Smart Crocs: Intelligent Footwear for Enhanced Elderly Independence through Human-Centered Design

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In a world of rapidly aging populations, maintaining independence and safety in everyday life is a pressing concern for many older adults. With age, physical and cognitive limitations can make daily routines more challenging. This project explores the concept and development of "Smart Crocs," a pair of smart shoes designed to support elderly users with intuitive interaction, safety features, and minimal technological friction. Our work addresses not only functional requirements but also emotional needs, such as avoiding feelings of dependence and overcoming anxiety about using new technologies. Through human-centered design methodology, we developed a high-fidelity prototype that integrates LED lighting, fall detection, voice interaction, and emergency alerts into everyday footwear. The prototype demonstrates technical feasibility while prioritizing user autonomy and simplicity of interaction.

CCS Concepts: • **Human-centered computing** → **Accessibility design and evaluation methods**; **HCI design and evaluation methods**; • **Computer systems organization** → *Embedded systems*.

Additional Key Words and Phrases: Human-centered design, assistive technology, elderly care, smart footwear, fall detection, accessibility

1 Introduction and Topic

The global population is aging at an unprecedented rate. By 2050, the proportion of the world's population over 60 years will nearly double from 12% to 22% [1]. This demographic shift brings significant challenges, particularly regarding safety and independence in daily living. Falls represent a critical health concern for older adults worldwide, with an estimated 684,000 individuals dying from falls globally each year, of which over 80% occur in low- and middle-income countries [2]. Adults older than 60 years of age suffer the greatest number of fatal falls, while approximately 37.3 million falls severe enough to require medical attention occur annually [2].

In the United States alone, over 14 million adults ages 65 and older report falling each year, with about 37% of those falls resulting in injuries requiring medical treatment [3]. The financial burden is substantial, with fall-related healthcare costs projected to exceed $101 billion by 2030 [4].

Technology, if applied sensitively and effectively, can provide subtle yet meaningful assistance to address these challenges. However, elderly users often experience technology anxiety and resistance due to complexity, unfamiliar interfaces, and fears of dependency [5]. This creates a critical need for assistive technologies that operate in the background while preserving user autonomy and dignity.

Recent advances in smart footwear technology have shown promising applications in healthcare monitoring and fall prevention. Smart shoes have ushered in a new era of personalized health monitoring and assistive technologies, incorporating accelerometers, gyroscopes, and pressure sensors to enable functionalities such as gait analysis and fall detection [6]. Research has demonstrated that smart footwear can achieve high accuracy rates, with some systems reporting sensitivity rates above 96% and specificity rates above 98% for fall detection [7].

This project explores the concept and development of "Smart Crocs," a pair of smart shoes designed to support elderly users with intuitive interaction, safety features, and minimal technological friction. Our work addresses not only functional requirements but also emotional needs, such as avoiding feelings of dependence and overcoming anxiety about using new technologies. The concept was guided by personas like Gerda (75) and Willma (85), elderly individuals who live alone and face mild sensory and mobility challenges. While Gerda uses a smartphone with difficulty, Willma experiences light vision impairment. Both value autonomy but recognize the need for subtle support.

Smart Crocs are designed to meet such needs with features including responsive LED lighting, voice commands, and an emergency alert system that functions without the need for complicated interfaces. The goal is to create a product that enhances independence without being invasive or overly technical.

2 Design Process

Our design approach followed human-centered design (HCD) principles, which emphasize placing the user at the heart of the design process to create effective solutions that cater to users' unique challenges and desires [8]. HCD emphasizes empathy, extensive user research, and iterative testing to ensure that the final product genuinely benefits its end-users [9].

2.1 User Research and Persona Development

The design process began with empathetic research and the development of personas that reflect real user needs. We identified that elderly users face a fundamental tension between needing support and maintaining independence. Through our research, we uncovered three core user needs that became central to our design:

Independence (Selbstständig): Users want support without feeling dependent. Technology should work in the background to help (e.g., warnings, emergency calls). As our persona Wilma (85) expressed: "I want to live independently for as long as possible and be able to organize my daily life myself."

Security (Sicherheit): Technology must function simply and be there in emergencies (emergency systems, reminder functions). Users need assurance that help will arrive quickly when needed, as Wilma lives alone but receives help from care services and family.

