Concept Generation

EML 4551C – Senior Design – Fall 2011 Deliverable

Team # 17

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Project Sponsor

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Table of Contents

Introduction

The current generation of assistive walking devices is limited in their traversable terrain and functionality. Many of these devices are meant only for indoor operation and offer little assistance to the user beyond structural support. Those individuals who require assistance walking and wish to travel outdoors can be deterred by the smallest of hazards, such as grass, gravel, or hills. For many individuals, scooters or electric wheelchairs are unnecessary or too expensive for their needs, and rollators offer limited safety and control. To further empower the disabled and elderly community, new classes of automated assistive devices are being developed. This project aims to create the initial research platform for the eventual design of a semi-omni-directional robotic walker.

Similar devices, as shown in Figure 1, have been designed to assist patients after knee or hip joint operations by providing stability, walking gait suggestions, and fall prevention. These devices, however, are designed specifically for use indoor operation, and are not intended for day-to-day use. Figure 2 shows an assistive walking device developed by the Korean Center for Intelligent Robotics designed for outdoor operation. This device is large and does not offer semi-omni-directionality, so practical indoor operation is not realizable.

Figure 1: National Taiwan University: Advanced Control Lab “Assisted walker robot”

Figure 2: Korean Center for Intelligent Robotics outdoor walking system

While these devices and other standard walkers offer some functionality and assistance, there is not yet an existing device designed to assist the elderly or disabled in a vast range of environments while maintaining high functionality. For this reason, a test platform is required to research the control schemes necessary for a more versatile assistive walking device.

Project Specifications

The goal of this project is to design and create the structural foundation of a fully-functional, highly stable semi-omnidirectional outdoor robotic walker. The walker must be able to operate on sloped ground, up to 10 degrees, as well as on outdoor multi-terrain surfaces, such as gravel and grass. Because this device is intended to be used by a common user, the design must be constrained to standard walker dimensions; namely, to fit through a doorway (32 inch maximum) and around tight corners. However, our model will be implemented in such a way to allow significant outdoor functionality. We want to support the user up to 45 degrees of lateral motion from any central axis. Considering environmental hazards and human error, an inherent resistant force will assure the user constant stability and dependence.

To ensure familiarity for the user, standard walker dimensions and specifications will be conserved wherever possible. This includes utilizing 1 inch diameter aluminum piping in the framework for lightweight durability, supporting up to 300 pounds (standard), adjusting the handle height between 32 and 39 inches (standard), and utilizing a tapered design frame with a wider base of 24 inches and an adjustable handle width between 11 and 24 inches.

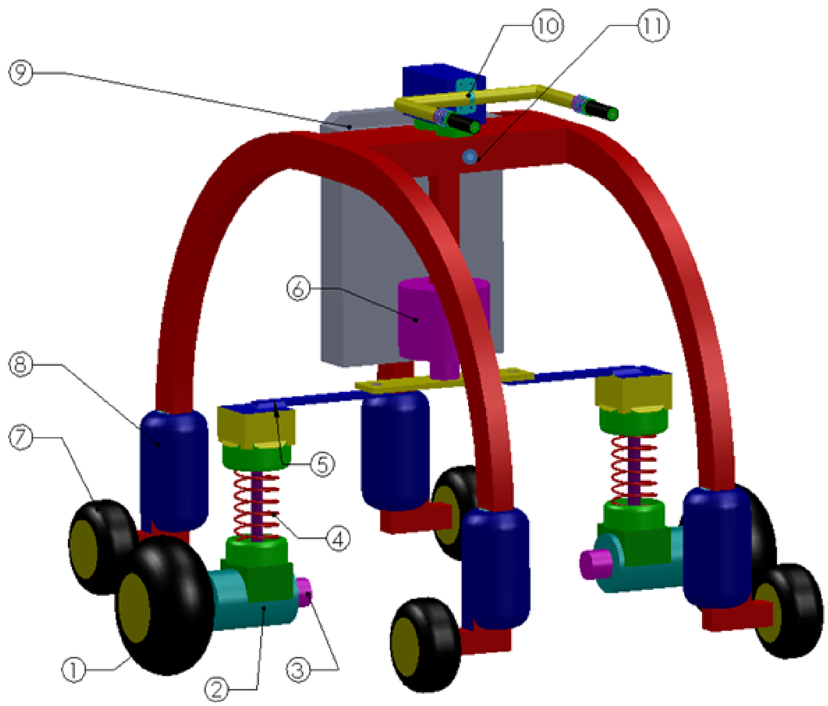
To allow the device to traverse both indoors and outdoors, the wheels or tracks will be at least 11 inches in diameter. The device will be able to move transversely at any angle 45 degrees or less from the center axis. This will require the use of casters or omni-directional wheels. The device should be able to utilize its full range of motion in any of its designed environmental conditions at a maximum of 5 mph.

