Redesigning Low Cost Smart Walking Cane for Visually Impaired Individuals Using Design to Cost

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Abstract

Mobility and independence remain significant challenges for individuals with visual impairments, particularly due to the limited availability of affordable assistive technologies. This study presents the redesign of a low-cost smart walking cane using the Design to Cost (DTC) approach, which emphasizes cost as a key design constraint without compromising essential functionality. The research methodology includes user needs analysis, concept development, material and component selection, prototyping, and performance testing. The proposed cane integrates a PVC shaft, an ultrasonic sensor, an Arduino Nano microcontroller, and a vibration motor to provide tactile feedback when obstacles are detected within a range of 2–30 cm. The prototype demonstrates responsive performance, ease of use, and ergonomic suitability, with an estimated production cost of approximately IDR 120,000, making it accessible to low-income users. Despite its effectiveness, the system is limited by a short detection range and the absence of advanced navigation features. Overall, this study highlights that simple and cost-efficient design strategies can produce functional assistive devices, contributing to improved safety, independence, and quality of life for visually impaired individuals, while offering a foundation for future development of more advanced and inclusive mobility aids.

Keywords: *Affordable Smart Walking Cane, Arduino Nano, Design to Cost (DTC), Ultrasonic Sensor, Visual Impairment*

1. INTRODUCTION

Mobility is one of the most essential aspects of daily life, yet it remains a major challenge for individuals with visual impairments. Navigating safely in both familiar and unfamiliar environments requires not only physical support but also reliable tools that can help detect obstacles and provide environmental awareness. The traditional white cane, while widely used, primarily functions as a contact-based tool, meaning obstacles are only detected after physical interaction. This limitation increases the risk of accidents, especially when encountering obstacles above ground level or at a distance. As a result, many visually impaired individuals still face difficulties in achieving full independence and confidence in their mobility.

Walking canes for visually impaired individuals are currently available in various types, ranging from simple conventional canes to smart walking canes equipped with ultrasonic sensors or Internet of Things (IoT)-based technology. Although the innovation provides additional benefits, its relatively high price is a barrier for many visually impaired individuals to access it. As a result, most still rely on standard canes, which have limitations in detecting hazards or providing maximum

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comfort.

The main problem that arises is the gap between user needs and purchasing power. Visually impaired individuals need a cane that is effective, ergonomic, durable, yet still affordable. In this context, the design-to-cost (DTC) approach can be a solution. DTC is a product design method that sets cost limits as one of the main parameters from the initial design stage (Retolaza et al., 2021). This method emphasizes product design by considering specific cost limits as the main parameter without sacrificing the product's core function. Thus, innovation can be focused on design efficiency, material selection, and cost-effective production processes. This means that the product is designed by simultaneously considering function, quality, and cost, so that the final result meets user needs while also being affordable for the target market.

Design to cost is not just a cost reduction strategy, but also a systematic approach that involves adjusting features, selecting relevant technologies, and optimizing the supply chain. DTC is oriented towards achieving target costs without sacrificing the desired core quality. Through this method, products can be designed to meet the needs of the target users while remaining competitive in the market (Retolaza et al., 2021). The application of this method to the redesign of the walking cane is expected to result in a product that is functional, simple, and affordable for people with visual impairments.

Besides cost factors, ease of use and comfort are also important considerations in the design of a walking cane for visually impaired individuals. The cane should be lightweight, easy to store, strong, and comfortable to grip. The chosen material must support the product's durability while not significantly increasing costs. DTC promotes integration between technical, material, and cost aspects from the beginning of the design process, allowing compromises between function, comfort, and price to be achieved through the selection of alternative materials and component simplification (Hari et al., 2008).

In many developing countries, including Indonesia, the majority of visually impaired individuals have financial limitations. This leads to low access to more advanced assistive technology. Therefore, the availability of walking canes at a low price that still meet safety and functional standards becomes very important. By applying the DTC method, production cost limits can be determined in advance, ensuring that product design truly aligns with the target market's capabilities. With affordable products, it is hoped that the independence and quality of life of visually impaired individuals can be significantly improved.

