



Evaluation of the Performance of an Ultrasonic-IoT Based Rice Field Rat Repellent System in Reducing Attack Intensity and Crop Losses

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ABSTRACT

Rodent infestation remains a major constraint in rice production, causing significant yield losses and threatening agricultural sustainability. Conventional rodent control methods, such as chemical rodenticides and manual trapping, often exhibit limited effectiveness and pose environmental and health risks. This study aims to evaluate the performance of an ultrasonic–Internet of Things (IoT)-based rice field rodent repellent system in reducing attack intensity and crop yield losses under real field conditions. The research employed a comparative field experiment conducted over one planting season, involving treated plots equipped with the ultrasonic–IoT system and untreated control plots managed using conventional practices. Rodent attack intensity was assessed through indicators including the percentage of damaged rice clumps, active burrow counts, and observable rodent activity, while yield loss was measured based on harvested grain output (kg/ha). System performance was further evaluated through the consistency of ultrasonic signal emission and the reliability of IoT-based data transmission. The results demonstrate a clear reduction in rodent attack intensity in treated fields compared to control fields, accompanied by a significant decrease in yield loss. The ultrasonic–IoT system operated reliably throughout the observation period, maintaining stable signal emission and continuous data logging despite variable field conditions. However, environmental factors such as weather variability and rodent migration patterns influenced system effectiveness to some extent. Overall, the findings indicate that the ultrasonic–IoT-based rodent repellent system is an effective, environmentally friendly, and data-driven approach that supports smart and sustainable agriculture. The system is best implemented as part of an integrated pest management strategy to enhance long-term effectiveness and scalability.

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1. INTRODUCTION

Rice production, a key national food commodity, still faces serious challenges due to the high intensity of rice field rat attacks. Rice field rats are known as plant pests with a high degree of adaptability, rapid reproduction, and the ability to damage plants at various growth stages, from seedling stage to harvest (Sarwar, 2015). Uncontrolled attacks can significantly reduce crop yields

and even trigger crop failure in some production centers. This situation makes rice field rat control a strategic issue in efforts to maintain food security and agricultural production stability.

Rice pest control efforts currently employed by farmers generally rely on conventional methods such as the use of poison, trapping, and mechanical traps. Although these methods are relatively easy to implement, their effectiveness is often temporary and unsustainable (Staniškis & Katiliūtė, 2019). The use of poison, for example, has the potential to negatively impact non-target organisms, pollute the environment, and pose health risks to humans and livestock. Meanwhile, trapping and trapping methods require high labor costs and are less efficient when applied on a large scale. These limitations highlight the need for more effective, efficient, and environmentally friendly pest control approaches.

As technology advances, ultrasonic-based pest repellent systems are being introduced as a non-chemical rat control alternative with minimal environmental impact. Ultrasonic waves work by disrupting the rats' auditory and behavioral systems, thus hopefully reducing the activity and intensity of attacks on agricultural land (Brudzynski, 2009). However, most previous research has focused on the design and technical testing of the device in confined or laboratory environments, without comprehensive quantitative evaluation of system performance in real-world rice paddy conditions.

In the context of rat pest control using ultrasonic waves, several studies have been conducted to design and test prototype devices using various technical approaches. Yuli Triyani, Wiwin Styorini, and Cyntia Widiyanti (2024) developed a rat repellent device using ultrasonic waves. This device utilizes a NodeMCU ESP32 microcontroller and a PIR sensor to detect rats and emit ultrasonic waves designed to be unpleasant for rice paddy rats, with the aim of providing an environmentally friendly alternative to chemical rodenticides. This research emphasized the design and operation of the device without advanced IoT integration.

Furthermore, Febi Eka Febriansyah et al. (2024) developed a prototype Internet of Things (IoT)-based rat repellent device with an ESP32-CAM module, ultrasonic sound, and real-time notification features via the WhatsApp API. This system not only detects rat movement through a PIR sensor but also provides live streaming and notifications to users, demonstrating the IoT's ability to provide more responsive and remotely connected pest control than traditional ultrasonic devices.