The device will be controlled by a PC104 computer stack as provided by our sponsor, and user input will be regulated via an intuitive and simple driving system. This system will utilize user force inputs inherent with walking as the commands for steering and driving the device to allow for a more natural operating environment for the user. Functional control schemes will be able to provide numerous added functions such as fall prevention, object avoidance, localized navigation, and stand-up/sit-down assistance. The device will be design to minimize weight and cost; however there are no strict limitations on either. Initial upper estimates of each are approximately 100 pounds and $5,000 respectively.

Concept 1

Concept one, shown in Figure 3, can be considered as the middle road between all designs. It combines some of the best aspects from several of the designs however since it is not tailored to any one objective it certainly lacks specialty skills. Concept one is sturdy and balanced with its six wheels and allows for small payload capacity however the 6 casters make true omni-directional movement quite difficult. This design does however allow ample space for electronics and includes such features as fall detection, stand-up assistance, and object avoidance. Concept one is capable of object avoidance as the six wheels, with appropriate suspension, allow cameras and lasers to maintain a more level relation with the ground while traversing difficult terrain. The single steering motor makes the control algorithms simpler as it limits some variables; however, Ackerman steering requires limited steering motion. Both wheels must turn on common pivots preset during construction. This means that unforeseen events could not be dynamically adapted to during operation. The single motor steering also necessitates a very strong motor to turn both wheels.

Concept one will be controlled using a force plate design. The force plate resolves the forces in all axes with associated torques as well. The advantage of this is that there are no moving parts and that the control algorithm can adjust steering properties on the fly. The disadvantage of the force plate is the cost and limited force capability. The force plate would not be able to take the full force of a human falling. There would have to be additional hardware to limit the force input to the force sensor. All control devices will have the ability to be passively adjusted by the user. This requires less hardware and controls however does necessitate that the user have the strength and dexterity to operate the adjustments. The six wheel design does allow for one or even possibly two casters to fail and still have an operable device. The air-filled tires allow for additional shock absorption while allowing for varying traction performances based on the average psi of the tires. Air-filled tires are also widely available and simple to implement however, they are more likely to fail though. Punctures or broken valves can render the tires useless, potentially disabling the system if this were to occur on a driving wheel.



1) **Driving Wheel**
2) **Driving Motor**
3) **Encoder**
4) **Elbow Couple**
5) **Adjustable Spring**
6) **Damper**
7) **Spring Housing**
8) **Elbow Couple**
9) **Ackerman Steering**

Figure 3: Concept One Design

Pros:

1) Sturdy, well balanced and robust
2) Ample electronics space
3) Common implementation of steering and driving motors
4) Good Outdoor Operation and Traversibility

