MIE301: Report Template

Exoskeleton Project Proposal

Group number: 2

Vishwa Sivapalan

Puneet Dhaliwal

Cole Enright

Zain Glover

Albi Limani

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1.0 Introduction

BW Systems is presenting the StrideAssist, a lower-body exoskeleton designed to support users experiencing limited mobility. The device provides powered assistance at the hip, knee, and ankle to reduce effort during walking and stair ascent while maintaining a natural gait.

Market research and feedback from clinical partners highlighted a key limitation in current assistive mobility devices. Most exoskeletons are designed for a single type of impairment, restricting compatibility across patients with different physical needs. For example, Figure 1 shows the Keeogo Walking Assistance Device, which effectively supports individuals with arthritis, sclerosis, and Parkinson's disease [1] but cannot accommodate users with lower-limb amputations. To address this gap, the client requested a modular exoskeleton capable of operating in multiple configurations, including support for above-knee amputations, below-knee amputations, or reduced strength with no amputations.

Figure 1: Keego by B-Temia Robotic Exoskeleton

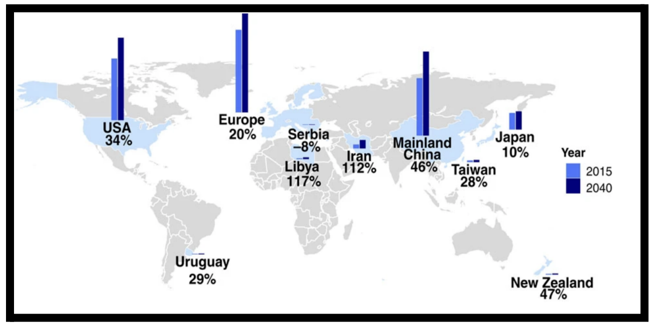

Figure 2: Projected increase in the number of individuals with ALS from 2015 to 2040

This request aligns with a growing demand for adaptable and cost-efficient mobility devices that can adjust as patient needs evolve. The target user group includes individuals with degenerative conditions such as amyotrophic lateral sclerosis (ALS) and patients in physical rehabilitation. As global life expectancy rises, the number of individuals with chronic diseases is expected to increase significantly [2]. Figure 2 highlights the projected rise in ALS cases, reinforcing the need for versatile mobility solutions. These trends demonstrate why the client requires a more adaptable system that can support a wider range of patients without relying on separate device models. Therefore, the StrideAssist must be redesigned to function effectively across multiple user configurations while reducing manufacturing complexity.

2.0 Current Market Design

Current walking exoskeletons on the market rely on electric motors as their primary actuation method. These systems typically use between two and four motors, with the most common configurations placing one actuator at each hip (Figure 3), or an actuator at each hip and each knee (Figure 4) [3], [4].

The structural frame of these devices is typically built using rigid materials such as aluminum alloys, steel tubing, or carbon-fiber composite [3], [5]. These materials provide stiffness to transfer torque from the motors to the user's limb without deformation. While these materials are ideal for transferring motor torque without flexing, they limit full geometric customizability according to each user. To increase comfort, soft fabric padding or conformal liners are integrated where the frame interfaces with the user.

The most common attachment points include a belt or harness around the hip region, straps located above the knee, and occasionally additional straps along the shank. These attachment points ensure that the device aligns with the user's joints while walking [6]. While enough to accommodate average body dimension users, current designs do not accommodate users outside standard ranges.

