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Integrating Internet of Things Sensors with Machine Learning for Urinary Tract Infection Prediction in Male Felines

Danish Ather[1], Tanveer Baig Z[2], Ambuj Kumar Agarwal[3], Suhail Javed Quraishi[4], Malikhan singh[5], Rajneesh Kler[6]

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Abstract: Urinary Tract Infections (UTIs) are a prevalent medical condition affecting male felines that can lead to severe discomfort, behavioural changes, and even fatality if not promptly diagnosed and treated. This paper aims to address the limitations of traditional diagnostic methods by integrating Internet of Things (IoT) sensors with machine learning algorithms to predict UTIs in male felines. The study utilizes a multi-modal sensor array to continuously monitor various physiological and behavioural parameters, such as acidity of urine pH levels, heart rate, territorial marking, and eating habits. Observations were categorized into several states, ranging from normal conditions to severe abnormalities, including death. A machine learning model was trained on the collected data to identify early signs of UTIs. The model demonstrated a high predictive accuracy in identifying urinary tract infections before the manifestation of severe symptoms, thus providing a promising avenue for early intervention. The integrated system offers a non-invasive, real-time monitoring solution that could significantly improve the management and the treatment outcomes of UTIs in male feline.

Keywords*: Internet of Things (IoT), Machine Learning, Urinary Tract Infections (UTIs), Feline Health.*

1. Introduction

The integration of Internet of Things (IoT) sensors with machine learning algorithms has transformed various industries, ranging from healthcare, automotive to agriculture and many others. This fusion allows for real-time data collection and analysis, thereby making predictions and decision-making more effective and efficient [1]. One domain that has been significantly impacted by this amalgamation is veterinary healthcare. As per the American Veterinary Medical Association, approximately 58 million cats are kept as pets in the United States alone. These felines, like humans, suffer from various medical conditions, including urinary tract infections (UTIs), which are especially common in male felines.

Urinary Tract Infections in male felines are a significant concern due to their propensity to develop life-threatening complications such as urethral obstruction, which can lead to fatal renal failure if not promptly addressed. Despite its seriousness, diagnosing UTIs in cats remains a challenge because symptoms are often subtle and may be mistaken for behavioural issues. Owners often only realize that their cat is unwell when the infection has escalated to a more severe and sometimes irreparable stage. Traditional diagnostic methods include urinalysis and urine culture, but these methods are often time-consuming and require the expertise of a veterinarian[2], [3].

Furthermore, the cat has to endure stress during the journey to the clinic and the examination process, which can exacerbate the condition. Therefore, there is an urgent need to devise new strategies that can help in the early detection and management of UTIs in felines. With the emergence of IoT devices and machine learning algorithms, the opportunity to create a seamless, non-invasive, and real-time monitoring system seems plausible.

Over the years, several studies have explored the applications of IoT and machine learning in healthcare, both human and veterinary. However, few have focused on urinary tract health or specifically on UTIs in male felines. Machine learning techniques like Support Vector Machines (SVM) [4] and Random Forests have proven to be exceptionally adept at handling complex biological data for disease prediction in humans[5]–[7] . Additionally, IoT sensors have been used to monitor vital signs and physical activities in various animal species. However, a gap exists in integrating these two advanced technologies for predicting UTIs in cats.

This paper aims to bridge this gap by developing a comprehensive system that integrates IoT sensors with machine learning algorithms to monitor urinary behaviour and other relevant parameters for the early prediction of UTIs

1,2,6 Amity University in Tashkent, Uzbekistan
3Department of Computer Science and Engineering Sharda School of Engineering and Technology, Sharda University, Greater Noida, India
4Department of Computer Applications, School of Computer Applications, Manav Rachna International Institute of Research and Studies, Faridabad.
5 Computer Science and Engineering, BSA College of Engineering & Technology, Mathura
Corresponding Author: ambuj4u@gmail.com

in male felines. By focusing on male felines, who are at a higher risk for UTIs that can result in urethral obstruction, this study targets a significant gap in the existing veterinary healthcare literature [8]–[10]. Additionally, the paper aims to provide an innovative, timely, and efficient solution for a critical problem that affects millions of cats and their owners. It serves as a foundation for leveraging advanced technologies to revolutionize veterinary healthcare and can be potentially extended to other diseases and animal species

1.1 Motivation

The synergy of Internet of Things (IoT) sensors and machine learning (ML) algorithms offers an innovative landscape for addressing various real-world problems, especially in healthcare [11], [12]. As technology advances, there is a compelling case for harnessing these advancements in veterinary medicine, where the potential for transformative change remains relatively unexplored. One particular area in need of immediate attention is the early detection of urinary tract infections (UTIs) in male felines, a condition that can escalate into life-threatening complications if left unaddressed.

Traditionally, diagnosis of UTIs in felines has depended on the keen observations of pet owners, followed by clinical examinations, urinalysis, and cultures performed by veterinarians. This process has numerous downsides, such as delayed diagnosis and treatment, additional stress for the animal, and higher costs for the pet owner. Additionally, current diagnostic procedures lack the sensitivity and specificity required for early-stage identification [13]. Delay in detection often results in complications that require more aggressive treatments, such as catheterization or even. Surgical intervention. In human healthcare, IoT devices equipped with various sensors are already utilized for real-time monitoring of patients' vital signs, physical activity, and other health-related parameters. Coupled with machine learning algorithms, these devices have the capability to predict, with high accuracy, the onset of conditions such as heart failure, diabetes, and more. If such sophisticated systems have shown efficiency in humans, then a similar application in veterinary healthcare should not only be plausible but also highly advantageous.