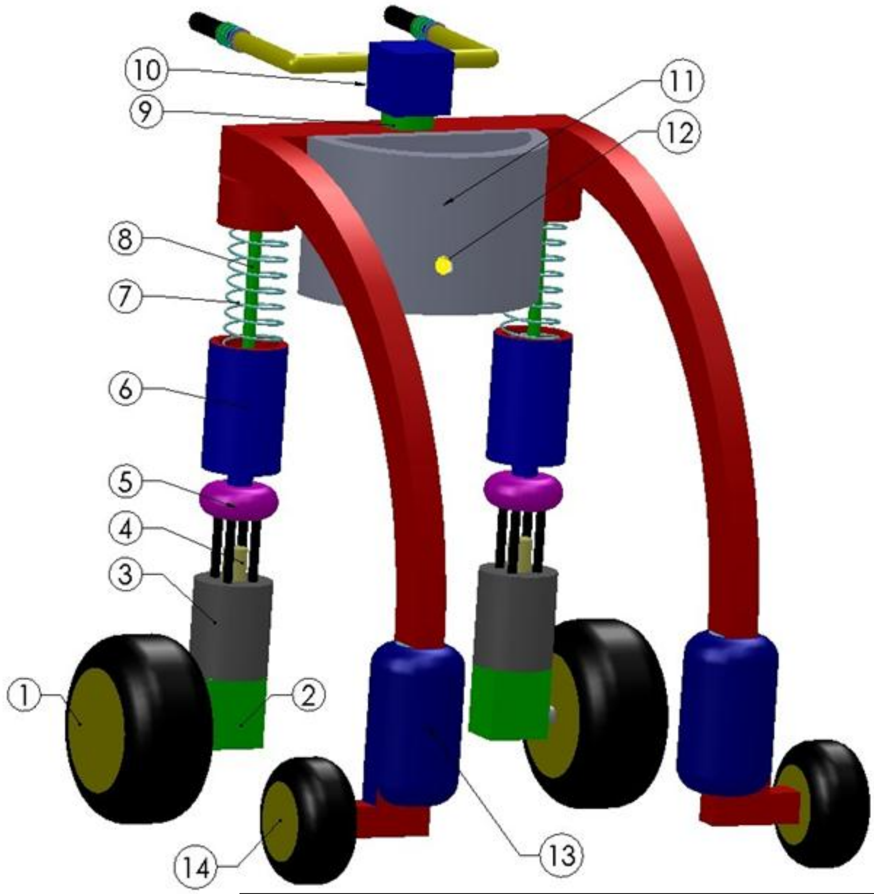
Cons:

1) Limited steering capabilities
2) Fragile Tires
3) Large/Heavy Structure
4) Foreign Walker Design
5) Expensive

Concept 2

Concept two most resembles a typical walker. This concept offers the best versatility coupled with the one of the highest degrees of user friendliness. One of the distinct advantages of this design is the true omni-directional steering. Each steering motor paired with a driving motor is fully capable of spinning the driving wheel 360 degrees. This can provide true holographic movement to the walker. Another design feature is the puncture-less tires. The tires implemented on this concept will be a honey-comb design to provide additional suspension as well as resistance to puncture. The control for this design will be accomplished with a spring driven system using two potentiometers. The displacement of the spring on the handle the user will be using will correlate to a displacement in the potentiometer and thus an input to the system. These controls provide a cheap and stable platform for the user to interact with the system. The passive suspension and dimension adjustment also helps to keep the price down while providing additional robustness.

The necessity for an additional steering motor and thus additional motor controller will certainty drive the price up while also making the controls more complicated. Due to the full rotation of the driving wheel more expensive encoders are required that can provide an absolute position as opposed to a relative position in comparison to the initial orientation. These encoders are referred to as absolute encoders. This concept provides for fall detection, stand-up assistance as well as object avoidance, thus making this design very user friendly.



