Periodic Leg Movement Exercise Device

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BME 401B: Final Report

April 20, 2018

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Overview of Our Project

Periodic leg movements during sleep (PLMS) is a condition which disrupts sleep by causing uncontrollable jerking of the legs and arms. Approximately 3.9% of the total population experiences PLMS.[1] This number is significantly higher in those with underlying neural pathologies, such as multiple sclerosis, transverse myelitis, and spinal cord injuries. Counter stimulation is technique that introduces new sensations, such as leg movement or vibration, to counteract signals sent from the brain to the limbs that lead to the uncontrollable leg movements. This technique has helped relieve symptoms of restless leg syndrome, a similar and often co-occurring condition.[2] Our goal is to create a safe device for use during sleep that uses the principle of counter stimulation to alleviate the symptoms of PLMS.

Verification Plan Results

Verification of the Periodic Leg Movement Device specifications was done according to the verification testing plan listed in Appendix A.

*Note: Changes were made to the original verification plan. Force was measured using a Vernier Structures and Materials tester by measuring the difference in force felt by the side of the platform as the device moved back and forth. The minimum and maximum forces experienced were measured in order to identify the range of forces felt by each leg. Weight was measured by placing the device on a Vernier Force Transducer plate and the resultant force (in N) was divided by 9.8 m/s^2 to obtain the weight (in kg) of the device.

Table 1. Verification Plan by Specification and Results of Testing

Specification	Original Metric	Prototype Metric	Justification/Explanation
Frequency of Movement	0.25 to 2.5 Hz	0.4 (low) to 0.6 Hz (high)	The range of displacement fell within our original specified range. While 0.4 - 0.6 Hz is a relatively low frequency, in future prototypes, the PWM speed of the motor or the pause time between the back and forth movements can be changed within the software code to assign desired frequencies to the low, medium, and high settings. We believe that a lower range of frequencies is better for maintaining sleep quality and safety while using this device.
Displacement	0 to 30 cm	7 to 10 cm	The measured displacement falls within the lower end of our specified range. A smaller displacement range is desirable as it allows for better sleep quality and safety.
Force	< 150 N per leg	8.7 - 16 N	The measured force of this device was much less than the specified metric of 150 N per leg. The low force felt by each leg as the device moves back and forth allows for safety while using the device.
Weight	< 10 kg	9 kg	The measured weight of 9 kg falls under our original specified limit of 10 kg. The low weight of the device results in easier assembly and disassembly.
Cost	< $1000	$341.22	The cost of the working prototype fell well within our set budget of $1,000. Even if future prototypes were made with durable plastic, rather than fiberboard and styrofoam, the maximum cost would be about $500, which still falls under the specified budget.

Dimension	Length < 200 cm, Width < 70 cm	80 cm (width) x 50 cm (length) x 30 cm (height)	The length satisfies the original metric, but the width exceeded the original metric by 10 cm. This expansion was necessary due to the large size of the motor we used, but in future prototypes this width could be cut down to be under 70 cm if a different size motor was used. In addition, the functionality of the device is more important to our client than the width.
Installation	Does not require daily disassembly/assembly; 1 person sitting in a wheelchair can set up	One time assembly; difficult to set up while in wheelchair	This device only needs to be set up once. However, the large width means that the user would probably need help from another person to assemble it. As discussed above, in future prototypes the width of the device can be decreased, making the device easier to install.
Adjustable to Individual	Fits any leg diameter up to 23 cm and any leg length	Fits leg diameters of 13 cm	For this prototype, we decided to downsize this specification and have the device accommodate the average sized human calf (a diameter of about 13 cm) as that is the approximate size of our client's legs. In future prototypes, the top platform can easily be made wider and taller to accommodate larger leg diameters.
Operating Time	At least 12 hours	At least 6 hours	When Divya slept using the device, the device ran for 6 hours. We assume the device can run for longer because it is powered by a wall outlet.
Software Interface	Allows user to control device program while lying down; Operates in a range of 6 ft; Wide range of control: automatic mode for sleep; manual control for wake Minimal interference	Can operate while lying down; Operates within 6 feet; Handheld control accommodates for wide ranges; automatic and manual controls; no foreseen interference	We decided to use a Bluetooth app for the software interface so that our device is compatible with the Periodic Leg Movement Disorder Sensing Device. The use of a phone app allowed for ease of use in any position or at wide ranges. There was no interference seen. The app allows for an automatic setting (the user can specify a setting, go to sleep, and then stop the device after waking) as well as manual use awake.

Safety	Causes no short or long-term damage to user Contains no toxic materials or chemicals and no exposed electrical components Cords not harmful or disruptive to user Low friction: avoids sores due to friction over long term use	Causes no short or long-term damage to user Contains no toxic materials or chemicals and no exposed electrical components Cords not harmful or disruptive to user Low friction: avoids sores due to friction over long term use	See our DesignSafe analysis below.
Comfort	Lifts legs < 20 cm above rest of body < 1 kg weight attached to each leg Should not be unpleasant to use, allows user to remain asleep Allows user to shift positions throughout sleep	Legs lifted 17 cm; 0.05 kg weight rest on the legs; comfortable to use throughout the night while maintaining normal sleep (see survey results in Appendix D)	This prototype fell under our set limit of the height that the legs should be lifted, and there was very little weight placed on each leg, allowing for comfort while sleeping. The flexibility of the top flap allowed for shifting of positions while asleep, while the padding provides cushioning and comfort to any part of the body that may come in contact with the device.
Sound	< 30 dB_A	48.1 - 61 dB_A	We measured sound levels of 55 to 62 dB_A, but the base level sound of the room was 54 dB_A. After factoring in base level noises, we obtained our actual measurement. This is over our desired specification, but Divya was still able to sleep with the device, so we believe it is acceptable. In the future, noise can be reduced with padding.
Due Date	Completed by May 1, 2018	Completed by April 20, 2018	The working prototype and verification and validation of specifications were completed by April 20, 2018, so the deadline of May 1, 2018 was met. Some aesthetic touches were made between April 20 and May 1.

Design Safe Analysis

The main users of our device will be the patients themselves, as the device is designed for home use during sleep. However, we believe that other people such as doctors, nurses, caregivers, or family members may assist in the operation of the device. Many of the tasks these different users would perform with our device would pose the same risks. Therefore, we found it useful to create an “All Users” category to encompass these common risks, and then “Patient” and “Non-Patient” categories to assess specific risks. Therefore, hazards for “All Users” are present for everyone, hazards for “Patients” are present only for those specifically using the device, and hazards for “Non-Patients” are present only for people around the device who are not specifically using the device. “Non-Patients” can include doctors, nurses, caregivers, family, or others. We assessed the hazards posed to our users using DesignSafe software, the results of which are summarized here. Our specific analysis results are given in Appendix B and in the attached Excel file DesignSafe.xlsx.