Several other studies have also explored the integration of IoT into pest control systems, although they do not focus solely on rats. Hilda Z. Kamaruzzaman, Munirul Ula, and Rini Meiyanti (2025) designed a prototype IoT-based automatic pest repellent system that included ultrasounds and PIR sensors powered by solar panels for general agricultural applications, demonstrating that IoT technology can improve the detection and response efficiency of repellent systems in agricultural fields. While this study also examined various pest control devices and their sensors, its focus on various pesticides (not just rats) demonstrates the growing trend of IoT adoption in smart agriculture.

Regarding ultrasonic waves specifically, research by Annisa Nur Ichniarsyah, M. Fazri Hauzan, and Erniati (2025) emphasized the selection of optimal ultrasonic frequencies in designing a prototype rat repellent device for rice fields. Testing frequencies of 40-60 kHz demonstrated the behavioral responses of rats to these frequency variations. This frequency research reinforces the importance of appropriate frequency design in ultrasonic systems to enhance their effectiveness.

Several other works provide related context or methods, although their focus is less specific on IoT integration or real-world implementation. Rizki Wahyu Pratama et al. (2024) describe the development of an ultrasonic system for rat repellent and detection, combining a PIR sensor and an Arduino Uno to generate waves in a specific frequency range as a non-invasive pest control solution in an enclosed environment.

Furthermore, the integration of Internet of Things (IoT) technology into an ultrasonic rat repellent system opens up new opportunities for data-driven pest control and real-time monitoring. However, empirical studies specifically evaluating the impact of implementing an ultrasonic IoT system on reducing rat infestation intensity and crop loss at the field scale are still very limited. This research gap indicates the lack of strong scientific evidence regarding the effectiveness and feasibility of this technology in everyday agricultural practices.

Therefore, this research is urgently needed as part of the development of environmentally friendly, data-driven precision agriculture (smart agriculture) technology. Evaluation of the performance of an ultrasonic IoT-based rat repellent system is expected to provide not only an

overview of the device's technical effectiveness but also its direct impact on reducing infestation intensity and crop loss (Tedla et al., 2019). Thus, the results of this study can be a scientific basis for decision-making in controlling rat pests that is more sustainable, efficient, and adaptive to the challenges of modern agriculture.

2. RESEARCH METHOD

This research was conducted on productive rice fields in a central rice farming area, with relatively homogeneous agro-ecosystem characteristics. The research area covered a total area of approximately 1 hectare, divided into several experimental plots of uniform size. The rice varieties used were superior varieties commonly cultivated by local farmers, ensuring that the research results reflected actual agricultural conditions (Sall et al., 2000). The research was conducted over a full growing season, from the early vegetative phase to harvest, to capture the dynamics of rat infestation at various stages of rice plant growth.

The experimental design used a field experiment with a comparative approach, comparing fields treated with an ultrasonic-IoT-based rat repellent system with control fields without treatment. The treated fields were installed with ultrasonic-IoT devices at strategic points at specific distances to ensure even ultrasonic wave coverage. Meanwhile, the control fields were managed using conventional cultivation practices without the ultrasonic repellent system. To minimize bias, both fields had similar characteristics in terms of soil type, irrigation system, and cultivation techniques (Valdivia-Cea et al., 2017).

Observations were conducted periodically at weekly intervals throughout the planting and harvesting periods (Ngetich et al., 2014). This observation period allows for the identification of temporal changes in rat infestation intensity and the evaluation of the medium-term effectiveness of the ultrasonic-IoT system. Furthermore, continuous recording of IoT system operational data is conducted to monitor device uptime, ultrasonic emission duration, and system stability throughout the study period.