1) Honeycomb Wheel
2) Elbow Gearbox
3) Driving Motor
4) Encoder
5) Rotary Connection
6) Steering Motor
7) Spring
8) Damper
9) Controls Base
10) Spring Driven Controls
11) Basket/Electronics
12) Camera
13) Swivel and Suspension
14) Caster Wheel

Figure 4: Concept Two Design

Pros:

1) Familiar walker design
2) True omni-directional movement
3) Cheap, sturdy controls
4) Puncture-less tires
5) Excellent versatility
6) Extremely user-friendly

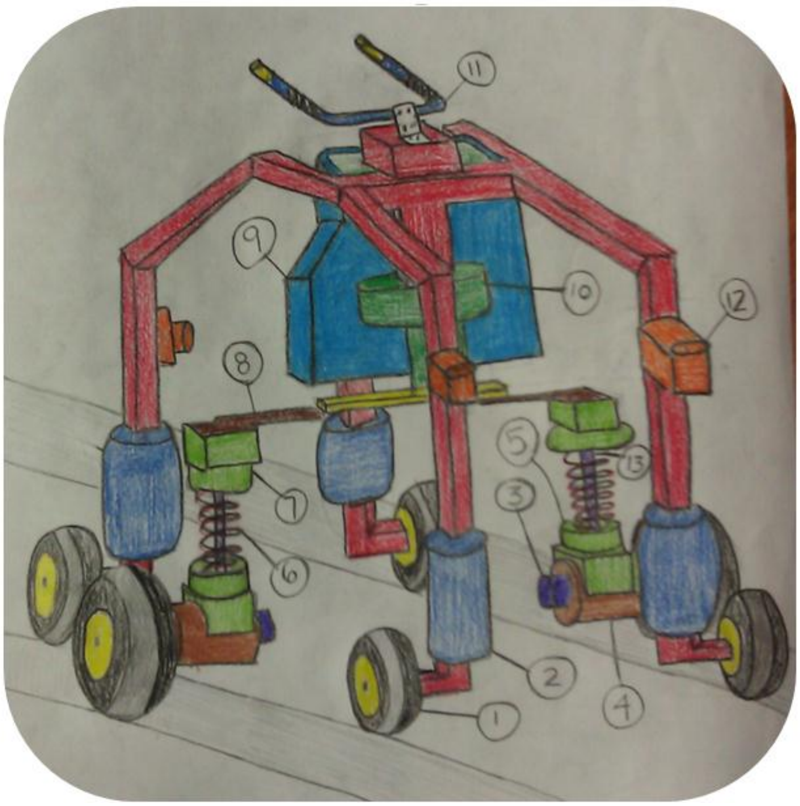
Cons:

1) Single tire failure could render walker useless
2) Less stable if one was to fall backwards
3) Limited space for electronics
4) Limited payload capacity
5) Additional motor and electronics required
6) Expensive

Concept 3

Concept three equates as the most adept walker. Designed to mainly support and assist a heavy payload, concept three implements a reinforced design that exhibits a variety of advanced technical features. In order to better distribute large loads and effectively reinforce or “beef-up” our walker, steel crossbeams will be added to our frame. For complete support, this design has 6 caster wheels (2 driving and 4 passive). Durability is increased with the number of casters, considering the possibility of one or more casters breaking or malfunctioning. However, this design is still built to be semi omnidirectional. The walker will contain 3 motors (with encoders), one for steering and one for each driving wheel. Our design will also feature a set of 7 lasers mounted in multiple critical position on the walker to guide the user safely and efficiently around certain terrains. A sensor will be mounted at each crossbeam intersection (2), as well as on each back and front leg of the walker (4) with one in the middle of the walker, facing the user (1). Essentially, there are two sets of sensors (3 in the middle and 2 in back) to detect and implement the stand-up and fall/slip systems and two sensors in the front to allow a 180 degree peripheral viewing range to make our walker object-avoidance capable. An intelligence system will interpret the laser data and provide reasoned judgment to flag decision markers as a basis for action.