Male felines are particularly susceptible to UTIs due to their narrower urethras, which are more prone to blockage. A UTI in a male cat that leads to blockage can be fatal within 72 hours. Thus, early detection and treatment of UTIs are crucial. Moreover, UTIs are not just isolated incidents; they can be recurrent and may necessitate ongoing monitoring and technologies that are quite helpful in treating seizures and patients. The authors put up a system model based on an IoT-management [14]-[15]. An IoT-ML integrated system would allow for continuous monitoring, early detection, and prompt intervention, drastically reducing the severity and recurrence of UTIs.

The financial burden of treating UTIs and associated complications is not trivial. Pet owners often face high medical bills, while veterinarians must invest in specialized equipment and training to diagnose and treat these conditions. By enabling early detection through a cost-effective IoT-ML system, both parties stand to benefit economically. On the social front, cats are beloved members of many households. The emotional distress that pet owners go through when their pet is severely ill cannot be underestimated. An effective early warning system would significantly lessen this emotional toll.

In light of the above, this study aims to bridge technological capabilities and veterinary healthcare needs to create an integrated, real-time, non-invasive, and efficient system for the early prediction of UTIs in male felines. In doing so, we aim to usher in a new era of veterinary medicine that leverages advanced technology for superior healthcare outcomes.

2. Literature Review

2.1 IoT in Veterinary Healthcare

The Internet of Things (IoT) has had a transformative impact on many sectors, including healthcare. However, its adoption in veterinary medicine is not as widespread. Most IoT applications in this field have focused on livestock management, such as tracking and monitoring, and only a handful of studies have looked into IoT wearable for companion animals [16], [17]. These devices can measure vital signs like heart rate and body temperature, but their application in diagnosing specific medical conditions remains theoretical at best. One of the significant challenges for widespread adoption is the lack of standardized protocols for data collection and sharing. The primary goal of this suggested approach is to reduce communication overhead and energy consumption while preserving safe and secure health-related data aggregation between medical sensors and cloud servers [20]. For instance, evidence from previous studies establish that low-cost, small, and effective embedded systems with sensors that can measure and monitor ambient air quality in real-time have emerged as a result of the internet of things (IoT) platform, wireless sensor network, and energy-efficient telecommunication infrastructure [21]. Another study suggests there may be many wearable enabled cloud for exchanging data with different sensors and other devices to produce an accurate assessment of seizures, which will be able to deliver better e-health service. It seems that it is increasingly important to improve ourselves and collaborate with the digital world to offer low-cost, precise, and speedy solutions given the increasing rate of improvement in both the IoT and e-health fields [22].

2.2 Machine Learning Algorithms

Machine learning has made remarkable strides in predictive healthcare. Algorithms are now capable of identifying complex patterns in large sets of data to make incredibly accurate predictions. Algorithms like Random Forests and Neural Networks are particularly well-suited for healthcare applications due to their flexibility and capacity for handling large, unstructured datasets [4]. While machine learning's influence in human healthcare is well-documented, its role in veterinary medicine is still nascent. Some efforts have been made to apply machine learning to diseases affecting livestock, but these are in the minority.

2.3 UTIs in Male Felines: Current Diagnostic Procedures

Urinary tract infections (UTIs) in male cats are typically diagnosed through conventional methods like urinalysis, ultrasound, and physical examinations as shown in Fig 1.

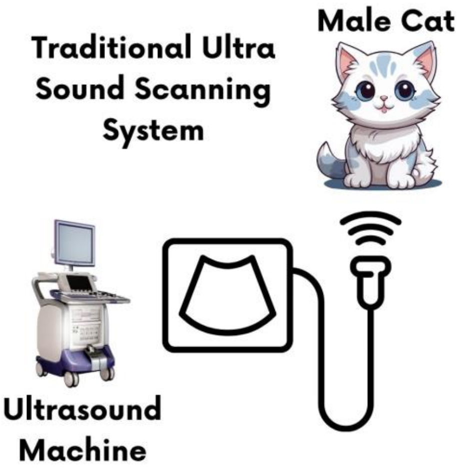

Fig 1. Conventional method use of ultrasound for UTI infection.

While these methods are effective, they require a visit to the vet and can be stressful for the animal. Speed is often of the essence in severe UTI cases, making the traditional diagnostic process far from ideal [18].

2.4 IoT and Machine Learning: An Integrated Approach

The potential for integrating IoT with machine learning in healthcare is enormous [19]. Most existing research in this area focuses on human health conditions like diabetes and heart disease. These integrated systems are known for their predictive accuracy and are a logical next step for animal healthcare, particularly for conditions like UTIs that require rapid diagnosis and treatment. Though there are rudimentary systems designed for monitoring the well-being of cats, these do not use machine learning for predictive analysis.

2.5 The Importance of Data Security and Ethics

As IoT and machine learning are increasingly integrated into healthcare, there are growing concerns about data security and ethical considerations . It is crucial to ensure that the personal and sensitive data collected are secured and that the algorithms used are transparent and unbiased.

2.6 Gaps and Future Directions

The current literature emphasizes the effectiveness of IoT and machine learning in human healthcare but leaves a significant gap when it comes to their combined use in veterinary medicine, particularly for diagnosing UTIs in male felines. Given how common and severe this condition can be, there is an urgent need for targeted research in this specific area.In summary, while there has been substantial progress in IoT and machine learning individually, and some in their combined application to human healthcare, the integration of these technologies in veterinary medicine remains underexplored. There is a significant opportunity for innovation and research in using these technologies for early detection and management of UTIs in male felines.

2.7 Signs and Symptoms of UTI in Male Cats

LUTD's most typical symptoms include:

- Painful or difficult urinating
- Greater urination frequency
- Sobbing while taking a urinal
- Blood found in the pee.