Through our DesignSafe risk analysis, we conclude that our device will pose low to moderate risk to users. Before mitigation steps, our device posed moderate risk to the user. We accept these risks as our device is mechanical and therefore has inherent risks associated with its use. Our highest concerns are repetitive movement and physical injury to the user by excessive force. We hope to mitigate the risks associated with these hazards by limiting the maximum force our device exerts on the legs and decreasing the frequency of our device’s motion. We also added ample cushioning to prevent the development of sores. We hope to mitigate all of our risks as much as possible through responsible design and proper warnings to the user. For the purposes of this project, some mitigation steps were not performed, but would be in future iterations of this device.

Validation Plan Results

Our client, Dr. Kerri Morgan, was on family leave when our device was completed and tested, so we were unable to perform validation testing on her. We therefore performed validation testing on ourselves. Because none of us experience PLMS, we were not able to determine the effectiveness of our device at preventing PLMS. Because we did not want to risk damaging our device, only Divya slept with the device overnight, and Erica and Devin tested the device while awake for one hour to test comfort.

Even though we were not able to have our client validate the device, we are confident that our device will be effective in reducing the severity of PLMS while the user remains asleep because we have confirmed the comfort and safety (see Appendix B and D). We have also confirmed that the device operates throughout the night, and achieves the proper displacement and frequency needed for adequate leg exercise that reduces PLMS severity. This prototype passed validation testing as it uses the principle of counter stimulation (via induced movement of the legs) to reduce the severity of PLMS symptoms.

Assembly of Device

Listed on the next page are the parts used in the building of this device, organized by category. For more information about the specific details of each part, such as prices, sources, lead times, and specifications, please see Appendix E. For CAD replications of the parts, please see Appendix F. A circuit schematic, wiring diagram, mechanical drawings, software summary, and assembly directions are also included in this section.

Parts List

- **Motor Components**
  - 12 V Motor
  - PWM Motor Driver
- **Pulley and Rail System**
  - Pulley Adapter
  - Timing Belt
  - Linear Rail Kit - includes 4 platform mounts, 4 rail mounts, and 2 pulley mounts
  - 2 x 1 ft Rails
  - Socket Head Cap Screw
- **Screws**
  - #6 1” screws
  - #8 1 ¼ ” screws
  - #6 ¾ ” screws
  - #6 ½ ” screws
- **Platform**
  - Styrofoam
  - Fiberboard
  - Velcro
  - Sandpaper
  - Gorilla Glue
  - Weldbond Glue
  - Pure Foam Cushion
  - Sewing Materials
  - Cotton Fabric
- **Software Interface and Circuitry**
  - Bluetooth Module
  - Arduino Uno
  - Jumper Wires
- **Power Supply**
  - 12 V AC to DC Power Adapter
  - 2.1 mm to Female DC Power Adapter

Circuit Schematic

Shown below is a circuit schematic showing the connections between the Bluetooth module, the Arduino Uno, the PWM Motor Driver, and the Motor.

Figure 1. Circuit schematic showing connections between Arduino Uno, Bluetooth module, motor driver and motor. The Arduino is also connected to an external 9V battery (not shown) and the motor driver is connected to our 12 V AC/DC power adapter (not shown).

VMOTOR and GND should be connected to the Positive and GND terminals of the power supply, respectively.

*Note: The motor driver used in the Circuit Schematic and the Wiring Diagram is not the same as the one we used in our device since ours was not available in the Fritzing software, which was used to generate these diagrams. However, their wiring method is the same and either motor driver can be used in the device.

Wiring Diagram

Shown below is the wiring diagram showing the connections between the Bluetooth module, the Arduino Uno, the PWM Motor Driver, and the Motor.

Figure 2. Wiring diagram showing connections between Arduino Uno, Bluetooth module, motor driver and motor. The Arduino is also connected to an external 9V battery (not shown) and the motor driver is connected to our 12 V AC/DC power adapter (not shown).

Mechanical Drawings

Shown below are perspective views of computer generated replications of the mechanical design of our device. These models were made using CAD Inventor Professional 2016. Figure 3 shows the base platform component with the motor and pulley and linear motion system attached, while Figure 4 shows the device with top and base platforms attached via motor, pulley and linear motion system. The circuitry and software interface components, as well as the power cord connection, sit on top of the base platform near the motor. The recess in the base platform on the face at which the motor is inserted was closed up with styrofoam, and 3D printed boxes that are meant to shelter the circuitry, motor, and pulley system were added. These aspects are not shown in Figures 3 and 4 for purposes of clear visibility of the device's assembly. The exploded view and run through of the assembly process can be found in the assembly.avi file attached via Blackboard.

Figure 3. Perspective view of the base with motor, linear rail system, and pulley system attached.

Figure 4. Perspective view of the assembled base with the linear rail system and moving platform attached.

Software Code

The software for this project was developed using Adafruit's Bluefruit LE nRF51 open source software. Although the code in the MotorDriver_SoftwareInterface file was developed by us, the header files included in this project were developed by Adafruit and all Bluetooth code is based off of Adafruit's example. The MotorDriver_Software Interface file and the header files are attached in Blackboard. The application used to control this device can be found for iOS here: https://itunes.apple.com/us/app/adafruit-bluefruit-le-connect/id830125974?mt=8.

This software interface makes use of the Adafruit Bluefruit LE Connect application, which connects to the Bluefruit module and sends commands to the module, which then prompts the Arduino to control the motor. Once Bluetooth communication via the iPhone app and the Bluefruit module has been enabled, the program continuously prompts for a valid command: either "high", "medium", "low", or "stop". Once a command has been given, the program sets the speed and pause time, and runs the motor through a continuous loop of clockwise and counterclockwise motion that will continue until a new command is entered. A flowchart of the software can be found in Figure 5 below.

Figure 5. Software code flowchart for control of device movement.