An active suspension system will be used to counteract the effects of the walkers bulky size and weight; namely to keep the sensors as level and properly calibrated as possible. Active suspension also improves the quality and handling of the walker. All of the necessary electrical components and computer systems will be housed and mounted in safe and accessible location on the walker. A storage space (bin) for personal items or belongings will also be mounted on the frame. Ackerman steering will be used in our design, where the radius of curvature of the front wheels fall in a line that is perpendicular to the rear wheels. Concept three’s system is ultimately more precise as Ackerman steering corrects the problem of slippage during the execution of a turn. On the downside, this design offers limited indoor use due to its bulky dimensions and caster placement. The cost of production also exceeds practical measures, making this design more theoretically sound. Due to the cost of advanced technical features and systems implemented within this design, the practicality of this design is lowered.



1) **Caster Wheel**
2) **Caster Suspension / Shaft Swivel**
3) **Motor Encoder**
4) **Driving Motor**
5) **Spring Elbow Couple**
6) **Spring**
7) **Spring Housing**
8) **Ackerman Steering**
9) **Basket / Electronics**
10) **Steering Motor**
11) **Spring Driven Handle**
12) **Laser Sensor**
13) **Spring Dampers**

Figure 7: Concept Five Design

Pros:

1) Designed for a heavy payload
2) Durable, solid frame with added supports
3) Good Outdoor use (increased access & mobility with object avoidance system)
4) Active Suspension
5.) Intelligence Systems
    - Laser guided fall/slip assistance
    - Stand-up assistance
    - Basic laser guided object avoidance

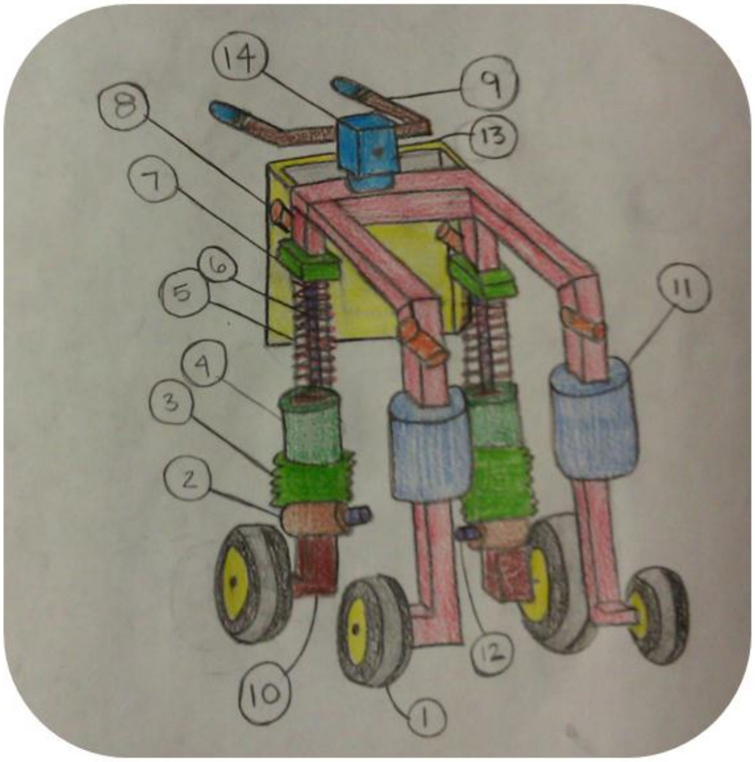
Cons:

1) Bulky Frame (limited indoor use)
2) Fragile Tires
3) Heavy structure
4) High cost
5) User transitional ease

Concept 4

Concept four is one of the more advanced walker designs. It's designed for increased speeds with better access/mobility characteristics. This walker has many profound features, namely the laser sensor technology. Fall detection, stand-up assistance and object avoidance technology are all made available through the implementation of laser sensors. However, the walker's passive suspension system can lead to detrimental system damage.