Previous research has focused more on developing smart canes with high-tech features such as ultrasonic sensors, GPS, or cameras (Riswanto et al., 2025; Tullah et al., 2020; Utomo et al., 2023). Although beneficial, this technology often increases the complexity of care and production costs. Meanwhile, research on redesigning conventional canes with a cost-effective approach is still relatively limited. In fact, according to DTC theory, innovation doesn't always mean adding advanced features, but also how a product can be made more efficient within a set budget without reducing its core functionality (Mörtl and Schmied, 2015)

Thus, the walking cane redesign research using the design-to-cost method aims to address the need for effective and affordable mobility aids. The main focus is to ensure the basic functions of the cane remain optimal, while achieving efficiency in design and material aspects. Based on these considerations, this research aims to redesign a smart walking cane for visually impaired individuals using the Design to Cost approach. The objectives of this study are to identify user needs related to safety, comfort, and usability; to develop a cost-effective design using simple and readily available components; and to produce a functional prototype that enhances obstacle detection while maintaining affordability. Ultimately, this research seeks to contribute to the development of inclusive, practical, and sustainable mobility aids that can improve the independence and quality of life of visually impaired individuals.

2. METHODOLOGY

2.1 Research Process

The research process begins with user observation and interviews regarding the existing design, with the aim of identifying the needs, problems, and limitations experienced by users. The data obtained at this stage serves as the foundation for formulating a new design. Subsequently, the research enters the core process of Design-to-Cost, which begins with defining the design objectives and scope to clarify the boundaries and cost targets to be achieved. The next stage is the identification and evaluation of design alternatives, where various concept options are examined based on their suitability for function, materials, and cost efficiency. After that, the design and prototyping were carried out, followed by implementation and testing to evaluate product performance against the defined functional standards and cost limitations.

The results of subsequent testing processes were analyzed in the analysis phase, which aimed to assess the extent to which the generated design met user needs and the cost targets set in the DTC method. Based on this analysis, the researcher then drew conclusions as an answer to the problem formulation and as recommendations for future product development. The end of the entire process was marked by the completion stage, which summarized the research findings. With this approach, the DTC method ensures that the resulting product not only focuses on functionality and quality but also considers cost affordability from the design stage to implementation.

2.2 Redesign

Product design and development encompasses all processes related to the existence of a product, including all activities from consumer identification to the finished product reaching the consumer. While "redesign" in English, the use of the word "re-" refers to repetition or doing something again. Some definitions of redesign from various sources: The American Heritage dictionary of the English language (2006) states that "redesign means to make a revision in the appearance or function of," which can be interpreted as making a revision in appearance or function. (*Collins English Dictionary*, 2009) that "redesign is to change the design of (something)," which can be interpreted as changing the design of (something). Helmi believes that redesign is the planning and redesigning of a work to achieve a specific goal (Cited from Lisal et al., 2024). Based on the conclusion of the two definitions above, redesign or redesigning aims to produce better benefits than the original design or to produce different functions from the original design.

2.3 Smart Walking Cane

A smart cane is an evolution of the conventional cane, specifically designed for the visually impaired by incorporating sensory and electronic technology to enhance environmental detection capabilities. Theoretically, smart canes integrate technologies such as ultrasonic sensors, infrared, GPS, or cameras to detect obstacles on the road surface as well as objects around the user (Shah et al., 2021). Data from

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the sensor is then processed and translated into signals such as vibrations, sounds, or haptic feedback that the user can understand (Pataropura et al., 2023). From a theoretical standpoint, smart canes aligns with the concept of assistive technology, which are devices designed to enhance the independence and quality of life for individuals with physical (Atyaf Ayman Euyz Hashem et al., 2025). Smart canes offer advantages in enhancing user safety, orientation, and mobility by minimizing the risk of accidents due to visual limitations.

