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(Research Article)

Integrating product design principles to design a smart assistive cane

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Abstract

This paper presents the design of a smart assistive cane using the principles of product design and quality assurance. The smart cane is aimed at improving the safety and independence of individuals with walking difficulties. The proposed cane incorporates advanced features such as GPS navigation, fall detection, adjustable height, and integrated storage. A comprehensive design process was employed, including a thorough analysis of user needs through a Kano analysis, followed by the selection of appropriate materials and manufacturing methods. The cane's structural integrity and functionality were assessed through rigorous testing and finite element analysis. This research contributes to the development of assistive technologies that can incorporate user's necessities and builds quality into the product with the design process, significantly enhancing the quality of life for individuals with mobility challenges. It serves as a potential demonstration to designers and researchers to incorporate product design, optimization, and quality assurance principles in design of similar assistive technologies and products.

Keywords: Product design; Assistive technology; Smart cane; Design for manufacturing

1. Introduction

Walking, a fundamental human activity, can be hindered by various factors such as aging, injuries, and certain medical conditions. Traditional walking canes, while providing basic support, often lack the advanced features necessary to address the diverse needs of users Traditional walking canes, while providing basic support, often lack the advanced features necessary to address the diverse needs of users (Wong & Yang, 2013). While smart solutions have shown great potential in various tackling many user problems, including them in design is a significant challenge (Aponte-Luis et al. (2018). Incorporating sensors can be beneficial to the design in multiple ways Chen & Xia, 2022. To address these limitations, this paper proposes a novel smart cane design that incorporates innovative technologies. The proposed smart cane aims to address the following key challenges:

- **Safety:** The cane will incorporate fall detection sensors and GPS tracking to alert caregivers in case of emergencies.
- **Independence:** Advanced features like adjustable height and interchangeable base pads will empower users to navigate various terrains with ease.
- **Convenience:** Integrated storage and charging capabilities will enhance the overall user experience.

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2. Material and methods

2.1. User Needs Analysis and Concept Generation

A Kano analysis, as described by Kano et al., on preliminary survey results from 50 potential users, (1984), was conducted to identify user needs and prioritize features. This technique categorizes features into three categories: "must-have," "performance," and "attractive."

Features Present	1-Dislike	2-Live with	3-Neutral	4-Must be	5-Like	Total
GPS	3	1	3	2	18	24
Adjustable Handle	3	1	4	3	13	24
Retention Lanyard	2	2	7	5	8	24
Folding	0	3	3	4	14	24
Battery for phone	5	1	8	0	10	24
Fall detection	0	2	3	4	15	24
Smartphone connectivity	5	2	7	2	8	24
Interchangeable base	1	0	3	8	12	24
Danger alert	1	2	3	1	18	24
Interchangeable handle	1	1	4	4	14	24
Lightweight	0	1	2	7	14	24
Visually appealing	0	4	10	2	8	24

Figure 1 Results of Kano Analysis

Based on the Kano analysis, several concept designs were generated through brainstorming and functional decomposition. These concepts were evaluated using a Pugh matrix to select the most promising design.

2.2. Design and Development

2.2.1. Design Requirements

The following design requirements were established:

- **Weight:** Less than 0.5 kg
- **Height:** Adjustable between 36 and 42 inches(Capurro et al. 2023)
- **Load Capacity:** 270 kg (2650 N) (considering a safety factor of 3 on the average human male weight of 89.4 kg
- **Cost:** Less than $200
- **Battery Life:** At least 24 hours

2.2.2. House of Quality (HoQ)

A House of Quality (HoQ) was introduced by Hauser and Clausing in 1988. It was used here to translate customer requirements into engineering characteristics. This allowed for a systematic approach to identify critical design parameters and trade-offs.

		Engineering Characteristics													
Improvement Direction		↓	↓	↓	↑	↑	↑	↑	↑	↓	↑	↓			
	Units	g	mm2	mm	mm	Mpa	dB	mAh	%	mm3	lm	$	Competition benchmarks		
Customer Requirements	Importance Weight Factor	Weight	Base Area	Stick Max. Diameter	Stick Max. Height	Material Rigidity	Alarm Loudness	Battery capacity	Fall Detection Success	Volume after folded	Flashlight luminosity	Cost of Cane	WeWalk Smarth Cane		
Ergonomic design	3	3	1		9								5		
Good base stability	5	1	9		1	3							1		
Long lifetime	4					9		1				3	3		
Effective Danger Alarm	2	3		3	1		9	3	1			9	2		
Battery durability	3	9		9	1			9	3	3	3	3	5		
Lightweight construction	5	9	1	3	3	3		3	3		1		5		
Accurate fall detection	3								9			3			
Built-in storage	3	9		9	1					3					
Bright flashlight	3	1						3			9	3			
Foldable	4									9			3		
Low price	4	1	1			3		3	3		1	9	1		
Raw Score	739	126	57	75	55	78	18	73	65	54	45	93			
Relative Weight %		17.1	7.7	10.1	7.4	10.6	2.4	9.9	8.8	7.3	6.1	12.6			
Rank Order		1	7	4	8	3	11	5	6	9	10	2			

