EFFICIENCY MANUFACTYRING BY REAL-TIME MONITORING OF POWER TOOLS USING A SMART STORAGE BOX

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ABSTRACT: Storage of power tools is of utmost importance, primarily due to the limited storage space available and the need to ensure that all used tools are returned to their proper place, aiming to assure work / manufacturing efficiency. In response to this ongoing problem, the current study aims to develop an innovative solution: a smart storage box. This smart storage box is designed to provide users with real-time information about its content and location. Equipped with advanced sensors and connectivity features, the box will allow users to quickly and easily checking the presence and correct positioning of each tool, as well as where it is. By integrating technology into tool storage, represents a significant step forward in addressing the practical challenges faced by both individual users and larger organizations. The goal is to reduce time spent searching for tools, minimize the risk of loss or misplacement, and ultimately simplify workflow, and consequently *attaining manufacturing efficiency*.
KEYWORDS: efficiency, manufacturing, smart, storage, real-time monitoring, power tools.

1. INTRODUCTION

Storing power tools is a major challenge for both individual users and large organizations. One of the main difficulties encountered is limited storage space. In small workshops or on construction sites, space for tools is often limited, resulting in clutter and inefficient organization. Such a situation not only makes it difficult to quickly find the necessary tools but can also lead to their damage due to improper storage [1].

1.1 Background and Issues

In addition to the issue of space, ensuring that tools are returned to their proper place after use is another significant challenge. In the absence of an effective monitoring system, tools are often misplaced, lost or even stolen. This not only *generates additional costs for replacing lost tools but also affects the efficiency and productivity of work teams*. In large environments, such as factories or sprawling construction sites, locating a single tool can consume valuable time, disrupting workflow.

Furthermore, the lack of an adequate logistics management system can lead to inefficient use of resources. For example, tools may be doubled or even tripled unnecessarily due to not knowing the exact status of the inventory. Thus, the tools that are available are not used optimally, and teams may end up buying unnecessary additional equipment [2].

1.2 Proposed Solution Importance

In the context of the contemporary challenges of managing resources and optimizing operational efficiency. A smart storage box represents a significant advance in the field of tool management, bringing multiple benefits that meet the needs of both individual users and large organizations in manufacturing.

First, such a smart solution allows real-time monitoring of the presence and location of tools. By integrating advanced sensors and connectivity technology, users can quickly check that all tools are in their proper place. This considerably reduces the time spent searching for tools and minimizes the risk of loss or theft, thus ensuring better resource management in manufacturing processes.

Second, the proposed solution contributes to improving the organization and use of storage space. Effective organization reduces the risk of tool damage due to improper storage and ensures a longer tool life [1].

In addition to the practical aspects, a smart storage box also brings significant economic benefits. By reducing losses and the need to replace frequently lost or stolen tools, operational costs are reduced. In addition, real-time tool monitoring enables better planning and resource utilization, avoiding the purchase of unnecessary additional tools [2].

The development of a smart power tool storage box represents an innovative and practical solution to today's tool management challenges. Its benefits include real-time monitoring, efficient organization, significant cost savings and increased security, all of which contribute to better operational efficiency and optimized resource management.

2. STATE OF THE ART

Currently, the management of power tools, including their storage and monitoring, is conducted through a range of methods, each bringing unique advantages while also presenting notable limitations. Understanding these existing solutions and their gaps is essential for developing an advanced, more efficient system.

2.1 Existing Solutions

Several methods are currently employed to store and monitor power tools. These include:

Traditional storage boxes: These are basic storage units, typically made from metal or plastic, designed to hold and organize power tools. Traditional storage boxes are widely used due to their affordability and simplicity. They are available in various sizes and configurations, suitable for different types of tools. However, they are limited in their functionality, offering no built-in monitoring capabilities or advanced security features. This means that while tools can be neatly stored, there is no way to track their presence or ensure they are accessed only by authorized personnel (Figure 1) [3].

Figure 1. Traditional storage boxes [4].

Manual tagging and inventory systems: In this approach, each tool is tagged, often with a barcode or RFID tag, and an inventory list is maintained, typically on paper or in a basic database. Users must manually update the inventory list whenever a tool is checked out or returned. This method can work effectively in small, well-organized environments where the number of tools is manageable. However, it is time-consuming, labor-intensive, and prone to human error. The reliance on manual entry increases the risk of discrepancies in the inventory records, leading to potential tool loss or misplacement (Figure 2) [5].

Figure 2. Manual labeling systems [6].