2.4 Design to Cost

The Design for X (DfX) concept is an approach in product design engineering that emphasizes the importance of considering various critical aspects (X) from the early stages of product development. DfX is a set of design principles aimed at optimizing specific characteristics so that a product not only functions according to user needs but also has advantages in the production process, cost, reliability, and sustainability (Song et al., 2022). Generally, DfX has several main branches, each focusing on a specific aspect (Figure 1).

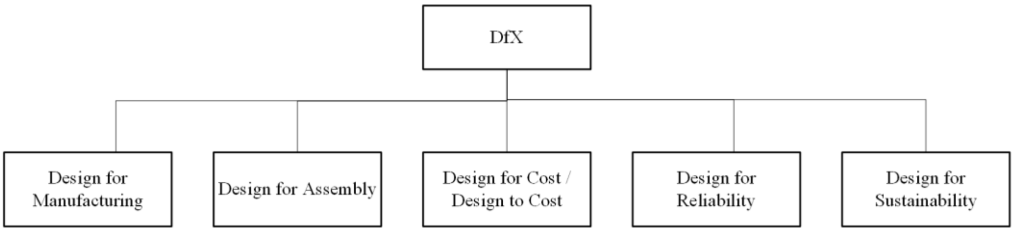

Figure 1 DfX Framework

Based on the framework in Figure 1, Design for Cost or Design to Cost (DfC/DtC) holds a significant position, especially when products are intended for users with financial limitations (Favi et al., 2016). DtC is an approach that ensures products are designed with target costs in mind from the early design stages. According to Mörtl and Schmied (2015) DtC is not just about cost reduction, but a systematic effort to balance quality, function, and price so that products remain accessible to the target users. In other words, cost is not placed as the final outcome, but rather as a design constraint that must be considered integrally alongside functional and technical aspects.

Design to Cost (DTC) methodology enables designers to meet cost goals established at the early stages of product definition. This leads to a situation where the system's overall target cost is necessary, much as, say, the system's overall reliability. Design, development, and production expenditures now account for a large portion of a system's original cost. As a result, in DTC, cost is given the same priority as schedule and performance and is constantly assessed throughout the design and manufacturing phases. Based on the following components, DTC oversees and regulates cost concerns in all development processes, based on the following elements (Hari et al., 2008):

1. Target cost distribution among project cost variables. Target costs are determined by the market or company conditions as well as the price that the client is willing to pay.
2. Provide data and tools for designers to estimate costs and design to fulfill budgetary goals. It is the duty of every designer and design team to reach the budgeted target cost.

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3. Costs are managed using Design to Cost Reviews (DTCR) and cost estimation for every cost aspect. The management continuously assess if the design complies with the goal cost.
4. Corrective measures where necessary to cut expenses. Corrective action is taken right away if the target expenses are exceeded during any stage of the development process.

3. RESULTS AND DISCUSSION

3.1 Design to Cost (DTC) Redesign Process

3.1.1 Define Objectives and Scope

The main objective of this research is to redesign a low-cost walking cane for the visually impaired using the Design to Cost (DTC) approach. Specifically, this research has several objectives:

1. Identifying the primary user needs related to the function, comfort, and safety of the walking cane.
2. Setting affordable production cost targets without compromising the product's core functionality.
3. Designing an affordable, lightweight, and durable walking cane with appropriate material selection.
4. Integrating the Design to Cost principle to ensure that every design decision considers both functionality and cost efficiency.
5. To produce a prototype that can be implemented as an inclusive and affordable mobility aid solution.

The scope of this research is focused on redesigning the walking cane by considering functional and production cost aspects. This research does not emphasize the development of advanced technologies such as integrating GPS or IoT, but rather focuses on simplifying the design and selecting cost-effective materials for making smart walking cane. The scope of the research also includes the user needs observation stage, cost target formulation, design alternative selection, and prototype testing on a limited scale. However, this study does not include an analysis of industrial-scale manufacturing, large-scale field trials, or the integration of smart software. With these limitations, research can be more focused on producing a walking cane design that meets the basic principles of affordability and functionality according to the Design to Cost method.

