Journal of Applied Engineering and Technological Science
Vol 6(2) 2025: 1356-1376

INTRODUCING B-SWEEP: AN INNOVATIVE BIRD-REPELLING DEVICE POWERED BY SOLAR CELLS AND SOUND WAVES, EFFICIENTLY PROTECTING AGAINST BIRD STRIKES IN AIRPORT AIRSIDES

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Received: 04 March 2024, Revised: 02 August 2024, Accepted: 18 August 2024
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ABSTRACT
The study aims to create a bird-repelling device called Bird-repelling with solar cell and sound wave energy efficient protection (B-SWEEP) to reduce the likelihood of bird strikes. The study employs a Research and Development (R&D) methodology, whereby data is gathered through a site survey to identify bird-highlighted places, including documentation of the quantity and variety of birds observed during a specific timeframe at the Politeknik Penerbangan Palembang—analysis conducted by measuring the range and power consumption effectiveness. The findings indicate that B-SWEEP generated sound waves at a distance of 100 meters with a maximum frequency of 500 Hz. The B-SWEEP test field is used six times, with a five-meter buffer between each experiment and the user. The purpose is to evaluate how well B-SWEEP can receive Wi-Fi. This test enables us to determine the distance at which B-SWEEP began to perform poorly when the user gave commands, and it helps improve B-SWEEP even further as a result of this research. It demonstrates how B-SWEEP deters birds in a field. Using solar panels for charging, B-SWEEP can function without electricity for one hour. Using an ESP32-CAM microcontroller to implement Internet of Things (IoT) technologies. Airport managers can recognize the kinds of birds that fly into the airside area with the help of this micro camera, including sparrows that are immediately linked to a telephone. Due to its sound and wave, the sweep audio signal might deter birds from nesting and visiting the airport airside. Integrating IoT-based automation technologies with renewable energy sources can facilitate the execution of the eco-airport initiative. Based on testing results and feedback from 51 respondents, improvements to B-SWEEP include enhancing usability by simplifying interface complexity and adjusting visual elements for greater appeal. Furthermore, expanding its capabilities to repel a wider range of animals through tailored ultrasonic technology would enhance its effectiveness and user satisfaction, making B-SWEEP a more versatile solution.
Keywords: *Airport, Audio Sweep, Birdstrike, Solar Cell.*

1. Introduction

The increasing bird population around airports is problematic because it can increase the risk of bird strikes, which can cause damage to aircraft and threaten flight safety. A bird strike is a collision event between an aircraft and birds or other animals during flight. Airplanes flying in the air can be hit by birds or other animals flying or in the flight path, which is a severe problem because collisions with birds or animals can cause damage to the aircraft and its engines. Data from the ICAO Birdstrike Information System (IBIS) report from 2008 to 2015 showed 97,751 reports of wild animal strikes (Suryana et al., 2023). This figure shows a significant increase compared to the previous period, 2001-2007, where there were 42,508 reports of wild animal strikes. These reports came from 91 countries out of 105 listed countries. The effects of wild animal strikes on aviation were reported 12,227 times. Of these reports, 2,550 cases with clear indications of effects on aviation were identified. Bird strike impacts have also occurred in Indonesia, including at Djuanda airport. Lion Air JT-800 with the Surabaya - Makassar route experienced a bird strike when it was about to start the engine on the apron. Within 15 minutes, an engine jet indicator in the cockpit indicated that it was not as it should be and indicated engine damage that obstructs airport operations and passenger comfort. Efforts to mitigate bird strikes include deploying nets to prevent birds from obstructing airport operations. However, this approach is deemed less effective, particularly for birds flying at higher altitudes than the nets or those flying around the perimeter of the nets. Smaller birds or other animals may still pass through or penetrate the nets. With the advancement of technology, several innovations of bird repellent have been implemented, relying on advanced technology.

Research by (Lian et al., 2021) He discovered a kind of grass that may be made into airport bird-repellent grass, which would lessen the likelihood of airport bird strikes and produce harmful alkaloids. Bird-repellent devices at airports often use sound devices operated by power sources such as batteries or electricity. In (Yang et al., 2020) he suggested an STM32-based remote monitoring system that gathers signals from the bird-repellent equipment's temperature, pressure, power supply voltage, and sound sensor. The STM32 serves as the system's control and data processing core. ZigBee technology is uploaded to the host computer to examine the gas cannon's state and the bird-repelling apparatus's functionality. Research conducted by (Palupi & Basuki, 2019) he made a sound generator with direct output using speakers directly powered by electricity. The range of sound released by the speaker so that the sound pressure level is above 75 dB, which will reach as far as approximately 256 meters, is obtained at 80.6 dB for Horn TOA type speakers and 76.4 dB for Piezoelectric Tweeter type speakers. The range of 256 meters is enough to reach the area around the runway of Juanda Air Surabaya if the Equipment is installed as far as 100 meters on the side of the runway.

Previous research has provided insights into the frequency and impact of bird strikes on aviation and various mitigation strategies. However, this study aims to fill notable gaps in the literature. Firstly, some efforts have been made to develop bird-repellent devices, such as sound-based systems, including using a car unit equipped with bird-repellent devices. However, the existence of this tool is still felt to be very insufficient, both in terms of the number of sounds that can effectively repel birds and the number of car units; there remains a lack of comprehensive solutions that effectively repel birds without causing negative environmental impacts. Therefore, researchers want to make a tool to repel birds based on SKEP/42/III/2010 concerning Guidelines and Procedures for Civil Aviation Safety Regulations Part 139-03 Management of Wild Animal Hazards at Airports called Bird-repelling with solar cell and sound wave energy efficient protection in Indonesian. One solution that can be implemented is utilizing renewable energy sources. According to (Mızrak & Kızılcan et al., 2022; Algarni & H. Mohamed, 2022; Ali et al., 2023; Behi et al., 2022; Glenna et al., n.d.; Kamati et al., 2022; Omer, 2014; Samatar et al., 2023; Wang et al., 2024; Weldegiorgis, 2023) Solar energy can be accessed for free and abundantly, thus reducing dependence on electrical energy resources—previous research is still in airports. In addition, using renewable energy technologies supports the global vision of reducing carbon emissions and supporting eco-airports.

Developing a Bird-repelling with solar cells and sound wave energy efficient protection is proposed to improve the design of a bird-repellent system that uses a sollar-cell energy to overcome the bird-strike problem in aviation industries, especially in Indonesian airports. Addressing the limitations of existing research and focusing on the specific context of Indonesian airports will contribute valuable insights into mitigating bird strikes and enhancing flight safety. This research aims to 1) create a bird-repellent system that is environmentally friendly and operates autonomously using solar energy, 2) design a bird-repellent device using solar cell powered audio sweep at the airport airside (B-SWEEP), 3) conduct field testing and user experience testing.