Storage boxes with electronic locks: these are enhanced versions of traditional storage boxes, equipped with electronic locking mechanisms that restrict access to authorized users only. These systems add a layer of security by requiring a PIN, keycard, or biometric verification to open the box. While this feature helps prevent unauthorized access and potential theft, it does not actively monitor the tools inside. There is no capability to track whether a tool has been removed or returned, nor is there information on the tool's current location within or outside the box (Figure 3) [7].

Figure 3. Storage boxes with electronic locks [8].

Power tool management software solutions: These solutions involve specialized software, often accessible through mobile apps or online platforms, that allows users to register, track, and manage tools. The software can include features such as inventory management, maintenance scheduling, and usage tracking. While these platforms offer enhanced organization and can significantly improve inventory management, they generally depend on manual input from users to update the status of tools. Additionally, they lack real-time monitoring, meaning they cannot provide instant updates on the presence or location of tools (Figure 4) [2].

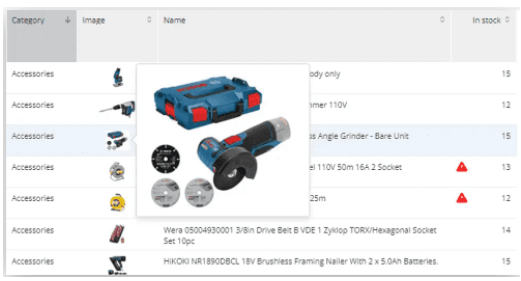

Figure 4. Tool management software solutions [9].

2.2 Gaps in Existing Solutions

Despite the various benefits offered by current solutions, they also exhibit significant limitations,

which highlight the need for a more sophisticated approach to power tool management (Figure 5):

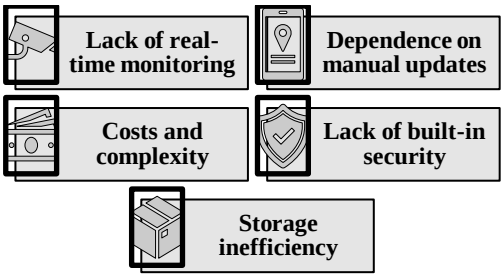

Figure 5. Gaps in the current storage boxes.

Lack of Real-Time Monitoring: A major shortfall of existing systems is the inability to monitor tools in real time. Without real-time tracking, it is challenging to know the immediate status or location of a tool, leading to inefficiencies and increased risk of loss or theft.

Reliance on Manual Updates: Many current solutions require users to manually update inventory records, which can introduce human error. Inaccuracies in tracking can result in misplaced tools, delays in work, and potentially costly replacements.

Cost and Complexity: Advanced solutions, such as those involving software or electronic locks, can be costly and complex to implement. This makes them less accessible to individual users or smaller organizations, who may not have the resources to invest in these systems.

Lack of Built-In Security: Basic storage solutions, such as traditional boxes, do not incorporate advanced security features, making them vulnerable to unauthorized access and theft. Even more advanced boxes with electronic locks do not provide comprehensive security, as they lack monitoring capabilities to ensure tools are returned after use.

Inefficiency of Organization: Existing storage solutions do not always optimize space efficiently, nor do they ensure that tools are organized in a manner that prevents damage or makes them easy to locate. Poor organization can lead to wasted time and reduced productivity.

2.3 Relevant Technologies

In order to develop a smart storage box that responds to the identified gaps, the product will integrate the following advanced technologies (Figure 6):

Advanced Sensors: The smart storage box will incorporate presence and motion sensors, which will automatically detect when tools are added or removed. These sensors will enable real-time monitoring, allowing users to know the exact status and location of each tool at any moment.

IoT (Internet of Things) Connectivity: By equipping the storage box with IoT connectivity, the system will be able to transmit data to a mobile or web application. This feature will allow users to access real-time information about their tools from anywhere, improving flexibility and responsiveness in tool management.

Notification and Alert Systems: The system will include sophisticated monitoring algorithms that analyze data from the sensors. If a tool is not returned to its designated place or is moved outside a predefined area, the system will automatically send notifications and alerts to the user. This proactive approach will significantly enhance the security and management of tools [10].

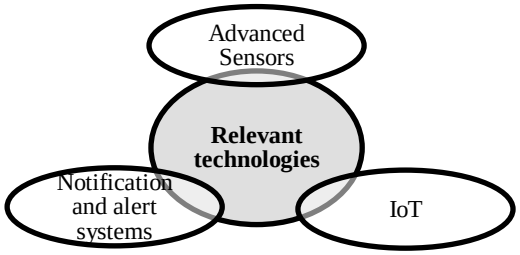

Figure 6. Relevant technologies to be implemented.