3.1.2 Identify and Asses of Design Alternatives

Identify Design Alternatives phase is carried out by identifying various design alternatives that can be applied to the smart walking cane product. These alternatives include variations in the selection of the stick material, the type of sensor used, the feedback mechanism, and even the energy source employed. For example, the material for the pole can be considered from aluminum, PVC pipe, or carbon fiber, taking into account factors such as strength, weight, and cost. For sensors, there are alternatives such as ultrasonic, infrared, or LIDAR sensors, each with its own advantages and disadvantages. Similarly, the warning system can be tactile vibrations, audio signals, or even a combination of both, depending on user preference and design complexity.

Next, in the Assess of Design Alternatives stage, each identified alternative is evaluated based on specific criteria such as cost, functionality, ease of production, and user convenience. For example, the use of ultrasonic sensors is considered cheaper

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and quite effective for short-range detection compared to LIDAR, although it has limitations in long-range accuracy. Aluminum material is superior in strength and lightness compared to PVC, but it has a higher production cost. Vibration-based warning systems are more intuitive for the visually impaired than audio signals because they reduce the risk of environmental noise and are easier to perceive directly.

Based on this assessment, the selection of the best design must consider the balance between functional and cost aspects in accordance with the Design to Cost principle. The ideal alternative is the use of a PVC cane, an ultrasonic sensor with medium detection range, and a vibration motor as a tactile warning system. This combination is considered the most efficient in terms of affordability, durability, and user comfort. With this approach, the resulting smart walking cane is expected to provide an effective solution for the visually impaired without burdening production costs or selling prices. The list of main components used is as follows:

1. A PVC pipe rod 100 cm long was chosen because it is lightweight, strong, and economical, making it suitable for use by people with disabilities without burdening their mobility activities.
2. The ultrasonic sensor installed at the end of the cane detects the presence of obstacles or objects with an effective range of 2 cm to 30 cm.
3. The mini vibration motor embedded in the handle acts as a haptic feedback system.
4. A microcontroller (Arduino Nano) is used as the data processing center for the sensors and the main controller of the system.
5. The electrical system consists of jumper cables, connectors, and the soldering process required to connect all electronic components together neatly.
6. The outer casing serves to protect electronic components from physical damage and environmental interference such as dust and moisture.
7. Adhesives and assembly tools like epoxy glue, screws, and brackets are used to install components in the correct and sturdy positions.
8. Manual assembly labor, although simple, is still included into cost estimates because it involves time and technical skills to assemble and test the tool until it functions as intended.

The estimated cost required to produce one smart walking cane is presented in Table 1.

Table 1 Production Cost of Smart Walking Cane

Part(s)	Price (IDR)	Description
PVC Pipe (100 Cm, Ø 26 mm)	15,000	Main material for walking cane
Ultrasonic Sensor	15,000	Module for detection
Arduino Nano	40,000	Controller
Electrical Systems	10,000	Electrical wiring
Outer Casing	10,000	Protect electronic components
Adhesives	7,000	For assembling parts
Assembly Cost	15,000	Labor Cost
Total Cost	120,000	

Based on Table 1 the cost of this cane were assembled using readily available and low-cost components, which amounted to approximately Rp 120,000 per unit. The interpretation of these results indicates that the utilization of simple technologies such as ultrasonic sensors and microcontrollers can bridge the gap between the need for adaptive mobility aids and limited access to advanced technology.

3.1.3 Design and Prototype

The smart walking cane (shown in Figure 2) is designed with a focus on low cost and smart technology to assist users, especially those who are visually impaired and elderly individuals with low incomes. The design retains the traditional ergonomic cane shape for comfortable grip and ease of use, with a hook-shaped handle for mobility and stability. The shaft of the cane is designed to be strong and compact for lightness and portability, yet sturdy enough to support the user's weight. Additionally, this cane is integrated with ultrasonic sensors to assist visually impaired users when walking on roads with obstacles. The design also involves the use of durable, inexpensive, and non-slip materials at the ends to ensure safe use on various surfaces. The overall design prioritizes simplicity, comfort, and easy access to technology to enhance users' independence in daily activities.