This study holds significant importance in aviation safety and wildlife management. B-SWEEP will integrate automation and monitoring technologies, such as the ESP32-CAM microcontroller with a camera, to enhance the effectiveness and efficiency of bird management. The research also supports global efforts to reduce carbon emissions and promote environmental sustainability using renewable energy. Implementing effective bird-repellent measures can help minimize the risk of aircraft damage and operational disruptions, thereby enhancing flight safety and the comfort of passengers and airport personnel. B-SWEEP design used the Research and Development or R&D method from Borg and Gall (Praseptiawan et al., 2022; Sulistiano, 2022; Yanel, 2023) until the prototype-making stage. The innovative aspect of this research lies in developing the Bird-repelling with solar cell and sound wave energy efficient protection (B-SWEEP) prototype. Unlike traditional bird-repellent devices that rely on batteries or electricity, B-SWEEP harnesses solar energy, reducing operational costs and environmental impact. Furthermore, integrating robotics automation technology, such as the ESP32-CAM microcontroller with a camera, enhances bird monitoring and management capabilities, providing airport managers with valuable data for informed decision-making. This combination of renewable energy and advanced technology represents a novel approach to mitigating bird strikes, offering a sustainable and effective solution for airport environments.

2. Literature Review

Bird populations at airports can be a severe problem as they pose a risk to flight safety. Birds flying around runways and aircraft flight areas can cause bird-aircraft collisions, or bird strikes that can cause damage to aircraft and even threaten the safety of passengers. According to the document (Arshad et al., 2015; Coccon et al., 2015; Bernardino, 2021), the types of birds that often cause bird strikes at airports are gulls, pigeons, churches, and sparrows. Sparrows, also known as Passeridae, are one of the most recognizable bird species in the world and often cross airport areas. Sparrows have medium to large body sizes, their body length ranges from 30 to 35 cm. Their body shape is generally slender and aerodynamic, allowing them to fly quickly and agilely. Sparrows are well adapted to living in urban and rural environments. They have an Aves hearing range of 20-20,000 Hz (Hart et al., 2021; Kapul et al., 2017; F. Zhang et al., 2015). They usually nest in tall buildings, buildings, and building cracks. In general, the human ear is sensitive in the frequency region between 1 kHz and 5 kHz (Jacewicz et al., 2023; Kastelein et al., 2023; Moore & Vinay, 2023), and the human ear becomes less sensitive in shallow and high-frequency regions. As a sense of living things, human and animal ears, when hearing sounds in sensitive hearing areas with a level of violence reaching the threshold of pain, will feel uncomfortable or even pain in the sense of hearing (Di Stefano & Spence, 2022)(Kim, 2023). Sound waves in the environment will be captured and collected by the outer ear and then delivered to the middle ear through the tympanic membrane. Vibrations caused by sound waves will move the tympanic membrane, followed by the movement of the auditory bones. Musculus stapedius attached to the posterior stapes will contract at a strong sound and effectively lower its frequency when the wave is transmitted to the inner ear; this aims to maintain the integrity of the hearing organs. In Aves, the hearing range is 20-20,000 Hz and reaches 10 octa (Vedenev et al., 2023)(Livens, 2022)(Moyano et al., 2022).

Birds near runways and airport areas can cause operational and safety disruptions, especially if birds fly near aircraft that take off or land (Gradolewski et al., 2021; Metz et al., 2021; Nilsson et al., 2021). Audio sweeps at airports involve using sound-emitting devices that emit high or low-frequency sounds that cannot be heard by the human ear but may disturb birds. These devices are usually placed around areas of the airport, especially near runways and places where birds often congregate. This audio sweep technique aims to repel birds from airport areas and push them away from potentially hazardous zones. Some audio sweep devices can also be configured to emit sounds randomly, so birds cannot easily get used to the sounds. Solar cells are semiconductors that convert heat energy from light into electric current. Solar cell panels have developed in small or micro industries. Solar cells in the form of panel. In the process, solar cells produce a voltage of 0.5-1 volt depending on the intensity of light and the type of semiconductor substance used. Meanwhile, the intensity of the energy contained in sunlight that reaches the earth's surface is around 1000 Watts. However, because the usability of converting radiant energy into electrical energy based on the photovoltaic effect has only reached 25%, the maximum electricity production produced by solar cells is only 250 Watts per m2. This technology is quite advanced, and its advantages are that it is cheap, clean, and easy to install, operate, and maintain. Meanwhile, the main obstacles faced in developing solar photovoltaic energy are the significant initial investment and the relatively high price per kWh of electricity generated because it requires a sub-system consisting of batteries, regulator units, and inverters according to their needs(Almadhhachi et al., 2023; Nugraha & Priyambodo, 2020; Edward et al., 2019; Gonzalez Sanchez et al., 2021; Hardianto, 2019; Shalaby et al., 2022).

An SCC or solar charger controller is needed to work as a controller to adjust the electric current entering the battery, avoid overcharge, and stop the reverse current when there is no adequate sun source. In addition to the functions previously described, there are several other functions of the SCC, such as a solar panel voltage controller to prevent solar panels from charging the battery continuously so that, it will damage the cells contained in the battery. The SCC also detects battery voltage so that when the voltage is low, the SCC will automatically cut off the use of the battery (Nisrina et al., 2023).

The microcontroller used as an automation unit is the ESP32- CAM microcontroller. This device has an ESP32-CAM chip, a tiny OV2640 camera, and a micro SD card slot (Raju et al., 2022). The micro SD card slot can store images taken from the camera, store files, and monitor the surrounding environment (Tovar et al., 2018). This ESP32-CAM module can be widely used in various IoT applications. One lithium-ion battery 12 Volt is needed to operate B-SWEEP, a limited alternative backup power source for electrical loads, so it can continue to work with specific time limits. This tool can store electrical energy in the form of chemical energy. The battery is a power source for the entire electrical system and equipment. It is also used to store electrical energy during the charging process. The UPS battery has a voltage of 12 Volts with a current of 8.2 Amperes. In balancing the current of several prototype components, a relay is needed to connect the circuit indirectly with a switch that works based on electromagnetic principles. The microcontroller relay is an automatic. The output of this research is in the form of a pear sensor as a detection sensor if birds are passing through B-SWEEP and in determining the frequency sound issued through an 8-ohm speaker using an audio player component in the form of an MP3 player df + micro-sd.

Analyze the frequency characteristics of the bird hearing system; it is necessary to measure the characteristics of the sounds that birds often emit. In addition, to analyze the effect of aircraft sound, it is necessary to measure the characteristics of the sound emitted by the aircraft. One of the studies by (Hane et al., 2022) entitled "Automatic bird sound detection in long real-field recordings: applications and tools" concluded that the frequency sensitivity of bird and poultry responses ranged from 100 Hz to 8 kHz using audio sonic sound. Meanwhile, research by (Nurikhsani & Mupita, 2022) in a scientific journal entitled "Designing a Sparrow Pest Repellent Tool on Rice Plants Using Automatic Shock Waves Based on the Internet of Things (IoT)" has made a bird repellent tool using Arduino and PIR sensors and the addition of a Liquid Crystal Display (LCD). This research produces a way to monitor the rice field area, which is usually often disturbed by bird pests so that farmers' time is more effective in managing the rice field area and the expected rice yield increases because one of the many pests of rice plants can be overcome. Sound signals that are suitable for repelling sparrow pests are waves with a frequency range of 250 Hz - 500 Hz with a circuit that can be seen in the picture in the figure 1, below.