By integrating these technologies, the proposed solution aims to provide a more comprehensive, efficient, and secure method of managing power tools, addressing the limitations of current systems and offering users a significant upgrade in functionality.

3. SMART STORAGE BOX DEVELOPMENT

In this section, will be discussed the primary and secondary functions, product design, technical description, product functionality, and advantages and disadvantages of the developed product.

3.1 Primary and Secondary Functions

The developed product is designed to serve as an advanced tool management system, integrating multiple functionalities that ensure efficient monitoring, positioning, and tracking of tools. Below is a detailed explanation of the primary and secondary functions that the product must possess (Figure 7):

A. Primary Functions

1. Monitoring Tool Presence and Positioning:

- **Pressure Sensors (FSR - Force Sensitive Resistor):** These sensors are crucial for detecting whether tools are properly placed in their designated compartments. By measuring the pressure applied, the sensors provide real-time feedback. If a tool is missing or incorrectly placed, the sensors immediately detect this and alert the user.
- **Visual Feedback:** Based on the input from the sensors, an LCD/OLED display along with colored LEDs (green and red) provide clear visual indications to the user. When all tools are correctly positioned, the display will show "*OK*" and the green LED will

light up, signaling that everything is in order. If any tool is out of place or missing, the display will show "*NOK*" and the red LED will light up, indicating that further action is required.

2. Closure Feedback:

○ **LCD/OLED Display:** During the process of closing the toolbox, the display will provide information on whether all tools are correctly positioned and if the box can be safely closed. A "*OK*" message indicates that the tools are properly placed and the box can be securely closed. If the display shows "*NOK*," it serves as a warning to the user that the tools need to be checked again before the box can be closed.

3. Connectivity and Real-Time Monitoring:

○ **IoT (Internet of Things) Module:** This module facilitates real-time data transmission to a mobile or web application. Through this application, users can monitor the status of the tool box and the positioning of the tools remotely. This is especially useful in environments where tools are frequently moved or need to be tracked across different locations. The real-time data ensures that users are always aware of the current state of their tools, enhancing overall management and security.

4. GPS Localization:

○ **GPS Module:** This feature provides location tracking for the toolbox, allowing users to pinpoint its exact position at any given time. This is particularly beneficial in large environments such as construction sites or outdoor workspaces where tools are often relocated. By knowing the precise location of the toolbox, users can efficiently manage their tools and ensure they are always available where needed.

B. Secondary Functions

1.Loss Detection and Alerts:

○ **Pressure Sensors and Notifications:** If a tool is removed or moved outside a specified area, the pressure sensors will detect the change, and the system will send alerts to warn the user.

2.Space Efficiency:

○ **Efficient Organization:** The system helps maintain an organized storage space, preventing tool damage and ensuring optimal use of the tools.

3.**Power Supply and Energy Efficiency:**

○ **Power Sources:** The box can be powered either by an AC-DC adapter for fixed use or by rechargeable batteries for portability. The system is designed to save energy and operate efficiently over the long term.

The proposed smart storage box offers an advanced solution for organizing and monitoring tools, integrating essential functions such as monitoring tool presence through pressure sensors and visual feedback, IoT connectivity for real-time updates, and GPS localization for efficient tracking. Additionally, it provides important secondary functions such as loss detection and efficient space management, all powered by economical and sustainable sources.

