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Serenivice: An Arduino-Driven Automated Flea Repellent Device with Computer Vision Integration for Cat Flea Management

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Abstract: In the domain of feline flea management, the use of traditional repellents can inadvertently expose humans to health risks arising from potential cat aggression or fear responses. These reactions, encompassing injuries, infections, and skin irritations due to direct contact with fleas, underscore the need for a more sophisticated approach. An innovative solution is presented: an automated flea-repellent device designed to administer treatment and attract cats without human intervention. This device is equipped with a sensor that triggers the emission of flea repellent spray, while strategically placed attractants entice feline companions to create a soothing environment. Accompanying this is an intuitive mobile application serving as an alternative control method equipped with a computer vision, which allows remote monitoring of cat and flea presence. Notably, this study assessed the device and application using ISO 25010:2011 software quality standards, focusing specifically on functional suitability, usability, performance efficiency, and portability. The results indicate an overall mean satisfaction rating of 4.53 out of 5.00, signifying its effectiveness and safety. Additionally, the FOMO MobileNet V2 0.35 attains exceptional precision, recall, and a perfect F1 score of 1.00 in identifying background instances. However, challenges in the cat class, with 62.8% accuracy and a 32.8% error rate, suggest opportunities for improvement. Meanwhile, the model excels with 100% accuracy in flea detection. The nuanced evaluation, reflected in F1 scores, indicates a perfect balance in the background class and moderate performance in the cat and flea classes.

Keywords: *Automated Repellent Device, Feline Health Risks, Flea Management, Mobile Application Control.*

1. Introduction

Cat fleas, scientifically known as Ctenocephalides felis, are widespread and pose challenges due to their rapid reproduction, affecting the health of domestic cats worldwide [1]. They are significant disease vectors, capable of transmitting various pathogens to animals and humans, including cat scratch disease, flea-borne spotted fever, murine typhus, and plague [2]. Infestations can lead to discomfort and the transmission of infectious agents, emphasizing the need for swift action [3]. Various flea control methods, including bathing, powders, repellent collars, and sprays, are available, each with its own considerations regarding safety and effectiveness [4]. Understanding a cat's behavior and preferences during flea treatment is crucial, with options like using tasty food paste to alleviate stress [5]. Additionally, cat owners often use catnip and silver vine as treats for their cats, each inducing distinct behaviors, with catnip's effects typically lasting around 10 minutes and silver vine eliciting longer-lasting playfulness and sociability [6]. Proper execution of flea treatment procedures is essential for maintaining a flea-free environment, involving factors like correct application, adherence to product instructions, oral flea treatment medications, treating the home and yard and avoiding premature discontinuation of flea treatment [7].

In addressing cat flea infestations, motivation stems from three challenges: the need for safer methods to protect not only the feline companions but also their owners, the importance of efficient and compassionate intervention for treating resistant cats, and the vital necessity for expediting the identification phase to avoid the escalation of infestations and enhance the overall effectiveness and timeliness of flea management interventions. To meet these objectives, the research aims to develop an automated flea repellent device that operates without human intervention. Specifically, the goals include constructing a refillable, Arduino-driven automated flea repellent device; incorporating a scent release mechanism and attractants; and integrating a computer vision system into the device, enabling remote monitoring through a mobile application with additional features.

2. Literature Review

Advancements in pet care have been driven by the integration of IoT, robotics, and Arduino-based technologies. Automated pet feeder systems have been developed to cater to the needs of pets such as cats and dogs, ensuring food and water dispensing and monitoring their movements without human intervention [8]. These systems address the issue of pet neglect due to busy schedules, enabling pet owners to save time and remotely monitor their pets' feeding through IoT connectivity.

Robotics and IoT technologies have also revolutionized pet care, allowing individuals to adopt and care for pets despite busy schedules and limited family sizes. Leveraging IoT technology, robots can provide food and water to pets while sending regular notifications to the owners, reducing stress levels, and promoting pet welfare [9]. Additionally, IoT-based Pet Day Care Robots enable pet owners to remotely interact and care for their pets' using smartphones, enhancing communication, and providing convenience [10].