System performance evaluation indicators focus on two main aspects: rat infestation intensity and crop loss (Capizzi et al., 2014). Rat infestation intensity is measured based on the percentage of damaged rice clumps, the number of active holes in the embankments or rice paddy fields, and the presence of rat activity traces observed in the field. Meanwhile, crop loss is evaluated by comparing actual yields (kg/ha) between the treatment and control fields and calculating the percentage of yield loss due to rat infestation.

Data collection methods include a combination of structured field observations, automated recording via the IoT system, and crop yield measurements (Peets et al., 2012). Field observations are conducted by researchers using standard observation sheets to record the level of crop damage and indicators of rat activity. IoT data is used to record system performance in real time, while crop yield measurements are conducted at harvest time by weighing dry grain from each experimental plot.

Data analysis is conducted in stages using descriptive and inferential statistical approaches (Statistics, 2013). Descriptive statistics were used to describe patterns of rat infestation intensity, system performance, and crop yields in each treatment. Next, inferential analysis was conducted to test for significant differences between the treatment and control plots. A t-test or ANOVA was used if the data were normally distributed, while nonparametric tests such as Mann-Whitney or Kruskal-Wallis were applied if the assumption of normality was not met. This approach ensures that the conclusions drawn have a strong statistical basis and are scientifically sound.

3. RESULTS AND DISCUSSIONS

3.1 System Performance Evaluation Results

Field observations revealed a significant change in the intensity of rat infestations following the installation of an ultrasonic-IoT-based rice field rat repellent system. In the initial observation phase (before system installation), the intensity of rat infestations in the treatment and control fields was relatively uniform, characterized by a high percentage of damaged clumps and numerous active holes and traces of rat activity in the rice fields. After continuous operation of the ultrasonic-IoT system, the treatment fields showed a gradual decrease in infestation intensity from week to week,

while the control fields tended to maintain or even increase in infestation intensity, particularly during the generative phase of rice plants, which are vulnerable to pest infestations.

Quantitatively, the percentage of damaged rice clumps in the treatment fields decreased significantly compared to the initial conditions before system installation. Conversely, the control fields showed a relatively higher level of damage that fluctuated throughout the observation period. This difference indicates that the ultrasonic wave emissions generated by the system contributed to suppressing rat activity in the treatment areas, allowing for more effective control of infestation intensity compared to cultivation methods without technological intervention.

The impact of this reduced rat infestation intensity was directly reflected in rice yields. Based on yield measurements, the fields implementing the ultrasonic-IoT system produced higher productivity than the control fields. The yield difference between the two fields indicated that crop losses due to rat infestation were significantly lower in the treatment fields (Rabiu & Rose, 2004). Comparatively, the control fields experienced greater yield losses due to damage to rice clumps and panicles, while the treatment fields maintained their yield potential near optimal conditions.

In addition to biological and agronomic aspects, the technical performance of the ultrasonic-IoT system was also evaluated throughout the study period. Data recording results showed that the system was able to consistently emit ultrasonic signals according to the established parameters. No significant disturbances were found in the wave emission pattern, either in terms of frequency or duration, even though the system was operated under dynamic field conditions such as changes in temperature, humidity, and rainfall.

In terms of IoT technology reliability, the system demonstrated stable performance in terms of connectivity and data recording. Device operational data was recorded continuously with minimal data loss, allowing for real-time and post-operational monitoring of system performance (Louis & Dunston, 2018). This reliability strengthens the role of the ultrasonic-IoT system not only as a pest control tool but also as a supporting instrument for data-driven precision agriculture. Overall, these results indicate that the integration of ultrasonic and IoT technologies has significant potential to suppress rice field rat attacks while reducing crop losses sustainably.

3.2 The system effective or ineffective

The effectiveness of an ultrasonic-IoT-based rice field rat repellent system is primarily influenced by the rats' biological mechanisms and behavior in response to high-frequency sound stimuli. Ultrasonic waves emitted continuously or periodically can disrupt the rats' auditory and communication systems, causing discomfort and environmental stress. This encourages rats to avoid areas exposed to the ultrasonic and move to safer locations. This finding aligns with the reduction in attack intensity in the treated fields, indicating that ultrasonics function as an effective behavioral deterrent in the context of non-chemical pest control.