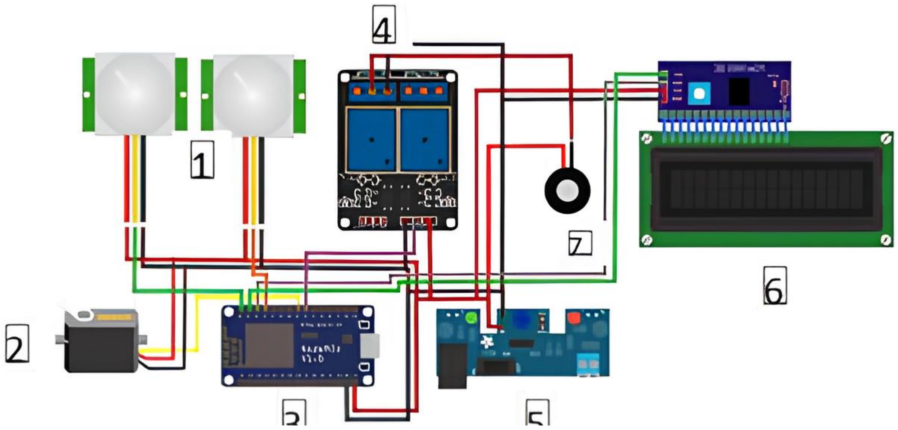

Fig. 1. Circuit Design of Tool

Research by (Hane et al., 2022) entitled "Utilization of Bird Repellent Tools to Increase Agricultural Productivity in Sukolilo District" Surabaya also made a bird repellent tool with several Arduino Nano components, 1 Channel Relay, Jumper Cable), Battery Components (UPS Battery 6V 7.5Ah, Step down, ACCU Charger, cable), Frame (Wood / Rod), Enclosure, Cans, Beater, Roof, Nail), and DC Motor (9 Volt) by providing innovation in the form of a sparrow pest repellent using sound to GAPOKTAN in Sukolilo sub-district, Surabaya. The tool is felt to maximally repel sparrow pests and provide efficient time to work with the tool. Then, research conducted by (Ramashini et al., 2022) in his scientific journal entitled "Bird Voice Recognition Using Mel Frequency Cepstrum Coefficient and Artificial Neural Networks on Bird Pest Repellent Systems," obtained the following data in table 1:

Table 1 - Strength Dominant Frequency of Bird Sounds

Birds	Frequency (Hz)	Sound Power (Db)		
		10 m	50 m	100 m
Gelatik	2813,9	82,5	60,4	51,4
Cekakak	3508,7	81,8	63,4	52,1
Bondol	3413,8	82,1	60,6	53
Gereja	3652,7	80,7	59,9	51,6
Perkutut	742	76,9	57,9	47,1

From table 1 above, a database of frequency responses of several bird species can be obtained. By taking the response frequency of the bird species, it is concluded that the sound of gunfire is suitable for repelling bird pests. Then, research conducted by the LIPI research team on "bird strike at Soekarno-Hatta airport" concluded that the frequency that responds to birds is 100-4000 Hz. The signal used for bird repellent is the sweep signal model.

Indonesia's geographical location along major migratory bird routes increases the risk of bird strikes, especially for airports near wetlands, rice fields, and coastal areas. These environments attract birds for feeding and nesting, thereby heightening their presence around airport vicinities . From a safety perspective, bird strikes significantly threaten flight operations. Incidents involving birds ingested into engines or colliding with critical aircraft components can lead to emergencies. For example, in 2017, a Garuda Indonesia flight experienced a bird strike during takeoff, resulting in an emergency landing and subsequent investigation. To mitigate these risks, technological solutions are being explored. Implementing bird-repellent technology at significant airports aims to enhance early warning capabilities and enable proactive measures (Feriyanti et al., 2019). In summary, the combination of Indonesia's geographic location and attractive environments for birds around airports significantly increases the risk of bird strikes, posing a severe threat to flight safety. Incidents like the 2017 Garuda Indonesia flight highlight the urgent need for practical solutions. Technological advancements, such as bird-repellent systems, enhance safety by providing early warnings and proactive measures to prevent bird strikes (Feriyanti et al., 2019).

Various bird-repellent technologies are employed worldwide to mitigate the risk of bird strikes at airports. These technologies range from simple visual deterrents to sophisticated radar systems, each with its advantages and limitations. For Example, Visual deterrents are among the most commonly used bird-repellent technologies. These include reflective tapes, predator decoys, and laser systems designed to scare birds away from critical areas. Reflective tapes and balloons with predator eyes can create visual stimuli that deter birds (Moniruzzaman et al., 2023). However, the effectiveness of visual deterrents can decrease over time as birds become habituated to them. Next, there are chemical repellents, Chemical repellents involve the use of substances that make areas unappealing or harmful to birds. These chemicals can be applied to surfaces where birds perch or feed. While effective in some cases, chemical repellents raise environmental and health concerns and require regular reapplication (Diaz, 2016). In addition, Audio deterrents utilize sound to repel birds. These devices play distress calls of birds or the sounds of predators, creating an environment perceived as dangerous by the birds. Research has shown that audio deterrents can be effective, especially when the sounds are varied and unpredictable (Di Stefano & Spence, 2022). Despite their effectiveness, birds may habituate to consistent sounds, reducing their long-term efficacy.

Existing research provides valuable insights into bird behavior and the development of bird-repellent technologies. However, critical gaps remain unresolved, including a lack of comprehensive understanding. Current research offers limited insights into the specific frequencies that effectively deter birds while minimizing disruption to airport operations. Furthermore, there is a need for further research to optimize bird-repellent methods, considering the diverse auditory sensitivities of bird species and the environmental impact of deterrent technologies. Several considerations are required to design an effective bird-repellent device for airport use. One of the biggest challenges in using B-SWEEP is habituation, where birds become accustomed to the emitted sounds and eventually ignore them. To overcome this issue, variations in sound patterns and frequencies are employed. This ensures that the generated sounds are not always constant, making it difficult for birds to adapt. Not all sound frequencies are effective for all birds, as each bird species has a different hearing range. Therefore, testing this device involves several bird species to determine the best sound frequencies to repel them. Additionally, this device uses solar power, so it is important to ensure that it receives enough sunlight for consistent operation, especially in areas that may experience prolonged cloudy or rainy weather. This issue can be addressed by adding battery energy storage and a backup power source. The solar cell-powered bird-repellent device with an audio sweep is integrated with a bird detection management system using the ESP 32 Cam to achieve maximum effectiveness. This integration allows remote monitoring to identify the types of birds at the airport, enabling quicker response times.