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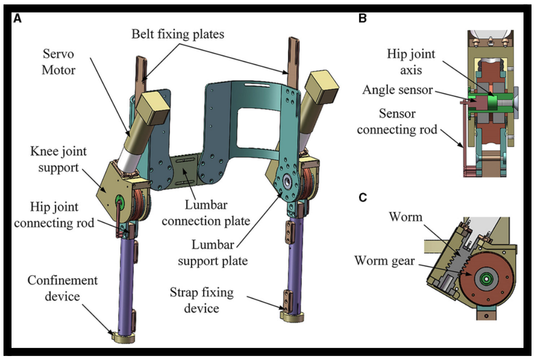


Figure 3: Walking exoskeleton with two actuators at the hip

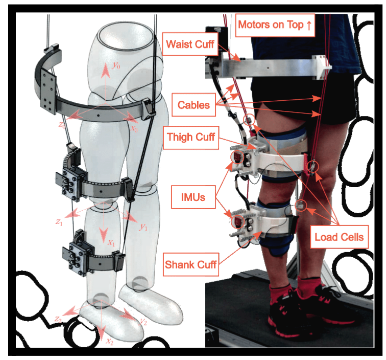


Figure 4: Walking exoskeleton with actuator at each hip at each knee

Different mechanical transmission approaches are also used across market designs. A common method is the implementation of a worm-gear reduction attached directly to the motor, allowing high torque output in a compact form (Figure 3) [3]. Other systems move the motors away from the limb entirely by using cable-driven transmissions or Bowden cables, reducing the mass located on the thigh and shank and improving user comfort (Figure 4) [4].

3.0 Objectives

The primary goal of this product is to provide a single exoskeleton platform that can be quickly adjusted for individual users while maintaining biomechanical performance and walking stability. Table 1 goes over the objectives and their rationale to comply with the goal of the design.

Table 1. Objectives and rationale

Objectives	Rationale
Compatible and adaptable to users with no amputation, below-knee amputation, or above-knee amputation	Current devices only serve no amputation impairments, limiting usability, thus medical devices must be user friendly, and have clear instructions.
Adjustable and customizable to specific limb length (width and height)	Patients vary in leg, stump, or limb length. Adjustable limb lengths ensure alignment and improve comfort.
Ensure user comfort during extended wear	Users must be able to wear freely with a reduction of pressure or skin irritation and ability to fit different limb sockets.
Maintain total prototype cost at or	Functional design prototype that meets manufacturing budget

below $250	and is cost effective for the client and those in need.

4.0 Proposed Design Changes

The following section will highlight the proposed and improved design. Figure 5 displays a concept CAD of StrideAssist.

