Mobility-Aid Smart Pants with Embedded Harness for Daily Use

by

Karen Chen

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ABSTRACT

Mobility aids help individuals that experience problems with moving around maintain autonomy, and can take many forms such as canes, crutches, walkers, among others. These devices are commonly used among the elderly, as decreased mobility is a natural effect of aging. In fact, mobility aids and gait training, often facilitated through the use of bulky gait trainers, harnesses, and or railings, have great potential to improve patient's cardiovascular health, blood circulation, and disease prevention. However, gait training is often inaccessible due to the heavy equipment required, impractical to purchase for individual use; giving patients more optionality in their mobility aids through everyday wearables could improve the overall health of the mobility-aid user population. In particular, smart garments can adapt to the user and the user's environment. These harness-embedded pants come into play as the pants are physically connected to the walker, so the harness effectively prevents the user from sustaining a potentially life threatening injury, while discreetly disguised as a regular pair of pants.

Thesis Supervisor: Harry Asada
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1. INTRODUCTION

Among the elderly population, aged 65 years or older, falls are far more than a minor pain or inconvenience. The effects of falling can be devastating on an individual's quality of life, with consequences ranging from disability and distress to long-term care admission, or, in extreme cases, even mortality. In the coming years, it is expected that falls among the elderly are expected to increase as the prevalence of chronic disease also increases[1]. While there exist gait trainers that help individuals safely improve the quality of their range of motion, and in doing so, quality of life, the equipment is expensive and requires facilitation from trained physical therapists or other healthcare professionals. Gait training often employs the use of harnesses which are bulky and difficult to put on and take off. This makes it especially difficult for seniors to use as it impedes their ability to use the bathroom with ease. Gait training is time intensive, expensive, and as such generally impractical for a population of an imbalanced economic and social background[2]. It is imperative to work towards providing long-term, accessible solutions to seniors as to give them the necessary tools to protect themselves, especially in the comfort of their own homes.

Figure 1-1: This is a traditional gait training setup. As depicted, the patient is harnessed into a complex treadmill system that requires a healthcare professional on standby to supervise, and intervene if necessary.

In addition to the financial and time burdens that physical therapy can incur, appearance-based factors make gait training and mobility-aid devices in general less appealing. There is no doubt that we live in an ageist society; as a population, we are conditioned to value youth, autonomy, and aesthetics. As such, the stigmas surrounding mobility aid use (such as walkers) are rampant among seniors[1]. This fear is often due to the appearance of aging and physical decline. Some individuals say they do not want to use an assistive device because they fear being seen as “crippled,” “an old lady,” “very sick”, or even “dying”. Others fear that, after accepting the use of a device, further decline would be inevitable[3]. However, the reality is that mobility aid devices save lives, not to mention billions of dollars in medical expenses. Innovations on these assistive medical devices have made them even more robust in protecting at-risk individuals from injury; however, the social barriers-to-use are omnipresent. By

considering the human factors in designing dynamic mobility aids, we aim to reduce these barriers-to-use.

The current most popular mobility medical devices for walking include canes, walkers, and crutches, all of which "increase a patient's base of support, improve balance, and increase activity and independence"[4]. While some canes and crutches have been adapted to fit a more stylistic aesthetic, they increase the patient's base of support minimally. Even walkers do not guarantee that patients will not fall while using them. However, Kamienski's innovative design of a robotic walker that mimics the structure of a gait trainer with its expandable base of support has been shown to drastically reduce the preventable injuries that result from insufficient or unsteady walker use[4]. A prediction algorithm that is trained to detect when a patient is falling communicates with the robotic walker and triggers the expandable base of support, making the walker untippable. Up until this point, the IMU has been attached to the user on a traditional harness, available on the commercial market. The current harness design demonstrates that the walker is effective in preventing the patient from falling, which returns autonomy to the user[4]; however, it does not necessarily address the stigmas surrounding assistive mobility technology in general. Also, existing harnesses have other practical issues such as being hard to take on and off, and they are uncomfortable to wear for long periods of time.