Technology-driven solutions have also transformed pet feeding,

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ensuring optimal care and hygiene. The development of automated pet feeding devices, powered by Arduino microcontrollers and equipped with weight sensors, has revolutionized the feeding process [11]. These devices automatically dispense pet food based on weight measurements, eliminating manual effort, and maintaining proper feeding quantities. Moreover, technology has been harnessed to address communication and care for stray pets, with intelligent feeding systems employing fuzzy logic and intelligent techniques to enhance human interaction and improve their welfare [12].

By utilizing IoT, robotics, and Arduino-based technologies, advancements in pet care have introduced automated pet feeder systems, interactive robots, and intelligent feeding devices, enhancing convenience, communication, and well-being for both pets and their owners.

3. Methodology

In this section, the researchers elaborate on the System Architecture, Research Development, Initial Design Prototype, Model Training, Data Collection, and Research Evaluation methodologies employed within the system. The system architecture is displayed in Fig. 1 Below.

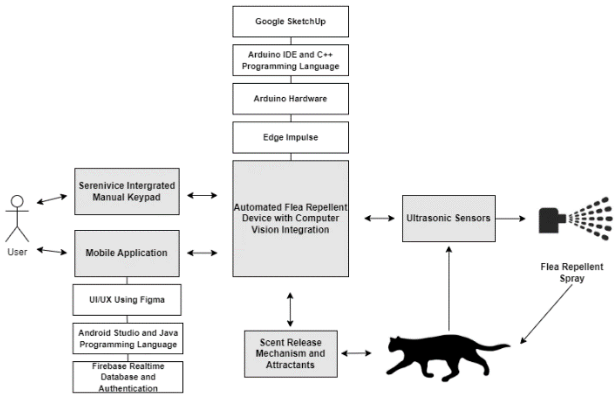


Fig. 1. System Architecture

3.1 System Architecture

This architecture encompasses various elements: the user, the automated flea repellent device furnished with integrated computer vision functionality and an incorporated manual keypad, the Serenivice mobile application, the scent release mechanism and attractants, as well as the ultrasonic sensor. The individual functionalities of the automated flea repellent device with computer vision were progressively developed within the framework of this system architecture and iteratively refined until all intended features and capabilities were successfully realized.

Interaction and control of the device are facilitated through two distinct avenues: utilization of the integrated manual keypad and engagement via the dedicated mobile application. The user assumes the pivotal role of overseeing, managing, and executing the operation of the Serenivice system. This involves inputting various commands, notably configuring the time interval for dispensing the flea repellent. Furthermore, the user bears the responsibility of replenishing both the flea repellent and the attractants within the device, tailoring these elements to align with the preferences of their respective feline companions.

The mobile application for Serenivice serves as an informative and remote platform, empowering users to exercise manual control over the Serenivice system and to monitor instances of flea infestations through their Android devices. Moreover, the application encompasses supplementary functionalities, including the tracking of historical data and the provision of treatment recommendations for improved flea management. The development of the Serenivice mobile application is executed through Figma's design tools, coupled with the utilization of Android Studio and Java programming for its construction. The core repository of user information is hosted within Firebase, serving as the primary database infrastructure.

The primary model here is the automated flea repellent device, which stands out due to its incorporation of both computer vision and a built-in manual keypad. Its primary task involves identifying flea infestations and administering flea repellent based on user instructions. To bring this concept to life, the prototype's three-dimensional design is crafted using Google SketchUp, serving as a foundational guide. Creating the physical prototype and crafting the necessary scripts is achieved using Arduino hardware and the Arduino Integrated Development Environment (IDE). The infusion of computer vision capabilities is made possible through tools like Edge Impulse. The effectiveness of the device is heightened by an ultrasonic sensor, which ensures that the device only activates when a cat is nearby, enhancing its precision. Additionally, a scent release mechanism is employed to attract cats to the device's location. This intricate setup is implemented using Arduino hardware, which plays a vital role in its functionality.

