage for arm and torso motion was proposed, selected, analyzed, manufactured, assembled and controlled by electrical system implementation.

Based on the analysis for power requirement, two 135 W motors were used as the only driving actuators for the mechanized pedestrian motion while the torso and arm motion are passively driven using gear and pulley systems.

An ultrasonic detection system was implemented in addition to the mannequin control system to allow repeated testing of fixed condition. The two electrical systems were controlled wirelessly by the user and could communicate with each other via radio module.

A functioning prototype based on the selected design concept was delivered as the project outcome. All requirements were validated via direct parameter measurement and data obtained from MyRIO data acquisition system except for the speed requirement of 1 m/s due to balancing issue. Recommendations regarding changing the wheel structure and torso gear fixture were discussed to resolve the problem. In addition, design changes such as enlarge the motor power to 200 W to increase speed and fine tune the controller to maintain accurate speed were also included as recommendation for future work.

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1 Problem Description

An average of thirty to forty thousand people die in car accidents each year in the US, among which 14 percent are pedestrian related fatalities (Barickman, F., et.al. ,2014). The large number of death inspired the development of automated vehicle system with many researches focused on pedestrian detection systems for collision avoidance. The University of Michigan Mobility Transformation Center (MMTC) is currently building a test facility with aims to test these systems for effectiveness but currently lacks test equipment especially for pedestrian crash avoidance systems. Thus, the solution to this problem is to build a mechanized pedestrian that mimics the walking and standing motion of a pedestrian so that MMTC researchers will be able to conduct tests.

The Mechanized Pedestrian for Automated Vehicle Development Project is sponsored by the University of Michigan Mobility Transformation Center (MMTC). Specifically, this project is supervised by Prof. Huei Peng and Dr. Jim Sayer.

2 Motivation and Background

To reduce the fatality in auto-related accidents especially for pedestrians, automakers worldwide such as Toyota, Mercedes-Benz, and Ford have taken interest in research surrounding Pre-Collision Systems (PCS), technology that automatically avoids collisions with other vehicles, objects, and pedestrians. Although PCS has already been implemented in certain high-end vehicles (Yi, Q., et.al., 2013), they are not perfect, largely due to the fact that it is unsafe to test this feature on actual humans. The PCS detects a pedestrian based on its arm and leg motion in different scenarios, which can be very challenging and expensive to replicate. Hence, a portable mechanized pedestrian that can be used to test a variety of possible collision situations for the PCS systems is needed.

To carry out realistic tests for automated vehicle systems, the MMTC is currently is in the process of constructing the Mobility Transformation Facility (MTF) which is a 30-acre “city” completely dedicated to the testing of automated vehicles that can simulate various roadway situations

There are a number of existing mannequins that are being used in PCS testing as shown in Figure 1 and Figure 2. However, many of them are not portable as they rely on big overhead gantries to maintain the balance of the mannequins and provide propelling force. The presence of an overhead gantry and pulling wire fixture may interfere with the PCS system’s ability to detect the pedestrian accurately.

In addition, the overhead gantry test setup also makes it relatively difficult to conduct test under different traffic scenarios, which is important in the case of pedestrian collision avoidance system. As there are several scenarios in which most pedestrian fatalities occur with four of them

shown in Figure 3. The system pictured in Figure 1 only accounts for the first scenario of pedestrian fatalities but no other crash scenarios.

Therefore, MMTC asked us to create a portable mechanized pedestrian that runs on its own without being dragged by an overhead gantry to test different scenario to be used in MTF.



Figure 1: Outdoor mannequin utilizing overhead gantry (Carpenter, M. G., et.al., 2013)



Figure 2: Indoor mannequin utilizing overhead gantry (Yi, Q., et.al., 2013)

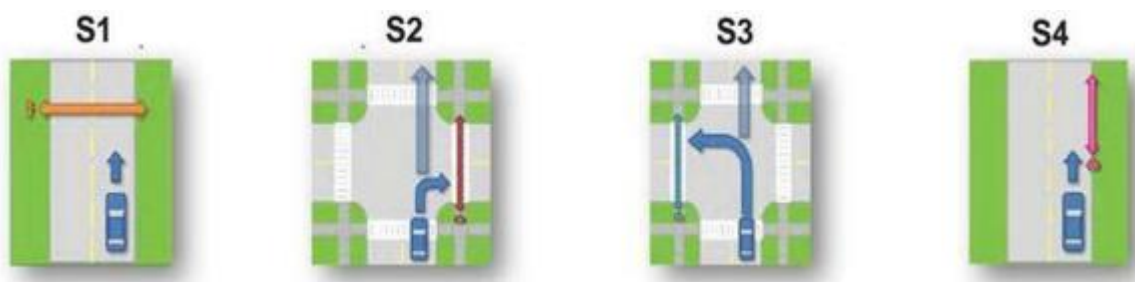


Figure 3: Pedestrian fatality scenarios (Barickman, F., et.al., 2014)

3 Project Requirements and Engineering Specifications

3.1 Project Requirements

With the deliverable of the project specified as a functional prototype corresponding documentation, the project requirements serve as a guideline for the entire design process. To establish a baseline for what defines a functional mechanized pedestrian that can be used to test automated vehicle systems for pedestrian collision avoidance, four primary project requirements were provided by the sponsor as summarized below. The prototype should:

1. Look like a human and closely mimic the arm and leg motions of an actual pedestrian.
2. Not have overhead gantry and be portable in a truck.
3. Be easy to set up for the next test quickly.
4. Be cost efficient.

These four project requirements cover different major aspects of the mechanized pedestrian including the overall function realization as a test mannequin for automated vehicle system, the dimension and weight of the mechanical structure, the limit of complexity in terms of resetting time, and the efficiency in terms of utilizing resources. A detailed analysis of the requirements and the engineering specifications derived from the requirements can be found in the next section.

3.2 Engineering Specifications

To meet the six project requirements specified by the sponsor, each requirement has been translated into several engineering specifications that are quantitatively measurable or qualitatively determinable by conducting tests on the fabricated prototype. This section introduces the engineering specification corresponding to the six project requirements discussed in the previous section respectively.

3.2.1 Mimic of Human Appearance and Pedestrian motion

To test the automated vehicle system with emphasis on pedestrian detection and collision avoidance, the mechanized pedestrian prototype to be created needs to be similar to a human pedestrian in terms of both its appearance and motion so that it can trigger the detection system of the automated vehicles as a human pedestrian. This requirement is interpreted as the following engineering specifications.

1. Available motion type including walking and standing
2. Detectable by Pre-Collision Systems as human pedestrians
3. Travel speed ranges from 0 to 1 m/s
4. Gait Stride 30 ± 2 inches

Based on the type of test to be conducted at MTC, the sponsor agreed to that the prototype should be able to walk and stand like a human pedestrian. This can be verified qualitatively by

evaluating the motion of the mechanism in terms of moving and remaining still on its own without support when no external force other than gravity and ground supporting force are exerted on the prototype.

The second engineering specification was derived from the needs of the PCS vision detection system (Yi, Q., et.al., 2014, Jan.). The detectable specifications involves a profile similar to human pedestrian and small disturbance to the detection system caused by the non-human shape mechanism. The verification of this specification can be done via actual testing of the prototype against automated vehicle systems and compare the detection rates.

The third specification was based on the average walking speed of pedestrians including fast pace walking but not running as the sponsor clarified the current target testing involves pedestrian motion of walking rather than running. This specification can be verified by measuring the movement speed.

The last specification went with the definition of walking in terms of gait stride, which is the distance from initial contact of one foot to the following initial contact of the same foot for a human being. For the mechanized pedestrian, the gait stride means the distance from two feet when it switches the motion from one leg to another. The distance is set to be 30 ± 2 inches based on average value (Zhang, Z., et.al., 2014).

3.2.2 Portable with No Overhead Gantry

As discussed in the background and motivation section, many test setups for automated vehicle pre-collision systems utilize large overhead gantries and cables balance and pull the mannequin. The overhand gantries are large in scale and inconvenient to setup for different test scenarios and therefore does not satisfy the requirement of being portable. As overhead gantry driven has been eliminated as an option, the following specifications for dimensions and weight of the mechanized pedestrian are established.

1. Height: 65-70 inches.
2. Chest: 36 ± 5 inches
3. Waist: 31 ± 5 inches
4. Hips: 36 ± 5 inches
5. Weight: Less than 100 lbs

Based on discussion with the sponsors, an agreement on building a 50th percentile adult male for the size of the mechanized pedestrian has been reached. The dimension data of a 50th percentile adult male are obtained from reference literature [3]. The weight is estimated by the average lifting force a human being can exert and equals one sixth of the standard capacity of a dolly that can be used to load the mechanism on to a truck.

3.2.3 Easy and Quick Reset

To complete tests under different scenario and repeated tests for the same setup to obtain enough data points to do statistical analysis within a limited time, the reset procedure should be done quickly and easily. The engineering specification based on a conservative estimation of time for the mechanized pedestrian to walk across the road and return is used.

1. Reset time for the next test less than 1 min.

3.2.4 Cost Efficiency

Although mass production of prototype is not required, it is ideal to reduce the cost of the prototype in case of rebuilding due to severe crash damage or other unexpected accidents. The specification for cost is given directly by the sponsor.