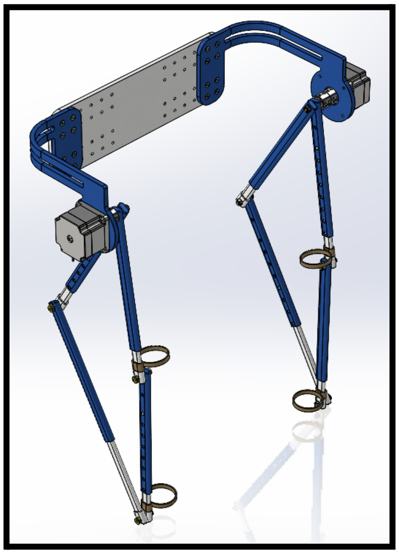


Figure 5: SolidWorks Assembly of StrideAssist

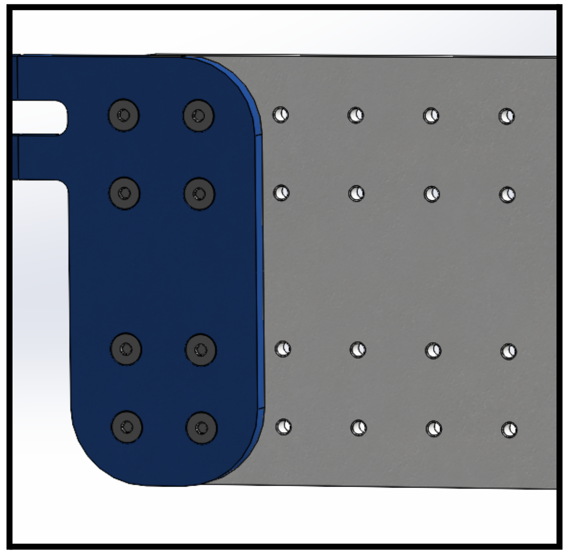


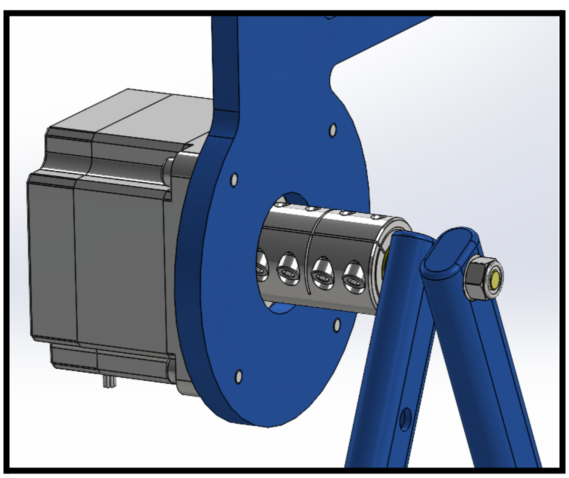
Figure 6: Lumbar Support Customizability

There are several features that improve the comfort and customizability of StrideAssist to allow usage for any person. As shown in Figure 6, the width of the exoskeleton can be controlled through 8 M6 screws, enabling a lumbar width of 21.5 cm - 50.0 cm. This adjustability is critical as the adult lumbar width across the general population varies from approximately 21.5 cm to 50 cm depending on sex and body mass index.

The length of the above and below knee links in addition to their support links can be controlled through spring loaded push-pins, similar to what is found in crutches (Figures 7, 8). Moreover, straps are located at the bottom of each joint to attach to the user. This allows the total length of the leg joints to vary between 33.0 cm - 62.5 cm. Ultimately this can accommodate users with a short or tall stature, and also those with limb-length discrepancies such as those with amputations.

Figure 7: Link Mechanism   Figure 8: Link Length Variability Mechanism

Figures 9 and 10 provide an outline of the link's transmission. A NEMA 34 Stepper Motor (1) is bound to an M8 shoulder head screw (3) using a bore clamping shaft coupler (2). This prevents relative motion between the screw and motor. The shoulder head screw is press-fit into a bushing (4) in the nearby link, and the bushing is press-fit and epoxied into the nearby link (the leftmost link in Figure 10). Therefore the link has no relative motion to the motor. The shoulder screw continues into the outermost link (on the right side in Figure 10), fitting through a second, looser bushing (5), before being closed by a locknut (6). This transmission system ensures there is no slippage between the motor and input link, while allowing free movement of the second link. Note that all other linkage bindings throughout other joints are equal to Figure 10, except for using the looser bushing (5) for both links, and of course not including a motor or coupler. This allows the input link to drive all other links.



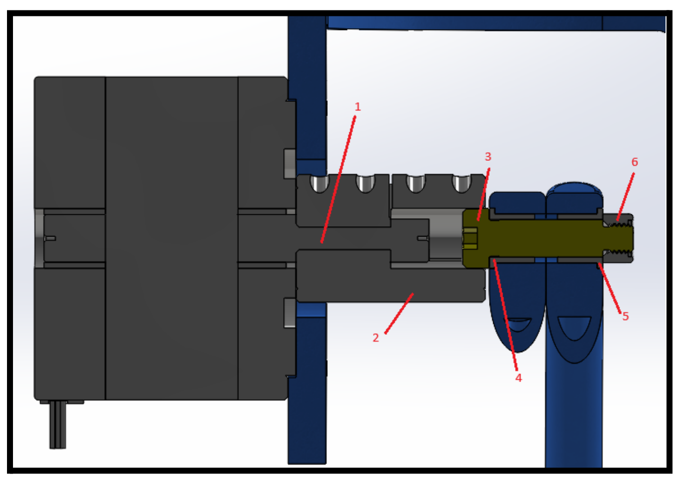


Figure 9: Transmission Perspective View   Figure 10: Sectioned Transmission System