3.2 Research Development

The study follows an agile development methodology, allowing Serenivice to adapt to changing requirements effectively. It consists of six distinct phases, including the following: Requirements, Design, Development, Testing, Deployment, and Review.

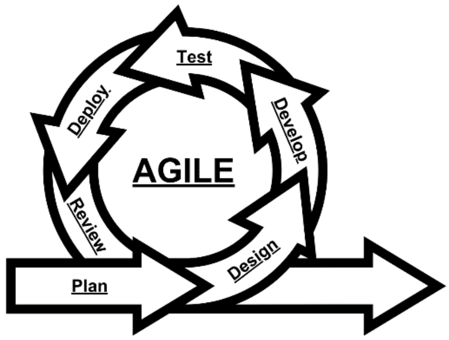


Fig. 2. Agile Methodology

In the Requirements stage, researchers gathered relevant information to define the system's requirements. This led to the discovery of two important features: a cat flea repellent device with an attractant and a mechanism for releasing scents; and a computer vision system built into the device. This system could be monitored through a mobile application offering additional features such as historical data tracking and treatment recommendations. The requirements stage also included a preliminary study of the device and application, including the identification of necessary software and hardware resources for utilization.

Subsequently, in the design phase, the researchers employed flowcharts as visual aids to illustrate the system's architecture, interactions among various features, and user interactions with the mobile application, providing a clear representation of the system's flow and functionality. During the development phase, the project's objectives were successfully achieved, beginning with the creation of a device model using 3D design software. The system was then constructed using Arduino IDE for hardware integration, while the mobile application's layout and user interface were designed using Figma and implemented through Android Studio and Java. During the testing phase, two assessments were carried out to verify the effective functionality, usability, performance efficiency, and portability of the system. Any identified flaws or defects were promptly addressed to ensure the system's optimal performance. Upon successful completion of these phases, the deployment process was initiated, with the developers providing user manuals, maintenance procedures, and a system management plan to guide users in effectively operating the system. Finally, the review stage involved the evaluation and approval of both the prototype and mobile application to ensure compliance with all system requirements, concluding the Agile development cycle.

3.3 Data collection

The data collection process involves two main steps. Firstly, the model is trained using a dataset comprising photos of cats and fleas. This dataset includes a total of 1011 photos, specifically gathered for the purpose of training the model to detect cats and fleas.

On the contrary, the second step of data collection entails obtaining data from the participants. They received a demonstration of how the device operates and tested it by allowing their cats to use the device. After observing the device in action, participants received questionnaires and were asked for their evaluations.

3.4 Model Training

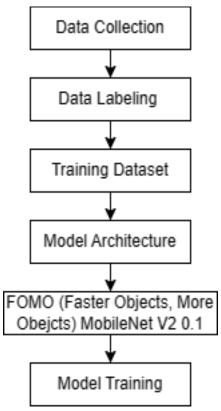


Fig. 3. Computer Vision Model Training Pipeline

The study focused on training a specialized computer vision model using a dataset exclusively comprised of images featuring cats and fleas. To ensure a comprehensive representation, the dataset was carefully curated, encompassing various poses, environments, and perspectives portraying both cats and fleas.

Each image underwent meticulous labeling to distinguish between instances of cats and fleas. This meticulous annotation process was pivotal for enabling supervised learning, allowing the model to discern and learn from these distinct categories effectively.

The chosen architecture, MobileNet v2 0.1, was tailored precisely for this task. Despite the constrained dataset, MobileNet v2 0.1 adeptly processed image features, extracting relevant characteristics associated with both cats and fleas. Its efficient design allowed for effective utilization within the limited dataset scenario.

Subsequently, the training phase began by feeding the restricted dataset into the MobileNet v2 0.1 architecture. Through iterative adjustments of the model's parameters, the model underwent refinement aimed at enhancing its ability to accurately discern and differentiate between cat and flea instances in the images.

This research methodology, centered around a limited dataset of cat and flea images, demonstrates a focused and specialized approach in training a computer vision model. Leveraging meticulous dataset curation, precise annotation, and the utilization of a specifically chosen architecture, the study aimed to maximize the model's capability to distinguish between these specific categories within the dataset's constraints.