Process of Device Assembly

1. 3D-print 2 pulley risers, 4 platform riser mounts, the pulley box, and the motor box.
2. Cut fiberboard and Styrofoam following the dimensions in the ‘base’ CAD drawing in Appendix F and drill holes as shown.
3. Cover the Styrofoam in cotton fabric.
4. Glue the fiberboard on top of the covered Styrofoam as shown in the ‘base’ CAD drawing.
5. Cut a 34 cm x 36 cm piece of fiberboard for the platform. Cut two 10.5 cm x 36 cm pieces of fiberboard and screw into the sides of the first piece to create a platform as in the ‘platform’ CAD drawing using #6 1” screws.
6. Cut and add upholstery foam to the inside and outside surfaces of the platform.
7. If motor does not have a smooth shaft, file down so it is smooth. Add the pulley adapter to the motor. Place the motor in the 12 cm x 18 cm x 7 cm recess created by the wood and Styrofoam in the orientation given in Figure F.3 of Appendix F. Secure the motor with additional padding. It will be secured further by a cover later in the assembly process.
8. Assemble the pulley anchor by using the two pulley mounts included in the linear rail kit. Place the other pulley adapter in between the two mounts and add the socket head screw cap through the center holes, securing with a nut.
9. Add two platform mounts to each 1 ft rail then add a rail mount to each end of each rail. Screw the platform mounts onto the bottom of the platform 10 cm in front each side of the platform, using #6 1-¼” screws. Make sure the platform is oriented with respect to the rails as shown in Fig. F.2A of Appendix F.
10. Staple the timing belt down the center of the platform, aligning it parallel to the rails.

11. Add the timing belt to the pulley adapters on the motor and the pulley anchor. Line up the holes of the 2 pulley risers with the drilled holes in the base directly across from the motor, then line up the holes of the pulley anchor on the risers. Screw in the pulley anchor and risers using 4 #6 ¾" screws.
12. Line up the rail mounts to the drilled holes in the base as shown in Fig. F.1C of Appendix F. Screw in the platform via the rail mounts using #6 ½" screws.
13. Add the Pulley Box over the pulley and screw in using #6 ½ in screws.
14. Wire the motor to the motor driver and Arduino following the circuit schematic and wiring diagram given in the report above. Wire in the Bluetooth module.
15. Upload the code in the MotorDriver_SoftwareInterface file to the Arduino.
16. Screw in the Motor Box over the motor and circuitry using #6 ½ in screws.
17. Pair the Bluefruit App with the motor and begin using the device.

Instruction Manual for Periodic Leg Movement Exercise Device

Device Overview: This device consists of a padded moving platform into which the user can place their legs. This platform uses a gentle back and forth motion to increase blood flow and create a sensation of legs, and thereby reduce symptoms of periodic leg movement in the body. This device is intended for home use, and should be placed on a bed or other sleeping surface. *Note: This device is intended to be used during sleep to lessen the symptoms of periodic leg movements. It is not intended to be a stand-alone treatment for Periodic Leg Movements. Please consult with your doctor for more information and to determine a treatment plan.

Preliminary Instructions:

1. This app is controlled via the Bluefruit LE Control application. Please download and install the Adafruit Bluefruit LE Control application onto your SmartPhone. The application can be found in Apple or Android application stores.
2. Check to make sure that Bluetooth capabilities on your phone are enabled.

Assembly and Use

1. Your device should come preassembled. Before placing the platform on the bed, lay down a yoga mat or other no-slip pads between the bottom sheet and top blankets of the bed. The mat should be positioned so that your calves will rest on the mat while you lie in a comfortable sleeping position.
2. Place the periodic leg movement exercise device on top of the non-slip mat. Make sure to place the device at least 6 inches away from the edge of the bed so as to prevent the device from falling off the bed.
3. Find the velcro holding one side of the padding covering the top of the device in place, and undo the velcro so that the top padding is attached on only one side. Insert your

legs into the space in the platform, and reattach the velcro so that the top padding as attached on both sides.

4. Adjust the device positioning as needed.
5. Plug in the periodic leg movement exercise device using the power cord attached to the device.
6. Open up the Bluefruit app. The page that comes up should be the Central Mode tab. Make sure that the option for “Show unnamed devices” is not selected and that the option for “Must have UART service” is selected.
7. Select the device known as Adafruit Bluefruit LE and click connect.
8. Once the device has been connected, click on the UART mode option. You are now ready to control the device.
9. In the Bluefruit app, type one of the following commands and hit return:
    a. “High”: This will set the device on its highest frequency of movement.
    b. “Medium”: This will set the device on its medium frequency of movement.
    c. “Low”: This will set the device on its lowest frequency of movement.
10. The device will run continuously until instructed to stop. To stop the device, enter “stop” into the Bluefruit app and hit return.

<u>Moving and Maintenance Instructions:</u>

- Before moving the device, make sure that the device has been stopped and that the power cord is disconnected.
- Be careful when moving the device, and if possible, have two people move the device.
- Remove fabric covering of platform periodically and wash.

Warnings:

- Do not attempt to use device on any part of the body other than the legs.
- Do not attempt to change any part of the electrical wiring or mechanical design of the device. This may cause device malfunction or injury.
- Keep open flames away from the device, as materials are flammable.
- Keep liquids away from the device, particularly the wiring and power cords.

Compatibility with Sensing Device

While the Periodic Leg Movement Exercise Device works as a stand-alone device to use during sleep and while awake to reduce the severity of PLMS, it can incorporate the PLMS Sensing Device created by senior design group 12. The sensing device senses the movements of the leg muscles during sleep, and if the frequency of movements are above a specified threshold, it will provide feedback to our device.

In the future, we can combine both devices by setting different frequencies of back and forth movement to correlate with different thresholds specified by the sensing device. The device can include a setting in which back and forth movement only begins if severe periodic leg movements are actively occurring, and stops if they are not. The client can go to sleep with the the exercise device turned on to this setting and the sensing device turned on. Thus, the exercise device initially has a frequency of 0 Hz, but if or when the sensing device sends feedback that the legs are experiencing severe movements, the exercise device will begin to move at the frequency corresponding to the threshold of movement identified by the sensing device. The integration of both devices can lead to a more holistic therapeutic approach to people who experience PLMS.

Future Directions

In the future, we hope to make our device more user-friendly and marketable. First, we will use a durable covering and base made of a plastic such as acetal instead of fabric and wood to decrease the weight of the device and minimize the use of flammable materials. Since our device mostly requires rectangular pieces, we can buy sheets of acetal and machine it ourselves. Curbell Plastics ships sheets of acetal with 2-5 day shipping. A 2 ft x 4 ft sheet costs $61.02, and we would require about 2 sheets, thus increasing the overall cost of our device to around $500, which is still half of our client's proposed budget. We will also decrease the size of the base, as we overestimated the size we would need for this prototype. We can cut off 5 cm of the width as is, and in future designs, we would optimize the positioning of our components to keep the width of the device under 70 cm. We also will enclose the rail system to increase the safety of our device. In the future, we will also do careful calculations to widen our frequency range and implement a sliding scale of frequencies for the user to choose. As discussed above, we will add a sensing mode to our device and incorporate the work done by Group 12.