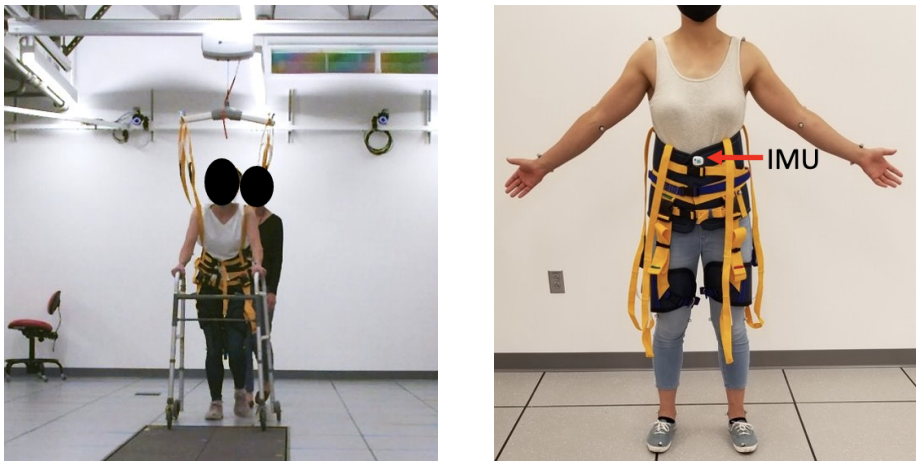

Figure 1-2: This is a data collection setup showing how the IMU is attached to the walker user with a complex harness system. The images clarify how cumbersome it would be for a patient to have to put on and take off the harness, especially multiple times per day.

By attaching this sensor to the user's body on a wearable garment and integrating the body support harness into everyday clothing, specifically, a pair of pants, we can drastically reduce the social stigmas of using this innovative mobility aid, as well as making the experience comfortable and convenient for the user. In order to work, the smart pants are tethered to the walker. The design will be robust in terms of meeting the physical needs of the patient as well as meeting other human factor considerations–ease of handling and willingness to use. In this way, users of this integrated mobility device system–robotic walker, IMU, harness-embedded pants–have a discreet, built-in layer of additional security, providing them with the autonomy to make their way through their days with confidence.

2. OBJECTIVE

The objective of this project is to design and fabricate the harness-embedded smart pants to address the gap in accessible mobility-aid technology, providing users with an alternative to traditional gait training methods that is convenient and presentable to use at home and in public,

and provides the user with autonomy through ease of wear (putting the pants on and taking them off). This final prototype will be important for demonstrations of this mobility aid system, operating as a whole. A functional visual of this innovative mobility device system will show potential users and other experts in the healthcare industry, such as doctors and physical therapists, a viable alternative to the clunky gait trainers currently on the market that are impractical for daily use. Ultimately, with this pair of smart pants, I aim to reduce the social barrier-to-entry of walking mobility aids, in particular, the robotic walker designed by Emily Kamienski, Paolo Bonato, and Harry Asada.

Furthermore, sleek pants with a supportive embedded harness have additional potential applications in other recreational circumstances, such as rock climbing. As such, a provisional patent has been filed on this work.

3. DESIGN CONSIDERATIONS

The target persona for these smart pants with an embedded harness is an elderly individual that already uses a walker or would benefit from using a walker. They are designed for comfortable wear throughout the day, and they are easy to take on and off. This characteristic is important for toilet use throughout the day. Furthermore, the target user desires autonomy, and by using this smart garment, they can be more confident that they are safe from injury due to falling throughout the day.

3.1 Body Support

The nature of these harness-embedded pants as a weight-bearing garment requires certain specifications that ensure the user’s safety.