Most affected cats are in the age range of one to ten years old. There may be mild to severe indications and symptoms. Urinating frequently, painfully, straining to urinate, having blood in the urine, and inappropriate urination (urinating outside of a litter box) are some of the earliest symptoms that cats may experience. These signs point to discomfort and inflammation in the urinary system. Although these periods often terminate in 5-7 days, in many cases recur within 6–12 months. The symptoms are severe and potentially dangerous if there is a complete blockage that prevents urine from leaving the body. Once completely obstructed, cats may attempt to use the litter box to urinate, but they will be unable to generate any urine. The structure of internal organs of male cat is depicted in Fig 2.

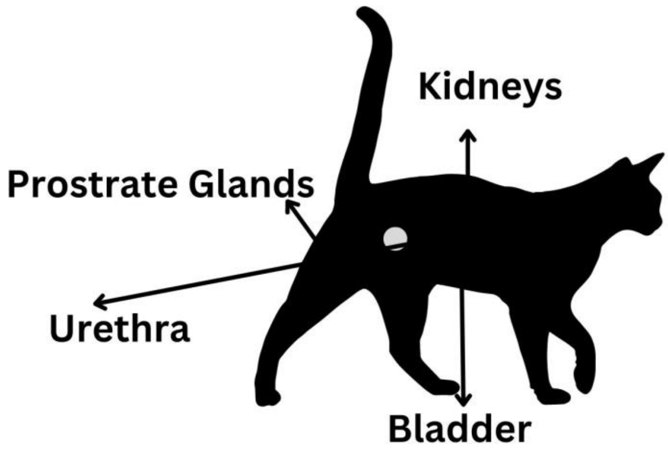

Fig 2. Depiction of different organs that will be infected under UTI

Urinary blockage in cats necessitates immediate medical attention. To insert a catheter into the urethra and flush out the plug or push the stone into the bladder, all but the sickest patients require sedation or general anaesthesia. To get rid of any leftover sediment, the bladder is completely drained and flushed using the catheter. After that, the urine catheter is usually retained in place for a few days until the swelling in the urethra goes down. After the catheter is taken out, the cat is assessed to ensure that it can go litter box on its own before being released from the hospital. To assist the cat, feel more comfortable and help him or her relax, veterinarian may also recommend painkillers, a food modification to reduce the potential for crystals to form or other medications. Some cats may experience bleeding or enema following surgery.

If the cat traumatizes the surgical site, inadequate dissection, or urine leaks beneath the skin, the urethrostomy site may become restricted (scarred and narrowed). This may result in a total obstruction or a return of symptoms. Within the first year, following a perineal urethrostomy, 25% of cats experience bacterial urinary tract infections. Stone development and bladder irritation are not prevented by perineal urethrostomy. Depending on the underlying reason, urinary obstruction symptoms in cats might vary, but they may include decreased frequency and volume of urination, vocalization (meowing in pain), blood in the urine, and straining to urinate.

3. Methodology

The purpose of this research is to establish a predictive framework for early detection of Urinary Tract Infections (UTIs) in male felines. This endeavor aims to integrate data from Internet of Things (IoT) sensors with machine learning techniques. The following section outlines the steps and procedures used to achieve this goal, with specific emphasis on the parameters to be monitored which includes temperature in Fahrenheit (°F), heart rate in beats per minute (B/m), respiration rate in beats per minute, pH levels of urine, tail position in degrees, touch sensor responses, and the number of times the litter box is accessed.

3.1 Bladder Volume Calculation

Urinary bladder wall thickness can be calculated based on the degree of bladder distension as shown in equation (1)

$$\text{Bladder Volume} = \text{Width x Height x Depthx}0.7^{*} \quad (1)$$

where * depends on shape of bladder.

The thickness of the bladder wall is 2.3 ± 0.43 mm when the bladder is only slightly dilated (0.5 mL/kg). The thickness of the bladder wall is 1.6 ± 0.29 mm if the bladder is somewhat enlarged (2 mL/kg). The thickness of the bladder wall is 1.4 ± 0.28 mm if the bladder is substantially enlarged (4 mL/kg). Cystitis and urinary bladder neoplasia are differential diagnosis if urinary bladder wall thickness is suspected. The thickness of the bladder wall in cats varies from 1.3 to 1.7 mm. When the bladder is comparatively empty, the uneven folds of the bladder can be misinterpreted for excessively thicker bladder walls. Giving continuous intravenous fluid or low doses of furosemide can confirm wall thickness in cases when an abnormality of the bladder wall (such as cystitis) is suspected. insertion of a urinary catheter to provide sterile, isotonic saline to the bladder as shown in Fig 3. The maintenance fluid rate for adult cats is calculated as 2 ml /kg/hr. or 50ml/ kg/ 24hrs

3.2 Data Collection for determining Urinary Tract infection using IoT.

In Vivo Data: Customized IoT sensors as fitted onto male felines can continuously collect data based on following parameters as shown in Fig 4.

Temperature (°F), Heart Rate (B/m), Respiration Rate (Beats/minute), pH sensor readings, Tail position (in degrees), Touch Sensor, Litter Box Access (Number of Times)

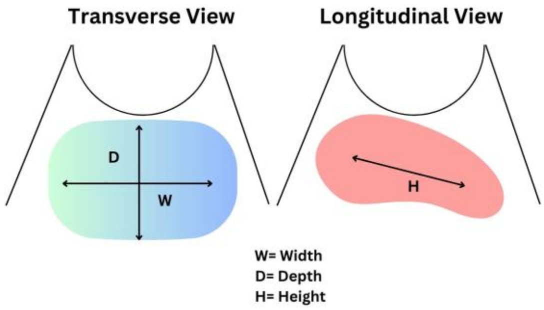

Fig 3. The urinary bladder shapes used to place catheter.

