cirCAT: Cat Centered Smart Home System and Veterinary Complementary Devices

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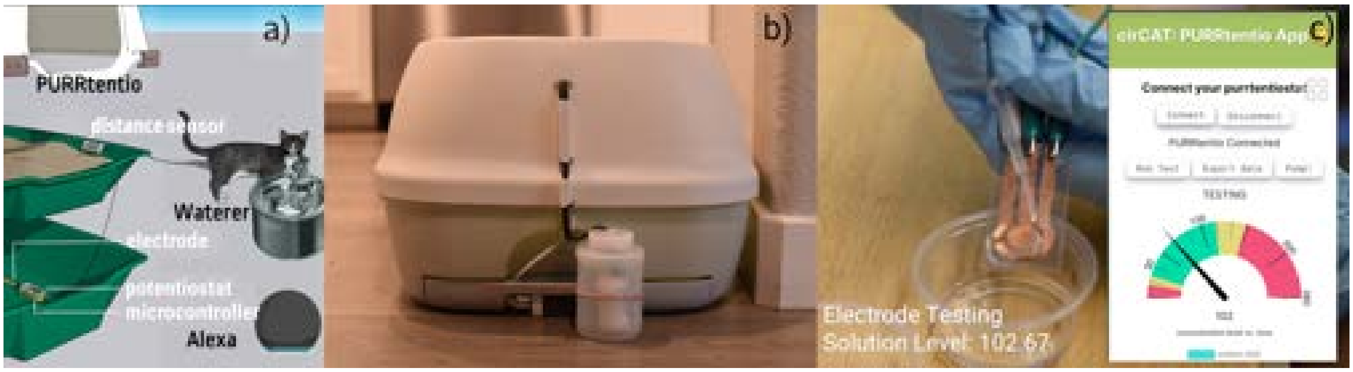

Figure 1: a) Components of PURRtentio & other devices of cirCAT b) PURRtentio c) DIY electrochemical biosensor testing

ABSTRACT

Project cirCAT is a comprehensive Smart Home system designed for cats and their caregivers. By integrating various smart cat devices such as litter boxes, scales, feeders, and waterers, cirCAT enables a seamless and holistic view of cat health, considering both body composition and lifestyle patterns. It complements veterinary care by facilitating early detection and management of health conditions. The system monitors cat behaviors and previously inaccessible data like sodium and glucose levels in fluids, allowing for lifestyle adjustments. Our research explores cat-human interaction, including visualization interfaces and feedback mechanisms. Our initial development, PURRtentio, is a litter box equipped with electrochemical biosensing for continuous monitoring of analytes in feline urine. It offers valuable insights and, when integrated with other cirCAT devices, provides a holistic view of cat health, enabling monitoring of behavior-health relationships and lifestyle adjustments.

CCS CONCEPTS

• **Human-centered computing** → **Interactive systems and tools**; **Interaction devices**; • **Applied computing** → **Life and medical sciences**.

KEYWORDS

biosensor, electrochemistry, potentiostat, urinalysis, smart home

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1 PROBLEM STATEMENT

Feline urine provides valuable diagnostic information for assessing health conditions[4], but this information is not readily available to general practitioners as it requires clinical lab testing, which can be costly and time-consuming [42]. Repeated tests further add to the inconvenience. To address this gap, we propose cirCAT, an IoT system of Smart Home devices designed specifically for cats, serving as a complementary tool in veterinary care, promoting owner awareness of cat health and providing additional chemical insights for diagnosis and care. The project aims to improve communication and relationships between devices, cats, and human caregivers.

Animal Computer Interaction (ACI) and technology for animals are rapidly growing fields, with a focus on dog-centric wearables and activity monitoring. However, there is a need to expand research to other animal species and explore the potential of IoT integration [6, 39, 46]. By incorporating IoT convenience and veterinary care complementing devices, we bridge the gap between average pet owners and professional veterinary care. PURRtentio, one of our developed devices, is an integrated litter box with electrochemical capabilities for continuous and unobtrusive monitoring of cat urine at home. It includes a DIY three-electrode biosensor, potentiostat, microcontroller, distance sensor, and web app, with a rinsing mechanism to enhance sensor lifespan.

Our goal is to have a positive impact on cats, owners, and veterinary professionals. We will explore communication dynamics between devices, users, and the impact on human-animal relationship. Introducing electrochemistry for monitoring cat's health, this research opens up opportunities to study the benefits of IoT for pets, influence of ACI on caregivers, data visualization for owners and veterinarians, and expansion to other animals including humans.