Figure 2 Results from House of Quality

Material	Sy/ρ		E/ρ		C x ρ/Sy		Overall Rating (G) $\frac{aR_1 + bR_2 + c(1 - R_3)}{a + b + c}$
	A1	R1	A2	R2	A3	R3	
6061 Aluminum	0.1	0.48	25.93	0.97	28.04	0.03	0.808
4140 steel	0.1	0.27	26.75	1	30.27	0.03	0.744
6AL4V titanium	0.2	1	25.74	0.96	925.1	1	0.654
	a = 1		b = 1		c = 1		

Figure 3 Material Selection Matrix

2.2.3. Material Selection

A material selection matrix was used to evaluate candidate materials based on properties such as strength, weight, cost, and manufacturability. 6061 aluminum was selected as the primary material for the cane's shaft and chassis due to its favorable properties.

2.2.4. Design for Manufacturing and Assembly

DFMA principles were applied to optimize the design for efficient manufacturing and assembly. This involved simplifying the design, minimizing part count, and selecting suitable manufacturing processes.

2.2.5. Finite Element Analysis (FEA)

A static FEA was conducted to assess the structural integrity of the cane under various loading conditions. The FEA analysis, conducted using ANSYS 2021 R1, confirmed the structural integrity of the cane, strong enough and found in the studies by Chen & Xia 2022. The results of the FEA analysis confirmed that the design can withstand the intended loads and stresses.

2.3. Risk Assessment and Mitigation

A risk assessment was performed to identify potential hazards and develop mitigation strategies. Key risks and mitigation measures include:

- **Material Failure:** Selecting high-quality materials and conducting rigorous testing.
- **Electronic Component Failure:** Redundancy and robust component selection.
- **User Safety:** Thorough testing and user trials to identify and address potential safety issues

Risk name	Risk effect	probability	Impact	risk score
Fracture of cane tube	slipping/falling of user resulting in physical injury, useless cane.	1	6	6
Breakage of the base	loss of balance, injury	2	4	8
Failure of handle/cane interface.	slipping/falling of user resulting in physical injury.	2	3	6
Wiring problem	minor electric shock to user, loss of powered systems	3	3	9

Figure 4 Risk Assessment

3. Results

3D CAD model was made in Solidworks 2021. This design includes the features that were decided to included, and made to reduce risk and improve quality.

Figure 5 3D CAD Model of the cane

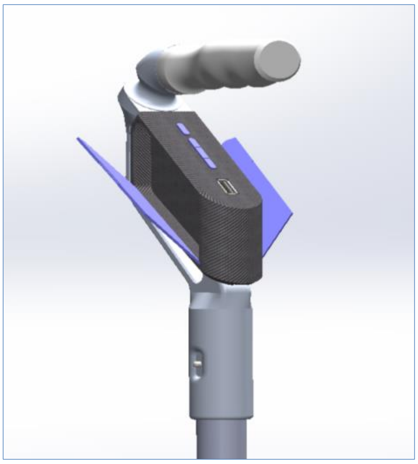

Figure 6 Close up of cane handle and storage area, as well as the tube-chassis interface

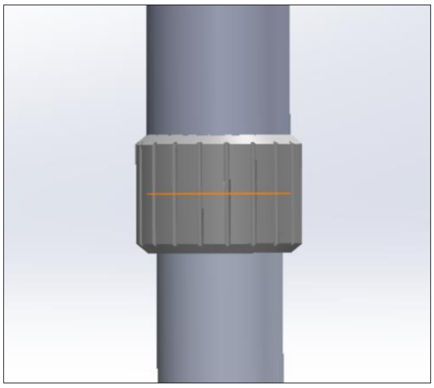

Figure 7 Height Adjustment Collar

3.1. Finite Element Analysis (FEA)

A static FEA was conducted to assess the structural integrity of the cane under various loading conditions. The cane was modelled in a 3D CAD software and meshed using a suitable element type (e.g., solid elements). Boundary conditions were applied to simulate the cane's interaction with the ground and the user's hand. A static load of 270 kg (2650 N) was applied to the top of the cane to simulate the maximum load it may experience. The model was set up with a fixed support on each of the 4 pads of the base.