3.5 Research Evaluation

In this section, the researchers introduce two research evaluations: Model Evaluation and System Evaluation. In examining the Model, the researchers utilized a confusion matrix to gauge the overall performance, considering metrics like accuracy, precision, recall, and F1-score. Ensuring the system operates effectively and meets the stipulated criteria necessitates a comprehensive specification and appraisal of the software product's quality.

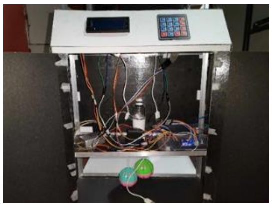
In the case of System Evaluation, the researchers apply the ISO 25010:2011 software quality model, concentrating on aspects like Functional Suitability, Usability, Performance Efficiency, and Portability.

4. Results and discussions

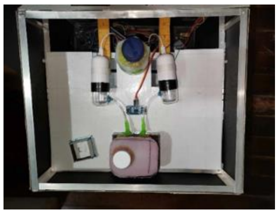
4.1 Device prototype

(a)

(b)



(c)



(d)

(e)

Fig. 4. Cat Flea Repellent Device Prototype

The Serenivice prototype represents a crafted device designed to address cat flea management in a comprehensive and cat-friendly manner. Externally, it features dimensions of 20 inches in height, 15 inches in width, and 15 inches in length, striking a balance between effectiveness and spatial efficiency. The device is finished in a clean white color, which serves a dual purpose - enhancing its aesthetics and aiding in the easy identification of fleas, a crucial element of efficient flea management.

On the upper back part of the device that can be seen in Fig. 4 (b) and (c), an intuitive user interface is found, comprising an LCD screen and user-friendly buttons. This strategic placement ensures that users can conveniently access and operate the device with ease. The device's rear section features a door-like panel that opens to reveal refillable liquid containers, simplifying the maintenance process and promoting long-term use.

Internally, Serenivice has the essential features designed to facilitate precise flea repellent application and cat attraction. The upper section that can be seen in Fig. 4 (d) contains a sensor within the device which serves as the trigger for flea repellent spray, ensuring precise activation when needed. To minimize any potential disturbance, two quiet sprays are utilized, guaranteeing the cat's comfort, and avoiding startled reactions. At the front that can be seen in Fig. 4 (e), a hole emits catnip scent, a natural attractant that captivates feline companions. In addition, an alternative attractant in the form of a moving cat toy is thoughtfully positioned below or at the bottom of the device. This holistic design approach seeks to diversify and enhance the device's allure, ensuring cats remain engaged with the lower section and their focus remains on the Serenivice device.

4.2 Model Evaluation

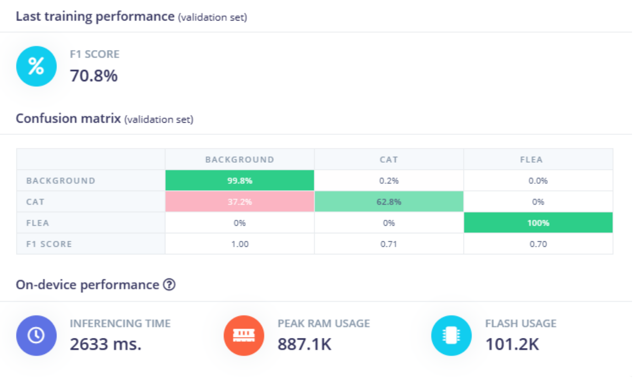


Fig. 5. Serenivice Confusion Matrix and Training Performance

In Fig. 5, the confusion matrix for the FOMO MobileNet V2 0.35 computer vision model reveals insights into its classification performance across different classes. Notably, the background class demonstrates exceptional accuracy, with a 99.8% true positive rate and a minimal error of 0.2%. This suggests that the model adeptly identifies instances of the background class. However, when it comes to the cat class, the accuracy drops to 62.8%, accompanied by a higher error rate of 32.8%. This indicates a relative struggle in correctly predicting instances of the cat class. On the other hand, the flea class achieves a perfect 100% accuracy, showcasing the model's proficiency in detecting instances of this class. The F1 scores further elucidate the model's performance. The background class attains a flawless F1 score of 1.00, reflecting a harmonious balance between precision and recall. In contrast, both the cat and flea classes yield moderate F1 scores of 0.71, implying room for improvement, particularly in the cat class. In summary, while the model excels in certain classes, there are opportunities for enhancement, as indicated by the F1 scores and varying accuracy levels across classes.