Conclusions

Our device can move a user's legs back and forth safely, and it is controllable by a smartphone app via Bluetooth. One of our main goals was a device that could be operated while asleep, which we demonstrated successfully through our validation testing. By moving the user's legs, our device should be effective in reducing the number of periodic leg movements during sleep through the principle of counter stimulation. We were able to meet most of our design specifications, but hope to improve upon our device in future iterations so that we can meet all of the specifications that we desired. We were able to produce our device for less than half of the cost we specified.

Going through the entire process of building a clinically relevant device left us with many practical skills that will benefit us as we move forward in our careers. We learned the importance of documentation, as our design notebooks served as a log in which all creative and intellectual ideas were stored. This is imperative as it shows the logic and thought processes behind each decision and brainstorming session that led to the finished product. We also learned that planning is extremely important before purchasing parts and assembling a product, as we had to make multiple orders to get all of the parts we needed. In addition, reaching out to experts and networking is essential in making a biomedical device, as it brings in mechanical, electrical, and computer science aspects. Networking was critical when we needed to find certain resources which we lacked to complete the device.

If we were to do this project again, we would plan more in the first semester, so that our submitted budget would reflect more accurately the parts we had to buy. We did not have a specific motion system included in our budget, and those parts as well as others caused us to spend more money than was approved for us by the BME department. Additionally, planning ahead would have allowed us to save time and dedicate more time to developing our software and increasing the controllability of our device. This may also have allowed us to combine our device with the device built by another group to sense periodic leg movements by the end of this semester.

Our device does not currently have any ethical drawbacks. However, if it were to be manufactured to the public and made of plastic, the environmental effect of the plastic products used would need to be considered. In addition, if plastic was used, the cost of the device would increase to about $500, which may not be affordable to everyone who experiences PLMS. The cost would thus provide an unfair disadvantage to those people, so we would need to find some way to make it less expensive or subsidized so that it is available to people across the socioeconomic scale. If we went to market with our device, we would need to be aware in our marketing strategy to promote safe use of our product and to not mislead our customers. There is no IP in our design to protect. Overall, we learned many specifics about the design process that we had never considered before, and this experience has prepared us for any future practical design projects.

References

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2. Mitchell, Ulrike. “Medical devices for restless legs syndrome-Clinical utility of the Relaxis pad.” Therapeutics and Clinical Risk Management, vol. 11, 3 Dec. 2015, pp. 1789–1794., doi:10.2147/tcrm.s87208.

Appendix A: Verification Testing Plan

Our verification plan is based on our design specifications, which are listed in full in Table 1. A description of our intended verification plan for each specification is listed below. For those specifications essential to our device's function, we have also discussed changes that will be made if the device fails the verification plan.

Frequency of Movement: Our device should have an adjustable frequency range from 0.5 - 2.5 Hz. To verify this specification, we will run the device for 30 seconds at all possible frequencies and count the number of complete back-and-forth movements by the device during those 30 seconds. The frequency can be calculated using $frequency = \frac{\#\ of\ oscillations}{time}$.

This procedure will be repeated for periods of 15 seconds, 1 minute and 5 minutes. These time-averaged frequencies will then be compared to verify that they do not vary widely.

If our device fails to cover and stay within this specified frequency range or cannot stay consistently at a specified frequency, we will adjust the programming of the device or the motor.

Displacement: The device must not displace the users legs by more than 30 cm. The displacement will be measured using a meter stick or tape measure to determine the distance between the legs at the two most extreme oscillation points. Excess displacement could lead to discomfort or injury to the patient, so if we are not within our specified parameter, we will adjust the length of the mechanical track or the length of time for which the motor runs in one direction to keep the displacement within a reasonable range.

Force: The force that the platform exerts to move the user's legs should not exceed 150 N per leg, or 300 N total, to prevent harm to the user. To verify the force, we will measure the time taken for the device to complete a full oscillation, Δt, using a timer and the distance covered by a full oscillation, Δx, using a measuring tape. We will then calculate a time averaged acceleration using $a_{average} = \frac{\Delta x}{\Delta t^2}$. To find the maximum acceleration, we will model the platform movement as a sine wave. The time average value of a sine wave is 63.7% of its peak value, so the peak acceleration is given by $a_{peak} = \frac{a_{average}}{0.637}$. Once the peak acceleration is known, the peak force can be calculated as $F_{peak} = a_{peak} * mass$. The masses of human legs can be taken from physiological calculations to get a full range of possible masses.

Weight: The weight of the device should not exceed 10 kg to make it light and easy to use**.** We will weigh our device using a scale that can accurately read masses on the scale of 10 kg.

Cost: The cost of this device should not exceed $1,000. This will be confirmed by adding up the costs of the individual items used in making this device.

Dimension: The dimensions of the device should not exceed 70 cm by 200 cm, with the 70 cm width including the distance covered by the platform as it moves side-to-side. To verify this, we will use a tape measure to measure the distance between the furthest oscillated points. This distance should not exceed 70 cm. Because the device does not move along its other axis of motion, we will simply measure the width of the platform to verify it does not exceed 200 cm.

Installation: Our product should not require daily assembly and disassembly, and should be possible to assemble while using a wheelchair. To verify this, we will have three users attempt to assemble and disassemble the device while using a wheelchair to determine if this is feasible.

Adjustable to Individual: Our device platform should accommodate legs with measurements of up to 70 cm in circumference, which corresponds to a diameter of approximately 23 cm, approximating the legs as cylinders. In order to provide a margin for error, we will assume the diameter is 30 cm, and use a tape measure to measure the space where the legs will rest.

Operating Time: This device should be consistently operable for up to 12 hours. To verify this, we will turn the machine on and videotape the device while it runs for 12 hours. We will then spot check random time points to see if the device is still running, and perform the frequency validation procedure described above to check the operation. Sufficient operating time is critical to the device functioning because the device must be able to operate overnight to alleviate PLMS, so if this specification is not met we will switch to a motor with a longer operating time.

Software Interface: The interface should be able to be used while the user is lying down, operate within a radius of 6 meters from the device, have minimal interference to the device's operation, and can change frequency or automatic/manual mode settings of the device. First, we will have a user positioned to use the device, and attempt to control it via remote control to determine if the remote is usable while the user is lying down. Second, we will test the functionality of the remote within a radius of 6 meters from the device. We will also test the device in a normal bedroom setting for 1 hour, and count the number of times the device is inoperable due to interference with the radiofrequency of the remote. Finally, we will set the frequency of the device using the software interface and perform the frequency verification test described above to determine if the software setting corresponds to an accurate frequency.