5.0 Analysis

For the walking motion, the goal is to have a customizable input that moves the foot at an average walking speed of 0.82 m/s [7]. In this case the input is a motor that oscillates the thigh back and forth. The mechanism will operate as a rocker-rocker four-bar linkage, see Figure 11. To achieve customizability, we need an algorithm that takes height parameters as inputs and outputs an appropriate frequency to oscillate the motor that generates the correct angular motion in the thigh, which will produce an average foot speed.

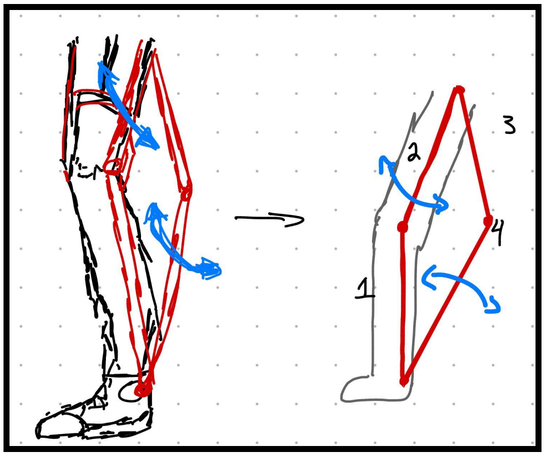


Figure 11: Stick Diagram of Mechanism

5.1 Achieving Oscillating Input and Proper Parameters

An Arduino Uno will be used to control a NEMA stepper motor and generate the required sine wave oscillatory motion. Simple control code was written to drive the motor based on two defined inputs: oscillation frequency and amplitude. See Figure 12 for an image of the Arduino code.

```
const float amplitude_deg = 10.0;   // swing amplitude in degrees
const float frequency_hz  = 1.0;    // sine wave frequency
const int stepsPerRev     = 6400;   // depends on ClearPath config
const float degPerStep    = 360.0 / stepsPerRev;

unsigned long prevMicros = 0;
float lastPos = 0;

void setup() {
  pinMode(stepPin, OUTPUT);
  pinMode(dirPin, OUTPUT);
  pinMode(enablePin, OUTPUT);
  digitalWrite(enablePin, HIGH);
  digitalWrite(stepPin, HIGH);
}

void loop() {
  // Time in seconds
  static unsigned long startMicros = micros();
  float t = (micros() - startMicros) / 1e6;

  // Desired position from sine function
  float targetPos = amplitude_deg * sin(2 * PI * frequency_hz * t);

  // Difference in position
  float deltaDeg = targetPos - lastPos;
  lastPos = targetPos;

  // Convert to steps
  int deltaSteps = round(deltaDeg / degPerStep);
```

```
  // Move motor by sending step pulses
  if (deltaSteps != 0) {
    digitalWrite(dirPin, (deltaSteps > 0) ? HIGH : LOW);
    for (int i = 0; i < abs(deltaSteps); i++) {
      digitalWrite(stepPin, HIGH);
      delayMicroseconds(5); // step pulse width
      digitalWrite(stepPin, LOW);
      delayMicroseconds(5);
    }
  }
}
```

Figure 12: Arduino Code for Stepper Motor

5.2 Reducing System to Velocity Polygon Problem

A typical person, regardless of size, has a total thigh swing of 40 degrees when walking [8]. Therefore the amplitude plugged into the code is a constant 40 degrees. Now the question becomes; What frequency should be input into the code to achieve normal walking speed? We look at the configuration of the mechanism when the angular velocity is at its peak. This occurs when the thigh angle measured from the vertical to the thigh (θ_2) is at half the amplitude, 20 degrees. We also approximate that at this position the foot speed is at the average walking speed 0.82m/s. The equation for this maximum angular velocity is:

$$\dot{\theta}_{2\,Max} = 2\pi f A \quad (1)$$

We make the approximation that link lengths of links one and two are the same, L_1, as they are for most humans. Therefore we take links three and four to be the shortest and longest links, respectively. To make sure this 4 bar behaves as a rocker-rocker:

$$(L_4 + L_3) > (L_1 + L_2)$$

To uphold this condition we choose $L_3 = 0.9L_1$ and $L_4 = 1.20L_1$. Choosing link 3 to be nearly as long as the main links and link 4 to be the longest link keeps the four-bar in a geometry that maintains favorable transmission angles throughout motion [9] . This improves how efficiently the mechanism can transmit forces and resist external loads, avoiding weak "toggle-like" positions. As a result, the linkage provides greater stiffness, smoother torque transfer, and better overall support for an exoskeleton application [10].

We have now reduced the problem to the velocity polygon problem shown in Figure 13.

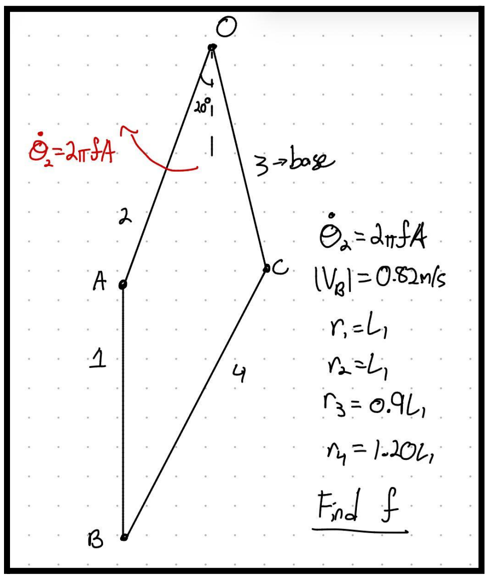


Figure 13: Velocity Polygon Problem

5.3 Solving Velocity Polygon

Using the relative velocity equation between points A and B, the solved velocity polygon is shown in Figure 14. The result is $|V_B| = |V_{foot}| = 1.24\pi L_1 f A$. As previously stated, the forward velocity needs to be 0.82m/s. This gives the following relation, assuming length length is approx $2L_1$:

$$0.82 = V_{foot} cos28 = (1.24\pi L_1 f A) cos60 \rightarrow f = \frac{1.64}{1.24\pi(leg\ length)Acos28} \quad (2)$$

This gives us an equation for the proper frequency that the motor should oscillate at to achieve normal walking motion, based on the user's input leg length. This formula is added to the arduino code, so the user only has to plug in their leg length, and the output should be the motor oscillating at the proper frequency. Note amplitude is a constant for any user.

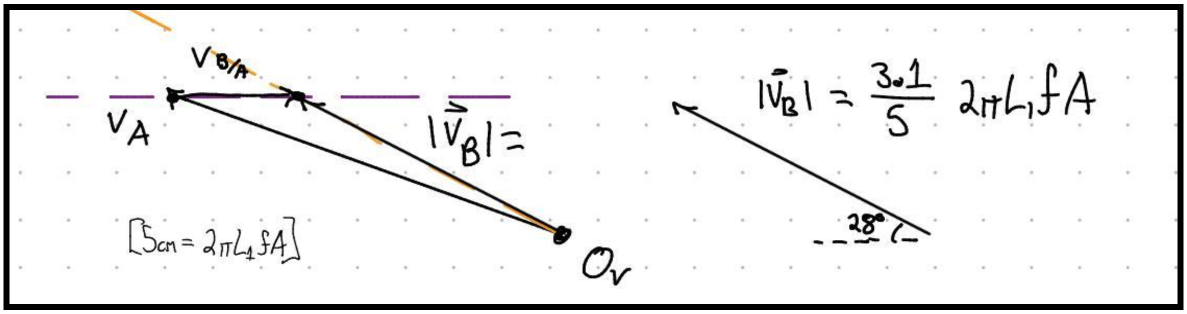


Figure 14: Velocity Polygon

5.4 Cost Analysis

Table 2 summarizes the estimated material and hardware costs required to manufacture a single StrideAssist unit, including the structural components, transmission hardware, electronics, and consumables. It is important to note that this estimate is significantly understated, as it does not account for research and development expenses, which would represent the most substantial cost for a complex system such as an assistive exoskeleton.