Figure 2 Design and Prototype of the Proposed Low-Cost Smart Walking Cane

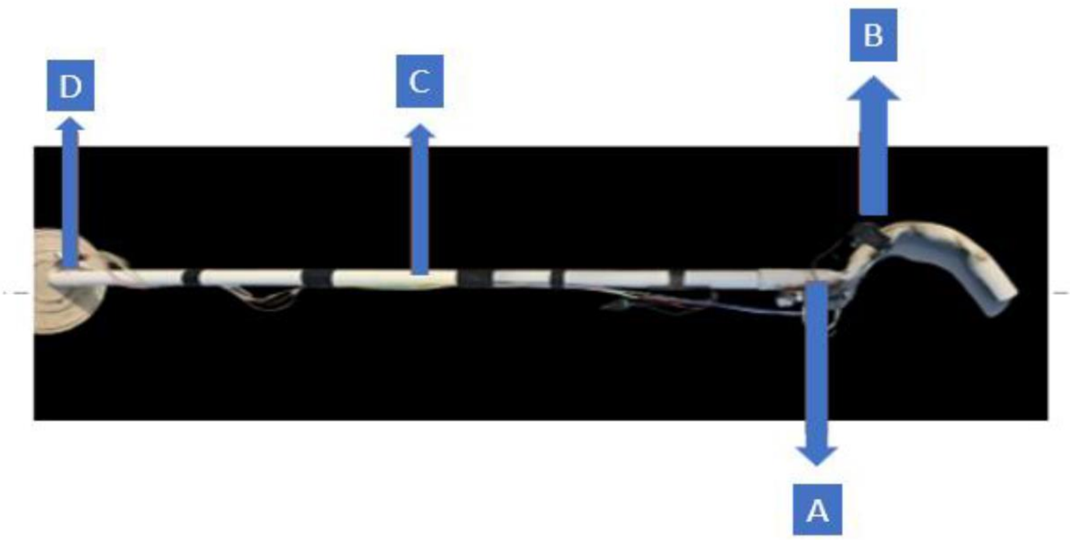

Figure 3 Components of Walking Cane

The smart cane for the visually impaired shown in Figure 3 has four main components that are integrated to support the mobility of visually impaired

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individuals. The first component is the Arduino Uno microcontroller (A), which serves as the control center or brain of the system. This microcontroller is programmed to receive data from the sensor, process the information, and provide a response in the form of an alert to the user. The main role of the Arduino Uno is very important because it determines the accuracy of object detection and the overall effectiveness of the system.

The next component is a dynamo with a mini vibration motor (B) that serves as a tactile warning system. This vibration feedback is very important because it can be felt directly by the user without requiring visual ability. The dynamo produces vibrations at a frequency of approximately 30 Hz when it detects an obstacle, allowing the user to immediately become aware of potential dangers around them. Additionally, the cane (C) itself is designed to be approximately 100 Cm long and 2.6 Cm in diameter, dimensions that are ergonomic and suitable for the mobility needs of the visually impaired.

The final component is the ultrasonic sensor (D), which detects objects in front of the cane at a distance of approximately 30 Cm. This sensor is a key element because it allows the user to know about obstacles before physical contact occurs. With this sensor, the user receives earlier warnings compared to conventional canes. The integration of all components microcontroller, dynamo, stick, and ultrasonic sensor makes this device a significant innovation for enhancing the safety and independence of visually impaired individuals in their daily activities.

3.1.4 Implementation and Testing

The product is a smart walking cane specifically designed to help visually impaired individuals navigate their daily activities more safely, adaptively, affordably, and independently. The redesign was done by substituting materials that made the product unaffordable for some. This material replacement is done while still considering the durability and strength aspects of the walking cane product when in use. Table 2 presents the results of experiments conducted at various distances with interference.