It is critical that the user have full control over the device in case they should experience harm or discomfort while operating the device. If the above specifications are not met for the remote control, we will allow the user to control the device using a 6-ft long cable to allow for both control and accessibility of the remote.

Safety: The device should cause no short or long-term harm to the user, contain no toxic materials or chemicals, contain no exposed wires or electrical components, have no harmful or disruptive loose cords, and use a low friction material to prevent bedsores. We will use Design Safe to assess the safety risks of the device. We will also conduct a separate verification test to determine whether the friction of the device is causing sores.The device will be used for a period of 7 hours, and the user will rate the discomfort they felt due to rubbing of the device padding according to the scale in Appendix D.

Comfort: The device should not be unpleasant to use and should allow the user to remain asleep or shift positions. It should also be no more than 20 cm above the height of the bed, and there should be less than 1 kg of weight attached to each leg. To verify these specifications, all three of our team members will sleep with the device and rate their comfort according to the questions in Appendix D. We will also weigh the mass of the material placed on top of each leg to confirm that it is less than 1 kg per leg, and measure the height of the legs relative to the torso using a tape measure or meter stick to confirm that it is less than 20 cm.

Sound: This device should have a noise level of less than 30 dB so as not to disturb the user's sleep. We plan to use a digital sound level meter to measure the sound levels at all different operating frequencies of the device.

Due Date: We will have a completed and fully working device as well as documentation of verification by May 1, 2018.

Appendix B: Design Safe Analysis Results

All users may perform the tasks of installing and moving the device, troubleshooting and problem-solving, normal use, and possibly misuse. Patients and non-patients are both affected specifically by the task of device-functioning, with different hazards associated for each user.

For installing and moving the device, we identified the hazards of crushing and pinching associated with transferring the device, slip/trip/fall, impedance of wheelchair movement, unexpected start, and lifting/bending/twisting. Many of these hazards can be mitigated by making the device easier to grip and carry. We accomplished this by rounding down sharp corners so that minimal pinching can occur during transfer of the device and by using lightweight styrofoam as the base to decrease the weight and increase grip. Our steps for mitigation reduce these risks from moderate to low-to-moderate risk. For troubleshooting, we identified the hazards of battery failure, improper wiring, and misalignment of mechanical parts. These hazards are low risk, as they would result in the device simply ceasing to function. We mitigated most of these hazards by adding 3D-printed covers to the electrical components and creating separate access to the battery. We can also secure the different parts of our device using longer screws and durable materials to prevent misalignment of the parts. After these steps, the risk remains low.

Normal use poses the hazards of unsanitary conditions, flames, static electricity, radiant heat, corrosion, water/wet locations, power supply interruption, and noise level > 80 dB_A. Mitigation of these hazards mostly involves choosing appropriate materials that are resistant to bacteria and mold, easy to clean, and non-flammable. Additionally, we will cover the electrical components to protect them from liquids, and include warnings to the user to avoid contact with liquids and to operate the device with a surge protector. Noise and sound levels may adversely affect users with moderate risk as the device will be running for long periods of time. The levels should be kept below 30 dB_A as stated in our specifications by using padding and covering loud components to absorb sound. Following these steps, we can decrease most of our risk levels to low.

Finally, misuse may include reprogramming the Arduino, playing with device, and moving other body parts instead of the legs. These risks can be serious, but quite unlikely since the device should not be used by children and access to the device will be through a specific app not the device itself. We will reduce these risks by decreasing the possible force and frequency of the device movement so that should it be misused, it cannot cause as much harm. We will also house the Arduino in a difficult-to-access way so that the parameters of the device movement cannot be changed easily. After mitigation, the risks decrease from moderate to low.

For the patient, there are specific risks associated with the functioning of the device. These include crushing and pinching associated with the device's operation, entanglement, unexpected start, machine instability, interference with Bluetooth, repetition, excessive force/exertion, and blocked exit. We mitigated crushing and pinching and entanglement of fabrics or loose objects by housing the moving parts of our device in 3D-printed coverings. The device may become destabilized by the device's movement which could pose a high risk to the user if it falls off of a bed or other high surface and moves the user's legs in a dangerous way. To mitigate this risk, we will add gripping on the bottom of the device and consider straps that can be used to attach the device to surrounding furniture.

Unexpected start, interference with Bluetooth, and excessive force/exertion pose a moderate risk because the user may not be able to stop the device if desired. We will decrease this risk by placing the Bluetooth module as close to the user as possible and using only low force and frequency to prevent injury to the user. Repetition is a high concern for us as our device oscillates back and forth and much of our target population is susceptible to bed sores.

We hope to decrease the severity of this risk by adding sufficient cushioning and advising our users to use the lowest frequency possible and only using the device when needed.

Finally, the device’s operation could make it difficult for the user to exit their bed. We could decrease this risk from moderate to low by allowing the side of the platform to be folded down or using a flat platform. Overall, our steps will decrease the risks from moderate-high to low-moderate. Non-patients face similar hazards - machine instability, unexpected start, and crushing or pinching - but at lower risk because they are not directly using the device. These risks are mitigated in the same ways as for patients, resulting in low risk overall.

Appendix C: Validation Testing Plan

To aid in our validation plan, we identified our client's primary and secondary needs for this device. The primary needs were specified by our client and are absolutely necessary for client satisfaction. Our client and broader market primarily need a device that reduces the severity of PLMS, improves sleep quality, is comfortable enough for use while sleeping, and allows for control over the device movement if desired. These parameters are the most important for our client and are the main goal of our device.

In order to verify that these needs are met, we will continue to test the user's control of our device via the Software Interface verification testing plan. We will also test our working prototype ourselves as part of the comfort and safety verification testing plan to verify that it is comfortable enough for use while asleep. Once we have confirmed that the device is sufficiently comfortable and safe to use, we will give our client the prototype to test whether it can satisfactorily reduce the severity of PLMS and improve sleep quality. These phases of testing involving human users should be performed carefully - starting at small intervals of use - to minimize risk of injury to the users. To verify that our device does alleviate the symptoms of PLMS, we will direct our client to record her sleep with and without the device and self-report the number of leg movements and rate the severity of the leg movements using the survey in Appendix B. Self-reporting is most appropriate in this case to protect the privacy of our client. We will also collect information on sleep quality with and without the device. If we fail to meet these primary needs, we may have to redesign our device to be more effective and comfortable to use, possibly through incorporation of more motors or padding. We may also add a vibrational component or look into other mechanisms of motion.