1. The mechanized pedestrian prototype should cost no more than 1500 U.S. dollars.

3.3 Additional Concerns

In addition to the listed project requirements, the project sponsor also mentioned two concerns for the prototype that are not strongly enforced as requirement but are desirable for the system. The additional aspects to concern involves the surrounding operation condition of the prototype and the robustness of the system and are given as:

1. Be able to operate outdoor on the pavement under different weather condition.
2. Be robust to light bump.

Although no test was conducted during the validation process, special care had been taken during the design phase.

4 Concept Generation and Selection

The brain storming process of the concept generation and selection process involved three steps which utilized three different tools. First, a wide range of ideas are considered and filtered using a morphological analysis with nine categories. Second, for each category of the morphological analysis, a pugh chart or elimination based on requirement process was used to reach the final selection. Third, a functional decomposition is performed to divide the mechanized pedestrian into sub systems as a guideline for detailed analysis.

4.1 Concept Drawings

Based on the established user requirement, several concepts were generated during the brain storming of the team. Three representatives are presented in this section to illustrate the variety of ideas considered.

4.1.1 Mannequin on Track

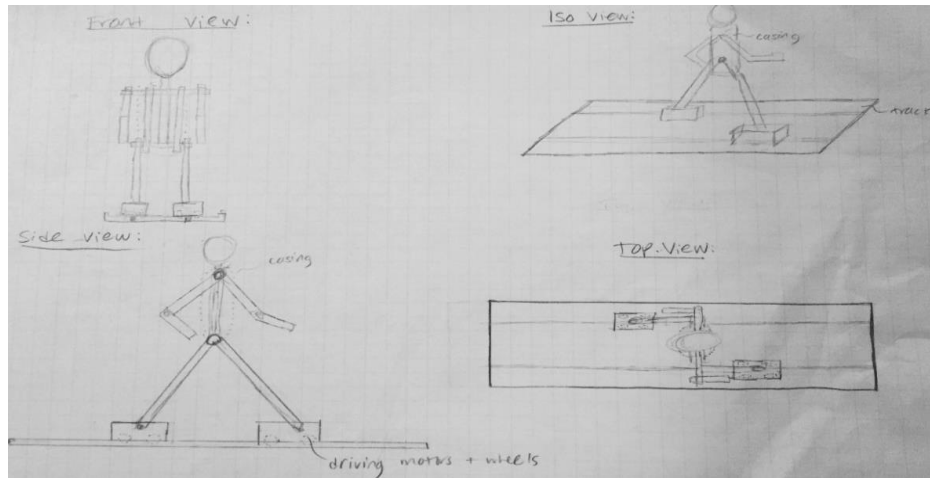


Figure 4: Mannequin on Track

This design allows for a path of motion that cannot be modified, which is beneficial for the purpose of test repeatability. Each foot is confined to a linear path, and the drive mechanism is housed in the foot. The setup of the design allows for quick, simple setup and reset, with an adjustable speed option.

While this design may be convenient for repeated tests, there are some drawbacks. First, the track itself would be very difficult to transport quickly, as its size and shape would likely require two people to move. Also, there is the possibility that foreign objects or particulate could accumulate inside the opening of the track, meaning there would be some maintenance required to ensure the proper friction inside the track. The track could also be susceptible to permanent damage if it were to be run over by a motor vehicle or if it were bent as a result of the mannequin being struck, rendering the entire mechanism useless.

4.1.2 Mannequin on Cart

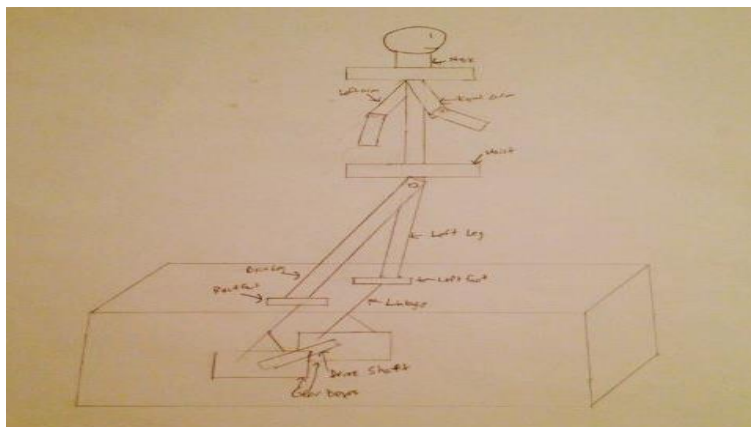


Figure 5: Mannequin on Cart

This design consists of a rolling cart with a linkage system that drives the motion of the mannequin to mimic human movement. The setup time for this design would be in line with the

specification for a quick set up since the collision would just roll the cart. There also wouldn't be a stability problem as the cart balances the mannequin completely. This would be a good design in a sense that it can closely mimic the movement of a pedestrian as the mechanism can be carefully designed.

However, due to the complicated mechanism involved in the driving cart, its volume will be significantly larger than a regular human feet, this would reduce its portability and likely to interfere with the detection systems. Another problem is that the linkage systems would have to be driven as well as the cart. These would both be driven separately which would require more actuators and an overall more complicated design.

4.1.3 Mannequin Pulled by Windlass

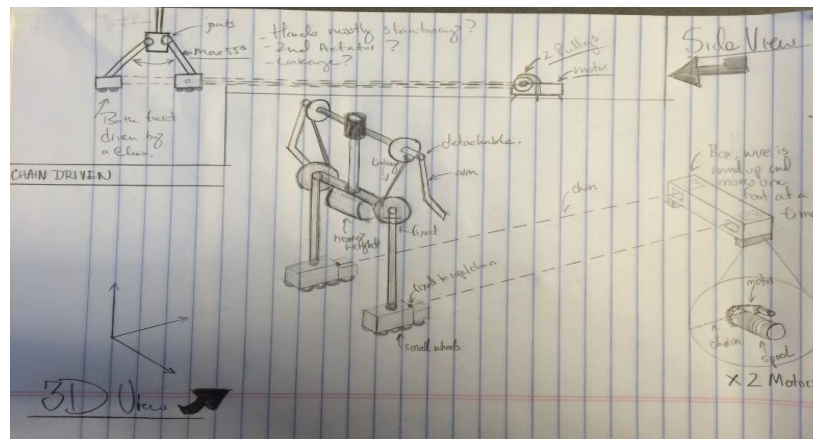


Figure 6: Mannequin Pulled by Windlass

This idea allows for a simpler placement and fitting of the actuators in the mechanized pedestrian. Instead of housing the motors for leg movement in the feet they will be placed at the end of the path of motion. The feet will be connected to a strong rope which then is connected to a spool that is then connected to a motor. Each foot has its own motor and rope. The motor winds up the rope for each foot cause movement of the legs and thus a human like walk. The legs are then connected to a linkage system that also moves the arms. In this drawing the linkage system is based of two circular plates that have a link between them. A heavy weight would be placed at the waist in order to facilitate a stable walking motion.

The drawbacks of design lie majorly in two aspects. First, the pulling of feet relies on constant tension in the chains/rope. A jerk could cause the mannequin to fall over or become unstable. Second, the chains/rope could interfere with lidar or radar systems or become tangled easily.

4.2 Concept Selection

Based on the project requirement, functional decomposition, the numerous ideas were gathered and put into the table to perform a morphological analysis as shown in *Figure 7*, and *Figure 8*. Selected concepts are highlighted in red in both figures.



















| 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  | Timing Belt  | | |
| Brake | Magnetic Clutch  | Friction Induced  | Hard Stops  | Worm Gear (self lock)  | | |
| Ground Roller | Track  | Ball Screw  | Aluminum Wheel  | Wheel with Rubber Tires  | | |

Figure 7: Mechanism Morphological Analysis

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

Figure 8: Power source, material and balance method morphologic analysis

Leg Motion: As six ideas were generated and the leg motion was considered the most important aspect for the motion of the mechanism by the team, a pugh chart with categories determined mainly by the project requirements was created as shown in *Table 1*. The motors in feet is selected as it has a balanced performance for the design criteria.

| 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 | + | + |

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

Table 1: Leg Motion Selection Pugh Chart

Arm Motion: The drawback for the implementing all joints with actuators lies in its mechanism complexity and cost. Free swing is easy to implement but is hard to control and difficult to maintain constant rate of motion due to friction. The linkage design for arm motion will impose large weight on the mannequin due to the extra mass of the linkage system. The timing belt system idea was selected as it allows the arm motion to be adjusted based on gear ratio.

Brake: To lock one foot on the ground while moving another, brakes are needed for both feet. Magnetic clutches are convenient to use but are generally too expensive for this application. Hard stops will wear and cause shock to the mechanism when suddenly engaged. Worm gears are self-lock but introduced large angular speed reduction that is not desired. Hence, the traditional friction induced brake is used for its cheapness and functionality.

Ground Roller: The track and ball screw concepts are both difficult to maintain for outdoor use where they are exposed to a variety of rocks and mud that can contaminate their path. The aluminum wheels tend to be slippery on wet surface which is inevitable for rainy weather condition. The wheel with rubber tire concept was selected.