2 RELATED WORKS

2.1 Smart Home and IoT

Several IoT technologies for pet care were created, focusing on monitoring behavior, emotional, and other aspects of an animal's life [39, 43, 46]. These devices are often wearable and primarily designed for dogs, but they contribute to the concept of a technological space for animals and humans. Previous studies have highlighted the potential of human-assisted animal interaction with technology, enhancing human-animal relationships and providing research data collection opportunities [8]. Motivated by the human-animal bond, researchers have designed technology to improve daily activities at home for children [35]. Exploring the role of "trust" in animal-centric robotic spaces, one study examined how animals and humans engage with systems and each other [6]. These works inspire our development of a smart home system specifically targeted towards cats and their caregivers.

An ACI smart home system like cirCAT opens up research opportunities in the realm of human-animal relationships and interactions. Previous works in the field of ACI provide a framework for research directions. For instance, studies on dog activity monitoring systems have assessed the influence on human-dog relationships and supported dog caregiving [46]. Environmental audio monitoring systems have been examined for improving the quality of life for patients and caregivers through the recognition of barking patterns [1]. Similarly, using AI, researchers have assessed animal behavioral patterns, temperament, and emotions [19], as well as recognized animal emotions based on visuals [13]. In the case of cirCAT, one potential research direction involves employing AI for analyzing cat activities with Smart Home devices and electrochemical testing.

2.2 Urinalysis

Feline urine can be used as a diagnostic to assess health conditions through urinalysis, especially used for lower urinary tract issues [4], but this information is not always available to general practitioners as they only can be obtained from clinical lab, which can be costly in price and time [42]. Repeated tests multiply the inconvenience. We propose PURRtentio (one of the cirCAT's devices) to serve as a complement to veterinary care. Owner awareness of cat health would be encourage. The chemical status of the cat's body at home would also be a helpful addition to aid in veterinary diagnosis and care.

2.3 Electrochemistry

PURRtentio introduces a reusable and continuous electrochemical biosensing method for assessing feline urine. While previous works have explored colorimetric and visual chemical indicators in cat litter for detection purposes [16, 23, 51], researchers have identified electrochemistry as the preferred approach for electrochemical litter box systems [3, 21, 22, 26, 32, 40]. The use of electrochemical biosensors offers advantages such as continuous fluid monitoring, incorporation of a rinsing system for extended biosensor lifespan, and integration of data logging and visualizations into a single system.

Initially focusing on sodium due to its variability [49], manipulability through diet, and relevance to cat health [27, 36], the project later expanded to include glucose sensing. Glucose level analysis is essential for routine urinalysis and plays a crucial role in monitoring cats with diagnosed conditions like diabetes, as well as aiding in accurate diagnosis for undiagnosed cats exhibiting relevant symptoms [15, 18, 52].

3 IMPLEMENTATION

3.1 PURRtentio Implementation

Currently, we developed project PURRtentio that involves the fabrication of our own electrochemical biosensors, the implementation of hardware and software, and the IoT server configuration.

Not only PURRtentio, but also cirCAT aim to bring professional care closer to home through affordable and accessible DIY biosensors for urinalysis. The compact biosensor, 0.7 by 2 inches, uses antioxidant-free, oxidation-resistant copper tape electrodes on a hydrophobic polyurethane (PU) substrate, minimizing unwanted electrochemical behaviors [9, 34, 53]. PU serves as a suitable substrate, offering a hydrophobic flexible body for bending and fluid dripping [5, 11, 17, 30].

For sodium detection, the biosensor is activated using a sodium activation solution, while glucose detection involves an enzyme solution and a cross linker solution for accurate and interference-free results. Exposed electrode areas are insulated with a barrier solution to protect the conductive leads [1].

3.1.1 Hardware and Software. The base hardware includes an Adafruit Feather HUZZAH V2 board. Cat detection and rinsing in PURRtentio utilize a VL53L0X Distance sensor (ToF) and a 3V submersible fluid pump. The Rodeostat Featherwing V0.3 R1 potentiostat from IO Rodeo, with modified circuitry and software implementation, is employed. For analyte detection, Open Circuit Potentiometry (OCP) measures the voltage difference between the working and reference electrodes without applied voltage for sodium detection [47]. Glucose detection utilizes Chronoamperometry (CA), applying a stepped voltage to the working electrode and measuring the resulting current [2, 12]. Our project successfully implements both OCP and CA for sodium and glucose detection, respectively, considering biosensor behaviors and communication time required for Wi-Fi with the web app.