Secondary client needs include the option for use while awake, ease of use, simple installation, and an automatic function when the user is asleep. The device also should not disrupt anyone else sleeping in the bed. Several of these parameters will be achieved through verification of our specifications. For example, our sound and size specifications were designed to minimize disruptions to bed partners, and our verification testing will see that these specifications are met. For more holistic validation testing, we and our client will simulate the experience of setting up the device and controlling it while awake and allowing it to run automatically when asleep. We will first set up our device using a wheelchair, as many people in our target market, including our client, use wheelchairs. If this is difficult to do, we will reconfigure our device to improve ease of use. Our client will also set up our device in her bed and report on any difficulties encountered. She will test the device while awake and report on its effectiveness. The automatic function can be evaluated through video recording and self-reporting by the client on the success of the device. We will also survey her partner to ascertain the disruptiveness of the device to other people. If we fail to meet these secondary needs, we may incorporate minor changes to our device design, material, or programming.

Appendix D: Verification and Validation Survey Results

Table D.1. Verification and Validation Survey Results

	Divya	Erica	Devin	Average
Safety				
On a scale of 0 (meaning no rubbing or discomfort was experienced) to 10 (meaning painful friction sores were created while using the device), how much rubbing or discomfort did you encounter while using this device?	4	2	2	2.67
Comfort				
How many hours of sleep did you achieve?	6	N/A	N/A	6
Rate your quality of sleep from 0 (being worst) to 10 (being perfect and uninterrupted).	6	N/A	N/A	6
How many times do you wake up (on average) from PLMS each night without using the device?	N/A	N/A	N/A	N/A
How many times did you wake up while using the device?	4	N/A	N/A	4
On average, how severe from 0 (being least severe) to 10 (most severe) is your PLMS without using the device?	N/A	N/A	N/A	N/A
On average, how severe from 0 (being least severe) to 10 (most severe) is your PLMS while using the device?	N/A	N/A	N/A	N/A
For the Partner (if applicable):				
How many times were you awoken from your partner's use of the device?	N/A	N/A	N/A	N/A
On a scale of 1 (being least disruptive) to 10 (most disruptive), how disruptive was the device's functioning to you?	N/A	N/A	N/A	N/A

Appendix E: Parts Specifications

Motor Components

Table E.1. Product details and specifications for motor components.

Part	Product Name	Product Number	Price	Source and Lead Time	Specifications
Motor	Uxcell Reversible Worm Gear Motor High Torque Speed Reducing Electric Gearbox Motor	JCF63R	$78.43	Uxcell via Amazon 2 days	**Voltage:** DC 12 V **Speed:** 60 RPM **Power:** 60 W **Torque:** ≥ 8 N.M **Motor Size:** 63mm x 100mm/2.5" x 3.9" **Shaft Diameter:** 10 mm/0.39” **Cable Length**: 30 cm/11.8” **Mounting**: M6 screw **Material:** Plastic, metal **Net Weight:** 1350 g **Certification:** CE, RoHS **Link:** https://www.amazon.com/uxcell-Torque-Reversible-Electric-JCF63R/dp/B0732JRM5G/ref=sr_1_45?ie=UTF8&qid=1518385894&sr=8-45&keywords=high%2Btorque%2Bdc%2Bmotor&th=1

Motor Driver	DROK Motor Speed Controller DC 12V/24V/36V Motor Speed Control Module 12A High Power Industrial PWM Electric Motor Drive Regulator Board	200337	$16.99	DROK via Amazon 2 days	**Input Voltage Range:** DC 9-36 V **Current:** 12 A (without heat sink) **Voltage provided:** 5V (to power microcontroller) **PWM Effective Range:** 0.1% ~ 100% **PWM Signal Frequency Range:** 0 - 100 kHz **PWM Minimum Effective Pulse Width:** 200 ns **Control Signal High Level Voltage:** 2.0 ~ 5.5 V **Control Signal Low Level Voltage:** 0 V~0.8V **Link:** https://www.amazon.com/gp/product/B074FR4BBJ/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1

Note: The uxcell motor originally came with a notch on the motor shaft, which had to be filed down in order to accommodate the pulley adapter.

Pulley and Linear Motion Track System

Table E.2. Product details and specifications for pulley and linear motion track system.

Part	Product Name	Product Number	Price	Source/Lead Time	Specifications
Pulley Adapter	Orish Aluminum GT2 40 Teeth Timing Pulley 10mm Bore Synchronous Drive Belt Wheel for 6mm Width Belt	O3D040	$12.99 (for two adaptors)	Orish via Amazon.com 7-10 business days	**Bore Diameter:** 10 mm **Belt Width:** 6 mm **Teeth Number:** 40 teeth **2GT Pitch:** 2mm **Link:** https://www.amazon.com/gp/product/B01H94CK66/ref=od_aui_detailpages00?ie=UTF8&psc=1
Timing Belt	2GT Timing Belt Closed Loop	FBA_2P-1140-2GT	$17.88 (for two belts)	BBQ Driver via Amazon.com 2 days	**2GT Pitch:** 2mm **Belt Height:** 1.52 mm **Tooth Height:** 0.76 mm **Pitch Length:** 1140 mm **Width:** 6mm **Teeth Number:** 570 **Breaking Strength:** 86 N/1 mm **Link:** https://www.amazon.com/2GT-Belt-Timing-Closed-Loop/dp/B018HN8576/ref=lp_15968979011_1_10?srs=15968979011&ie=UTF8&qid=1523290074&sr=8-10

Rails	Aluminum Rods	4634T34	$9.01	McMaster Carr 2 days	**Material:** 6061 Aluminum **Cross Section Shape:** Round **Diameter**: 8mm **Length**: 1 ft ROHS Compliant **Link:** https://www.mcmaster.com/#4634T34
Pulley Shaft	5/16 in. x 3-1/2 in. Internal Hex Socket Cap-Head Cap Screw	21598	$1.87	Home Depot 1 day	**Drive Style:** Internal Hex **Screw Length:** 5/16 in **Screw Diameter:** 3 - ½ in **Head Style:** Socket Cap **Link:** https://www.homedepot.com/p/Crown-Bolt-5-16-in-x-3-1-2-in-Internal-Hex-Socket-Cap-Head-Cap-Screw-21598/203575567?keyword=030699215980&semanticToken=20030+++%3E++++st%3A%7B030699215980%7D%3Ast++cn%3A%7Bnull%7D++3069921598+%7Bproductkey%7D

Linear Motion Rail Kit: Rail supports, Linear slide blocks, and Zinc Alloy Pillow Block Bearing	Mergorun 200mm Horizontal Optical Axis & 8mm Lead Screw Dual Rail Shaft Support Pillow Block Bearings & Flexible Shaft Coupling for digital coordinate measuring equipment Set of 15	d0006	$31.89	Mergorun via Amazon.com 2 days	**Contains:** • 2 pcs x 8x200mm steel Optical Axis • 2 pcs x 55x13x30mm Zinc Alloy Pillow Block Bearing • 4 pcs x 42x32x11mm Aluminum Rail Shaft Support • 1 pcs x 200x8mm Stainless Steel Lead Screw Rod with Nut • 4 pcs x 8x34.5mm Linear Slide Block • 2 pcs x 5x8mm D19L25 Flexible Shaft Coupling **Link:** https://www.amazon.com/gp/product/B06XPCY1LS/ref=od_aui_detailpages00?ie=UTF8&psc=1

Note: Although the entire kit was ordered, only certain parts of this rail kit were incorporated into our final design. The parts used are listed under the "Parts" section of the table.