- The most fundamental functional requirement of these pants is that the embedded harness is strong enough to support the patient's full weight, as well as any strain from the impulse of falling.
- More specifically, if a user were to fall and rely on the embedded harness and walker system for weight-bearing, the stress on the harness would be concentrated in the upwards direction.
- Therefore, the upwards load on the belt of the harness must be safely distributed over the waist of the pants.
- Also, the straps connecting the leg loops to the belt should be firmly reinforced.
- Finally, the harness-embedded pants must be form-fitting such that they will stay in their intended form and positioning on the body if the user does fall, thus supporting the user as any external harness would.

3.2 Ease of Use

In order for these pants to effectively protect from potential injury, users must have the desire to wear them.

- From a social acceptance point of view, this means that the garment should present as a pair of pants rather than a mobility-aid.
- Furthermore, in order for the user to find these pants to be practical for daily wear, they must be easy to put on and take off, **and** they cannot significantly impede bathroom use.
- Finally, the pants and embedded harness must have some level of adjustability for comfort throughout the user's day.

All of these factors, discreet design, ease of dressing, and adjustability, contribute to the **wearability** of the smart pants with embedded harness.

4. DESIGN CONCEPT

A novel design concept of harness-embedded smart pants will be presented in this section. A sensor attached to the belt will provide the walker with the data necessary to detect when or if the user is about to fall. In order to ensure that users are willing to use this tool on a daily basis, the harness will be embedded on the inside of the pants so that it is largely invisible from the outside. This will contribute to the user's confidence while wearing the pants, resulting in the double-edged effect of wearing the pants at a high frequency and being protected at a high frequency. Above all, that is, with the additional functionality of the attached sensor and embedded harness, these pants will first and foremost fulfill the role of any other pair of pants. The "smart" and "harness" aspects of the pants means that the user will be able to confidently move about without fear of injury as well as comfortably dress and undress as they normally would.

4.1 Body Support

The strength of the embedded harness directly affects how safe the user will be while wearing it, so it was imperative to construct the harness to meet the strength requirement of supporting the user's weight. The textile used to construct the harness is the same textile as seatbelt strap, which is made of one hundred percent woven polyester, and designed to have a high tensile strength. The textile can bear a load of 1360-2722 kilograms[6]. In many places throughout the embedded harness, the textile is further reinforced by doubling the layer to further increase the durability and strength. In this case, the stitch pattern of each connection point in the harness is also important in making sure the design is robust. All of the stitching was done with nylon–for its high dimensional stability– and done with straight stitches–because it is the

strongest stitch pattern[7]–along the principal fabric axes of the woven polyester, as it is the strongest and stiffest in the principal axes[8].

As described above, the stress on the embedded harness is concentrated in the upwards direction if the user's full weight is being supported by it. As such, it is preferable to distribute this load across a longer distance, rather than traditional belt loops. Therefore, the belt loops were replaced with a woven polyester sleeve, attached to the pants with nylon straight stitching.

Figure 4-1: This figure shows the significance of redistributing the load (due to the user's weight) across the length of the reinforced belt. As shown, a traditional belt loop would experience high stress bearing the entire load of an individual's weight, but the smart pants have a special belt loop that distributes the weight along the entire length of the belt.

Finally, the embedded harness is sleek and form fitting, nestled comfortably inside the pants. Thick fabric elastics sewn to the woven polyester keeps the leg loops fitted to the user throughout the wear of the smart pants. Furthermore, the waist belt is adjustable to the user's comforts and needs.

4.2 Ease of Use

These smart pants are easy to use as they are not so different from a regular pair of pants. The harness is embedded in the pants so there are no additional garments to put on or take off. The harness is barely visible except for the belt, which many individuals use on a daily basis already. The only other visible part is the physical attachment point to the walker, but this is inevitable given the functional requirements of this mobility aid system in fully supporting the user's weight, if need be.

This pair of smart pants is designed to have minimal impact on bathroom use, which was a concern brought up by a medical professional from Spaulding Rehabilitation Hospital. The leg loops in the embedded harness will not impede bathroom use as they are tightened around the user's thighs and the upper part of the pants is largely unaffected. Furthermore, the d-rings on the side of the belt can be easily detached via the d-rings on the walker, and the belt of the harness requires little dexterity once adjusted to the size of the user's waist (only has to happen once).