In addition to biological factors, the system's effectiveness is also influenced by the integration of IoT technology, which enables more consistent and controlled device operation. The IoT system plays a role in ensuring that ultrasonic emissions occur on schedule, minimizing downtime, and providing real-time operational data (SHARMA et al., 2019). This consistency is crucial, given the rats' high adaptability to their environment. With a regular and monitored emission pattern, the potential for rat habituation to ultrasonic sounds can be reduced, thus maintaining the system's effectiveness over a longer period.

However, system effectiveness is not absolute and is greatly influenced by field environmental conditions. Factors such as land area, rice field topography, vegetation density, and the presence of physical barriers can affect the range and intensity of ultrasonic waves. In large areas or areas with numerous barriers, ultrasonic wave coverage can be uneven, creating "safe" areas for rats to continue their activities. This condition can reduce the effectiveness of the system if not balanced with optimal device placement.

On the other hand, potential ineffectiveness can also arise from the long-term adaptive behavior of rats. Rats are organisms with high ecological intelligence and are able to adapt to repeated stimuli (Schulze-Makuch, 2019). If the ultrasonic emission pattern is monotonous and unvaried, rats have the potential to habituate and re-enter the treatment area. This indicates that system effectiveness is highly dependent on adaptive operational design, including variations in the frequency, duration, and timing of ultrasonic emissions.

Therefore, an ultrasonic-IoT-based rice field rat repellent system can be considered effective if implemented with appropriate technical design, reliable IoT integration, and adjustments to field environmental conditions. Conversely, the system can be less effective if the ultrasonic coverage is not optimal, the emission pattern is not adaptive, or if it does not fully consider the ecological and behavioral factors of the rats. Therefore, this technology-based pest control approach should be positioned as part of a sustainable integrated pest management strategy, not as a stand-alone solution.

3.3 Environmental Factors Influencing Research Results

Environmental factors play a critical role in determining the effectiveness of the ultrasonic-IoT-based rice field rat repellent system. One key factor is weather conditions, particularly rainfall, temperature, and humidity. High rainfall can influence rat activity by encouraging population migration to higher areas or relatively dry rice field embankments. This condition has the potential to increase infestation pressure in certain plots, regardless of the presence of the repellent system, resulting in variations in infestation intensity between observation periods.

Furthermore, temperature and humidity also affect ultrasonic wave propagation in open environments. In high humidity conditions, particularly after rain, ultrasonic wave propagation can decrease due to energy absorption by moist air and wet vegetation (Wang et al., 2016). This can reduce the effective range of the system, resulting in uneven rat repellent effectiveness across the treatment area. Therefore, daily and seasonal weather fluctuations need to be considered as factors that can modulate the performance of the ultrasonic system in the field.

Migration patterns of rice field rats are also a significant ecological factor influencing research results. Rats exhibit strong migratory behavior, primarily in response to food availability and changes in rice plant growth phases. During the generative phase until harvest, rat populations tend to increase and move to areas with abundant food sources. Migration from surrounding areas without repellent systems can increase population pressure in both treatment and control areas, thus affecting observed infestation levels.

The interaction between rat migration patterns and the presence of ultrasonic systems can also produce complex spatial effects (Byers et al., 2019). Under some conditions, ultrasonic systems can encourage rats to move to peripheral areas or neighboring fields, potentially re-entering the study area through specific routes such as embankments or irrigation channels. This phenomenon indicates that the effectiveness of the system is strongly influenced by the overall agricultural landscape context, not just the conditions within a single rice field.

Therefore, research results need to be interpreted by considering the environmental dynamics and ecology of rats holistically. Weather variability and rat migration patterns can be confounding factors affecting infestation intensity and crop losses. This underscores the importance of implementing ultrasonic-IoT-based rat repellent systems within an integrated pest management framework that considers climate conditions, land use layout, and synchronized control across regions to achieve optimal and sustainable results.