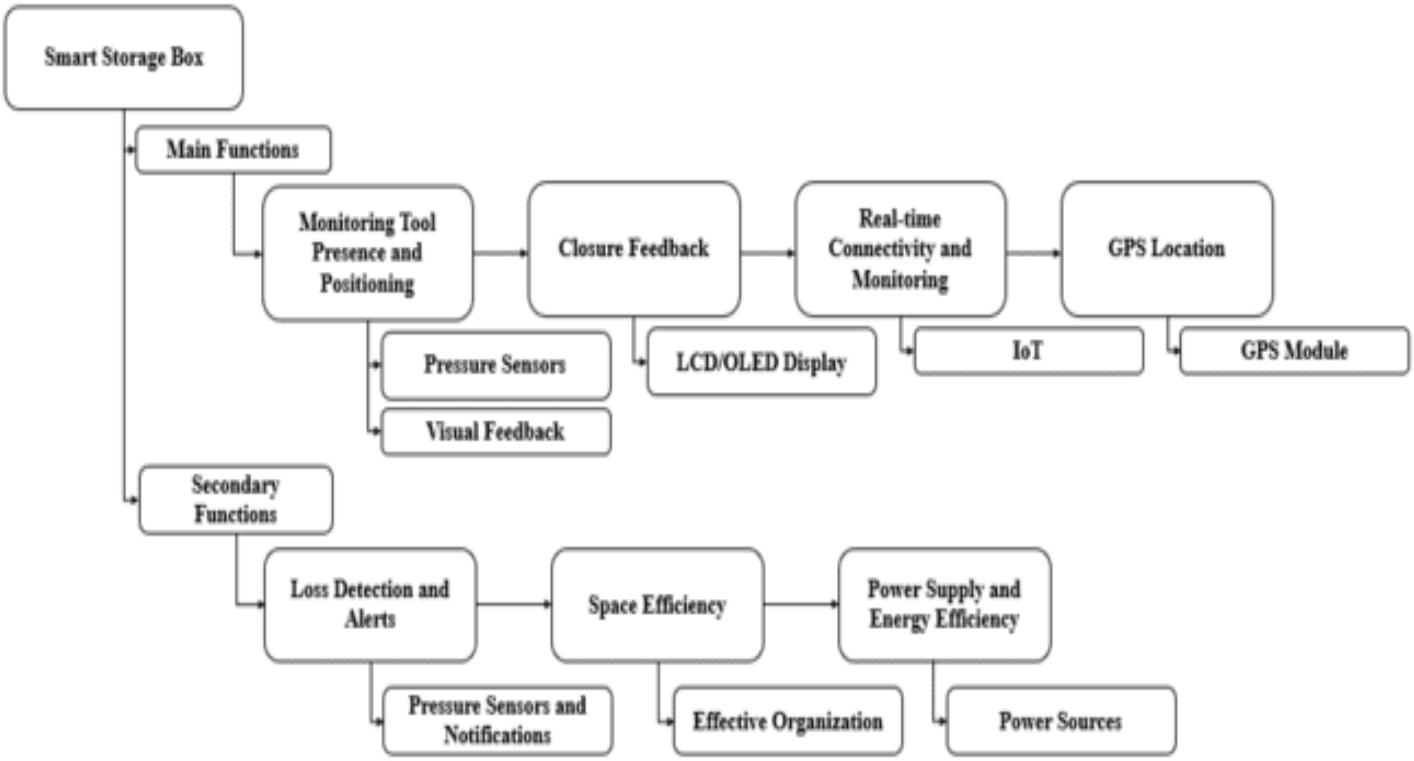

Figure 7. Primary and secondary functions.

3.2 Product Design

A smart storage box has been developed that provides the user with information about its contents when closed. This functionality is illustrated in Figures 8a and 8b.

Figure 8a shows an example where the storage box displays the message "*OK*" on an integrated screen when all tools are placed inside it. This indicates to the user that all the tools are in the right place and that they can safely close the box. This visual feedback allows the user to quickly and efficiently check that all tools are stored properly.

In Figure 8b, the smart storage box displays the message "*NOK*" on its screen at the time of closing. This indicates that not all tools are inside the box or that one or more are missing. This error message warns the user to recheck the contents of the box and ensure that all tools are inserted before closing. This functionality of the smart storage box brings multiple advantages. Users benefit from a useful tool to quickly verify that all tools are correctly replaced before leaving the job site or closing the box. This reduces the risk of forgetting or losing tools, contributing to organization and efficiency in the use and management of tools.

The design of this smart storage box, which provides visual feedback on its contents, assures users that all tools are inside the box and contributes to more efficient and safe equipment management.

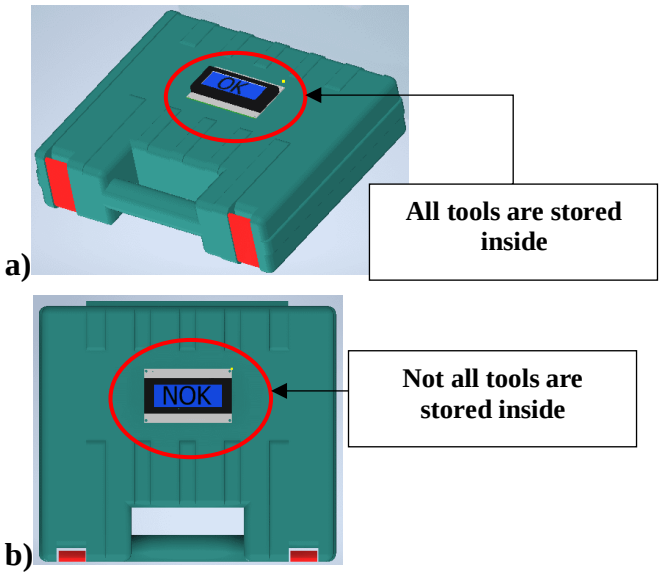

Figure 8. Smart storage box.