Simple Operation (Einfache Bedienung): Avoid complicated touch interfaces. Devices and interfaces must be intuitive without hidden functions. As Gerda (75) stated: "I want to use the technology, but it has to understand me, not the other way around."

Central concerns included the need for non-intrusive, reliable support systems that work in the background, especially in cases of low visibility or accidents. Our team focused on a design that would minimize the cognitive and operational load on the user, ensuring the system is intuitive and always ready when needed.

2.2 Design Principles

We applied human-centered design principles, iterating through multiple brainstorming and sketching phases before arriving at a concept that combined light-based feedback, voice activation, and balance monitoring. Key design principles included:

- **Simplicity:** No complex user interface or setup process
- **Responsiveness:** Reacts to voice and motion
- **Safety:** Provides assistance and alerts when a user might be at risk
- **Low maintenance:** Requires minimal user effort to operate or maintain

These principles were then translated into a low-fidelity prototype to validate the concept at an early stage. The choice of Crocs as the base footwear was deliberate—they are comfortable, easy to put on, and already familiar to many elderly users, reducing the learning curve for adoption.

3 Prototyping & Evaluation

3.1 Initial Low-Fidelity Prototype

Our initial low-fidelity prototype consisted of cardboard mock-ups shaped like Crocs, with LEDs and pressure sensors integrated to demonstrate the core interaction concept. The primary functionality was straightforward: when a user placed their foot inside the shoe, embedded LEDs illuminated to assist with night-time navigation. When not in use, the lights either remained dim or switched off entirely, minimizing unnecessary visual clutter while still allowing the shoes to be located in a dark room.

From a technical standpoint, we relied on simple, easily obtainable components: pressure sensors embedded in the sole to detect foot presence, and LED lights to provide immediate visual feedback. This basic setup allowed us to validate assumptions about interaction flow, perceived usefulness, and energy efficiency, while also confirming that the activation logic could be achieved with inexpensive microcontrollers.

3.2 Evaluation Approach

As the prototype was not yet wearable, we conducted an internal role-play evaluation to simulate user interactions. Scenarios included waking up at night and locating the shoes without turning on a main light, as well as mimicking a slipping incident while walking. Team members alternated roles as both user and observer, documenting observations and discussing potential improvements.

3.3 Insights from Role-play

One important finding was that the "always-on dim light" mode, while useful for locating the shoes, could disturb sleep if the shoes were stored within the bedroom. This prompted us to consider a voice-controlled activation feature—allowing the user to say a simple phrase such as "lights on" to trigger illumination. This preserves the benefit of finding the shoes easily while avoiding unnecessary nighttime glare.

In parallel, we explored the possibility of integrating a lightweight voice assistant for simple queries and alerts. Building on this, future iterations may include gyroscopes and accelerometers to detect falls, sudden trips, or abnormal shoe orientation. In such cases, the system could send a wireless alert to a caregiver's device, triggering an audible alarm or push notification.

3.4 High-Fidelity Prototype Development

Based on the findings from our low-fidelity prototype, we developed a high-fidelity version that integrates multiple sensors and interaction modalities:

Hardware Components:

- Custom case designed to fit Crocs footwear
- LED light strips for visual feedback and safety lighting
- Pressure sensors for foot detection
- Gyroscope and accelerometer for fall detection
- Microphone for voice command input
- Audio output for system feedback
- Wireless connectivity for emergency alerts

Core Functionality:

- **Automatic Activation:** LEDs activate when foot pressure is detected
- **Voice Commands:** Simple phrases like "lights on" for manual control
- **Fall Detection:** Gyroscope data analysis for sudden orientation changes
- **Emergency Alerts:** Automatic notification to designated contacts
- **Low-light Navigation:** Gentle illumination for nighttime movement

3.5 Design Iteration

Based on the findings from our low-fidelity prototype, we identified several areas for iteration:

Lighting Logic: Replace always-on dim lighting with on-demand activation, either voice-controlled or triggered by foot proximity sensors.

Emergency Feature: Add on-board fall detection using inertial sensors, coupled with automated caregiver alerts.

Real-World Testing: Recruit participants from the target demographic (e.g., "Gerda" or "Willma" personas) to validate comfort, usability, and acceptance.