Power Source: The battery is selected as the power source as it is portable, stable and plausible compared to other three ideas. The passive mechanism is not plausible due to friction and the flat surface on which the mechanism is moving. The plugged in concept contradicts the portable requirement and the spring loaded mechanism is not stable as it tends to have lower output force with the depletion of potential energy.

Cover: As the plastic models are too bulky for the application and the artificial skins are too expensive if it were to cover the entire mechanism, the clothes concept is selected for its ability to closely mimic the majority part of a pedestrian.

Filler: Considering the ability to maintain permanent deformation after being made into shape, the foam concept was selected for its convenient manipulation and ability to retain shape.

Structure Material: Aluminum was selected as the structure material for its convenience in machining compared with Carbon Fiber and PVC, and its smaller density compared with steel.

Torso Balance: The slider with isosceles shape linkage system is selected as the gravity balance and motors conflicts with the design preference to reduce the weight on the torso and reduce the number of actuators. However, the selection is not considered as optimal due to the possible large friction in the slider induced by off-axis force exerted by the linkage system. The team is actively exploring more mechanism design concepts involving utilizing parallel linkage.

4.3 Functional Decomposition

The functional decomposition diagram shown in *Figure 9* covers the controller, energy consuming sub systems and corresponding mountings that realize the motion of the mechanized pedestrian. During the concept generation process, emphasis were laid on the battery, motor, linkage, transmission and wheels for the system as circled on the diagram.

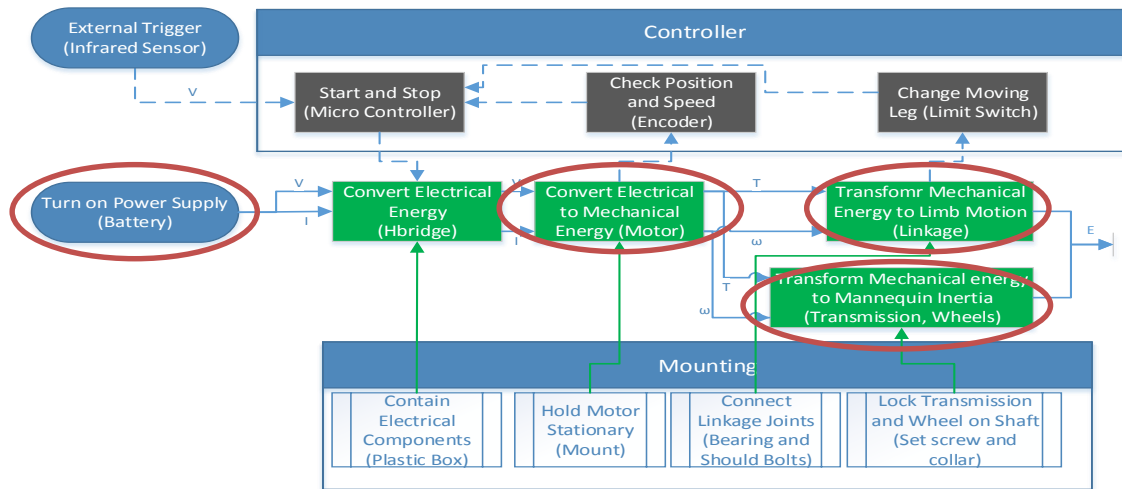


Figure 9: Functional Decomposition

5 Simple Physical Mock-up



Figure 10: Physical Mock-up

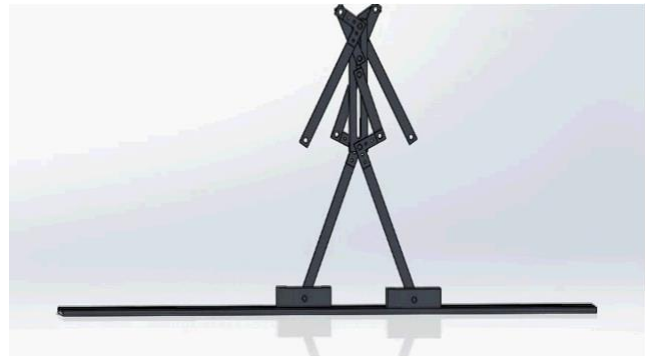


Figure 11: Solidworks Simplified Model

To illustrate the general mechanism of the selected concept, a simple physical mock-up was created using styrofoam, bolts and nuts as shown in *Figure 10*. Although not fabricated accurately as scaled down from the prototype design, the physical mock-up was able to perform

the motion required by using the selected mechanism. The torso remains straight up during walking and the force required to perform the motion is very small as the mechanism moves smoothly even with the rough design. This indicates a reasonable mechanism choice. Even so, the team is still working actively on designing a mechanism without using any slider joint.

In addition to the simple physical mock-up, a simplified Solidworks model was also created with the dimension equal to that of the actual mannequin prototype as shown in *Figure 11*. The model was used in the simulation and detailed design process for further analysis.

6 Selected Concept

The selected concept is supposed to utilize two motors in feet, linkage system for arm motion, friction induced brake, wheels with rubber tires, battery power source, clothes cover, Styrofoam filler, aluminum structure, and isosceles & slider for torso balance. The selected concept is considered superior to other ideas as partially mentioned in the concept generation section as it utilized all selected concepts from the morphological analysis with reasons justified in the concept selection section.

The major advantages of the selected concept involve closely mimicking the motion of human pedestrian, being portable, having very small mechanism causing disturbance to detection system and reasonable cost for implementation.

The major disadvantage of the selected concept lies in the torso balance mechanism design. As slider joints are well known for being difficult to implement with the presence of off-axis forces that are not in the direction the slider joints are designed for, the presence of linkage force on the bar for the system is considered a possible cause for large friction.

As the team has realized this issue and is actively working on new mechanism ideas for the design, the disadvantage of the selected concept can hopefully be resolved during the detailed design process with more careful engineering design and analysis.

7 Specific Challenges

Based on the project requirements and derived engineering specifications. Several engineering challenges specific to the mechanized pedestrian project have been identified in the early stages such that extra attention have been paid to resolve these problem for possible design failure.

The first challenge is to maintain the torso balance for the pedestrian without being pulled by cables connected to overhead gantry. As forces to ensure balance of the mechanized pedestrian are entirely exerted by itself, the center of gravity of the mechanism has been placed as low as possible during the design process. Detailed calculation and motion analysis has been conducted with simplified model to obtain a stable design. In addition, some degrees of freedom for an actual human pedestrian was sacrificed during the design of the mechanized pedestrian for stability concern.

The second challenge lies within driving the entire mechanism with a limited amount of actuators as both the first and second challenges mentioned involves reducing the number of actuators for rain resistance and stability. The limits on number of actuators increased the difficulty in motion transmission structure design such as linkages as complex motions need to be generated via very few actuators. In addition, finding the appropriate actuator that can provide the required power to drive the entire mechanism is anticipated to be an uneasy task.

The last identified challenge is to make the pedestrian simple enough that it can be reset quickly and easily. The one minute reset time is the current goal and would be feasible if the design that can be simply placed back without taking apart any mechanism to reset.

8 Final Design

Based on the generated concept, detailed analysis on critical components including the torso balancing structure, motor power requirement and force at waist shaft were considered. Based on the analysis result, parts were selected correspondingly. A detailed engineering drawing in Solidworks was created for manufacturing and illustration purpose.

8.1 System Overview

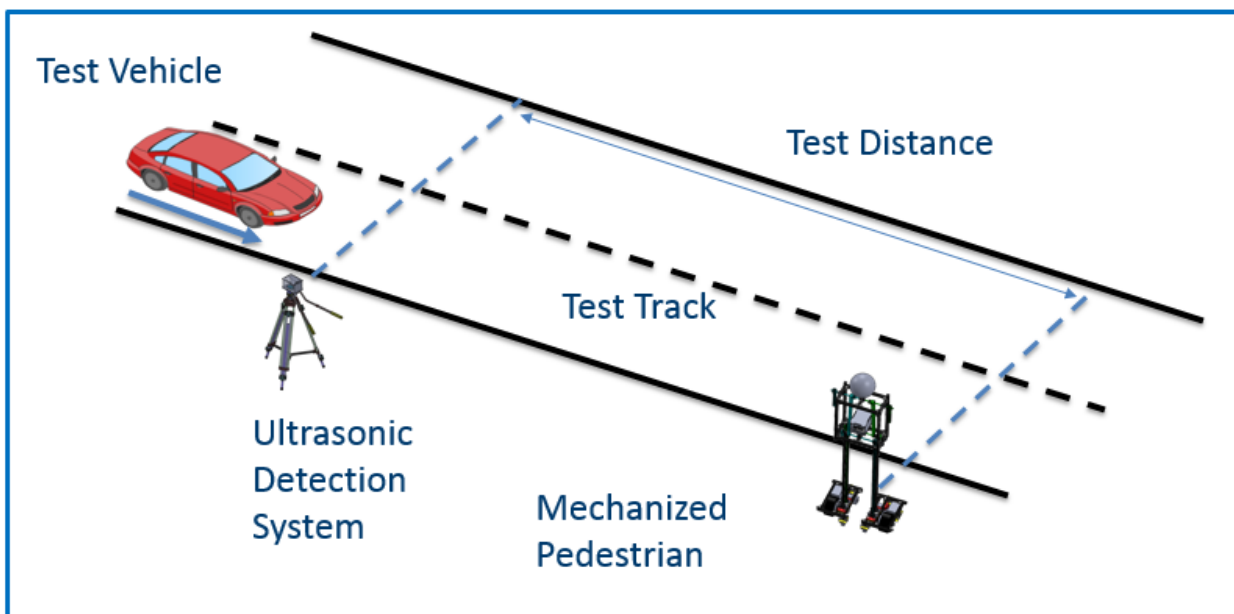


Figure 12: System Setup Overview

A high level overview of the system setup is shown in. When the test vehicle is detected by the ultrasonic detection system, a trigger signal will be sent to the mechanized pedestrian via radio communication. The mechanized pedestrian will then start walking across the street. The test distance can be fixed and measured in advance for repeated testing under the same test scenario.