Within the smart storage box, pressure sensors have been integrated to indicate to the user whether the tools are properly placed inside it. This functionality is illustrated in Figures 9, 10, and 11.

Figure 9 shows an example where the storage box displays the message "*OK*" and emits a green light when the tools are placed in the right place and apply proper pressure to the pressure sensors. This indicates to the user that all tools are in the correct position and are well placed inside the box. This visual confirmation and green light assures the user that the tools are safely stored and that they can close the box with confidence.

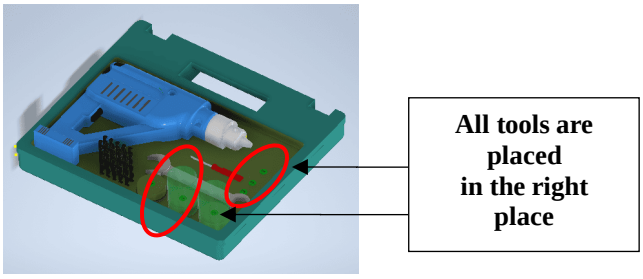

Figure 9. Checking if the tools are placed in the right place.

In Figure 10, the smart storage box displays the message "*NOK*" and emits a red light when the tools are not placed correctly inside the box or when the pressure applied to the pressure sensors is insufficient. This error message and red light alerts the user to check the positioning and securing of tools inside the box to ensure they are stored properly.

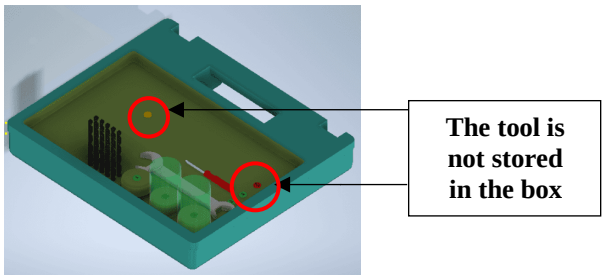

Figure 10. Two tools are missing.

In Figure 11, the smart storage box also displays the message "*NOK*" and emits a red light when the tools are not positioned in the right place, but applies adequate pressure to the pressure sensors. This indicates that the tools are placed in the box, but not placed in the correct position or replaced in the designated compartments. The user is thus cautioned to adjust the position of the tools to ensure they are stored properly.

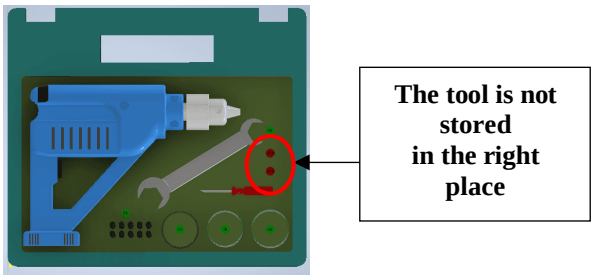

Figure 11. The tools have been placed in the right place.

This innovative smart storage box functionality, with pressure sensors and visual cues, ensures users that tools are placed correctly and applies adequate pressure inside the box. This contributes to better organization of tools, prevents damage to them and minimizes the risk of loss or confusion as to location.

3.3 Technical Description of the Operating Mode (Figure 12):

Pressure Sensors: Force Sensors Resistive (FSR) that can detect the presence and positioning of tools. These sensors are mounted in the compartments of the box, underneath each tool.

Controller: A microcontroller to collect data from the sensors and control the display and LEDs. An Arduino board can be used for this purpose due to its simplicity and flexibility.

Display: An integrated screen to display "*OK*" and "*NOK*" messages. The display can be a 16x2 LCD or a smaller OLED.

LEDs (Green and Red): LEDs for additional visual feedback. The green LED indicates that all tools are correctly placed, while the red LED signals an issue (missing or incorrectly positioned tools).

Power Supply: A suitable power source for the microcontroller and sensors, such as an AC-DC adapter or a rechargeable battery pack.

Connectors and Cables: Connectors and cables to link all the components together.

GPS Module: A GPS module to transmit the real-time position of the tools to the microcontroller.

Software: Code for the microcontroller to manage the sensors and control the display and LEDs.