In summary, research on bird-aircraft collision mitigation has emphasized the importance of understanding bird hearing systems and developing effective repellent strategies. While existing studies have made significant contributions, gaps persist in optimizing repellent technologies and minimizing environmental impact. This study addresses these gaps by comprehensively characterizing bird auditory responses and refining bird deterrent methods for enhanced airport safety. The subsequent sections will detail the methodology and findings of this research, building upon existing literature to contribute to the field of bird strike prevention.

3. Research Methods

3.1 Method and Type of Research

The authors used the Research and Development (R&D) method in this study. This method is used to produce specific products and test their effectiveness. R&D is a series of processes or steps to develop new products and improve existing products so they can be accounted for. According to Borg and Gall, there are ten stages of research and development. This research included 8 out of 10 stages because, Due to the limited time available for conducting this research, the research and development steps were restricted to the eighth step, the product testing phase. The tenth stage, which involves product marketing, is irrelevant as the focus is not on commercial marketing but instead on implementation and operationalization at the airport. This limitation aims to ensure that the research process can be completed thoroughly and on time so that the results obtained remain valid and reliable to support the main objectives of this research, which can be seen in Figure 2 below.

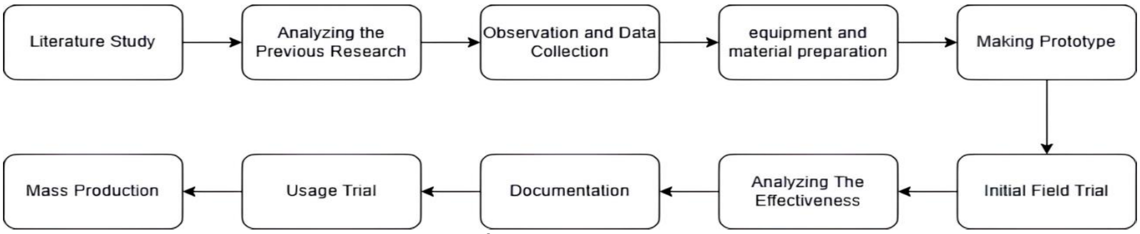

Fig. 2. Research and Method from Borg and Gall (Susanti & Sholihah, 2021)

This research produces a product in the form of a bird-repellent tool that is tested on the Palembang Aviation Polytechnic field, which resembles a runway of 3200 m x 45 m with dimensions 1: 50 and a scale adjusting to the runway of Sultan Mahmud Badarruddin II Palembang Airport.

3.2 Diagram of Tool Design Stages

In the making of B-SWEEP, there are stages up to documentation, which can be seen in Fig. 3 below.

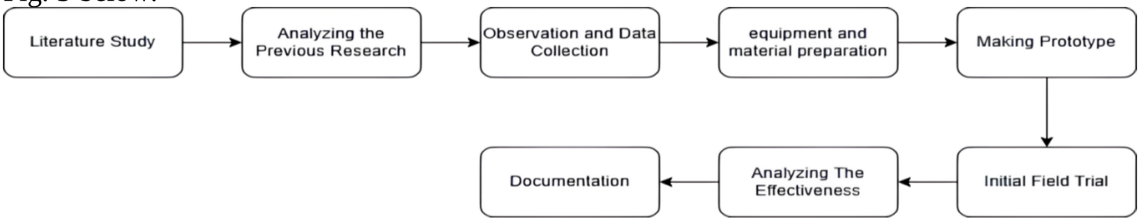

Fig. 3. Diagram of Tool Design Stages

The following explains the research method in Fig. 3. In the first stage of the literature study, the author uses various written sources, such as articles, journals, and documents relevant to the study. This study focuses on applying renewable energy sources at airports and the concept of airport automation, which has implemented eco airports without overriding the function of bird-repellent devices. The second stage is the author's analysis of several previous studies that examined tools similar to B-SWEEP and noticed several opportunities to maximize existing bird-repellent tools, such as adding several solar cell components, cameras, and IoT that can be connected directly through smartphones to make the tool support the eco-green program without reducing the primary function of B-SWEEP.

The third stage is observations, a data collage, which is the case study that was made to observe the behavior of birds around certain areas, especially in locations that are often gathering places for birds. This observation aims to understand bird behavior patterns, the types of birds that often appear, and the intensity of bird presence at certain times. Data collection in this study involved a site survey to identify areas most frequented by birds. This involves recording the number and types of birds seen in a certain period located at the Palembang Polytechnic field as well as conducting interviews and questionnaires to the grounding and electrical building technicians to find out information and how effective bird repellent devices or B-SWEEP are in overcoming bird-strike at the airport. The fourth stage is to design a circuit scheme with the help of Tinkercad and Sketchup software. Some placements, components used, and coding to run the application in this design stage have been well organized.

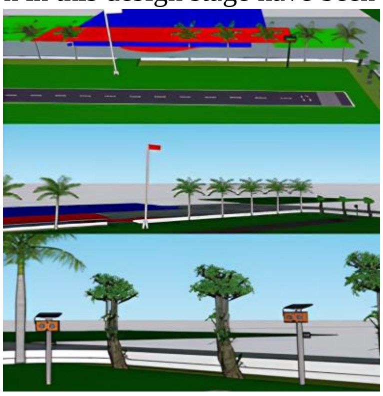

Fig. 4. B-SWEEP Planning using Software

The Next step is the B-SWEEP Prototype, which refers to the assembly with the design that has been made before. The stages in making B-SWEEP are assembling the components and inputting the coding. In the sixth stage, after completing the B-SWEEP prototype circuit, the researcher directly implements B-SWEEP in the field with a predetermined position. In the seventh stage, Analyze the effectiveness of B-SWEEP according to 1) range and power consumption and 2) user experience. Researchers measure power consumption by measuring the initial voltage of the battery when it is first used; the tool used to measure the battery is a digital multimeter. This measurement aims to determine how much battery power consumption is used in every minute of the experiment by comparing the initial voltage of the battery; the measurement is carried out five times, and each measurement will be carried out for 1 minute. At the trial stage, the B-SWEEP range that the user can control is carried out six times; each experiment will be carried out at 5 meters from the user. This aims to determine how effective the Wi-Fi range that B-SWEEP can receive through a smartphone hotspot has been previously set. By measuring this distance, it can be seen at what distance the robot has started not to be able to respond well to commands given by the user, and this will undoubtedly be useful for developing B-SWEEP even better from this research. The user experience was conducted in the form of a list of questionnaires from a sample of 51 cadets of Politeknik Penerbangan Palembang. The questionnaire has eight questions to assess hedonic and pragmatic aspects. User experience of B-SWEEP can be obtained by including feedback from users or stakeholders who have tested B-SWEEP to provide insights into its usability and practicality. This will help understand how B-SWEEP is used in practice and identify areas that need improvement to enhance the overall user experience. UEQ is a testing method that utilizes questionnaires to assess and evaluate user satisfaction levels. In this testing, the UEQ-S, a short version of the UEQ, consisted of 8 items and seven scales to measure the user experience (Amalia et al., 2022, 2024).