8.2 Prototype Mechanical Structure Overview

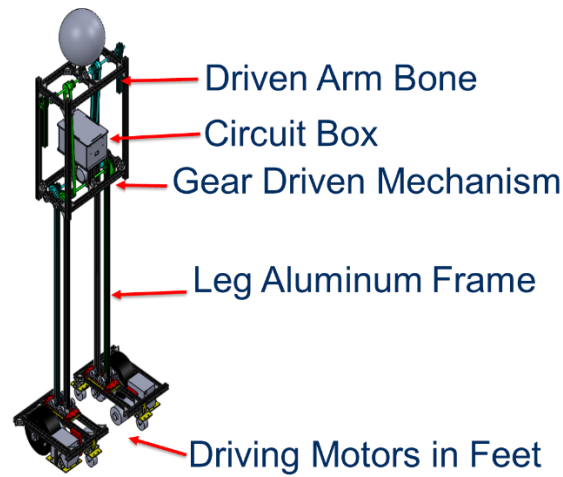


Figure 13: System Setup Overview

An overview of the Solidworks CAD drawing is shown in *Figure 13*. The detailed Solidworks model is drawn to real scale with the selected component based on the engineering analysis and material ordering. All fixtures and framing can be converted to engineering drawing for manufacturing purpose. Notice that the arm structures of the CAD model is the bone structure and were wrapped up with insulation foams to mimic human arm.

8.3 Material Selection for Manufacturing Concern

To reduce the amount of manufacturing needed, cater to possible adjustment made during the design process and allow flexibility in mechanical structure such as tension adjustment of timing belts, the structure of the mannequin was designed to use 20 mm by 20 mm T-slotted aluminum extrusion which allows easy adjustment after fabrication. A number of fixture were designed such that they can be made out of aluminum plates, which can be manufactured relatively easily using water jet and milling machine for hole drilling and surface height adjustment.

8.4 Mannequin Balancing and Arm Motion

Compared to the originally selected concept, the proposed design has a significant difference with the mechanism for keeping the torso straight up and prevents the ankle from bending to the same direction when the mannequin is standing straight with details illustrated in *Figure 14*.

Torso Balance: As can be seen from *Figure 12* and *Figure 14*, each leg of the mannequin are composed of one four bar linkage with shape of a parallelogram. This mechanism eliminated the need for a slider joint to maintain torso straight up and saved the space designated to the linkage.

Standing Position Ankle Balance: With the four bar linkage in place, two pairs of gear were mounted to the shafts which connect to the left and right leg via shaft lock respectively. These

two pairs of gears prevented the rotation of two both leg to the same direction with respect to the torso structure. Combining the gears with the parallel four bar linkage system, the mannequin ankle joints are prevented from bending towards the same direction by mechanism and thereby eliminating the need for using actuators to maintain standing balance.

Arm Motion and Control: The waist structure as shown in *Figure 14* also includes timing pulley locked to the shaft for variable arm motion by changing the number of teeth. In addition, an absolute encoder was included to provide feedback to the current position of the mannequin.

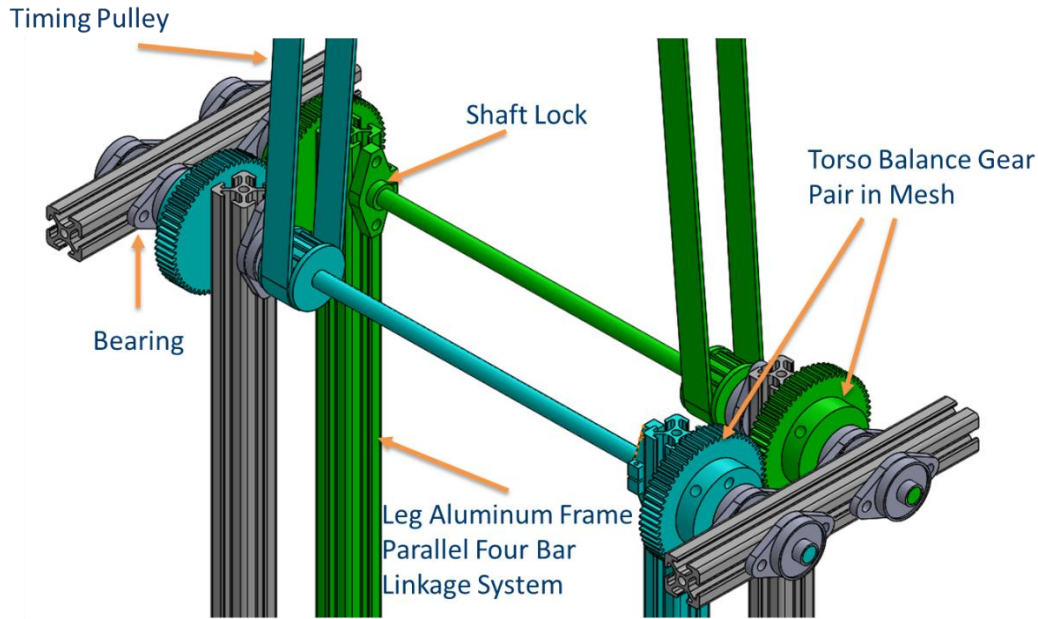


Figure 14: Torso Balancing Structure at Waist

8.5 Mannequin Driving Structure

With the feet in mind concept, the detailed driving feet structure for the mannequin is shown in *Figure 15*. As labeled in the figure, the bulky parts with large mass were majorly put onto the two driving carts as the mannequin feet.

Feet Size: The mannequin feet design gives a height of 5 in., width of 10 in. and length of 13 in. which is a bit larger than the size of a regular human feet in terms of height and width. However, considering the motion range of a human foot in terms of height, which is around 6 in., the height of the driving cart structure is smaller and therefore can be used as confirmed by the sponsor. In addition, the width of the feet does not affect the detection system much as majorly the left or right side profile of the mannequin will be tested to simulate a pedestrian crossing a road. Hence, the cart geometry satisfies the requirement.

Walking Motion: To mimic the walking motion of the pedestrian, one motor and one friction induced break were implemented on each foot. The purpose of the break is to lock the foot in

place on the ground when the other foot moves forward. Without the break, the mannequin would be doing an ice-skating motion, which is significantly different from walking motion of a pedestrian. To allow the mannequin structure to walk in a straight line repeatedly and turning around of the mannequin was not required by the sponsor, one large driving wheel with tire and two smaller supporting rubber wheels without turning capability were used on each foot.

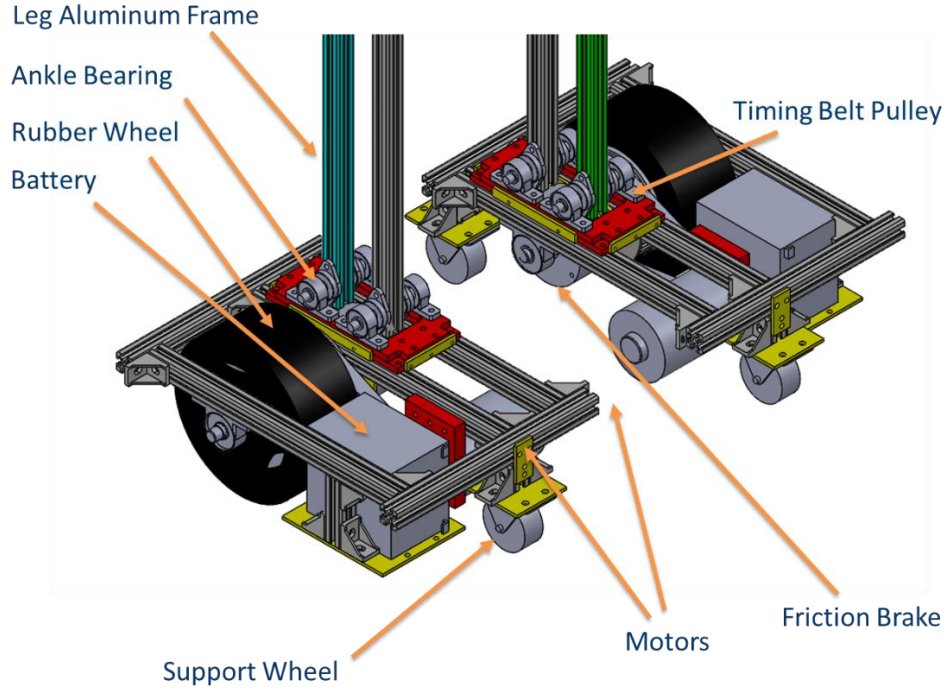


Figure 15: Driving Structure at Feet

8.6 Engineering Analysis

8.6.1 Motor Power Estimation

With the proposed concept, a simplified model of the mannequin legs and feet were created to estimate the required motor power. A force analysis was first performed to obtain the required friction force for driving the mannequin as shown in *Figure 16* and *Figure 17*.