Concept 4 has four air-filled puncture-less tires, two driving and two caster wheels. Two driving motors (with encoders) will power the rear wheels, while one motor powers the steering. The walker will be composed of a light yet durable material able to withstand any system shock. Disregarding the cost of extraction and purification, a Titanium frame would make the walker very lightweight while not sacrificing any structural integrity. Titanium is a low density, highly-ductile material with a relatively high melting point and fairly low thermal conductivity. All these characteristics make titanium an excellent candidate for our speedy lightweight walker model.



1) **Caster Wheel**
2) **Driving Motor**
3) **Rotary Connections**
4) **Steering Motor**
5) **Spring**
6) **Damper**
7) **Spring Housing**
8) **Laser Sensors**
9) **Force Plate Driven Handle**
10) **Driving Wheel**
11) **Caster Suspension**
12) **Motor Encoders**
13) **Basket / Electronics**
14) **Laser Sensor**

Figure 7: Concept Five Design

Pros:

1) Fast, lightweight walker design
2) Semi omnidirectional navigation
3) Force Plate Recognition System
4) High Indoor Use
5) Object Avoidance, Fall detection, Stand-up assistance

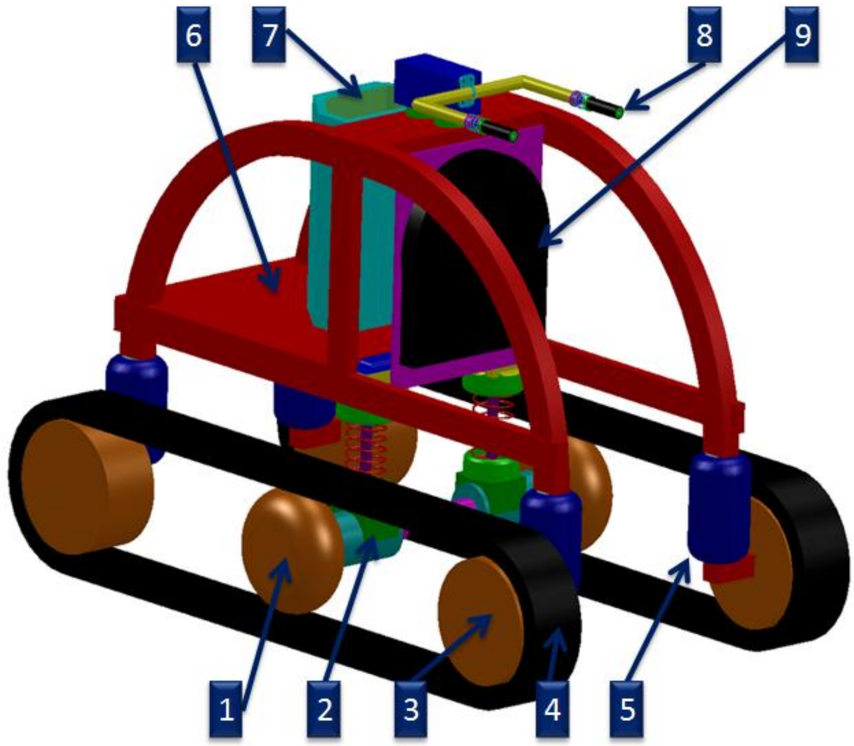
Cons:

1) Limited Payload Capacity
2) Fragile components (Force Plate)
3) Limited Outdoor use
4) Limited payload capacity
5) Low Demand for speedy walker, expensive
6) Slightly less durable and resilient compared to other designs

Concept 5

This concept focuses on the device’s ability to traverse the widest range of terrain possible. The most substantial difference between this design and other concepts involves the driving mechanism. As seen in Figure 7, wheels are replaced by treads to allow the device to traverse through sand, mud, and snow. These treads are driven by a single large driving motor and utilizes a skid steering system. This results in semi-omni-directional capabilities. In addition to the fall prevention and stand-up/sit-down assisting features discussed in previous designs, this device will feature a front-mounted laser for object detection and avoidance and include a fold-down chair for riding if the terrain becomes too difficult for walking. To compensate for the potential of added weight from a rider and for the largely unstable terrains this device is design to traverse, an active suspension system will be implemented. The dimension adjustments will be limited and passive due to sizeable hardware, but a large basket will provide substantial payload capacity.