3.6 Benefits and Limitations

Our current prototype demonstrates several key benefits:

Benefits:

- **Enhanced Safety:** Fall detection enables preventive measures and emergency notifications
- **Interactive Communication:** Audio output provides warnings and guidance
- **Visual Safety:** LED lighting improves visibility in low-light conditions
- **Automatic Activation:** Energy-efficient operation through pressure detection
- **Health Monitoring:** Potential for gait analysis and movement tracking

Limitations:

- **Power Management:** Regular charging required, increasing maintenance burden
- **Error Sensitivity:** False alarms possible; fall detection not 100% reliable
- **Privacy Concerns:** Data security risks and cyber security vulnerabilities
- **Comfort Issues:** Embedded technology may affect wearing comfort
- **Durability:** High daily usage stress on electronic components
- **Software Dependency:** Features rely on functioning app or software systems

3.7 Limitations of Current Approach

Several limitations must be acknowledged in our current prototype:

- Electronics remain externally mounted and not fully integrated into the shoe form factor
- No empirical user testing with members of our target demographic
- Limited long-term durability testing under real-world conditions

Ultimately, these steps will guide us toward a functional, wearable prototype capable of extended in-the-wild testing, with potential integration into a companion app for caregivers to monitor safety events and daily activity patterns.

4 Outlook and Conclusion

The Smart Crocs project demonstrates how thoughtful, user-centered design can make assistive technologies more approachable for elderly users. By embedding sensors and intelligent responses into an everyday item like shoes, we aim to create a product that enhances independence without being invasive or overly technical.

4.1 Future Development Steps

Our next development phases include:

Prototype to Product: Develop a high-fidelity prototype using actual Crocs, focusing on improved integration of electronics and real-world performance testing. This includes miniaturizing components and improving the robustness of the system for daily use.

App Integration: Create a companion mobile application or web interface for:

- Displaying fall detection data and movement patterns
- Managing emergency contact notifications
- Monitoring battery status and system health
- Providing family members with non-intrusive activity updates

Real-world Testing: Conduct extended evaluation with elderly participants in their home environments to validate:

- Long-term usability and acceptance
- System reliability under various conditions
- Impact on user confidence and independence
- Integration with existing daily routines

4.2 Research Contributions

This work contributes to the growing field of assistive technology design in several ways:

- Demonstrates the application of human-centered design principles to elderly-focused assistive technology

- Shows how everyday objects can be augmented with smart capabilities while preserving familiarity
- Provides insights into balancing technological sophistication with user simplicity
- Offers a framework for developing non-intrusive monitoring systems that preserve user dignity

4.3 Broader Implications

Smart Crocs represent a broader approach to assistive technology that prioritizes user agency and normalcy. Rather than stigmatizing medical devices, embedding assistance in everyday objects can help elderly users maintain their self-image while gaining safety benefits. This approach aligns with the principles of Universal Design, creating products that benefit users across age ranges and ability levels.

The project also highlights the importance of emotional considerations in the design of technology for elderly users. By focusing on autonomy, simplicity, and non-intrusiveness, we address not just functional needs but also psychological well-being and social acceptance.

Ultimately, Smart Crocs aim to strike a balance between assistance and autonomy, allowing elderly users to feel supported, without feeling dependent. The combination of simple interactions (such as pressure detection and voice commands), reliable safety features, and a discreet design philosophy offers a promising direction for wearable assistive technologies.

In the near future, we plan to explore the connectivity of the app to allow family members or healthcare professionals to monitor alerts and provide remote assistance when needed. The ultimate goal remains to create technology that empowers rather than constrains, supporting aging in place while maintaining dignity and independence.

5   Distribution of Work

The Smart Crocs project was completed through collaborative effort across multiple domains:

Nina: Focused on user research and persona development, performed role-play evaluations, and came up with trade-offs and look-out.

Xara: Covered the 3D printing process as well as modeling. She helped with the research and came up with the user flow for the demo.

Marcus: Led the technical implementation and hardware integration, developed the high-fidelity prototype, managed sensor integration and system architecture.

Philipp: Product management and presentations created. Helped with the basic setup of the technical prototype.

All team members contributed equally to the conceptual development, design iteration process, and final documentation. The interdisciplinary collaboration between design research, technical implementation, and user experience expertise was essential to project success.

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