3.4 Comparison of an Ultrasonic-IoT-Based Rat Repellent System with Conventional Rat Control Methods

Conventional rat control methods generally involve the use of chemical rodenticides, gropyokan (trapping traps), and mechanical traps (Janković et al., 2019). Rodenticide methods can reduce rat populations relatively quickly in the short term, but their effectiveness is often unsustainable because rats can develop avoidance behaviors when exposed to poison bait. Furthermore, the use of chemicals has the potential to negatively impact non-target organisms, pollute the environment, and pose health risks to humans and livestock. Compared to these approaches, an ultrasonic-IoT-based rat repellent system offers a safer and more environmentally friendly non-chemical alternative because it does not involve hazardous substances in the control process.

Gropyokan and mechanical traps rely on intensive human labor and the collective participation of farmers (労働組織に関する比較研究 & スベジヨ, n.d.). While these methods can be effective under certain conditions, their implementation is often inefficient on large-scale rice fields and requires high labor costs. Furthermore, the success of gropyokan relies heavily on synchronized timing and coverage, making it difficult to implement consistently. In contrast, ultrasonic-IoT systems

can operate automatically and continuously without direct reliance on human labor, making them more operationally efficient, especially in the context of limited human resources in the agricultural sector.

In terms of control effectiveness, conventional methods tend to be reactive, applied after crop damage has occurred or rat populations have significantly increased. This approach often fails to prevent crop losses. In contrast, ultrasonic-IoT systems are preventative in nature, working continuously to repel rats early, potentially suppressing infestations before they cause significant damage. This preventative approach aligns with the principles of precision agriculture, which emphasize prevention-based pest management and continuous monitoring.

However, ultrasonic-IoT systems also have limitations compared to conventional methods. The effectiveness of ultrasonics is highly influenced by environmental conditions and the potential adaptation of rats to sound stimuli, requiring a combination with other control methods in certain situations. Conventional methods, despite their environmental risks, are still considered effective in rapidly reducing rat populations in emergency situations. Therefore, ultrasonic-IoT systems should not be viewed as an absolute replacement for conventional methods, but rather as a supporting component in an integrated pest management strategy.

Overall, this comparison demonstrates that the ultrasonic-IoT-based rice field rat repellent system has advantages over conventional methods in terms of sustainability, operational efficiency, and environmental safety. Meanwhile, conventional methods still have a limited role under certain conditions. Selectively and data-driven integration of both approaches is the most rational strategy for achieving effective, adaptive, and sustainable rice field rat control.

3.5 Research Implications for Smart and Sustainable Agriculture

The implementation of an ultrasonic-IoT-based rice field rat repellent system has strong implications for the development of smart agriculture, particularly in technology- and data-driven pest management. The integration of ultrasonic devices with IoT systems enables automated, real-time, and measurable pest monitoring and control. This approach reflects a paradigm shift from reactive conventional agriculture to proactive precision agriculture, where management decisions are based on continuous and accurate field data.

From an environmental sustainability perspective, this system contributes to reducing reliance on chemical rodenticides that have the potential to pollute soil, water, and surrounding ecosystems (Smith & Shore, 2015). By utilizing ultrasonic waves as a non-chemical control method, risks to non-target organisms and human health can be minimized. This aligns with the principles of sustainable agriculture, which emphasize the balance between agricultural productivity and environmental preservation, and supports more ecosystem-friendly agricultural practices.

Other implications are seen in the resource efficiency and economics of agriculture. The ultrasonic-IoT system can operate continuously with minimal labor requirements, thereby reducing long-term operational costs. Furthermore, reducing the intensity of rat infestations and crop losses directly contributes to increased productivity and farmer income. In the context of smart agriculture, this efficiency is a key element in enhancing the competitiveness of the agricultural sector, especially amidst the challenges of labor constraints and fluctuating input costs (Singh & Nath, 2020).