F_L and F_R represents leg force, which are balanced at ankle by N_L , N_R , f_L , and f_R correspondingly. N_D and N_S indicate the driving wheel and supporting wheel normal force exerted by the ground with f_D and f_S indicating the corresponding friction force.

By using parameters labeled on the free body diagram and neglecting the rolling friction of the supporting wheels f_S , the following analytical result can be obtained:

$$F_R = F_L = \frac{mg}{2 \cos \theta} = \frac{N_L}{\cos \theta} = \frac{N_R}{\cos \theta} = \frac{f_L}{\sin \theta} = \frac{f_R}{\sin \theta} \rightarrow f_L = f_R = \frac{1}{2} mg \tan \theta \quad (\text{Equation 1})$$

$$f_S \approx 0 \rightarrow f_D = f_L = \frac{1}{2} mg \tan \theta \quad (\text{Equation 2})$$

$$P = f_D \cdot v \cdot SF = \frac{1}{2} SF \cdot mgv \tan \theta \quad (\text{Equation 3})$$

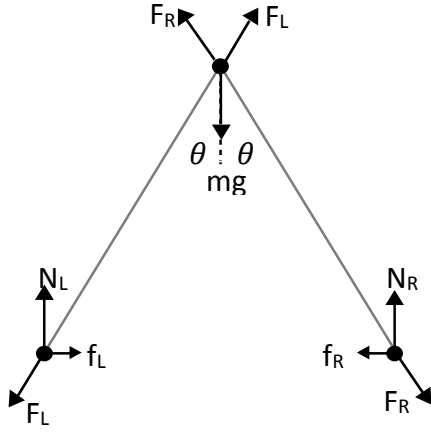


Figure 16: Leg Free Body Diagram

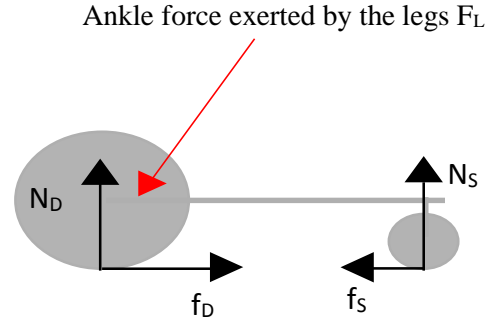


Figure 17: Foot Free Body Diagram

Based on the length and cross section area data of the aluminum extrusion in the torso structure and the mass of the gears, the mass of the components that are supported by the waist shaft m was estimated to be 10 kg. As the human leg maximum spreading angle during walking is in general less than 60° (Zhang, Z., et.al., 2014), the maximum value of θ was estimated to be 30° . Based on *Equation 1* and using the $= 9.81 \text{ m/s}^2$, the friction force f_D was calculated to be 28.32 N. A dynamic analysis done on the model using Solidworks CAD software yield similar result as shown in *Figure 18*, which gave a maximum value close to the analysis from simple model.

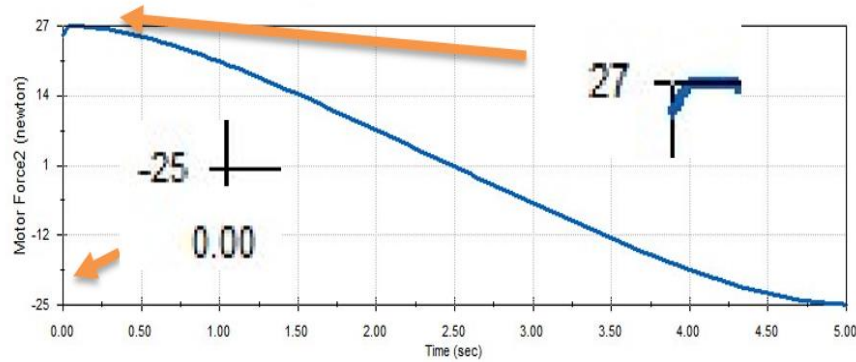


Figure 18: Solidworks Simulation for $m = 10 \text{ kg}$

With the specification of 1 m/s as the mannequin moving speed, the moving speed of a single foot should be doubled to yield 2 m/s. With a safety factor of 2 and *Equation 3*, the power of a single motor is estimated to be 113.28 W, which is approximated as 120 W for motor selection.

A variety of motors were considered during the selection process as shown in *Figure 19*. The electric scooter motor was chosen for its suitable power and reasonable price. In addition, this motor was designed to be water proof, which is helpful for operation in different condition.




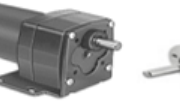

| | Electric Bicycle | Electric Scooter | Robots | Assembly Line | Extreme Condition |
|------------------------|---|---|--|---|---|
| Motor Picture |  |  |  |  |  |
| Size (in) | 4*4*3 | 2.5*2.5*4 | 1.2*1.2*2 | 3.3*3.3*12.6 | 1.77*1.77*3 |
| Power (W) | 350 | 135 | 60 | 186.4 | 150 |
| Max Speed (RPM) | 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 |

Figure 19: Motor Selection

8.6.2 Motor Power Estimation

Due to the length of the shaft at the waist for supporting the structure, deflection analysis of the shaft for the worst case scenario in which the leg separation angle is 60° was conducted for concept bearing and shaft selection. The free body diagrams are shown in *Figure 20*.

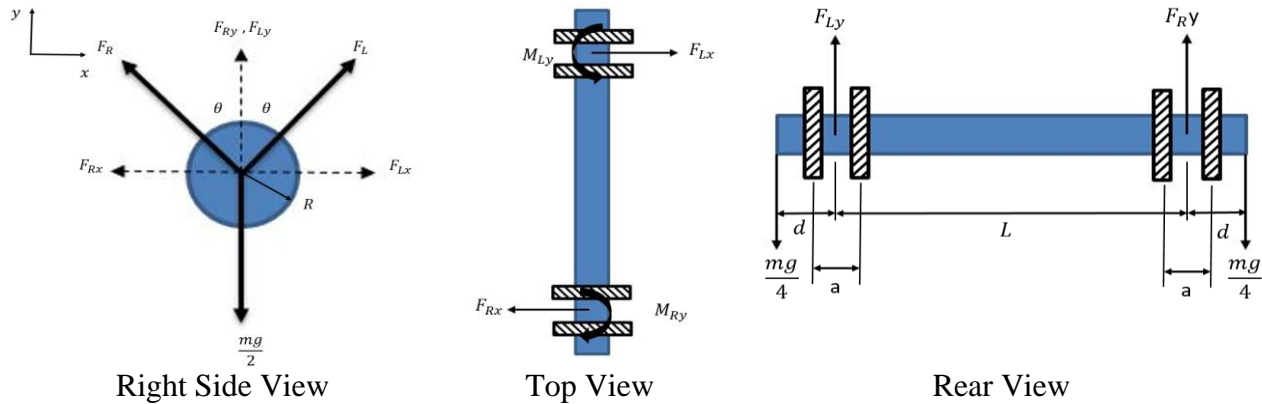


Figure 20: Waist Shaft Free Body Diagram

During the analysis, the force exerted by the torso is simplified to be a concentrated load of $\frac{mg}{4}$ at each end of the shaft as two shaft provide four contact points together. Although the moment supplied by the torso bearings serves the purpose of reinforcement, the moments were neglected during the process for easiness of calculation and count as safety factor such that no safety factor were involved in the following calculation.

With the established coordinate system, the following equations can be obtained by applying static equilibrium and using the theory of beam bending.

$$|F_R| = |F_L| = \frac{mg}{2 \cos \theta} \rightarrow |F_{Rx}| = |F_{Lx}| = \frac{mg}{2} \tan \theta \quad (\text{Equation 4})$$

$$\begin{cases} |M_{Ry}| = |M_{Ly}| = \frac{mg}{2} L \tan \theta \rightarrow |F_{Bx}| = \frac{mgL}{2a} \tan \theta \\ |F_{By}| = \frac{mg}{8} \end{cases} \rightarrow |F_B| = mg \sqrt{\left(\frac{L \tan \theta}{2a}\right)^2 + \frac{1}{64}} \quad (\text{Equation 5})$$

$$\begin{cases} |\delta_{x_max}| = \frac{mgL^3}{3\pi ER^4} \tan \theta \\ |\delta_{y_max}| = \frac{mg(d-a)^3}{6\pi ER^4} \end{cases} \rightarrow |\delta_{max}| = \frac{mg}{6\pi ER^4} \sqrt{[2L^3 \tan \theta]^2 + \left[\frac{(d-a)^3}{2}\right]^2} \quad (\text{Equation 6})$$

where M represents moment, δ represents deflection, $|F_B|$ representing the magnitude of the force on the bearing, and all other dimension parameters as shown in

Figure 20. The detailed design with components availability considered yielded the dimension parameter as $L = 202 \text{ mm}$, $a = 30 \text{ mm}$, $d = 76 \text{ mm}$, $R = 4 \text{ mm}$, and $E = 200 \text{ GPa}$ for steel. With an estimation of $m = 10 \text{ kg}$ and $g = 9.81 \text{ m/s}^2$, the following results can be obtained $|F_B| = 191.1 \text{ N}$ and $|\delta_{max}| = 0.97645 \text{ mm}$.