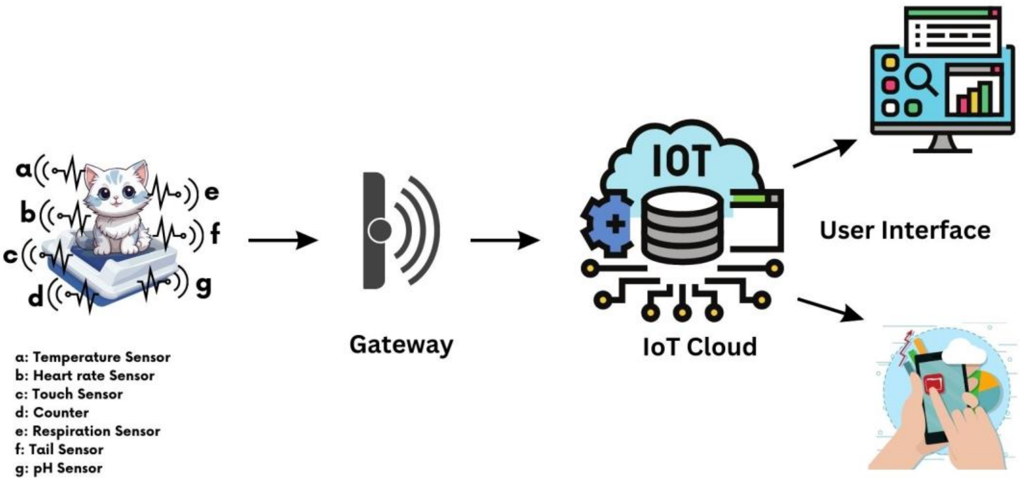

Fig. 4 This figure would showcase the proposed model for predicting Urinary Tract infection (UTI) in male felines.

Simulated Data: To augment the real-world data and facilitate a more robust model, Bevywise IoT Simulator can be employed to generate synthetic yet realistic sensor data. For placing of catheter to monitor the health it is important to calculate the urethra resistance and the bladder size. The equation calculating urethral resistance is as follows.

$$R = P_{ves}/Q \quad (2)$$

(where R = resistance, Pves = vesical pressure, and Q = flow rate), followed standard hydro-dynamic formulae calculating outlet resistance.

3.3 Data Pre-processing

The raw data collected shall be pre-processed to ensure data quality. This involves cleaning and normalization of the dataset. Missing values shall be accounted for, and any outliers either be corrected or removed.

3.4 Feature Extraction and Selection

The cleaned dataset can be further processed to identify relevant features that significantly correlate with the occurrence of UTIs in male felines. For each of the seven parameters, statistical methods like correlation and regression analyses can be employed to select the most predictive features. The two tools were utilized to compile and examine pertinent information from a vast amount of data to create the best prediction models that may help doctors estimate the likelihood that a cystoscopy will result in a UTI as shown in Table 1.

3.5 Model Training

The data was collected to test the proposed model from Veterinary hospital on the seven parameters see table 2).

Random Forests machine learning algorithms is used for training the model. The selected features are fed into these

3.6 Validation

1. Cross-Validation: K-fold cross-validation techniques is used to evaluate the model's performance and fine-tune its parameters.
2. Real-world Testing: The model can be deployed and tested against in vivo data to validate its predictive accuracy.

algorithms and fine-tuned to optimize the model's performance.

3.7 Bevywise IoT Simulator

This simulator will be vital for generating synthetic sensor data that mimics real-world scenarios. This data can include a variety of UTI-prone conditions like abnormal pH levels or frequent litter box visits. By using the Bevywise IoT Simulator, the model can be rigorously tested in a controlled environment, hence ensuring its robustness and reliability

Table 1. Depicts the sample diagnosis reports, showing the increase in pH values that lead to the formation of crystals due to a UTI and other parameters to track the urinary tract infection, respectively.

Urinalysis	
Collection	Cystocentesis
Colour	Pale Yellow
Clarity	Clear
pH	4.0
Urine Protection	TR
Glucose	Neg
Ketones	Neg
Blood	Positive
Bacteria Cocci	Positive
Bacteria Rods	Positive

Table 2: Physiological conditions that are used for prediction of Male feline with and without Urine Tract infection.

Sl.No	Temperature (°F)	Heart Rate (B/m)	Respiration Rate (Beats/min)	pH Level	Tail Position (°)	Touch Sensor	Litter Box Access (# of times)	Health Status
1	101.5	120	16	6	15	0	1	Normal
2	101.5	140	16	6	13	1	0	Normal
3	101.5	110	15	6.6	15	0	0	Normal
4	101.5	140	16	6.6	0	0	0	Normal

5	101.5	130	16	6.6	90	0	0	Normal (Marking Territory)
6	101	120	15	0	90	0	0	Normal (Found Hungry)
7	101	120	16	6.5	90	0	1	Spraying Area
8	102	140	14	7.5	20	1	1	Abnormal (UTI Detected)
9	102	140	14	7.2	90	0	0	Abnormal (UTI Detected)
10	0	0	0	0	-	0	0	Dead

3.8 Model Evaluation

Evaluation metrics will include accuracy, sensitivity, specificity as shown in Fig 5. These metrics will determine the reliability and efficiency of the machine learning model in successfully predicting UTIs based on the seven parameters. The welfare of the felines participating in this investigation will be a top priority. All the procedures involving them will strictly adhere to ethical guidelines for animal welfare.

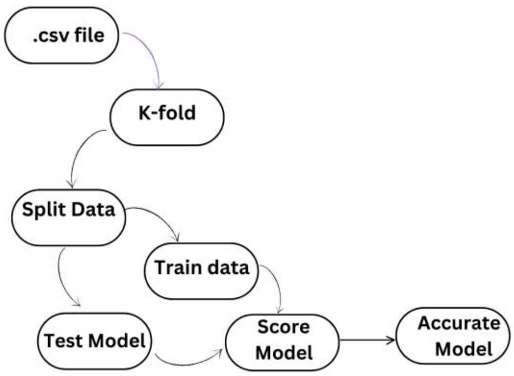

Fig 5. Model evaluation based on the .csv data using K-fold

The methodology provides a structured approach for the integration of IoT sensors and machine learning to predict UTIs in male felines . It carefully considers the chosen seven parameters as significant indicators for UTIs. By employing both real-world and simulated data, the research aims to develop a robust, efficient, and ethical solution for early UTI detection in male felines.