The use of solar cells at the airport not only reduces dependence on conventional energy but also harnesses renewable energy, effectively supporting the concept of an eco-green airport (Pastika, 2021). By utilizing renewable energy sources, the airport reduces its carbon footprint and contributes to global efforts in combating climate change. Additionally, the eco-friendly utilization of materials like B-SWEEP in building structures, which possess excellent thermal insulation properties, helps maintain temperature stability and overall energy efficiency. This integration of B-SWEEP aligns with the eco-green concept by promoting sustainable construction practices, further reducing energy consumption and greenhouse gas emissions. These combined efforts demonstrate the airport's commitment to environmental impact and the advancement of eco-friendly initiatives within the aviation industry. The last stage is documentation; the researchers conducted a documentation study by photographing and recording several activities using B-SWEEP as a data source to support the research.

4. Results and Discussions

4.1 Tool Design

The design of B-SWEEP utilizes solar energy as a power source to charge and turn on the B-SWEEP that will be used. Solar energy use can be converted into electrical energy using a 20WP solar panel equipped with an ESP-32 CAM microcontroller to automatically control and monitor the movement of B-SWEEP. The energy resources produced by solar panels can charge the 12V UPS Accu optimally and do not cause damage due to excessive voltage due to the addition of the UBEC 5 Volt SCC (Sollar-Cell Controller). The amount of Accu voltage used is approximately 12 VDC. B-SWEEP is shaped like a traffic light with dimensions of L x W x H, 44 x 24 x 175 cm. With these dimensions, ATC personnel are expected to not experience any disruptions in monitoring the aircraft movement area, as found in Fig. 5. B-SWEEP is equipped with a camera that is directly integrated into a smartphone. With the placement of body components made of aluminum. ESP32 CAM at the airport aims to enhance security and area monitoring and facilitate real-time operational monitoring. With its small size and low power consumption, this device is suitable for IoT solutions, enabling seamless integration with other systems for improved automation. Thus, ESP32 CAM enhances airport security, efficiency, and technological advancement. PIR sensor placement design gives the effect of a 180° range and vision, and the advantage of using a PIR sensor in bird-repellent devices lies in its ability to detect motion effectively. By sensing the heat emitted by moving objects, such as birds, the PIR sensor activates the repellent device, deterring birds from the area. This technology is efficient, cost-effective, and environmentally friendly, as it only activates when motion is detected, conserving energy and reducing the need for continuous operation. Additionally, PIR sensors are relatively easy to install and maintain, making them a practical choice for bird control applications throughout the range in Fig 9 below.

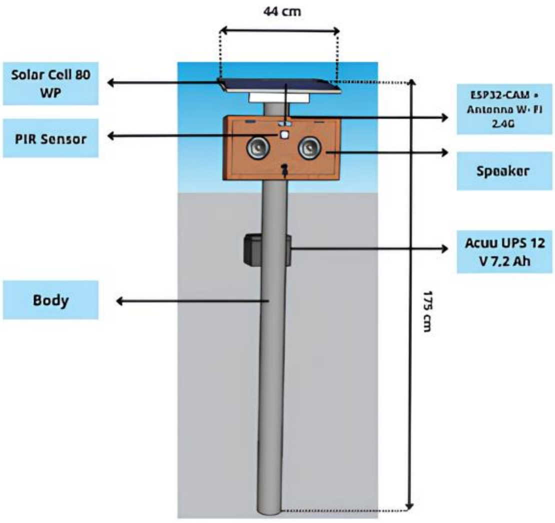

Fig. 5. B-SWEEP Specifications

Furthermore, this research's tool design is a prototype of the B-SWEEP bird-repellent tool with ESP32-CAM control and PIR sensor. ESP32-CAM will control and connect the components of B-SWEEP, namely two speakers, PIR sensors, solar panels, SCC, and Accu Ups. The design of the components can be seen in Figure 6 below.

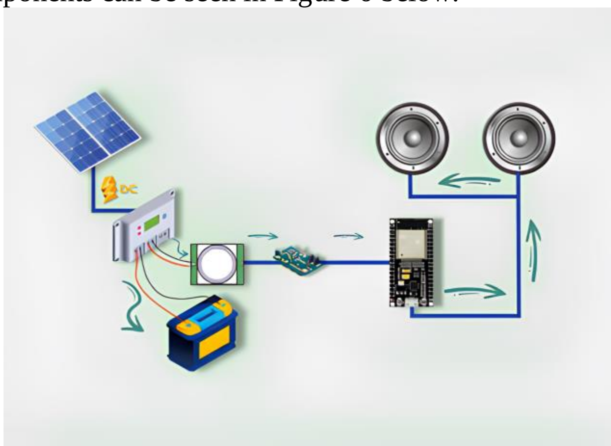

Fig. 6. Design of How the B-SWEEP Component Works

The main components of the B-SWEEP system include solar cells, ESP32 CAM, accumulator (accu), and PIR sensor. The synergy of all these components supports the effectiveness of B-SWEEPtos use in B-SWEEP applications. Solar cells reduce dependence on conventional energy, ESP32 CAM provides crucial monitoring, the accumulator (accu) provides backup power, and the PIR sensor detects motion triggering the repellent device. Thus, this comprehensive integration enables more efficient and effective use of B-SWEEP to address bird-repellent issues in the area. Therefore, all these tools contribute to the effectiveness of the B-SWEEP system.

4.2 Programming

The programming language used in the manufacture of B-SWEEP is C++. The program was uploaded to the Arduino UNO application to enter coding into the ESP 32-CAM using the source code of B-SWEEP.

4.3 Flowchart of Tool Operation

B-SWEEP has a flowchart explaining how to use the bird-repellent tool. The flowchart explanation in this study is presented in Figure 7 below:

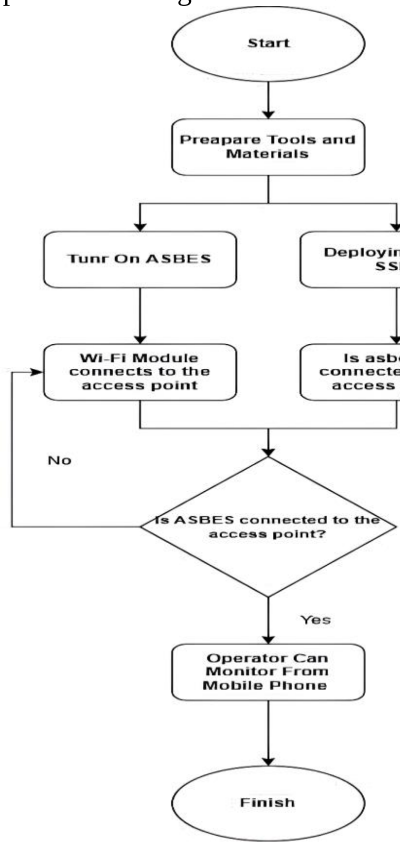

Fig. 7. B-SWEEP Operation Flowchart

The programming language made in the manufacture of B-SWEEP is a program that uses the C++ language, uploaded to the Arduino UNO application to enter coding into the ESP 32-CAM using the source code of B-SWEEP, which can be seen in the following link. After the device is well connected, the B-SWEEP can be controlled and monitored via smartphone. B-SWEEP can be directly operated to repel birds by controlling the distance of vision monitoring of bird Objects using the Wi-Fi ESP32- CAM module, which can be controlled as far as 50 meters in the open field and as image data collection. The tool operating procedure is a step needed to run B-SWEEP so that the audio sweep sound waves issued through the speakers can work according to the program that has been made. The description of the operation process is as follows: 1) Prepare tools and materials that will be used for B-SWEEP, 2) Turn on B-SWEEP, then the Wi-Fi and camera modules, 3) When it is turned on, the access point is entered, which is helpful as a link between the robot and the vision camera with the code 192.168.4.1 to the smartphone browser application so that the Wi-Fi ESP32 module will be connected to the access point that is connected to B-SWEEP which can be seen in Figure 8 below:

Fig. 8. Application Through Browser Connected to B-SWEEP Access Point.

4) If B-SWEEP is connected to the access point, B-SWEEP can see and monitor bird objects passing by the device, 5) If B-SWEEP has not connected to the access point, the robot will repeat to connect to the access point until it can connect to the access point, 6) After the device is connected, B-SWEEP can be controlled to repel birds, and all components will work, such as pear sensors, speakers and charging through solar cells, 7) The PIR sensor will work if a bird crosses the infrared that the sensor has released, 8) After the object crosses the sensor, the sound will automatically come through the speaker, 9) B-SWEEP can be turned off by disconnecting the smartphone.

4.4 Tool Assembly

After designing the tool, its assembly and testing are carried out. The tool assembly is carried out directly in the TRBU building workshop, and direct testing is carried out in the field, which can be seen in the following Figure 9 below.

Fig. 9. B-SWEEP Assembly

B-SWEEP testing was carried out directly on the Palembang Aviation Polytechnic field with a field size of 200 x 400 m2 and at the robot testing stage was tested in 3 stages, namely when testing the function of the tool, the durability of the battery condition when operating and the range of the detection sensor against birds. The test was carried out during the day until the afternoon in the field where the test was carried out. Tool testing starts from 12.00 WIB -17.00 WIB with the number of bird objects approved as much as one to six sparrows and as many as ten times the test. The tool testing focused on the function of the tool and the effect of sound waves on sparrows, and tool testing was carried out in the field attached in Figure 10 below.

Fig. 10. Implementation of B-SWEEP Testing in the Field

Next is to test the function of all tools, whether the finished tool is properly useful or has obstacles, and how the sparrow behaves when given sound waves. All the test results, results are listed in Table 3, table 4, and table 5 below.

4.4.1 Tool Function Testing

In testing the components used in B-SWEEP, the conclusion is obtained by expectations where all tools are standard and can be used. Some of the components tested can be seen in Table 2 below.

Table 2 - Tool Function Testing

Component	Expectations	Results	Conclusions
Sensor PIR	Can display conditions according to input from sensors	PIR sensors can detect movement	Finished
Solar Cell 80 WP dan Accu 12 v 7,2 Ah	Can charge normally	Accu outputs normal current characterized by testing using a 12v digital multimeter.	Finished
Speaker	Can output sweep audio smoothly	Can output the desired sound	Finished
ESP32-CAM + Antenna W- Fi 2.4G	Can transmit data from sensors and accurate pictures to smartphones with a more extended range of 2.4 G	Can transmit data farther and more precisely	Finished
DF MP3 Player	Can transfer data read through micro SD and forwarded to output	Can output sound and send sound data to the speaker normally	Finished

4.4.2 Measurement of Accu Consumption During Operation

Accu consumption measurements are made by measuring the initial voltage when first used; the tool used to measure batteries is a digital multimeter. The 12 Volt 8.2 Ah UPS battery can last 60 minutes using the usage duration formula, namely the battery capacity divided by the total usage power of all components. Five principal components will be added to the total current of all components: two 4-inch speakers with a total of 8A, one PIR 0.5 A, one ESP32 CAM + antenna 2.4 G 0.9 A, and DF MP3 Player 0.3 A.

The total current calculation process is attached in (1)

Total Current=SUM All Current of Component(…A+⋯A+⋯A) (1)

The conclusion of the sum is as follows

All Current = two 4-inch speakers with a total of 8A + one PIR 0.5 A + one ESP32 CAM + antenna 2.4 G 0.9 A + DF MP3 Player 0.3 A (1)

All Current =(8A+0,5+0,9A+0,A) =9.7 A (1)

Furthermore, the total number of batteries where the results were obtained was 8.2 Ah. is attached in (2)

Total Current of Accu UPS=Specification of UPS (MAh to Ah) (2)

The conclusion of the total battery capacity is attached in (2)

Total Current of Accu UPS=8200 MAh

Capacity (Ah) = Capacity (mAh)/1000 (2)

Capacity (Ah) = 8200 Mah/1000 (2)

Capacity (Ah)= 8.2 Ah

The last step is to calculate the entire duration of B-SWEEP usage by getting the result that B-SWEEP can last for one hour using a battery. However, if B-SWEEP is exposed to the sun, its power will not decrease because it is powered by solar cells. Presented in the calculation below:
Calculating the length of B-SWEEP e time is attached in (3).

Usage Time = (Total Capacity of UPS (Ah)/Total Current (A)) - (20% efficiency) (3)

Total Capacity of UPS (Ah)/Total Current (A): This part calculates the theoretical runtime of the UPS if it were 100% efficient. 0.8: This factor accounts for the UPS's 80% efficiency, implying that 20% of the energy is lost due to system inefficiencies. This measurement aims to determine how much battery power consumption is used in each hour of the experiment by comparing the initial voltage of the battery; the measurement is carried out five times without using a solar cell. Each measurement is carried out for 1 hour, and the results obtained are reduced every 1 hour to remove the final voltage by 0.30 volts. In other words, these inefficiencies reduce the UPS's actual runtime by 20% from the theoretical maximum.
Therefore, the 20% value is obtained and used in the formula below (3)

Usage Time= (Total of Acuu UPS (Ah))/(Total Current) - (20% efficiency) (3)

The conclusion of the total length of use of B-SWEEP is attached in (3)

Usage Time=(8.2 Ah)/(9.7 A) – (20% efficiency) (3)
= 1.24 Hours – (20% efficiency) (3)
= 1.24 Hours – 0,24 Hours (3)
=1 Hours (3)

This measurement aims to determine how much battery power consumption is used in each hour of the experiment by comparing the initial voltage of the battery; the measurement is carried out five times without using a solar cell. Each measurement is carried out for 1 hour, and the results obtained are reduced every 1 hour to remove the final voltage by 0.30 volts. The measurement data can be seen in Table 3 below.