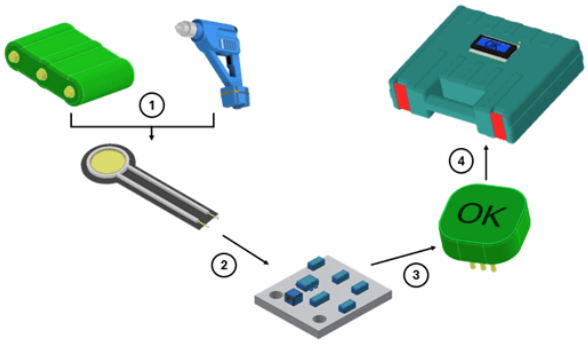

Figure 12. Technical description of the functionality of the designed product.

In Figure 13 the technical process of GPS module operation is presented.

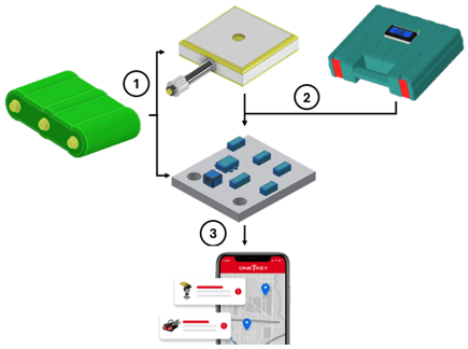

Figure 13. The technical process of GPS module operation.

Figure 14 shows the main components of the smart storage box.

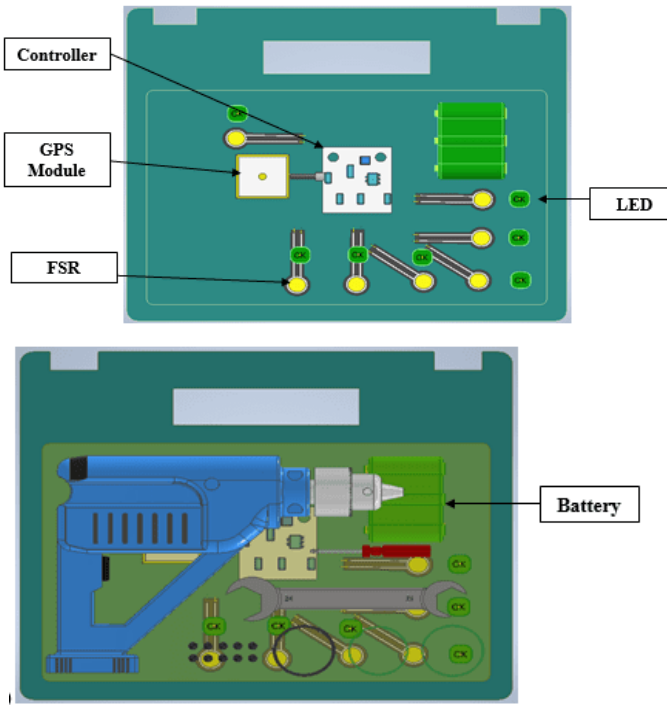

Figure 14. Main components of the smart storage box.

3.4 Description of Product Functionality

The functional role of a smart storage box for power tools is to provide an organized way to store and transport tools and drilling accessories, while also offering a range of smart features that can enhance the user experience.

The smart features of the storage box may include Bluetooth connectivity, allowing it to communicate with other devices such as smartphones or tablets. This connectivity can offer a range of benefits, such as real-time tracking of the box's location or monitoring the status of the stored tools.

For example, the user can receive notifications on their smartphone when the box is moved or opened or check the battery level of the tools stored inside the box. This information can help the user better manage their tools and prevent loss or damage.

The smart features may also include built-in sensors that can detect environmental conditions such as temperature or humidity. This information can be used to ensure optimal storage conditions for the power tools and their accessories, which can help extend their lifespan.

Overall, the functional role of a smart storage box is to provide a secure, organized, and efficient storage solution for tools and drilling accessories, while also offering a range of smart features that can enhance the user experience. Bluetooth connectivity allows for real-time tracking, status monitoring, and other benefits that can help improve the overall performance and longevity of the tools.

3.5 Advantages and Disadvantages of the Developed Product:

While the system offers enhanced security, real-time monitoring, and precise tool management, it also introduces potential challenges such as the need for regular sensor calibration and reliance on stable internet connectivity for optimal performance.

Advantages of the developed product:

1. **Improved Organization:**

- **Quick Check:** Users can quickly verify if all tools are correctly placed in the box before closing it, saving time and reducing stress.
- **Clear Visual Feedback:** The "*OK*" and "*NOK*" messages and light signals (green for *"OK"* and red for *"NOK"*) provide immediate and clear feedback, eliminating the need for additional manual checks.