By implementing a hybrid walking-riding operation scheme, this device allows the user to traverse easily across both standard and treacherous outdoor terrain. However, because of the bulky nature of the treads and large supportive structure, the device will not be very applicable for indoor operation. In addition, the treads and active suspension system will drive costs up and the extra hardware will substantially increase the weight. Because of the additional support, however, the device is expected to be fairly robust.



1) Driving Wheel
2) Driving Motor
3) Track Suspension and Tension Wheel
4) All-terrain tracks
5) Suspension
6) Front storage/seat
7) Basket/Electronics
8) Spring Input
9) Foldable Seat

Figure 7: Concept Five Design

Pros:

1) Great Outdoor Operation
2) Active Suspension
3) Riding Capability
4) Large Payload

Cons:

1) Minimal Indoor Operation
2) Passive Dimension Adjustments
3) Expensive
4) Heavy

Selection Criteria

Each of the previously discussed designs was scored based on the following selection criteria. The criteria were weighted with respect to each other with a standard comparison matrix. The criteria are described below and their weightings are listed following each description.

- Versatility: The device's ability to perform numerous functions in multiple environments and account for many user body types. This takes into account the control and function capabilities, the estimated traversibility, and the dimensional adjustment capabilities. (Overall weighting 15%)

- Robustness: The device's overall ability to not break. Examines number of complex mechanism and their resistance to failure. (Overall weighting 17.5%)

- User-Friendliness: The ease to which an individual can become acclimated to the different device functions as well as the cosmetic appeal. (Overall weighting 22.5%)

- Indoor Operation: The device's ability to operate indoors in a safe and efficient fashion. Turning radius and overall size are important considerations. (Overall weighting 14.5%)

- Outdoor Operation: The device's ability to operate outdoors in a safe and efficient fashion. Suspension, traction, driving power and steering mechanism are considered. (Overall weighting 23%)

- Cost: Both the initial investment necessary as well any foreseeable maintenance issues are compared. Low scoring options are very costly. (Overall weighting 4%)

- Weight: The overall size and weight of the device is taken into consideration and the requirements to move/support that structure. High weights scored low values. (Overall weighting 3.5%)

Conclusions

Each design was assigned a score based on the previously discussed criteria and put into the decision matrix as seen in Table 1. The table shows the criteria, their respective weights, and each concept's score on an absolute scale (1 being lowest, 5 being highest) and a weighted scale. The summations of these values represent the weighted average score for each design, and the highest three are highlighted in the table.

		Concept 1		Concept 2		Concept 3		Concept 4		Concept 5	
	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Versatility	0.15	3	0.450	5	0.750	3	0.450	3	0.450	3	0.450
Robustness	0.175	4	0.700	3	0.525	5	0.875	3	0.525	4	0.700
User-friendliness	0.225	3	0.675	4	0.900	2	0.450	5	1.125	3	0.675
Cost	0.04	2	0.080	2	0.080	1	0.040	1	0.040	1	0.040
Indoor	0.145	3	0.435	3	0.435	2	0.290	3	0.435	1	0.145
Outdoor	0.23	4	0.920	3	0.690	3	0.690	2	0.460	5	1.150
Weight	0.035	2	0.070	3	0.105	1	0.035	4	0.140	1	0.035
		Sum	3.330		3.485		2.830		3.175		3.195

Table 1: Selection Criteria Ratings

As seen in the Table, Concept 2 scored the highest with Concepts 1 and 5 following. Concepts 1 and 2 represent moderate to good scoring designs in relation to all presented criteria, whereas Concept 5 represents an optimization of the highest weighted criterion. These concepts warrant further detailed evaluation to determine our final design.

Sources

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