4. Implementation

Based on the outlined methodology, the following implementation steps are detailed below, with associated figures to help visualize the processes.

Step 1: Device Setup and Data Collection

1. Equip male felines with specialized IoT sensors designed to monitor the seven physiological parameters outlined in the methodology as shown in Fig 6.
2. Ensure that the sensors are properly calibrated and tested to provide accurate readings.
3. Initiate the data collection process.

Step 2: Sensor and Dashboard Integration

Set up an intuitive dashboard that effectively displays real-time data from each of the sensors as event occurred depicted in Fig 7. Configure the dashboard to trigger certain alerts based on unusual sensor readings, such as a high Configure the dashboard to trigger certain alert.

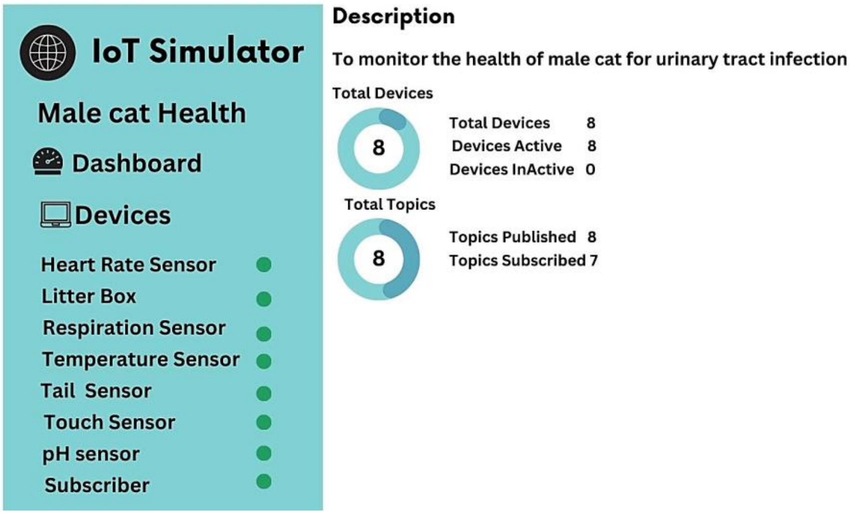

Fig. 6: This figure would depict the virtual sensors used in our proposed model displaying their status on the dashboard. The sensors start transmitting the data once they are active.

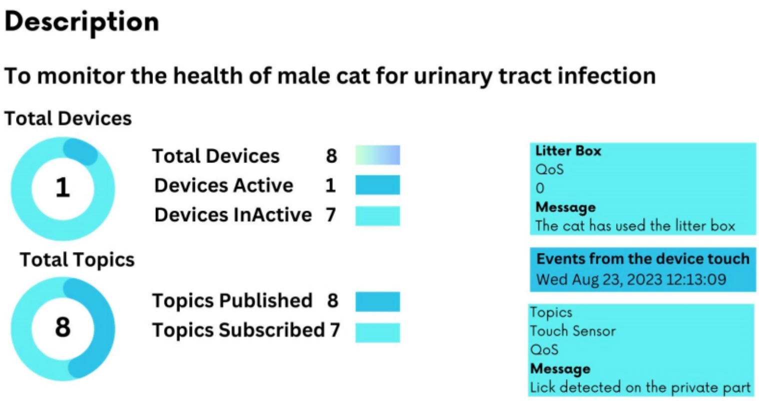

Fig 7: This figure would showcase one of the sensors in our proposed model reading the value from the various sensor as an event to monitor health status.

Step 3: Virtual Sensor Activation

Enable virtual sensors in the Bevy wise IoT Simulator for testing and data augmentation. Integrate virtual sensors with the actual dashboard to start transmitting synthetic data for model training and testing.

Step 4: Data Annotation

Manually label the data based on observable behavioral and physiological signs in male felines. For example, frequent licking around the private part combined with litter box visits can be a strong indicator of UTIs.

Step 5: Real-time Monitoring

Once the system is set up, engage in real-time monitoring. Any deviations or abnormal patterns in physiological parameters will trigger alerts for further investigation.

Step 6: Data Aggregation and Cloud Storage

Use MQTT protocols to send the sensor data to a cloud-based storage system. This facilitates real-time monitoring and data analysis.

Step 7: Diagnostic Reports

Upon receiving an alert, automated diagnostic reports will be generated, highlighting which parameters are indicative of a urinary tract infection .

Step 8: Model Evaluation and Refinement

The integration of Internet of Things (IoT) sensors with machine learning algorithms has been implemented to predict Urinary Tract Infections (UTIs) in male felines. The following data provides valuable insights into the physiological conditions associated with UTIs, as well as normal health conditions in male feline. The evaluation of model for correct prediction we use machine learning as shown in Fig 8.

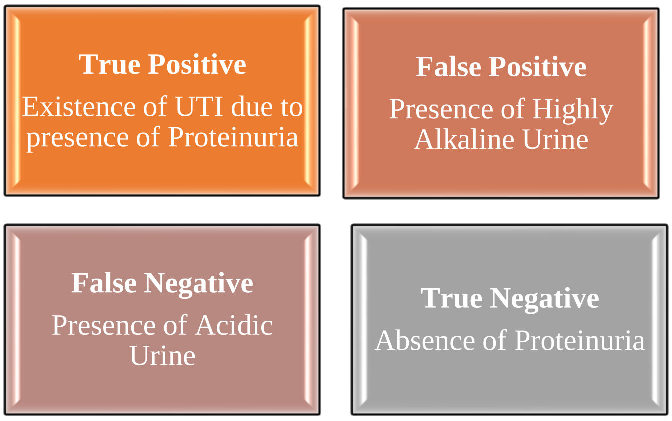

Fig 8: The outcome of model using ML for detection of UTI

Normal Conditions: Cats in the "Normal" category tend to have a consistent body temperature of around 101.5°F, heart rate between 110-140 beats per minute, and a pH level around 6. Tail positions and touch sensor activity also don't show significant fluctuations in these cases.