Figure 4-2: This figure shows the d-rings sewn into the belt of the harness (still removable, however) that are used to attach the harness embedded smart pants to the walker. The d-rings attach to a carabiner on the walker, and in this way, the embedded harness can work as intended, supporting the weight of the user in the case of a fall.

If the user does need to adjust the waist, it can easily be done by pulling the buckle and tightening or loosening the strap, similar to how an airplane seatbelt operates. Furthermore, the elastic band on the leg loops means that the user experiences all day comfort, as they are not too tight but can provide the needed support when employed if the user is in a potentially dangerous situation. The elastic bands also prevent the leg loops from riding up the user's legs throughout the day.

4.3 Design Concept Selection

By comparing the smart pants embedded with a harness to other more traditional mobility-aid harnesses, we show that this novel new design of embedding the harness into pants has the potential to be a viable everyday option for a large base of elderly users.

	Traditional Gait Trainer	Traditional External Harness	Smart Pants with Embedded Harness
Ease of dressing	0	0	+
Accessibility	0	+	+
Convenience to use	0	0	+
Social stigmas to use	0	+	++
Safety of user while using	0	-	-
Total	0	+ 1	+ 4

Figure 4-3: The Pugh chart compares traditional gait trainers and traditional external harnesses (both pictured in earlier figures) to the smart pants with an embedded harness. We can see that the smart pants design has bonuses on all of the columns compared to the traditional gait trainer except for the safety of the user while using it because of course, gait trainers are typically facilitated activities with a healthcare professional.

From this chart, it is evident that the robotic walker and smart pants system is a mobility aid that combines the benefits of gait trainers and traditional walkers, as well as keeping stigma to a minimum. The convenience it provides in terms of being easy to put on and take off, as well as being accessible for everyday users make the smart pants with the embedded harness a very viable option.

5. FABRICATION

5.1 Initial Prototyping

The initial vision for these harness-embedded pants included the harness on the outside of the pants rather than the inside.

Figure 5-1: This image shows the first proof-of concept prototype. Note that the vertical straps connecting the leg loops to the belt are missing, and the bottom of the pants are also missing.

The intention in this design was to make the adjustability of the embedded harness easy to access throughout the day to increase the comfort of the user. However, this design was not very discreet and as a result, would potentially discourage users from wearing it in a more public setting.

The first prototype of the harness-integrated pants provided important insight about the fabrication process of the subsequent prototypes. For example, it was useful to understand the best way in which to attach the woven straps to the body of the pants for user comfort and adjustability. Furthermore, the prototype was the first visual of smart pants, and it was evident that with the harness embedded to the outside of the pants, it would stand out from other pants.

Therefore, the second prototype of these pants has the harness embedded on the inside of the pants, the adjustability strap still hangs outside of the pants for convenient access.

Figure 5-2: These images show the second prototype with the harness embedded on the inside of the pants. The single leg loop has a strap coming out of the side of the pants which would allow the user to adjust the sizing of the strap, as shown in a blown up picture on the right. Note that this prototype did not include a belt.

Feedback from several advisors, including Professor Harry Asada and a healthcare professional from Spaulding Rehabilitation Hospital, suggested that a stiff strap that is adjustable may not be the best solution for the leg loop, but rather something elastic that goes farther down the patient's leg (i.e. something similar to bike shorts or leggings as the harness on the inside of the pants). I incorporated this feedback into the final prototype of the harness-embedded smart pants.

5.2 Final Prototype

The final prototype of the pants includes two leg loops of the two inch strap, which are adjustable by the length of elastic that is attached to them. These leg loops are connected to a vertical strap, and additional comfort is provided to the user by an extra layer of fabric between the harness and pants. D-rings are sewn into the belt that will be used as the attachment points for the walker, and the load on the belt is distributed along the length of the waist by an additional two inch strap in place of traditional belt loops (which are not designed to carry the weight of a human). The IMU in the front is attached to the buckle of the belt, and the IMU in the back is attached to the two inch strap which the belt is threaded through.