3.1.2 PURRtentio Form Factor: Litter box. Figure 1 shows the adapted two-layer litter box with integrated hardware. The discreet design minimizes cat attention, shown cat in Figure 4. The bottom layer houses the potentiostat system, fluid-absorbent pee pad, and rinsing system. Two layers of sift and funnel are located beneath a plastic surface covered with non-absorbent cat litter; enabling fluid flow to the biosensor. The upper layer incorporates ToF sensor to detect cat entry and triggers an electrochemical test (OCP or CA) upon cat exit, accounting for loitering time, informed by past research

[1] Zimmer and Peacock Biosensor Barrier Layer Solution: https://shop.zimmerpeacock.com/products/biosensor-barrier-layer-solution

Figure 2: Chart of communication flow within cirCAT

on cat pee time [10, 25, 33].[2] The rinsing system enables continued measurements, enhancing efficiency and performance [14, 44, 45].

3.2 Web App

To facilitate data visualization, we developed a web application, a modular component of Firebase, that connects to our database. The web app is establishes a BLE or Wi-Fi connection with cirCAT devices. It enables data visualization, connection management, and acts as a mediator for Smart Home communication (Figure 2), visualizing received data or commands from the database and sending relevant messages or action requests to Smart Home devices or IFTTT. For example, if abnormal level data is detected from PURRtentio, the web app can notify Alexa to set a reminder for calling the veterinarian and make necessary adjustments to feeders or other devices. With PURRtentio incorporated, the web app, shown in Figure 1c, presents and sends data with connection to the database. Visualizations of the most recent litter box usage, the estimated concentration level, and other electrochemical data is displayed in real time through a live graph with a color-coded gauge indicating concentration's normal or abnormal range[3].

3.3 Database

To encompass data transmission, storage, and manipulation of the cirCAT's devices, we implemented a database and hosting using Google Firebase [4] and Cloud Firestore (Figure 2). The Realtime Database handles live urine data from PURRtentio. This infrastructure will be especially relevant in future project phases when AI analysis of data from multiple devices may be employed. For example, we will correlate water intake data with urine analysis data to provide hydration information that is analyzed in accordance with with urine glucose levels, a vital aspect of health upkeep for diabetic cats [15, 28].

4 VALIDATIONS AND EVALUATIONS

Initial tests used sodium, for its variability. We tested five DIY biosensors; Cu, Cu with AgCl, Au with AgCl, AgCl, and C with AgCl, plus a control (ZP), with an industry potentiostat (EmStat). Copper-based ones performed comparably to the commercial sensor (ZP), showing mildly lower but consistently increasing slopes for potential V.S. concentration trendline. Cu achieved highest r-squared value among all, including control.

[2]PURRtentio GitHub: https://github.com/anonpapersandsuch/purrtentio
[3]PURRtentio Web Application: https://github.com/anonpapersandsuch/purrtentiowebapp
[4]firebase.google.com

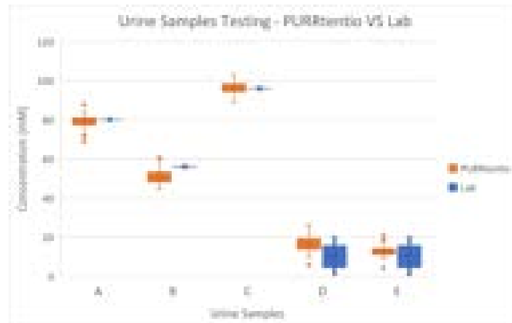

Figure 3: Results of urine samples test of various sodium concentration with PURRtentio and standard lab testing

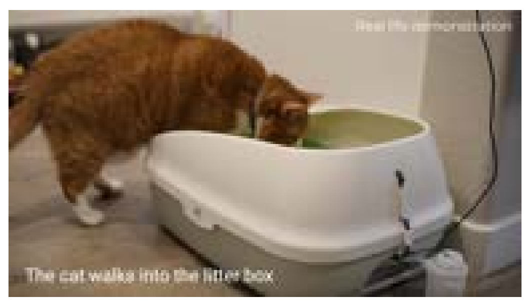

Figure 4: User Study: Feline Urine analyzed with PURRtentio

Expected hardware limitations like noise and oscillation [7, 48], were addressed through circuitry modifications and software accommodation of wavelength cycles. In a comparison test against EmStat, our finalized system, tested via ZP and our Cu sensor, yielded favorable results. The analysis of trendlines showed similar slopes and r-squared values, demonstrating strong comparability.