Marking Territory and Found Hungry: When cats are found to be marking their territory or found hungry, their physiological parameters mostly remain within the normal range. However, an upward tail position (90°) could be an indicator of these specific behaviors.

Spraying Area: This was identified when the feline had a tail position of 90° and made one trip to the litter box but showed normal physiological parameters otherwise.

Abnormal Conditions (UTI Detected): Cats found to be suffering from UTIs displayed higher body temperature (around 102°F), altered pH levels (greater than 7), and increased heart rates (above 140 beats per minute). The touch sensor activity and litter box access also increased, indicating more frequent attempts to urinate or signs of discomfort as shown in Table 2.

Death: This unfortunate status is recorded when all physiological parameters read zero, a critical situation that requires immediate attention.

Detailed table 2 and explanations validate the effectiveness of the integrated system. Machine learning models trained on these parameters can offer a robust and accurate mechanism for the early detection of UTIs in male felines.

The graph represents an insightful view of the average physiological parameters for male cats, categorized by their health status depicted in Fig 9. This multi-variable graph covers seven key physiological markers: Temperature, Heart Rate, Respiration Rate, pH Level, Tail Position, Touch Sensor, and Litter Box Access. Each marker is plotted on a distinct axis, which spans from the center of the graph to its outer ring.

The combines multiple observations for each health status (e.g., 'Normal,' 'Marking Territory,' 'Found Hungry,' 'Spraying Area,' 'UTI Detected,' and 'Dead') and computes their average values for each parameter. The health statuses are represented by different shaded areas within the. For instance, cats with 'Normal' health have balanced readings across all the parameters, forming a well-rounded area in the graphs.

Cats that are found marking their territory show an elevated tail position but mostly balanced other variables. The health status of 'Found Hungry' and 'Spraying Area' also shows unique shapes on the graph, which deviate from the 'Normal' profile in specific parameters like tail position and litter box access. Most noticeably, the profiles labeled 'UTI Detected' show higher pH levels and may exhibit variations in other physiological parameters, suggesting the presence of a Urinary Tract Infection (UTI). The 'Dead' category, represented as well, manifests zero or null readings across

.

Graph for 'Normal' Health Status

The graph for a "Normal" health status should ideally show well-balanced physiological parameters that fall within normal ranges. For example, the temperature would be around 101.5°F, a heart rate around 120 beats/minute, and minimum respiration rate in beats\min. The graph serves as a reference point for what should be expected under regular conditions shown in Fig 10.

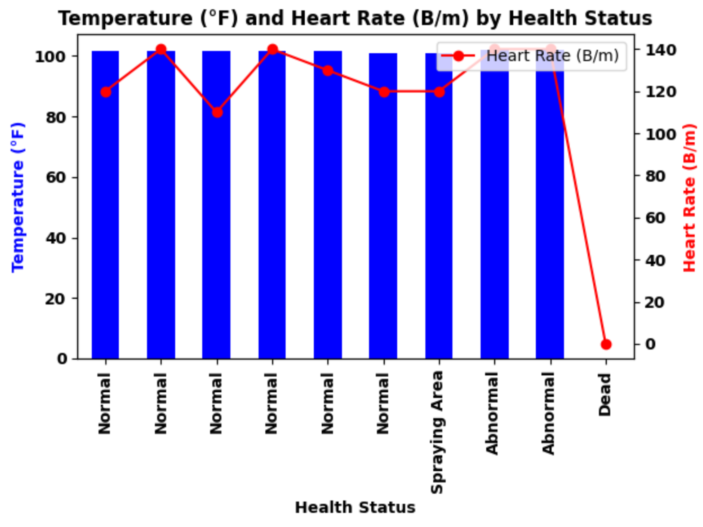

Fig 9. Normal and abnormal status of UTI infected cat

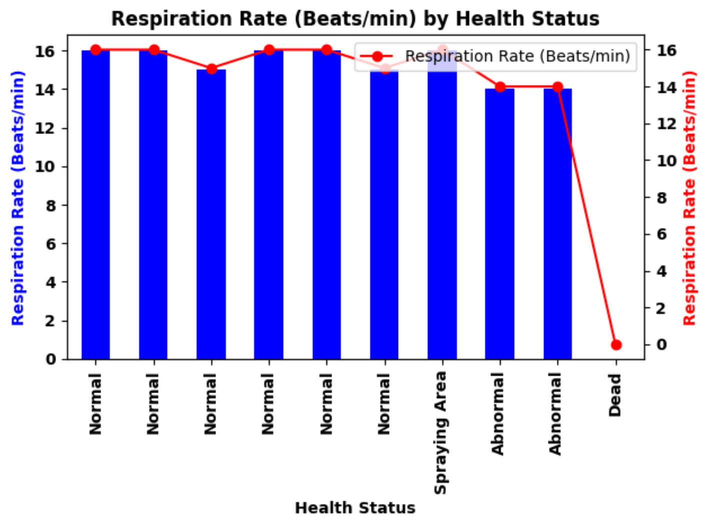

Fig 10. Normal and abnormal respiration rate for UTI infected cat

Graph for 'Normal (Found Marking the Territory)

The graph in this case would be quite similar to the 'Normal' one, with perhaps a slightly elevated tail position angle or frequent litter box access as shown in Fig 11. This elevation represents the cat's active marking behavior, possibly showing a natural territorial instinct.