Table 2 Product Testing

Experiment Number	Distance (Cm)	Vibrate	Vibration Produced
1	10	Yes	30 Hz
2	20	Yes	30 Hz
3	30	Yes	30 Hz
4	40	No	0 Hz
5	50	No	0 Hz

3.2 Analysis

This cane product is approximately 100 Cm long with a diameter of 2.6 Cm, and is made from lightweight PVC pipe material that is strong but not heavy when used. The selection of this material considers portability, durability, and low production costs to make it easily accessible to the general public. PVC pipes are also easy to shape, drill, and fit with electronic components without the need for special tools, making them an ideal material for both prototyping and small-scale production. In the handle section, there is an ergonomically embedded mini vibration motor, so the vibrations that appear as a warning signal can be clearly felt directly by the user's hand. The position of this motor is adjusted to the user's hand comfort so that it does not interfere with movement or cause fatigue when used for long periods. At the

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bottom end of the cane, an ultrasonic sensor is installed as an obstacle detection system. This sensor is integrated with an Arduino microcontroller housed in a protective casing on the cane's body. All electronic circuits are connected via jumper wires, solder, and sensor brackets, neatly packaged, safe, and resistant to normal daily use.

In the process of planning the production of a smart sensor cane for the visually impaired, there are a number of technical components and elements required to support the device's optimal functionality. These components were selected based on criteria of efficiency, availability, ease of assembly, and cost considerations. With an estimated production cost of Rp120,000 per unit, this smart cane is considered very inexpensive and affordable. The components used can be easily obtained in both local markets and online electronics stores. Additionally, the simple yet functional product design makes this tool suitable for mass production by communities, social organizations, and educational institutions, aiming to provide wider accessibility for visually impaired individuals in Indonesia.

In Table 1 consists of five experiments with varying distances from 10 cm to 50 cm. In the experiments with distances of 10 cm, 20 cm, and 30 cm, vibration occurred at a frequency of 30 Hz, indicated by the "Vibrate" column having a value of "Yes." However, at distances of 40 cm and 50 cm, vibration did not occur (the "Vibrate" column has a value of "No") and the vibration frequency was 0 Hz. This indicates that vibration only occurs if the distance is within a certain closer range, while at greater distances, vibration is not detected. This product is designed to be easy to use, lightweight, and energy-efficient, and can be used both indoors and outdoors (with a controlled environment). The vibration feedback provided has also been tested to ensure it operates within a sensitivity range suitable for visually impaired users, thus minimizing the risk of confusion or misperception during use.

4. CONCLUSION

This research successfully designed and developed a smart cane prototype based on ultrasonic sensors and vibration motors as an alternative mobility aid for the visually impaired. The research results show that the cane is able to detect the presence of obstacles within a distance of 30 cm responsively and provide direct vibration feedback at 30 Hz through a tactile motor installed in the handle. The design and cost of this cane were assembled using readily available and low-cost components, which amounted to approximately Rp 120,000 per unit. The interpretation of these results indicates that the utilization of simple technologies such as ultrasonic sensors and microcontrollers can bridge the gap between the need for adaptive mobility aids and limited access to advanced technology.

From an engineering perspective, the success of this project also demonstrates the practical implementation of cost-effective design principles. By selecting inexpensive local components, employing a minimalist design without sacrificing functionality, and utilizing simple production methods, this smart cane can be realized at a low cost without compromising the quality of the results. This serves as proof that budget limitations are not an obstacle to inclusive and widely impactful technological innovation.

This research could be made stronger by testing the cane in more realistic environments and involving a larger number of users to better understand how it performs in everyday situations. Adding user feedback through simple surveys or

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usability tests would also help show how comfortable and easy the device is to use. It would be helpful to include more detailed technical analysis, such as how accurate and responsive the sensor is, as well as information about battery usage. For future research, the cane could be improved by combining multiple sensors, adding smarter feedback (like varying vibrations or audio), and integrating features such as GPS or mobile connectivity, explore AI-based object detection, better ergonomic design, and wider testing in real life settings to ensure the product is truly useful and accessible for users.

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