Figure 5-3: These images show the final prototype of the harness embedded pants. The vertical straps of the harness are secured to the front of the belt (highlighted in green). The bottom image shows the inner fabric layer with the two leg loops and respective elastics sewn into them.

As shown, this design is wearable due to its discreet design and adjustability. It effectively supports the user in emergency situations, and works in harmony with Kamienski's innovative walker as a mobility-aid system designed for the modern world with special considerations to human factors.

6. CONCLUSIONS AND FUTURE WORK

This pair of smart pants was developed to work in tandem with Doctoral Candidate Emily Kamienski's reconfigurable robotic walker that features an expandable base of support to prevent tipping if its user is falling. The pants interface with the walker via contain an Inertial Measurement Unit (IMU) whose measurements are continually fed into a prediction algorithm that predicts that detects if/when the individual is about to fall; when a fall is predicted the IMU is triggered, the walker deploys its expandable base thus providing a stable structure that can fully support the user's weight.

These harness-embedded smart pants working in tandem with Kamienski's innovative walker design working as a mobility aid system holds great promise for the future of users with mobility limitations. As shown, this solution provides users with an opportunity to go about their lives with increased autonomy, confidence, and convenience, without presenting socially stigmatized signs of physical decline and reliance. In fact, this design has the potential to encourage users to move about more, given the added layer of security built into their mobility aids. As such, patients with a higher propensity for physical activity may even slow the effects of aging on the body.

While over the course of this project, there were several iterations of the harness-embedded pants resulting in the final working prototype, there are many questions and design intricacies yet to be addressed.

- First off, it is difficult to predict the direction in which the user might fall. In the case that the user tips backwards, the current design would not fully prevent injury as the user is only supported in the vertical direction.
- Therefore, it would be beneficial to include some horizontal support or attachment of the harness-embedded pants to the front of the walker in order to prevent the possibility of tipping backwards.
- Furthermore, the current d-rings attaching the harness to the walker have low maneuverability (hard to take on and off of the belt) and jangle around as the user walks. A thoughtful redesign would include a more autonomous connection between the d-rings and the walker.
- It would be great to replace these d-rings with a similarly robust attachment point that is easier to remove (for pants washing purposes) and consider a silicone coating so that they do not jangle around as the user moves about.
- The IMU's are currently attached to the pants with semi-permanent screws. The IMU's are not waterproof, so they also need to be removed before washing, so it would be beneficial to incorporate a snap-on snap-off mechanism so that the IMU's can be easily removed and replaced on the pants as needed.
- Finally, the IMU's need to be removed for occasional charging, and in accordance, it would be useful to the user if the IMU's provided a low battery warning signal.

As this design project has an intended user group–those with limited mobility who would benefit from having the autonomy associated with this mobility aid system–it would be imperative to collect feedback from this group in order to proceed. A visual sample of the garment may be used to survey patients to get feedback on the aesthetic qualities of the garment,

and whether or not they would be comfortable wearing it in public. Furthermore, the pants would need to be comfort-tested and strength tested to make sure that the product is in fact safe and durable over extended use.

Finally, there are several considerations in the production of these pants at a manufacturing scale. First off, the harness would be much easier to sew into the pants as part of the pants making process, rather than after the pants have already taken their final form. Throughout this process, I learned that it was quite difficult to sew loops of strap/fabric into pant holes, and it would have been much easier and have a more seamless appearance if everything was flat. Secondly, because of the use of elastic in these pants as the adjustability on the leg loops, it is imperative that these pants are sized correctly to each individual user. Before manufacturing at a larger scale, it is important to consider an inclusive standard sizing chart that accounts for different body types so that each user can be safely supported by the embedded harness. Finally, a larger scale manufacturing process of these pants might lend itself to developing similar products specialized for other industries where harness-embedded pants might meet the needs of other populations of users, such as rock climbers.

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