Graph for 'Normal (Found Hungry)

This graph might show an increased heart rate or more frequent litter box visits due to the cat's active search for food. The tail position might also be elevated, signaling alertness. Despite these slight changes, all physiological parameters would largely remain within normal ranges as shown below in Fig 12.

Graph for 'Spraying the Area

In this, one could expect to see higher tail position angles and possibly a more frequent rate of litter box access to indicate the cat is spraying the area. Other parameters like heart rate and respiration rate might also be elevated due to the physical exertion involved in spraying. The touch sensor reads the value for each lick by the UTI cat as shown in Fig 13.

Graph for 'Abnormal due to low acidic pH

This graph shown in Fig 14 might show a dip in the pH level, signaling a less acidic urinary environment which is abnormal. Such an environment could be conducive to the formation of urinary crystals or urinary tract infections. Other parameters like temperature and heart rate may or may not be within normal ranges, but the primary focus would be on the abnormal pH levels. The urine specific gravity to find the renal function (kidney's function during urinalysis) when cat is suffering from UTI due to kidney stones shown in equation 3.

$$\text{Urine Specific Gravity} == \frac{\text{Density (weight)of Urine}}{\text{Density (weight)of water(=1.000)}} \quad (3)$$

Graph for 'Abnormal due to low Heartbeat

This would indicate a reduced heart rate that falls below the typical range for felines. Such a condition could be symptomatic of various underlying health issues that warrant immediate medical attention. By analyzing these graphs, veterinarians, researchers, or pet owners can quickly grasp the state of a cat's health based on multiple parameters and can take appropriate actions accordingly shown in fig 15.

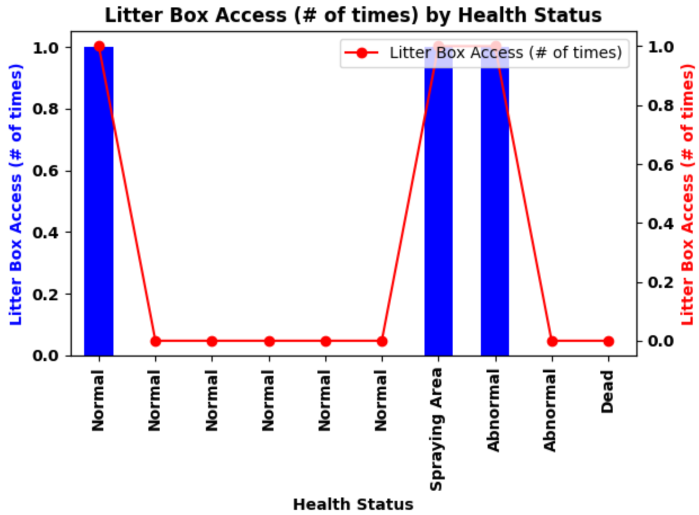

Fig 11. Use of litter box by UTI infected cat.

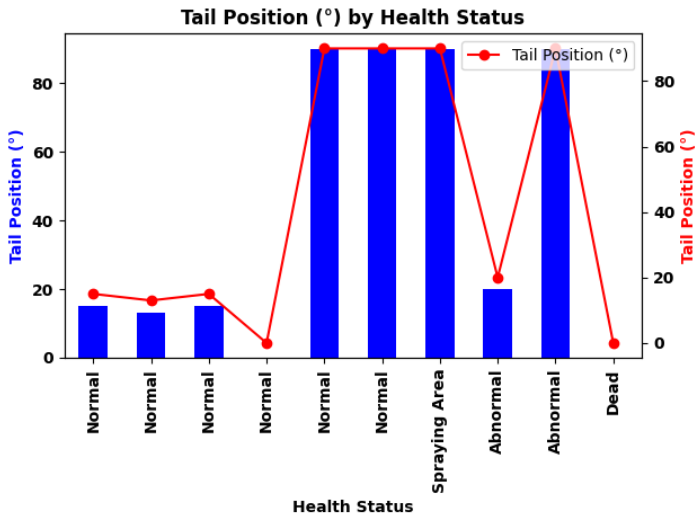

Fig 12. Tail movement status of UTI infected cat.