TABLE I FOMO (FASTER OBJECT, MORE OBJECT) MOBILENET V2 0.35

Classes	Precision	Recall	F1 Score
Cat	0.81	0.63	0.71
Flea	0.54	1.00	0.70
Background	0.99	1.00	1.00

The FOMO MobileNet V2 0.35 model summary provides a detailed evaluation of its classification performance across different classes. In the cat class, the model achieves a commendable precision of 0.81, indicating a high accuracy in its positive predictions, though it is accompanied by a somewhat lower recall of 0.63, suggesting a tendency to miss some actual cat instances. The resultant F1 score of 0.71 reflects a moderate balance between precision and recall. For the flea class, the model demonstrates a precision of 0.54, implying that its positive predictions for fleas are correct 54% of the time. Impressively, the model attains a perfect recall of 1.00, indicating its ability to identify all actual instances of the flea class. The corresponding F1 score of 0.70 signifies a well-balanced performance for flea detection. Notably, the model excels in the background class, achieving both high precision (0.99) and perfect recall (1.00), resulting in an outstanding F1 score of 1.00. In summary, while the model exhibits strong performance in identifying background instances, there is room for refinement in achieving a more balanced precision and recall for the cat and flea classes.

4.3 System Evaluation Results

In this section, the researchers disclose the outcomes of the system evaluation, derived from assessments by 36 participants utilizing the ISO 25010:2011 Software Quality Model.

TABLE II OVERALL MEAN RATING

Criteria	Mean	Evaluation
Functional Suitability	4.54	Strongly Agree
Usability	4.59	Strongly Agree
Performance Efficiency	4.47	Agree
Portability	4.53	Strongly Agree
Overall Mean	4.53	Strongly Agree

The provided data illustrates that the Functional Stability of the system achieved an average rating of 4.54, signifying a unanimous "Strong Agreement" among respondents regarding the system's ability to deliver functions meeting both stated and implied needs within specified conditions. Subsequently, Usability garnered an average score of 4.59, indicating a collective "Strong Agreement" among respondents regarding the system's capacity to be utilized by specified users to attain predefined objectives with effectiveness, efficiency, and satisfaction within a specified context of use. Thirdly, Performance Efficiency received an average mean grade score of 4.47, reflecting respondents' general "Agreement" on the system's efficiency in terms of resource consumption. Lastly, the Portability category attained an average score of 4.53, denoting a unanimous "Strong Agreement" among respondents concerning the ease of transferability of the system. The overall computed mean of 4.53 underscores a unanimous "Strong Agreement" among respondents with respect to the Functional Suitability, Usability, Performance Efficiency, and Portability aspects of the System.

5. Conclusion

Conclusively, the study's objectives culminated in the development of an Arduino-powered automated flea repellent device featuring refillable capabilities and designed to seamlessly alleviate and manage cat flea infestations. This innovative solution eliminates the need for human intervention by integrating a scent release mechanism with catnip and attractant, such as the strategically positioned moving cat toy, to enhance feline comfort and relaxation. Complementing this, the research introduced the FOMO MobileNet V2 0.35 computer vision model, seamlessly integrated into the device and a key feature of the mobile application. This comprehensive approach addresses not only the practical aspects of flea management but also incorporates cutting-edge technology for the efficient identification and monitoring of cat and flea presence.

Based on the study, it is recommended to consistently explore innovative solutions for mitigating cat flea issues. Specifically, it is suggested to enhance the device's durability through the utilization of upgraded materials, explore additional attractants effective for cats, delve into improved models for object detection, provide additional datasets relevant to the study, and fine-tune parameters to achieve improved outcomes.

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