Screws

Table E.3. Product details and specifications for screws.

Part	Product Name	Product Number	Price	Source/Lead Time	Specifications
#6 ½ " Screw	Spax #6 x 1 in. Philips Square Drive Flat-Head Full Thread Zinc Coated Multi-Material Screw (50 per Box)	4101010350131	$2.10 (for 50 pieces)	Home Depot Immediate	**Drive Style:** Phillips Square **Fastener Material:** Steel **Size:** #6 **Screw Length:** ½ inch **Thread Type:** Coarse **Head Style:** Flat **Link:** https://www.homedepot.com/p/SPAX-6-x-1-2-in-Phillips-Square-Drive-Flat-Head-Full-Thread-Zinc-Coated-Multi-Material-Screw-50-per-Box-4101010350131/202042126
#6 ¾ " Screw	Spax #6 x ¾ in. Philips Square Drive Flat-Head Full Thread Zinc Coated Multi-Material Screw (45 per Box)	4101010350201	$2.10 (for 45 pieces)	Home Depot Immediate	**Drive Style:** Phillips Square **Fastener Material:** Steel **Size:** #6 **Screw Length:** ¾ inch **Thread Type:** Coarse **Head Style:** Flat **Link**: https://www.homedepot.com/p/SPAX-6-x-3-4-in-Philips-Square-Drive-Flat-Head-Full-Thread-Zinc-Coated-Multi-Material-Screw-45-per-Box-4101010350201/202040986

#6 1" Screw	Spax #6 x 1 in. Philips Square Drive Flat-Head Full Thread Zinc Coated Multi-Material Screw (40 per Box)	4101010350251	$2.10 (for 40 pieces)	Home Depot Immediate	**Drive Style:** Phillips Square **Fastener Material:** Steel **Size:** #6 **Screw Length:** 1 inch **Thread Type:** Coarse **Head Style:** Flat **Link:** https://www.homedepot.com/p/SPAX-6-x-1-in-Philips-Square-Drive-Flat-Head-Full-Thread-Zinc-Coated-Multi-Material-Screw-40-per-Box-4101010350251/202040987?keyword=712216013643&semanticToken=20030+++%3E++++st%3A%7B712216013643%7D%3Ast++cn%3A%7Bnull%7D++712216013643+%7Bproductkey%7D
#6 1 ¼ " Screw	Spax #6 x 1 ¼ in. Philips Square Drive Flat-Head Full Thread Zinc Coated Multi-Material Screw (35 per Box)	4101010400321	$2.10 (for 40 pieces)	Home Depot Immediate	**Drive Style:** Phillips Square **Fastener Material:** Steel **Size:** #6 **Screw Length:** 1 ¼ inch **Thread Type:** Coarse **Head Style:** Flat **Link:** https://www.homedepot.com/p/SPAX-6-x-1-1-4-in-Philips-Square-Drive-Flat-Head-Full-Thread-Zinc-Coated-Multi-Material-Screw-35-per-Box-4101010350321/202040988

Platform

Table E.4. Product details and specifications for platform components.

Part	Product Name	Product Number	Price	Source/Lead Time	Specifications
Styrofoam	Cellofoam 3/4 in. x 1.21 ft. x 4 ft. R-3 Polystyrene Insulating Sheathing (6-Pack)	150705	$8.38 (for 6 sheets)	Home Depot Immediate	**Dimensions:** 3/4 in. x 1.21 ft. x 4 ft. **Insulation:** Sheathing **Weight:** 2 lbs **Link:** https://www.homedepot.com/p/Cellofoam-3-4-in-x-1-21-ft-x-4-ft-R-3-Polystyrene-Insulating-Sheathing-6-Pack-150705/205517302
Fiberboard	1/2 in. x 2 ft. x 4ft. Medium Density Fiberboard	1508108	$11.95	Home Depot Immediate	**Dimensions:** 1/2 in. x 2 ft. x 4ft. **Plywood Type:** Particle Board **Link:** https://www.homedepot.com/s/1%252F2%25202X4%2520MEDIUM%2520DENSITY%2520FIBERBOARD?NCNI-5
Velcro	Velcro Brand Industrial Strength Tape	10156083	$12.99	Michael's Immediate	**Dimensions:** 4 ft x 2 in **Link:** http://www.michaels.com/verlcro-brand-industrial-strength-tape-4ft/M10156083.html?dwvar_M10156083_size=4ft%20x%202%22&dwvar_M10156083_color=Black#q=velcro+is+4ft&start=3

Sandpaper	3M Aluminum Oxide Sandpaper, Assorted Grit	10211400	$3.49 (for 6 sheets)	Michael's Immediate	**Dimensions:** 3 ⅔ " x 9 in **Grit:** 2 fine, 2 medium, 2 coarse **Link:** http://www.michaels.com/3m-aluminum-oxide-sandpaper-assorted-grit/10211400.html#q=3M+AST+sand+sheet&start=1
Gorilla Glue	Gorilla Super Glue	10111196	$4.99	Michael's Immediate	**Net Weight:** 15 g **Dry Time**: 10-30 seconds **Link:** http://www.michaels.com/gorilla-super-glue/10111196.html#q=Gorilla+Glue&start=1
Weldbond Glue	Weldbond Universal Adhesive	10404940	$3.99	Michael's Immediate	**Net Weight:** 2 fluid ounces **Content:** Concentrated **Link:** http://www.michaels.com/weldbond-universal-adhesive-2-fl-oz/10404940.html#q=wellbound&start=1
Pure Foam Cushion	1" x 24" x 54" High Density Upholstery Foam	D005248S	$26.99	Michael's Immediate	**Dimensions:** 24" x 54" x 1" **Density:** 24 lbs/ ft^3 **Link:** http://www.michaels.com/1-x-24-x-54-high-density-upholstery-foam/D005248S.html