In conclusion, bearings with dynamic loading at 500N are readily available in the market which can easily satisfied loading condition in this case. Regarding the deflection, the current value is not relatively small compared to the overall dimension of the mannequin. In addition, considering the fixture at both end of the shaft and in the middle as shown in *Figure 14*, the overall deflection would be significantly smaller due to limited boundary condition. Hence, the force and deflection requirement are both satisfied in this case for a shaft diameter of 8 mm using the current geometry of the mechanism.

8.7 Electric Control System Hardware

To allow user interaction and control of the mechanized pedestrian test system, Arduino micro controllers were used in both the ultrasonic detection system and the mechanized pedestrian mannequin. The hardware components involved in the system as well as the signal and power flow label is shown in *Figure 21*.

The communication between the detection system and the mannequin is realized by using a pair of Xbee radio modules. To allow easy control and protect the circuit systems, all user operations should be conducted remotely. LCD screens are included in both the detection system and the mannequin to provide the user with information related to system status.

To enable accurate velocity control, an absolute encoder is installed at the torso of the mannequin to measure the leg separation angle as a feedback. The duty cycle of the pulse width modulation signal is then determined by the microcontroller based on the reference user input

and the feedback measurement. For purpose of controller tuning and validation, a data acquisition system with MyRIO and LabVIEW was setup as an additional component.

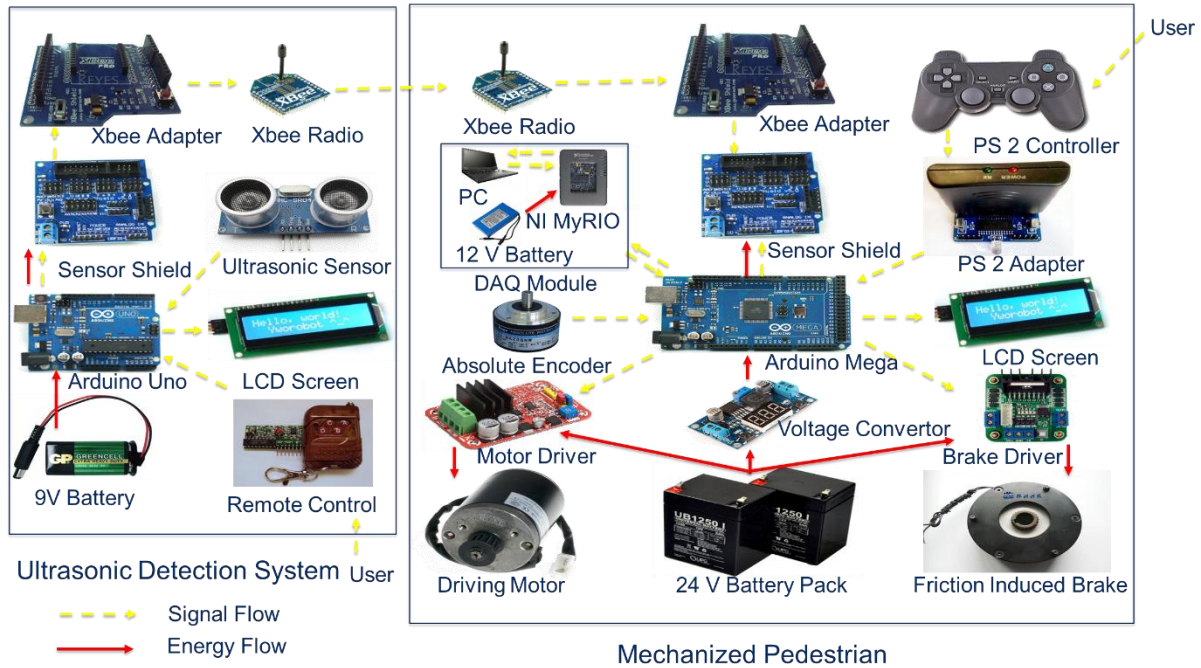


Figure 21: Electrical Component

8.8 System Operation Control Logic

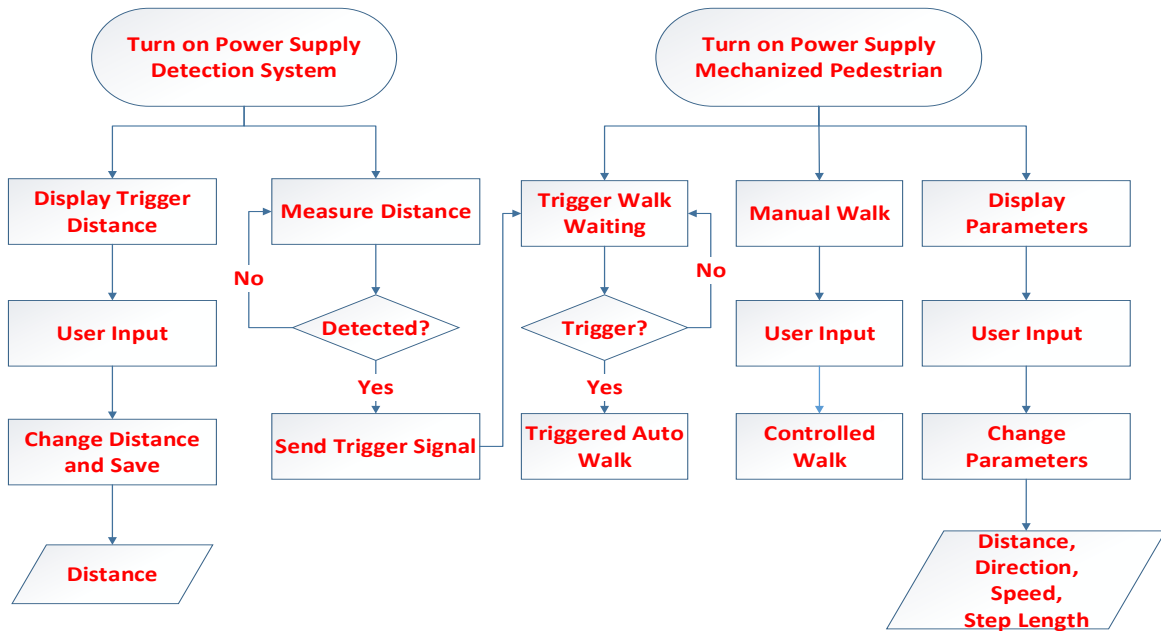


Figure 22: Micro Controller High Level Logic Flow Chart

With the system setup as discussed in the overview section, the mechanized pedestrian mannequin can be controlled directly by the operator or triggered by the ultrasonic detection system. Control Parameters can be modified by the user directly via remote control and stored in the micro controller without the need to make change to the source code. The high level program logic is summarized in the form of flow chart and shown in *Figure 22*.

9 Prototype Validation

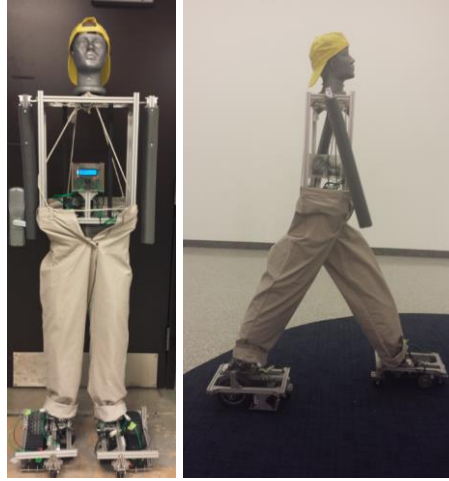


Figure 23: Final Prototype Pictures

Based on the design, a fully functional prototype with ability to mimic the walking and standing motion of pedestrian was completed. The front view and side view of the final assembled prototype with electrical systems is shown in *Figure 23*.

The mechanized pedestrian is fully functional in terms of the code logic and motion profile. Several tests were conducted during the validation process corresponding to the engineering specifications as discussed below.

9.1 Validation Procedure

Validation of the design was conducted corresponding to engineering specifications as listed in the user requirement and engineering specification section.

For the mimic of human appearance and pedestrian motion mimic, the dimensions of the mechanized pedestrian and step length were measured directly using ruler. The motion speed of the mechanized pedestrian was determined using the LabVIEW software with MyRIO data acquisition system. The angle measured by the absolute encoder was obtained by the Arduino Mega board and sent to the MyRIO data acquisition system for data analysis, recording and real time simulation of the current status of the mechanized pedestrian on computer. The front panel of the LabVIEW program is shown in *Figure 24*.