2. **Increased Safety:**

- **Loss Prevention:** The system reduces the risk of forgetting or losing tools, ensuring that all tools are properly replaced before transport or storage.
- **Tool Protection:** Ensures that tools are correctly placed, preventing damage and extending their lifespan.

3. **Enhanced Efficiency:**

- **Error Reduction:** Displaying the "NOK" message when tools are missing or improperly placed reduces errors and improves accuracy in tool management.
- **Workflow Improvement:** Users can work more efficiently, knowing that their tools are always in the right place and in good condition.

Disadvantages of the developed product:

1. **Initial Costs and Maintenance:**

- **High Investment:** Implementing pressure sensors and visual feedback systems can increase the initial costs of the storage box.
- **Maintenance:** Electronic systems and sensors require regular maintenance to function correctly, which may involve additional costs.

2. **Technical Complexity:**

- **Complex Implementation:** Integrating pressure sensors and feedback screens can be technically complex, requiring specialized knowledge and sophisticated design.
- **Risk of Failure:** Electronic components may be prone to failure, which could lead to display errors or the need for repairs.

3. **Sensor Limitations:**

- **Variable Accuracy:** Pressure sensors may have limitations in accurately detecting smaller tools or improperly placed tools, which can lead to false alarms.
- **Compatibility:** The system may be optimized for a specific set of tools and might require adjustments to work correctly with other types or sizes of tools.

4. LIMITS AND PRACTICAL CHALLENGES

Even though the smart power tool storage box solution has many benefits, there are also certain limitations and practical challenges that need to be addressed to ensure its effective implementation and use.

4.1 Limitations and Practical Challenges

During the development and implementation of the smart storage box for power tools, several limitations and practical challenges were identified that must be addressed to ensure the success and efficiency of the proposed solution (Figure 15).

High initial cost:

a. Challenge: Integrating advanced sensors and IoT connectivity modules involves significant development and manufacturing costs.

b. Impact: These upfront costs can be a barrier for individual users and small organizations that may not have the financial resources to invest in an advanced tool management solution.

Technological complexity:

a. Challenge: Implementing and maintaining advanced technologies such as IoT connectivity requires a high level of technical expertise.

b. Impact: Users without advanced technical knowledge may experience difficulties in effectively configuring and managing the smart box, which may reduce the adoption of the solution.

Battery life and power:

a. Challenge: Sensors and connectivity modules require constant power and battery life can be limited, requiring periodic maintenance and recharging.

b. Impact: The frequency of maintenance and the need to recharge batteries can be inconvenient for users and lead to interruptions in continuous monitoring of tools.

Infrastructure dependent connectivity:

a. Challenge: The optimal operation of the IoT system depends on access to a stable Internet network. In isolated locations or environments with poor connectivity, system performance may suffer.

b. Impact: Users working in areas with poor internet connectivity may have trouble using real-time monitoring and notification features.

Robustness and reliability of sensors:

a. Challenge: Presence and motion sensors must be sensitive and reliable enough to function properly in various usage conditions and environments.

b. Impact: Variable sensor performance can lead to false alarms or failure to correctly detect the presence of tools, thus affecting user confidence in the system.

User interface:

a. Challenge: The user interface must be intuitive and easy to use for people with varying technical skills.

b. Impact: A complicated or unintuitive interface may discourage users from using all system functionality, thereby reducing the overall effectiveness of the solution.

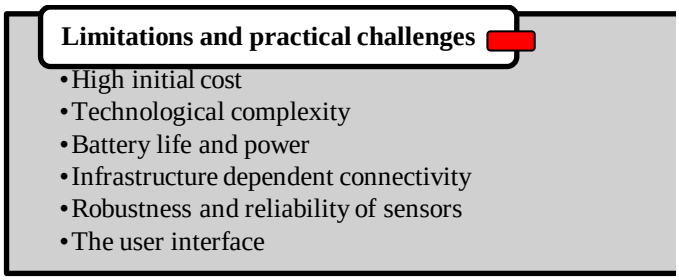

Figure 15. Limitations and practical challenges of the developed product.

4.2 Strategies for Addressing Limitations and Practical Challenges

In order to address these limitations and practical challenges, the following strategies can be implemented (Figure 16):

a. Cost optimization: Investigating more affordable alternatives for technology components and strategic partnerships to reduce production and implementation costs.

b. Training and technical support: Providing training sessions and ongoing technical support for users to facilitate their adoption and effective use of the solution.

c. Sustainable power solutions: Exploring sustainable power options, such as solar panels or other renewable energy sources, to extend battery life and reduce the need for frequent maintenance.

d. Improving connectivity: Implementing hybrid connectivity solutions that include both Wi-Fi and Bluetooth to ensure system operation in various network conditions.

e. Rigorous sensor testing: Conduct extensive testing to validate sensor performance and reliability under various usage and environmental conditions.

f. Developing a friendly user interface: Creating an intuitive and easy-to-use interface based on user feedback and usability tests to ensure an optimal experience.