Sewing Materials	25-Piece Travel Size Sewing Kit in Pink	555660891	$4.35	Walmart Immediate	**Components:** 25-Piece needle compact, 2 Thread spools(150 yds/137.2 m each), 8-in Scissor ,5-in Scissor, 10 Safety pins, 25 Ball point pins, 25 Straight pins, 1 Needle threader ,60-in Tape measure,1 Seam ripper,1 Seam gauge, 2 Marking pencils,1 Pin cushion,1 Thimble **Link:** https://www.walmart.com/ip/25-Piece-Travel-Size-Sewing-Kit-in-Pink/189631233
Cotton Fabric	Waverly Inspirations Homespun, 100% Cotton Solid Fabric	565670119	$3.58/yard	Walmart Immediate	**Dimensions:** 44” x 36” **Weight:** 120 GSM **Link:** https://www.walmart.com/ip/Waverly-Inspirations-Homespun-100-Cotton-Solid-Fabric-Apparel-Fabric-Quilting-fabric-Home-Decor-44-120GSM-Cut-By-The-Yard/55505993?variantFieldId=actual_color

Software Interface and Circuitry

Table E.5. Product details and specifications for software interface and circuitry.

Part	Product Name	Product Number	Price	Source/Lead Time	Specifications
Bluetooth Module	Arduino BLE SPI Friend	4328604613	$18.15	Adafruit via Amazon.com 2 days	**Dimensions:** 1" x 2" x 1" **Transport:** SPI at up to 4MHz clock speed **Link:** https://www.amazon.com/Adafruit-Bluefruit-SPI-Friend-Bluetooth/dp/B01F3U8V0W/ref=sr_1_9?ie=UTF8&qid=1523140961&sr=8-9&keywords=ble+for+arduino

Arduino Uno	ARDUINO A000073 DEV BRD, ATMEGA328, ARDUINO UNO R3 SMD ED	A000073	$26.95	Arduino via Amazon.com 2 days	**Operating Voltage:** 5 V **Recommended Input Voltage:** 7-12 V **Min/Max Input Voltage:** 6-20 V **Digital I/O Pins:** 14 **PWM Digital I/O Pins:** 6 **Analog Input Pins:** 6 **DC Current per I/O Pin:** 20 mA **DC Current for 3.3V Pin:** 50 mA **Flash Memory:** 32 kB **SRAM:** 2kB **EEPROM:** 1 kB **Clock Speed:** 16 MHz **LED_BUILTIN:** 13 **Dimensions:** 68.6 mm x 53.4 mm **Weight:** 25 g **Link:** https://www.amazon.com/ARDUINO-A000073-DEV-BRD-ATMEGA328/dp/B007R9TUJE/ref=sr_1_3?ie=UTF8&qid=1524103415&sr=8-3&keywords=arduino+uno
Wires	120pcs Multicolored Dupont Wire Kit	B072L1XMJR	$7.86 for 120 pieces	REXQualis via Amazon.com 2 days	**Dimensions:** 0.127mm, 36 AWG/ single root, 20cm(7.87inch)/axis; Standard 2.54mm headers and sockets **Type:** 40 male to female jumper wires, 40 male to male wires, 40 female to female wires **Link:** https://www.amazon.com/120pcs-Multicolored-Breadboard-Arduino-Raspberry/dp/B072L1XMJR/ref=sr_1_4?ie=UTF8&qid=1524103492&sr=8-4&keywords=wires+for+arduino

Power Supply

Table E.6. Product details and specifications for power supply.

Part	Product Name	Product Number	Price	Source/Lead Time	Specifications
2.1 mm to Female DC Power Adapter	10 Pcs 5.5mm x 2.1mm DC Power Cable Female Connector Plug for CCTV Camera	BWDYM	$2.95	Uxcell via Amazon.com 2 days	**Dimensions:**1.5” x 0.5” x 0.6” **Weight:** 0.32 ounces **Link:** https://www.amazon.com/gp/product/B005CMP434/ref=od_aui_detailpages00?ie=UTF8&psc=1
AC to DC Power Adapter	UL Listed AC 100-240V to DC 12V 10A 120w LED Light AC Adapter High Power Switching Power Supply US Plug for LED Strip Light	N/A	$31.99	Walmart Immediate	**Input:** AC 100-240V 50/60Hz **Output:** DC 12V **Maximum Current Draw:** 10A; **Compatibility:** Can plug in 12 V devices to 110 V outlets **Link:** https://www.walmart.com/ip/UL-Listed-AC-100-240V-to-DC-12V-10A-120w-LED-Light-Power-driver-AC-adapter-great-for-LED-Strip-Light-Module/200986635#read-more

Appendix F: Mechanical Drawings

Shown below are mechanical drawings of the assembled device. These models were made using CAD Inventor Professional 2016. Figure F.1 shows a front (Fig. F.1A), top (Fig. F.1B), and perspective (Fig. F.1C) view of the base platform component with the motor and pulley and linear motion system attached. Figure F.2 shows a side (Fig. F.2A), top (Fig. F.2B), and two perspective (Fig. F.2C and 2D) views of the device with top and base platforms attached via motor, pulley and linear motion system.

Figure F.1. A) Front view of base with pulley, motor, and rails attached. B) Top view of base. C) Perspective view of base.

Figure F.2. A) Side view of base with platform attached. B) Top view of base with platform attached. C) 1st perspective view of base with platform attached. D) 2nd perspective view of base with platform attached.

Scaled mechanical models of different components and parts used are shown below in Figures F.3 to F.16. These designs were made using CAD Inventor Professional 2016. Orthogonal views, including dimensions, are on the left and perspective views are on the right along with the name of the part/component. Additional details and specifications, if any, are listed on the right.

*Note: All dimensions shown are in centimeters.

Figure F.3. CAD Drawing of base with dimensions (cm).

Figure F.4. CAD Drawing of motor with dimensions (cm).

Figure F.5. CAD Drawing of pulley with dimensions (cm).

Figure F.6. CAD Drawing of timing belt with dimensions (cm).

Figure F.7. CAD Drawing of pulley riser with dimensions (cm).

Figure F.8. CAD Drawing of pulley mount with dimensions (cm).

Figure F.9. CAD Drawing of cap screw for pulley with dimensions (cm).

Figure F.10. CAD Drawing of rail mount with dimensions (cm).

Figure F.11. CAD Drawing of rail with dimensions (cm).

Figure F.12. CAD Drawing of platform mount with dimensions (cm).

Figure F.13. CAD Drawing of platform riser mount with dimensions (cm).

Figure F.14. CAD Drawing of platform with dimensions (cm).

Figure F.15. CAD Drawing of pulley box with dimensions (cm).

Figure F.16. CAD Drawing of motor box with dimensions (cm).