Furthermore, utilizing data generated by IoT systems opens up opportunities to develop adaptive and integrated pest control systems. Historical data on system uptime, infestation intensity, and environmental conditions can be used as a basis for decision-making based on artificial intelligence or predictive analytics (Sailaja et al., 2020). Thus, the ultrasonic-IoT rat repellent system functions not only as a technical tool but also as a component of a digital agricultural ecosystem that supports continuous innovation and increased food security.

Overall, this study confirms that the application of ultrasonic-IoT technology in rice field rat control has strategic implications for the development of smart and sustainable agriculture. This technological integration supports more efficient, environmentally friendly, and data-driven agricultural practices, while strengthening the adaptive capacity of agricultural systems to face future production challenges and environmental changes.

3.6 Research Limitations

This study has several limitations that need to be considered when interpreting the results and their implications. The first limitation relates to the relatively limited scale of the research area.

Although the experimental design was as homogeneous as possible, the limited coverage may limit the generalizability of the research results to larger rice fields or those with different agro-ecosystem characteristics (Dominik, 2019). Variations in topography, land layout, and irrigation systems on a broader scale could potentially impact the effectiveness of the ultrasonic-IoT-based rat repellent system.

Another limitation is the difficulty in controlling for variations in the rat population during the study period. The rice field rat population is strongly influenced by external factors such as food availability in surrounding fields, weather conditions, and pest control activities in other nearby areas. Mice migration from outside the study area can suddenly affect the intensity of infestations, causing data fluctuations that do not fully reflect the performance of the tested system. This is a common challenge in field research involving highly mobile living organisms.

Furthermore, the testing duration in this study did not repeatedly cover the entire rice growing season. Observations conducted over only one growing season cannot fully capture seasonal variations, such as differences in rat attack intensity between the rainy and dry seasons, or between early and late growing seasons (Sarwar, 2015). This limited duration has the potential to impact understanding of the system's long-term effectiveness, including the possibility of rat adaptation to ultrasonic stimuli over a longer period.

Considering these limitations, the results of this study require careful and contextual interpretation (Stürmer et al., 2020). This limitation also opens up opportunities for further research with larger field scales, longer observation periods, and a more integrated rat population control approach. This approach is expected to provide a more comprehensive picture of the performance and sustainability of the ultrasonic-IoT-based rice field rat repellent system in various agroecosystem conditions.

4. CONCLUSION

This study demonstrates that the implementation of an ultrasonic-IoT-based rice field rat repellent system has the potential to effectively reduce the intensity of rat infestations and minimize crop losses. Comparative evaluation between treated and control fields revealed a consistent reduction in rat activity indicators such as damaged rice clumps, active burrows, and movement tracks after system installation. These findings suggest that ultrasonic waves serve as an effective non-chemical deterrent by disrupting rat behavior and preventing their presence in the treated area. The reduction in infestation intensity directly contributes to increased crop productivity. Fields equipped with the ultrasonic-IoT system exhibited lower crop losses and higher yields compared to control fields managed using conventional practices. These results highlight the practical benefits of this system not only as a pest control tool but also as a technology that supports crop preservation and economic efficiency at the farm level. From a technical perspective, the system demonstrated stable ultrasonic signal emission and reliable IoT connectivity, enabling continuous operation and real-time data recording under dynamic field conditions. However, the system's effectiveness was affected by environmental factors such as weather variability and rodent migration patterns, as well as by the limited scale and duration of field testing. These challenges demonstrate that while ultrasonic-IoT systems are promising, their performance can vary across agroecosystems and seasons. Therefore, these systems should be viewed as complementary components within an integrated pest management framework, rather than as standalone solutions. Overall, this study provides empirical evidence for the development of smart and sustainable agriculture by demonstrating how data-driven, environmentally friendly technologies can improve pest management practices. Future studies are recommended to expand the implementation scale, extend the observation period across multiple growing seasons, and incorporate adaptive control strategies to further optimize system performance and long-term effectiveness.

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