Figure 8 Close up of cane base assembly and second-third tube joint

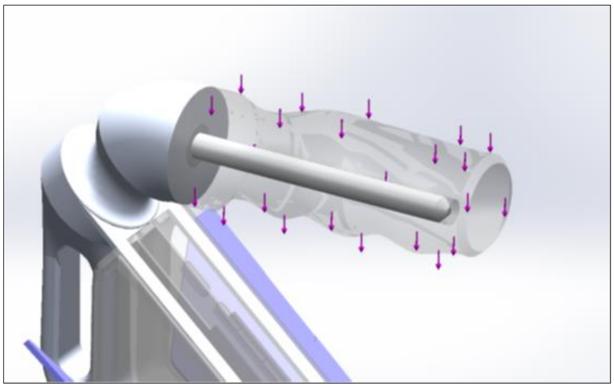

Figure 9 Force field for 2650 applied downward at the cane handle

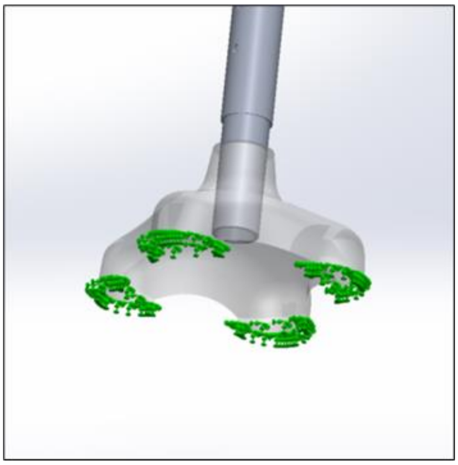

Figure 10 Fixed supports for model on each of the base pads

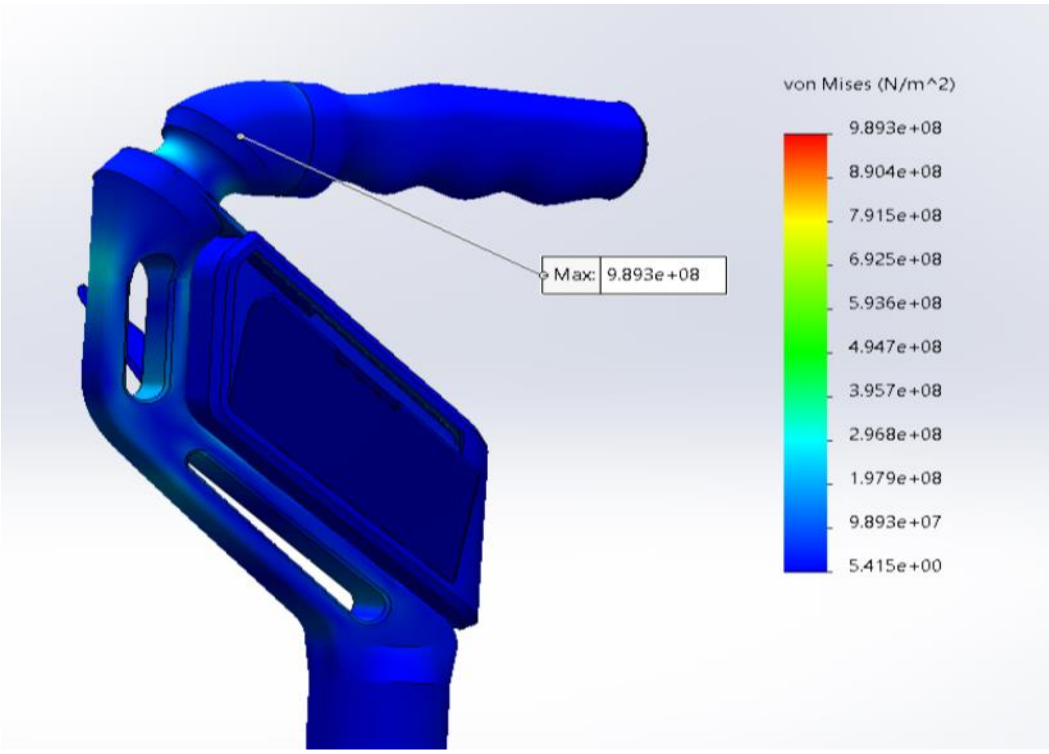

Figure 11 FEA results

The FEA results were analysed to identify stress concentrations and potential failure points. The von Mises stress distribution was visualized to assess the overall stress levels within the cane. The results confirmed that the design can withstand the intended loads and stresses, with adequate safety factors.

3.2. Design Validation and Testing

To ensure the smart cane's functionality and safety, a rigorous testing regimen was suggested.

3.2.1. Mechanical Testing

- **Static Load Testing:** The cane is to be subjected to a static load of 270 kg (2650 N) to assess its structural integrity and deformation.
- **Fatigue Testing:** Cyclic loading tests are to be performed to evaluate the durability of the cane under repeated use.
- **Impact Testing:** The cane should subjected to impact tests to simulate accidental drops and bumps.