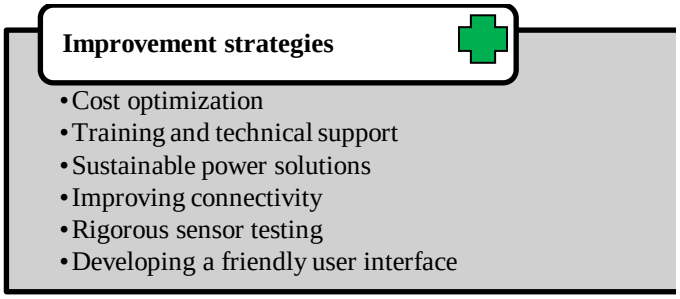

Figure 16. Strategies to improve the limitations and practical challenges of the developed product.

5. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In this section, the conclusions and future research directions will be discussed in detail.

5.1 Conclusions

The use of the smart storage box brings several significant benefits for both individual users and large organizations (Figure 17):

Real-time monitoring: One of the most impactful features of the smart storage box is its ability to monitor tools in real-time. This functionality allows users to immediately know the exact location and status of each tool, eliminating the need to manually search for them.

Efficient organization: The smart storage box is designed with flexible and adjustable compartments that can be customized to fit various tool sizes and shapes. This level of organization not only maximizes storage space but also ensures that tools are kept in an orderly manner, reducing the likelihood of damage. By maintaining an organized workspace, users can quickly locate and retrieve the necessary tools, leading to increased productivity.

Enhanced security: Security is a top priority in tool management, especially for expensive and critical equipment. The smart storage box addresses this concern with an electronic locking system that restricts access to authorized personnel only. This feature is complemented by motion detection algorithms that monitor the removal and return of tools.

Cost reduction: Accurate and real-time monitoring helps reduce operational costs by avoiding unnecessary tool purchases and reducing expenses associated with replacing lost or stolen tools.

Accessibility: Friendly user interface and IoT connectivity enable easy access to information and tool management from anywhere via mobile or web app.

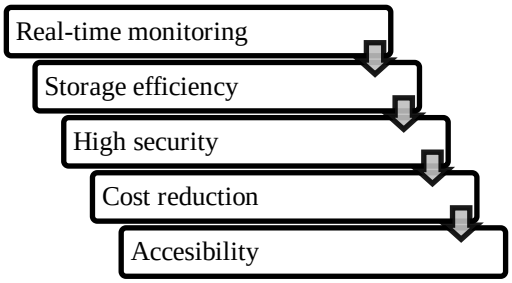

Figure 17. The benefits of the developed product.

5.2 Future research directions

For future improvement of the solution and exploration of new research directions, the following are suggested (Figure 18):

Optimizing manufacturing costs: Research and development of more affordable solutions without compromising system functionality and efficiency.

User interface improvement: Developing an even more intuitive interface that facilitates use by people with varying technical skills and includes additional functionality such as advanced analytics and usage forecasts.

Integration with other management systems: Exploring the possibility of integrating the smart storage box with other tool and inventory management systems to create a holistic resource management solution.

Sustainable energy: Investigating sustainable power options, such as using solar panels or other renewable energy sources, to extend battery life and reduce environmental impact.

Tests in various environments: Extend the testing of prototypes in various environments and usage scenarios to evaluate performance and identify possible improvements needed according to the specifics of each context.

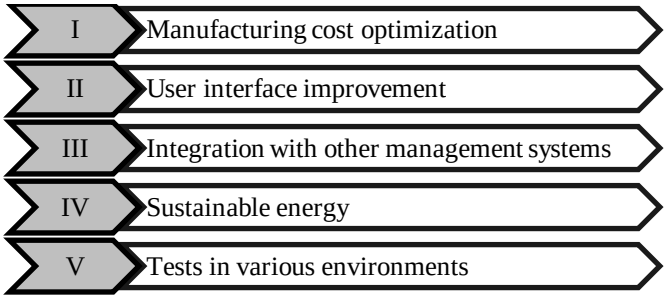

Figure 18. Future research directions.

By addressing these future directions, the proposed solution can become even more robust, accessible and efficient, thus contributing to optimized management of power tools and improved productivity in various fields.

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