The weight of the mechanized pedestrian was measured before assembly for different section of components separately. The result was obtained by summing all the mass together.

The quick reset specification was tested by recording the average time for putting the mechanized pedestrian on a dolly and move across the street with one lane in each direction.

The cost efficiency requirement was validated by summing the individual component costs as listed on the bill of material. The cost of components used on the final prototype and the cost of shipping and components for trials were calculated separately and added together.

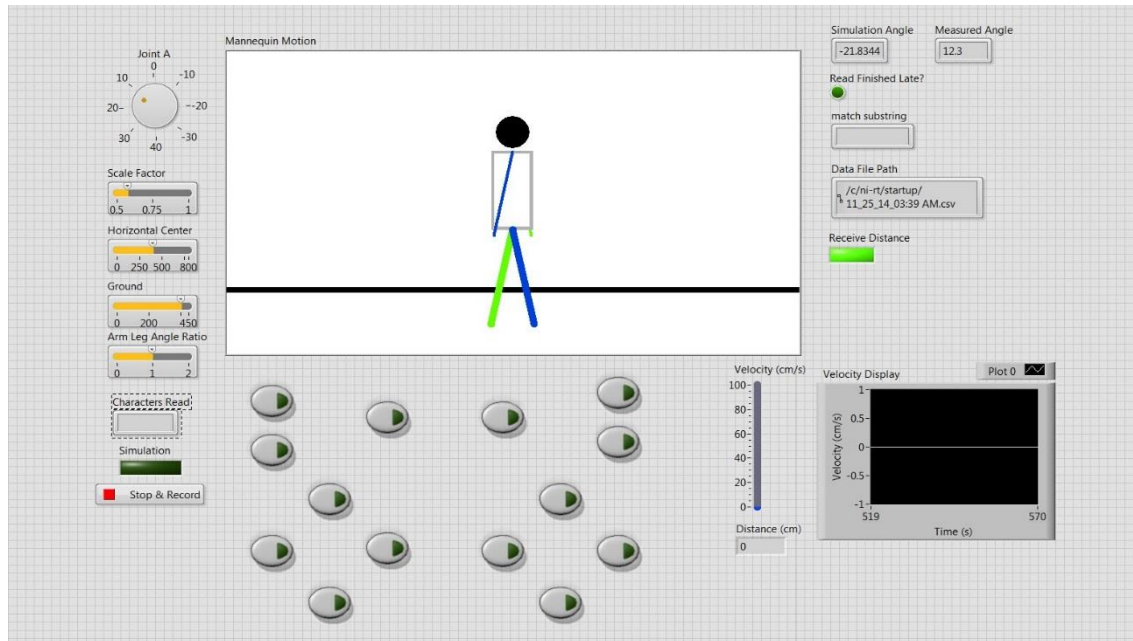


Figure 24: LabVIEW Data Acquisition System Interface

9.2 Validation Result

The validation of the mechanized pedestrian prototype went smoothly in most tests with results shown in *Table 2*.

| User Requirements | Test Parameter Values | Result |
|-------------------|--|--|
| Human-like | Height: 69 in Chest: 45.5 in | Height satisfied Chest marginally |
| Motion | 55% power speed: 0.75m/s Max step length: 32 in | Speed need increase Step length Satisfied |
| Portable | Weight: 45 lbs | Satisfied |
| Quick Reset | Average reset: 35 s | Satisfied |
| Cost Efficient | Used parts: \$927.6 Others: \$509.1 | Satisfied |

Table 2: Test Results

As can be seen from *Table 2*, all engineering specifications derived from user requirements are satisfied except for the mannequin walking speed. The speed of 0.75 m/s was obtained from the test data recorded by the MyRIO as plotted in *Figure 25* with a motor power pulse width modulation duty cycle of 55%.

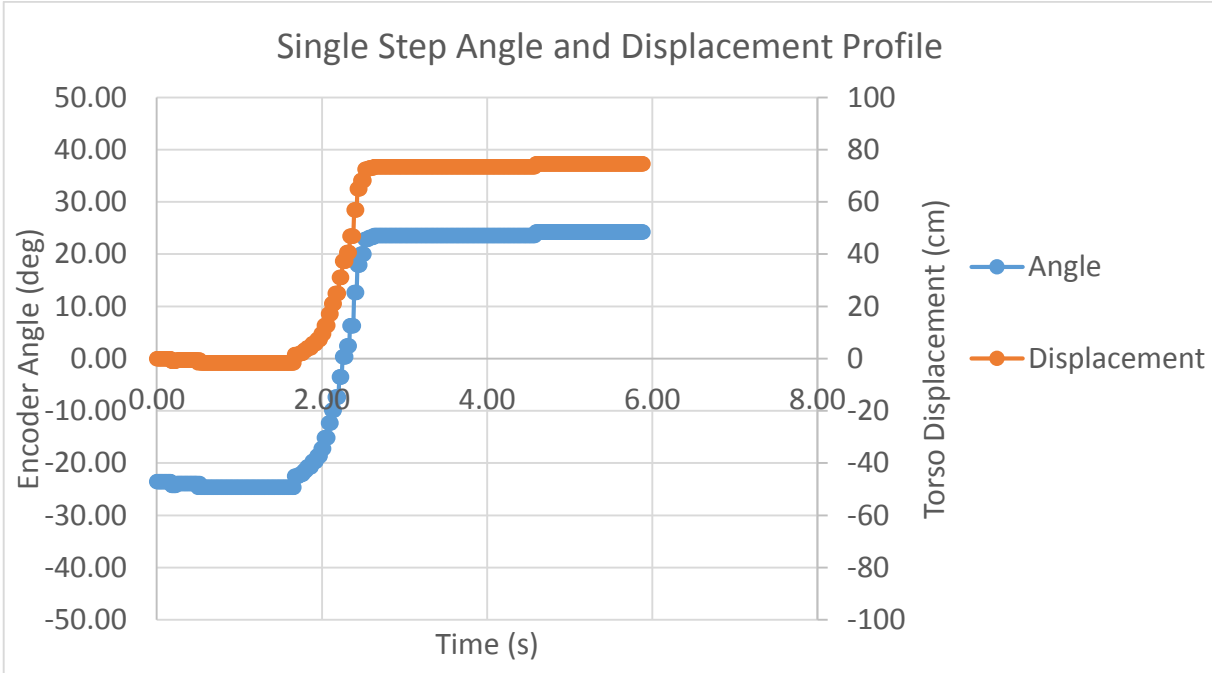


Figure 25: Mannequin Speed Test Data

The test was not conducted at full motor power as the mannequin would lose balance and tilt to the back left or back right direction if the motor power was set over 55%. This is primarily due to the fact that the dynamic loading of the mannequin has not been taken into consideration into the model during the design phase. The original design considered the static loading condition and modeled the mechanism as a two dimensional mechanism.

Although not reaching the speed of 1 m/s during the test, if the relationship between speed and motor power is assumed to be linear, the mechanized pedestrian could achieve a speed of approximately 1.2 m/s if the balance issue was resolved and proper control algorithm was implemented.

In summary, the mechanized pedestrian prototype satisfies most of the engineering specifications except the speed requirement of 1 m/s due to balance issue. Several proposed solutions are included in the future work section for improvements.

10 Future Work

From the test results of the mechanized pedestrian prototype, future work for the system majorly involves three aspects:

First, change needs to be made to the design of two supporting wheels and one driving wheel each foot to two driving wheels and redesign the torso gear shaft mount to reduce back lash for stability concern. This design modification helps to solve the balance issue during the speed test.

Second, the 135 W motors can be replaced by an off-the-shelf 200 W motors and corresponding driver boards to increase the maximum walking speed of the mannequin. As the sponsor mentioned that there might be a need for the mechanized pedestrian to walk at a higher speed in the future, this modification gives enough power for the actuators to realize the motion. A 200 W motor that can directly fit into the current fixture design has been located and could be installed easily to perform this update.

Third, a dynamic system model needs to be established and fine tune of the controller for the mechanized pedestrian will be necessary to obtain a relatively steady speed. Due to the limiting time and balance encountered during preliminary testing, the controller of the current system has not been fine tuned to achieve speed accuracy. A dynamic system model based controller tuning should be conducted on the prototype by using the DAQ system implemented by MyRIO to gain accurate control of the mannequin.