Table 3 - Measurement of battery consumption while operating

Experiment	Time (Hours)	Initial Voltage (Volts)	Final Voltage (Volt)
1	1 Hour	12,50	11,36
2	1 Hour	11,36	11,03
3	1 Hour	11,03	10,83
4	1 Hour	10,83	10,53
5	1 Hour	10,53	10,32

4.5 Testing Bird Behavior to Sound Waves

In testing bird behavior, researchers used two speakers to issue audio sweep sound waves from 0 Hz to 500 Hz for ten trials. This test was carried out by counting birds approaching the field and calculating the nearest bird's distance from the sensor. The farther the bird is from the sensor, the more difficult it is for the sensor to detect the presence of birds and the more birds that approach the sensor, the more accurate the sensor will detect the presence of birds. Due to the frequency response of sparrows at a frequency of 250 Hz, the sparrows will be tested at 500 Hz, resulting in a 100-meter test of 6 tests that sparrows will leave if the sound wave is increased to 500 Hz, where the implementation of bird expulsion is found in Figure 11, birds leave when the tool works and B-SWEEP images and determination of B-SWEEP testing distance can be seen in Table 4 below.

Fig. 11. Determination of B-SWEEP Testing Distance

Table 4 - Testing Bird Behavior using Sound Waves

The Presence of birds near B-SWEEP	The Distance the Bird approaches the sensor	Sound Wave Delivered	Sensor Condition Detected	Information
0	0	0	-	Undetectable
1	10 m	250 Hz	Detected	Tools make sounds, and birds leave
2	30 m	300 Hz	Detected	Tools make sounds, and birds leave
2	40 m	300 Hz	Detected	Tools make sounds, and birds leave
2	50 m	500 Hz	Detected	Tools make sounds, and birds leave
2	50 m	500 Hz	Detected	Tools make sounds, and birds leave
4	60 m	600 Hz	Detected	Tools make sounds, and birds leave
6	70 cm	500 Hz	Detected	Tools make sounds, and birds leave
6	90 cm	500 Hz	Detected	The tool makes a sound, and the bird leaves slightly
8	100 cm	500 Hz	Detected	The tool makes a sound, and the bird leaves slightly

User Experience of B-SWEEP is the feedback received from users and stakeholders who have tested B-SWEEP has provided us with invaluable insights into its usability, reliability, and practicality. This information, gleaned from real-world user experiences, has offered us a deeper understanding of how B-SWEEP operates in different scenarios and how users engage with it across various contexts. Furthermore, the results obtained from testing and the feedback received serve as a crucial foundation for formulating comprehensive improvement strategies and refining B-SWEEP to better meet user needs and expectations. It has been proven through field testing by technicians. Attached is the following figure 12.

Fig. 12. Field Testing B-SWEEP

Future Improvements of B-SWEEP: Enhancements planned for B-SWEEP involve integrating additional bird-repellent sounds designed to deter wildlife beyond avian species, including dogs, snakes, and other animals. By incorporating these features, B-SWEEP will be better equipped to address disturbances caused by a broader range of wildlife in designated areas, enhancing its effectiveness and utility. We remain committed to ongoing refinement and enhancement of B-SWEEP to ensure its continued effectiveness and usability for our users.

4.6 User Experience of B-SWEEP

The user experience was measured using UEQ-S with 51 respondents from the Palembang Aviation Polytechnic cadet's airport engineering technology study program. These items are shown in Figure 13.

obstructive	o o o o o o o	supportive
complicated	o o o o o o o	easy
inefficient	o o o o o o o	efficient
confusing	o o o o o o o	clear
boring	o o o o o o o	exciting
not interesting	o o o o o o o	interesting
conventional	o o o o o o o	inventive
usual	o o o o o o o	leading edge

Fig. 13. Item Testing UEQ-S

Figure 14 shows the items and scales used in testing with the UEQ-S method. The data collected from the respondents were then entered into the UEQ data analysis tool and used as input to calculate the developed application's user experience score. The results of the user satisfaction and experience testing using the UEQ method are shown in Figure 14.

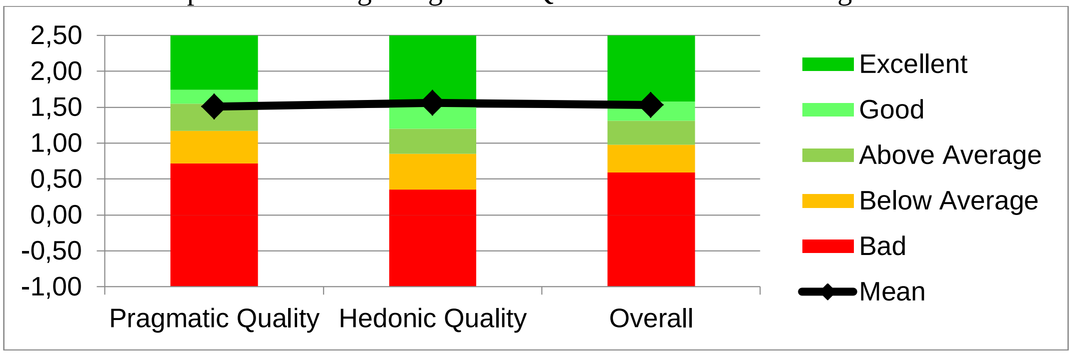

Fig. 14. Benchmarking Results of UEQ Testing Method

Figure 15 shows the benchmark results of B-SWEEP testing based on the UEQ method. The graph shows excellent user satisfaction levels across the eight evaluated aspects. Based on these results, it can be concluded that users are satisfied with B-SWEEP, and it meets their needs. Mean, variance and standard deviation values were obtained from the data processing. Mean represents the central measure of a given set of numbers, precisely the average value. Variance measures the average squared differences of values from the mean. This measure of central dispersion provides insights into how observed data is spread and distributed. Standard deviation is a statistical value indicating how much data from a statistical sample differs from the mean or average of the data, with variance being its outcome. UEQ facilitates its questionnaire users with free Excel-based data processing facilities. These facilities encompass various testing techniques such as validity testing, reliability testing using Cronbach Alpha and Guttman Lambda, and Confidence Interval for determining the accuracy of sample means. Confidence interval signifies the confidence level of most of the sample, which contains the actual population parameters.