Table 2. Parts List

Category	Estimated Components/Description	Approx. Cost (CAD)
Structural Frame	Lumbar plate, side-mount plates, curved upper-frame links (CNC aluminum plate/tubing)	$50 [11]
Adjustable Leg Links	All leg links (upper/lower/support), spring-loaded push-pins, straps	$40 [11]
Transmission / Motor Assembly	2 × NEMA 34 stepper motors + shaft couplers / bushings / shoulder screws / locknuts	$95 (2 × $47.06) [12]
Passive Joint Hardware & Fasteners	Shoulder screws, bushings, washers, spacers, M6 screws for lumbar width adjustability, nuts & washers	$15 [13]
Electronics & Power Supply	Motor driver (if not onboard), wiring, connectors, power supply unit	$30 [14]
Consumables & Finishing	Epoxy, adhesives, surface finishing (paint or anodizing), miscellaneous small parts	$20 [15]
Total Estimated Cost (Hardware & Materials)	—	≈ $250 CAD

6.0 Comparison of Current and Redesigned Mechanisms

The redesigned StrideAssist mechanism provides several functional improvements compared to existing exoskeleton designs while meeting the client's requirement for a single, adaptable platform.

Structurally, current market devices rely on fixed-length links and non-modular frames, which limits their compatibility to users with intact limbs. In contrast, the redesigned mechanism incorporates adjustable thigh and shank links, a width-adjustable lumbar frame, and interchangeable joint modules. These changes allow the system to accommodate users with no amputation, below-knee amputations, or above-knee amputations without requiring multiple device models.

Kinematically, existing devices typically depend on direct motor rotation without tailoring gait motion to individual users. The redesigned system instead uses a rocker–rocker four-bar linkage to generate the thigh motion. Velocity-polygon analysis provides a relationship between leg length and required motor frequency, ensuring the foot reaches an average walking speed of 0.82 m/s. This results in more natural motion and improved adaptability across different user geometries.

In terms of performance, the redesigned linkage avoids weak transmission angles by selecting favourable link proportions, improving torque transfer and smoothness compared to simple hinge-based mechanisms. Because the input frequency automatically adjusts to the user's leg length, the redesigned mechanism maintains consistent gait behaviour across different configurations.

From a usability standpoint, current exoskeletons offer limited options for comfort or alignment adjustments. The redesigned system includes adjustable cuffs and modular contact interfaces, improving pressure distribution and allowing proper joint alignment for both biological limbs and prosthetic components.

7.0 Conclusion

The redesigned StrideAssist successfully addresses the limitations of current exoskeleton systems by providing a single, adaptable platform capable of serving users with a wide range of mobility needs. Through adjustable link lengths, modular joint configurations, and improved contact interfaces, the design achieves the client's requirement for compatibility with no-amputation, below-knee, and above-knee users. Kinematic analysis demonstrated that the four-bar linkage and leg-length-based frequency relationship allow the device to reproduce a natural gait at the target walking speed of 0.82 m/s. The chosen link proportions and transmission approach ensure smooth motion and reliable torque transfer across different user configurations.

With an estimated hardware cost of approximately $250 and a consolidated modular structure, the StrideAssist offers a cost-effective solution while reducing manufacturing and maintenance complexity. Overall, the redesigned mechanism provides improved adaptability, motion quality, and user comfort, making it a strong and practical upgrade to conventional exoskeleton designs.

8.0 References

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