11 Project Timeline

To successfully complete the specification, concept generation, design and analysis, manufacturing, assemble and validation product development cycle in a timely manner and fabricate quality ensured prototype, a detailed project plan with six general stages was created. Detailed tasks corresponds to each mile stone are listed in *Table 3*.

| Task Name | Duration | Start | Finish | People in Charge |
|---|----------------|--------------------|---------------------|------------------------------|
| Confirm Project Requirements and Engineering Specifications | 2 days | Thu 9/11/14 | Fri 9/12/14 | All |
| Concept Generation and Selection with Preliminary Design | 11 days | Thu 9/11/14 | Thu 9/25/14 | |
| Design Concept Generation | 4 days | Thu 9/11/14 | Tue 9/16/14 | All |
| Functional Decomposition | 4 days | Thu 9/11/14 | Tue 9/16/14 | Bridget Cook |
| QFD Chart | 6 days | Tue 9/16/14 | Tue 9/23/14 | Kyle Ritsema |
| Preliminary Design Concept Drawing | 8 days | Thu 9/11/14 | Sun 9/21/14 | All |
| Concept Discussion and Selection | 2 days | Fri 9/19/14 | Sun 9/21/14 | All |
| Concept Selection Report | 3 days | Sun 9/21/14 | Tue 9/23/14 | Fangzhou Xia Nikhil Kumar |
| Design Review 2 | 0 days | Thu 9/25/14 | Thu 9/25/14 | |
| Detailed Design and Simulation | 13 days | Fri 9/26/14 | Tue 10/14/14 | |
| Mechanism Dimension Design | 6 days | Sun 9/21/14 | Fri 9/26/14 | Fangzhou Xia Nikhil Kumar |

| | | | | |
|---|----------------|---------------------|---------------------|------------------------------|
| Force Analysis | 6 days | Fri 9/26/14 | Fri 10/3/14 | Fangzhou Xia Kyle Ritsema |
| Mechanism Optimization | 2 days | Fri 10/3/14 | Sun 10/5/14 | Fangzhou Xia |
| Material Selection and Bill of Materials | 5 days | Sun 10/5/14 | Thu 10/9/14 | Bridget Cook Kyle Ritsema |
| Control System and Electric Components Selection | 5 days | Sun 10/5/14 | Thu 10/9/14 | All |
| Place order for some raw material for machining | 3 days | Thu 10/9/14 | Sun 10/12/14 | Fangzhou Xia Nikhil Kumar |
| Detailed Engineering Assembly | 3 days | Thu 10/9/14 | Sun 10/12/14 | All |
| Engineering Drawing and Manufacturing Plan | 3 days | Sun 10/12/14 | Tue 10/14/14 | Fangzhou Xia Kyle Ritsema |
| Safety Report | 4 days | Thu 10/9/14 | Tue 10/14/14 | All |
| Design Review 3 | 0 days | Fri 10/17/14 | Fri 10/17/14 | All |
| Purchasing and Prototype Fabrication | 15 days | Wed 10/15/14 | Tue 11/4/14 | |
| Propelling System Fabrication | 5 days | Wed 10/15/14 | Tue 10/21/14 | TBD |
| Linkage Fabrication | 10 days | Wed 10/15/14 | Tue 10/28/14 | TBD |
| Structure Assembly | 7 days | Thu 10/23/14 | Fri 10/31/14 | TBD |
| Dressing, Problem Solving and Finishing | 5 days | Tue 10/28/14 | Sun 11/2/14 | TBD |
| Design Review 4 | 5 days | Tue 11/4/14 | Sun 11/9/14 | All |
| Control System Implementation | 7 days | Thu 10/30/14 | Fri 11/7/14 | |
| Install Electrical Components | 9 days | Thu 10/23/14 | Tue 11/4/14 | TBD |
| Coding and Testing | 9 days | Tue 10/28/14 | Fri 11/7/14 | TBD |
| Design Test and Engineering Specification Validation | 10 days | Wed 11/5/14 | Tue 11/18/14 | |
| Dimension Measurement | 3 days | Wed 11/5/14 | Fri 11/7/14 | TBD |
| Moving Speed and Control Validation | 3 days | Fri 11/7/14 | Tue 11/11/14 | TBD |
| Weather and Road Condition | 8 days | Wed 11/5/14 | Fri 11/14/14 | TBD |
| Conclusion and Wrap up | 2 days | Fri 11/14/14 | Sun 11/16/14 | TBD |
| Design Review 5 | 0 days | Tue 11/18/14 | Tue 11/18/14 | All |
| Design Expo | 0 days | Thu 12/4/14 | Thu 12/4/14 | All |

Table 3: Project Gant Chart

12 Conclusions

Based on the information gathered from the sponsor, the problem to be solved in this project was identified as design and fabricate a prototype of mechanized pedestrian for testing of pre-collision systems at the MMTC test facility. By benchmarking previously existing test setups for PCS and considering the different scenarios need to be tested at MMTC test facilities, a mechanized pedestrian without overhead gantries and pulling cables is required by the sponsor.

The engineering specifications are then derived from the six requirements including the overall function realization as a test mannequin for automated vehicle system, the dimension and weight of the mechanical structure, the surrounding operation condition of the prototype, the limit of complexity in terms of resetting time, system robustness and the efficiency in utilizing resources.

By conducting functional decomposition, concept generation brainstorm, morphological analysis, pugh chart and elimination against requirements, a number of ideas for sub systems to realize the function of the mechanized pedestrian were considered and carefully filtered against the project requirement and engineering specifications correspondingly. A physical mock-up and a Solidworks model are created for the selected design. Apart from the advantage of the selected concept based on morphological analysis, the team identified the possible issue with large friction force in the slider joints involved in the selected joint and are currently working on generating more design ideas to resolve this problem.

With detailed engineering analysis, critical parts such as motor and waist shaft was selected based on the numerical result. The mechanical structure involved driving motors in feet and driven mechanism in torso for walking and arm motion. A one to one scaled Solidworks CAD model was created for manufacturing and illustration purpose. For ease of design change and manufacturing, T-slotted aluminum extrusions and plate fixtures were used in the design. A prototype was manufacture and assembled for the mechanized pedestrian.

The electrical system implementation involved mannequin control circuit components and ultrasonic detection system. With remote controller module, the system allows users to change and store important parameters such as reference speed and walking distance without code modification. The communication between the ultrasonic detection system and the mechanized pedestrian was also implemented with radio communication module.

The mechanized pedestrian prototype satisfies all the established specifications except for the speed of 1 m/s due to a balance issue that had not been taken into consideration during the design phase. Recommendations are made to resolve this problem for future improvements.

As a conclusion, a working prototype that meets most of the criteria was delivered in a timely manner. Recommendations for improvements are also provided by the team to help future teams working on this project to resolve the issue encountered during the implementation.

13 References

- Barickman, F., Albrecht, H., Elsasser, D. (2014), “*NHTSA’s PCAM Testing and Dummy Development*”. SAE International Presentation Slides.
- Carpenter, M. G., Feldmann, M., Moury, M. T., Skvarce, J. R., Struck, M., Zwicky T. D., & Kiger, S. M. (2013, July). “*Objective tests for forward-looking pedestrian crash avoidance/mitigation systems: annual report*” (Report No. DOT HS 811 793). Washington, DC: National Highway Traffic Safety Administration.
- Yi, Q., Chein, S., Brink, J., Chen, Y., Sherony, R., and Takahashi, H. (2013). "Development of Equipment to Evaluate Pre-Collision Systems for Pedestrians." Diss. Indiana U-Purdue U Indianapolis, n.d. Abstract. (n.d.): n. pag. Toyota Motor Corporation. Web. 5 Sept. 2014.
- Yi, Q., Chien, S., Good, D., Chen, Y. et al. (2014, Jan.). "*Development of a Lighting System for Pedestrian Pre-Collision System Testing under Dark Conditions*", SAE Technical Paper 2014-01-0819, 2014, doi:10.4271/2014-01-0819.
- Zhang, Z., Wong, C., Lo, B., Yang, G., (2014), “*A Simple and Robust Stride Length Estimation Method using Foot-mounted Micro Gyroscopes*”, The Hamlyn Centre, Institute of Global Health Innovation, Imperial College London, UK, URL: <http://www.bsn2014.org/poster/BSN2014-poster15p-zhang.pdf>

Bios

Bridget Cook



My hometown is Simsbury, CT and I have lived in New England my entire life. Outside of class, I am a captain of the club Ultimate Frisbee team here at U of M, and have been playing ultimate since freshman year. Within mechanical engineering, I am primarily interested in product design and development, and hope to get a job in this industry after I graduate.

Nikhil Kumar



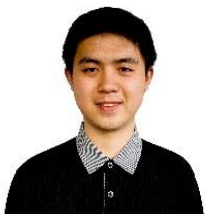
I grew up in Troy, Michigan, a suburb of Detroit. Growing up I was always enthralled by cars and wanted to work in the auto industry. This led to an early fascination with tinkering and building pretty much anything. I have great interests in applying my engineering knowledge to design science and user experience design. I currently work at Mountain Labs, an Ann Arbor based startup doing design and user experience work. I hope to continue this fruitful job in the future.

Kyle Ritsema



I grew up in Grandville, Michigan, a suburb of Grand Rapids over on the west side of the state. My dad went to the University of Michigan so growing up I was always a big fan and have always wanted to come here. I decided I wanted to go in to engineering sometime in High School based on the fact that I was always interested in learning how things function and that I was good at math and physics. I am unsure of what specifically I want to do after I graduate within mechanical engineering but I am most interested in R+D or systems design.

Fangzhou Xia



My name is Fangzhou Xia, a senior dual degree student major in mechanical engineering at University of Michigan and electrical and computer engineering at Shanghai Jiao Tong University, which is in my home town. My areas of interest in mechanical engineering are system control, product design and manufacturing automation. My current plan is to go on my study for a master or hopefully a doctor degree in mechanical engineering to obtain more knowledge and hone my. One fun fact of mine is that my nick name is “Bear”.