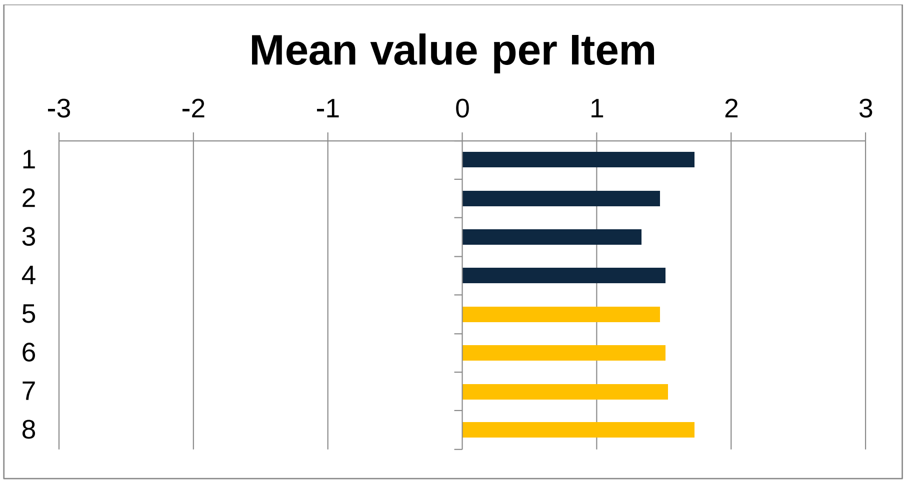

Fig. 15. Mean Value per Item B-SWEEP

In Figure 16, the results of the UEQ scale show a rating range from -3 (very poor) to +3 (very good). However, in practice, only values within a limited range are observed. This consideration arises because each respondent holds different opinions and tendencies. Some respondents may hesitate to provide honest answers to questions perceived as extreme. Therefore, observations of responses exceeding +2 or falling below -2 are generally avoided.

Table 6 - UEQ Scales

Short UEQ Scales	
Pragmatic Quality	1,510
Hedonic Quality	1,559
Overall	1,534

The UEQ scale can be grouped into pragmatic-quality and hedonic-quality aspects. Pragmatic refers to characteristics directly related to quality aspects, while hedonic pertains indirectly to quality aspects, as shown in the graph and table 6.

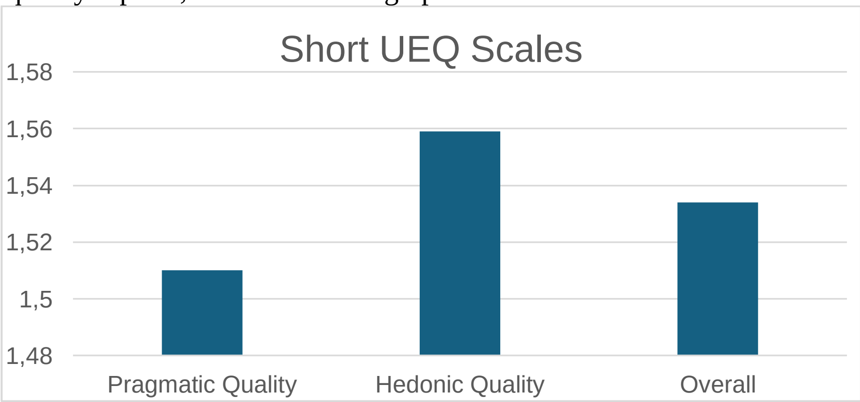

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Fig. 16. Short UEQ Scales Diagram

The table above summarizes scores from the Short UEQ Scales in Figure 20, divided into three main dimensions: Pragmatic Quality, Hedonic Quality, and Overall. The score for Pragmatic Quality is 1,510, indicating how well a product or system meets users' functional needs, such as usability and efficiency. Hedonic Quality scored 1,559, reflecting users' subjective experience regarding the aesthetic and emotional aspects of the product, such as appealing design and user satisfaction. Overall, the product or system achieved a score of 1,534, representing the overall assessment of these dimensions and providing an overview of the positive evaluation of users of the product or system. Below is a table that shows each question representing the eight scales in the table on the far right in Table 7.

Table 7 - Question Representing Scale

Item	Mean	Variance	Std. Dev.	No.	Negative	Positive	Scale
1	1,7	0,2	0,5	51	obstructive	supportive	Pragmatic Quality
2	1,5	0,5	0,7	51	complicated	easy	Pragmatic Quality
3	1,3	0,3	0,6	51	inefficient	efficient	Pragmatic Quality
4	1,5	0,4	0,6	51	confusing	clear	Pragmatic Quality
5	1,5	0,5	0,7	51	boring	exciting	Hedonic Quality
6	1,5	0,3	0,6	51	not interesting	interesting	Hedonic Quality
7	1,5	0,4	0,6	51	conventional	inventive	Hedonic Quality
8	1,7	0,2	0,5	51	usual	leading edge	Hedonic Quality

The table summarizes the mean, variance, and standard deviation values for eight items representing six evaluation scales. Discuss the potential improvements or modifications that can be made to B-SWEEP based on the testing results and feedback received. Based on data from 51 respondents, analysis of the Pragmatic Quality scale indicates that some aspects, such as complexity, efficiency, confusion, and conventionality of the solution, need to be reviewed. Improvements can focus on simplifying the interface and processes to reduce confusion and enhance user efficiency. Meanwhile, feedback on the Hedonic Quality scale, which assesses how exciting or boring the application is and how innovative or conventional it appears, suggests that visual and user experience aspects can be adjusted to increase its appeal and innovative impression. Therefore, modifications may include enhancing design aesthetics and interactivity and adding new features that are more engaging to users. Additionally, B-SWEEP can be improved by developing additional features capable of repelling other animals besides birds, such as snakes, civets, dogs, and cats. Implementing ultrasonic sounds specifically tailored to repel these animals can be effective. Further research on the appropriate sound frequencies for each animal must ensure the device operates optimally without disturbing humans. Thus, B-SWEEP can become a more comprehensive and multifunctional solution, providing broader protection against animal disturbances. The feedback from this testing is invaluable for setting priorities in further development of B-SWEEP, ensuring a more effective and enjoyable solution for users.

5. Conclusion

The increasing bird population around the airport, an area of aircraft activity, is a problem in the form of bird strikes, which can later cause damage to aircraft and threaten flight safety activities. So far, efforts to handle birdstrike at the airport have been carried out by AMC (Airport Movement Control) personnel, namely using one unit of a car equipped with bird-repellent devices, but this is still considered less effective both in terms of the number of sounds that can effectively repel birds and the lack of car units. With this problem, the author made a Bird-repelling with solar cell and sound wave energy efficient protection (B-SWEEP) design using the Research and Development or R&D method from Borg and Gall to the prototype-making stage. This prototype testing was conducted at the Politeknik Penerbangan Palembang on the airport airside miniature practice field. The test results show that B-SWEEP can produce sound waves with a maximum frequency of 500 Hz through the speaker output that can repel sparrows in the test area. The ESP32- CAM microcontroller equipped with a camera is expected to be easier for airport managers to use to know the types of birds that often enter the airport airside. A UPS 14440 Mah battery's stored power can last 60 minutes. In addition, researchers made a prototype by combining renewable energy-based robotics automation technology and using the primary source of solar cells to support Indonesia in realizing eco airports and Golden Indonesia in 2024.

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