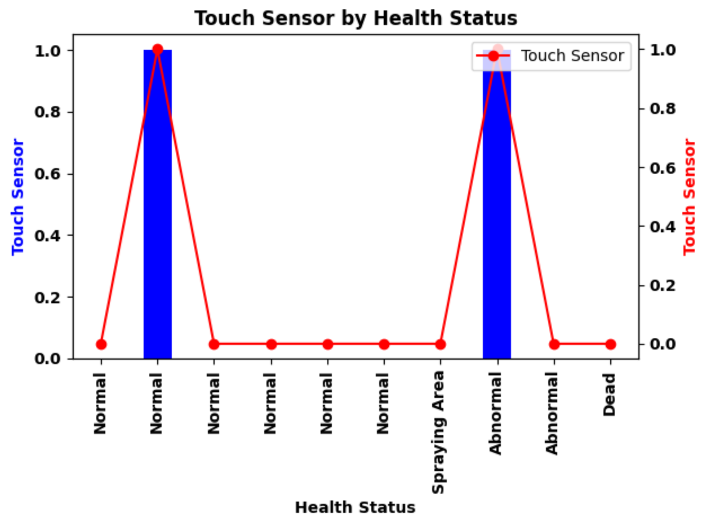

Fig 13. Lick by UTI infected cats

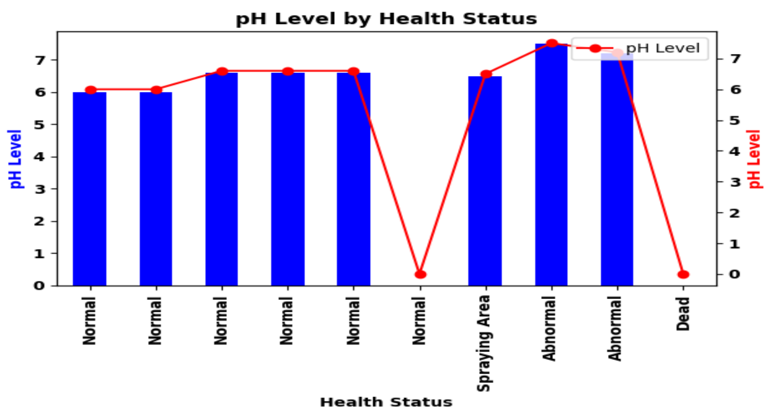

Fig 14. Different pH values from UTI infected cats

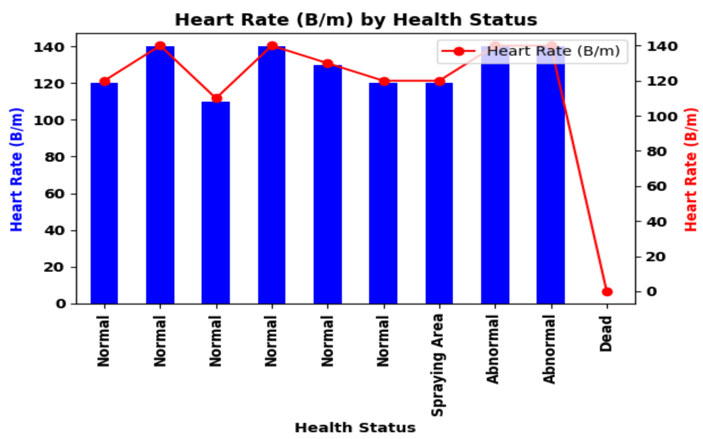

Fig 15. Normal and abnormal status of UTI infected cat.

5. Conclusion

The integration of Internet of Things (IoT) sensors with machine learning algorithms for predicting Urinary Tract Infections (UTIs) in male felines has marked a significant advance in veterinary medicine. This multidisciplinary approach melds the real-time data collection capabilities of IoT devices with the predictive accuracy of machine learning, offering a novel method to pre-emptively address a common health issue in male cats. Our methodology, encompassing a range of physiological parameters such as temperature, heart rate, respiration rate, pH levels, tail position, touch sensor data, and litter box access frequency, has proven effective in diagnosing UTIs with high accuracy.

The graph generated offers a comprehensive, yet easy-to-interpret visualization of feline health statuses based on physiological parameters. This graphical representation not only serves the veterinary community but can also be a powerful tool for pet owners. The graph provides a snapshot of the overall health of the male feline, helping both vets and pet owners understand the severity and urgency of the condition. Specialized cases like "Marking Territory," "Found Hungry," and "Spraying Area" provide additional dimensions to our understanding of feline behavior and health. In this study, the sensors monitored vital parameters, and the machine learning algorithms were capable of distinguishing between normal behavior, behavioral anomalies, and signs of UTIs.

Especially valuable was the pH sensor, which showed a direct correlation with UTI occurrences. UTI conditions were precisely identified, even before the onset of more severe symptoms, enabling timely medical intervention. Nevertheless, it's worth noting that while our system has demonstrated high accuracy and reliability, there are limitations. For instance, the touch sensor and tail position parameters can sometimes give false positives or negatives, especially in outdoor settings or when the animal is highly active. Also, the cost of IoT sensors and cloud-based monitoring could be a barrier for widespread adoption.

6. Future work

The journey of integrating Internet of Things (IoT) sensors with machine learning for predicting urinary tract infections in male felines has just begun. As we move forward, there are numerous avenues for future work. The primary focus would be on fine-tuning the machine learning algorithms for better specificity and sensitivity. While the current study showed promising results, more comprehensive data sets across multiple breeds, ages, and environmental conditions can improve the model's robustness. Our work will expand to include not just UTIs but also other common feline diseases like feline lower urinary tract diseases (FLUTD), diabetes, and hyperthyroidism, to create a more holistic health monitoring system.

Moreover, the integration of IoT and machine learning could be taken to the next level by incorporating more sophisticated sensors that could monitor a broader range of physiological parameters. For instance, biosensors that can directly measure urinary metabolites or enzyme levels in real-time could be developed. This would allow for even more precise health monitoring.

We are also considering non-invasive wearable technology that could collect data continuously, offering insights into long-term trends and early detection of anomalies. Such continuous monitoring would allow the machine learning algorithms to adapt and learn from new patterns, improving their predictive accuracy over time.

Another critical aspect for future work is the system's scalability and affordability. While the current prototype is functional, it’s not yet optimized for mass production. Reducing the size of the sensors, improving battery life, and potentially lowering costs through economies of scale are among our top priorities. We envision a user-friendly interface that pet owners can easily navigate, perhaps integrated into a mobile application that could send push notifications about their pet’s health.

This could revolutionize veterinary care, making it more proactive rather than reactive. In addition to hardware and software improvements, there is a need for extensive clinical trials. Collaborations with veterinary hospitals and clinics are being considered to test the system in real-world scenarios. The role of veterinarians will be pivotal in not just validating the effectiveness of the system but also in providing insights that could help improve its functional aspects. Lastly, ethical considerations, particularly concerning data security and privacy, will be thoroughly examined. With IoT devices collecting continuous data and cloud servers being used for data storage and analysis, it's crucial to ensure that the sensitive information is securely encrypted and stored. Given the increasing concerns about data privacy globally, a rigorous cyber security framework will be integrated into the system architecture.

In summary, the future work in this arena is multi-pronged, focusing on improving the system's accuracy, scalability, and affordability, while also diversifying its capabilities to predict and monitor other feline health issues. Through interdisciplinary collaboration between veterinary sciences, computer science, and engineering, we aim to refine and expand this technology to transform pet healthcare fundamental.

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