3.2.2. Electronic Testing

- **Functional Testing:** The functionality of the sensors, microcontrollers, and wireless communication modules should be verified. They must be calibrated to working conditions. Noise levels of alarm must be noted.
- **Battery Life Testing:** The battery life should be estimated to ensure adequate performance. Voltage and power ratings must be verified with multimeters,
- **Environmental Testing:** The cane was tested in various environmental conditions, including temperature extremes and humidity, to assess its robustness.

3.3. User Feedback

To gather user feedback and validate the cane's usability, a series of user surveys were conducted. Participants were asked to evaluate the proposed design’s aspect. The response are summarized as follows:

- **Ergonomics:** Comfort grip, and overall fit.
- **Functionality:** Ease of use, effectiveness of features, and battery life.
- **Safety:** Perceived safety and confidence when using the cane.

4. Discussion

This design approach yield a smart cane design offering a promising solution to enhance the safety, independence, and quality of life for individuals with mobility challenges. The integration of advanced features, such as GPS navigation, fall detection, and adjustable height, provides a significant improvement over traditional canes.

The FEA analysis confirmed the structural integrity of the cane, ensuring it can withstand real-world usage conditions. Rigorous testing of both mechanical and electronic components were suggested that would validate the performance and durability of the device.

The section view of the model to be used for manufacturing is shown below.

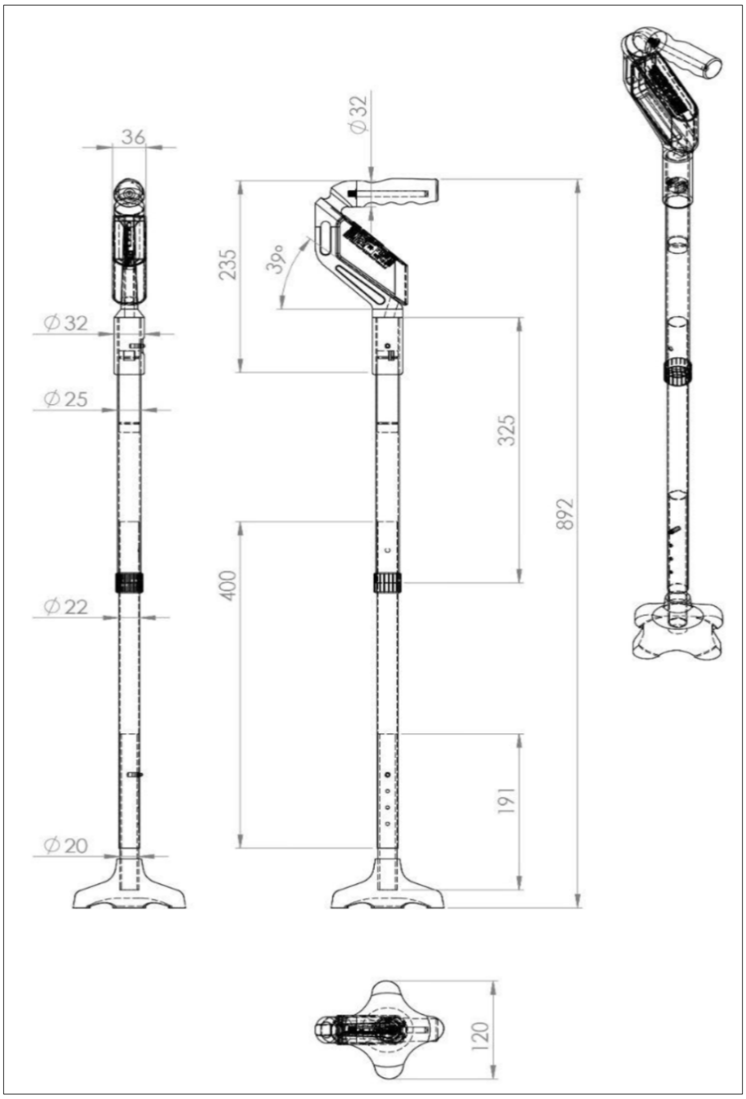

Figure 12 Section View of Cane with dimensions

5. Conclusion

The development of the smart cane with product design approach represents a significant step forward in assistive technology. By incorporating quality assurance as well as advanced features and with proposed testing, this innovative device has the potential to improve the quality of life for individuals with mobility challenges. This work is limited to one iteration of CAD model that yielded a minimum viable product. There are rooms for improvement as other versions can be tried for aesthetic appeal. Future research may explore additional features and design refinements to further enhance the cane's capabilities.

Compliance with ethical standards

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Disclosure of conflict of interest

The author declares no conflict of interest.

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