In final validation using feline urine samples, our system was compared to current veterinary standards. Lab tests were done for each sample prior to testing. Precision within 3mM of lab standards was achieved 75% of the time, with maximum deviation of 5mM. Additionally, our system provided specific value measurements below 20mM, categorized as "less than 20" in lab results. These results demonstrate the accuracy and reliability of our PURRtentio system in measuring sodium levels in feline urine, underscoring its potential for real-world feline health monitoring.

During a 72-hour case study with a cat participant, no visible signs of additional interest or irritation were observed, highlighting

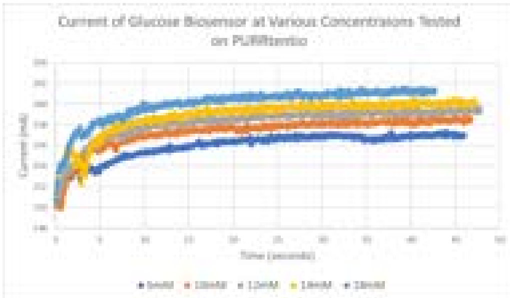

Figure 5: Testing PURRtentio chronoamperometrically with different concentration levels of glucose

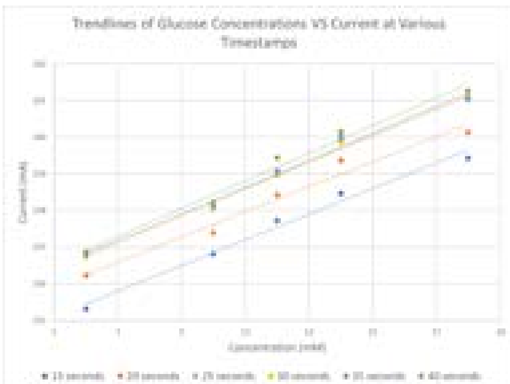

Figure 6: Trendlines of current values for each concentration at exact times after application of solutions

the unobtrusiveness of our system. The participant used PURRtentio six times during the testing period, and the measured levels varied based on feeding time, with elevations observed after meals [31]. Our system performed as expected, and no abnormalities were observed in the participant, supporting usability of our system and web app in real-world settings.

4.1 Glucose Testing

After validating our system, we implemented glucose sensing with Chronoamperometry (CA), which measures current with output voltage, with a standard industry glucose sensor (ZP). Data from CA follows the Cottrell equation, showing current decay over time [24, 38, 50]. Our results (Figure 5) demonstrate that each concentration stabilizes to a unique curve with a proportional amplitude after an initial spike. Concentration estimation can be performed at any timestamp using the trendlines, shown in Figure 6, matching the typical CA analysis method [2, 29, 37]. Further evaluations will be conducted to fully justify the effectiveness of our glucose biosensor system, following the approach used for sodium detection.

4.2 Experts Interview

We consulted veterinary experts who provided guidance for our electrochemical litter box system, their affirmations often aligned with our circAT Smart Home system and veterinary care goals. In interviews with seven experienced veterinary professionals, our system's non-invasive approach to urine sampling was confirmed, distinguishing it from traditional methods involving medical intervention. The potential of our system in assessing diabetic conditions requiring multiple biomarkers analyses was brought up, aligning with our implementation of glucose biosensing and future plans for supporting multiple analytes. According to three participants, our system can complement veterinary care by providing chemical insights into the cat's body at home. Continuous urine monitoring offers opportunities for studying drug filtration and urinary excretion. Integrating an applicable feeder with PURRtentio to track drug intake during feeding times was suggested for this.

5 EXPECTED WORK AND CONTRIBUTIONS

Our main goal is to integrate PURRtentio with other IoT devices to obtain a holistic understanding of a pet's welfare, enable automatic features to improve quality of life, and explore the possibilities that a Smart Home system brings for caregivers and pets. We will study how such a network can empower pet owners to proactively manage their cat's health.

Multiplexed Biosensing & Smart Pet Integration: When assessing urinalysis results, it is important to examine glucose alongside other markers, such as ketones and bacteria, for accurate diagnosis [41]. Our project aims to make PURRtentio a multiplexed potentiostat to address this consideration. Additionally, diabetic cats exhibit various factors, including different feeding habits and weight changes, in addition to abnormal urinalysis results [20, 28]. To achieve accurate diagnosis, a holistic examination of multiple factors, such as polyuria, weight loss, and dehydration, is necessary [15]. Our project series, using Smart Home technology, will address these needs by correlating health factors and diagnosing specific illnesses. By integrating Smart Home devices and leveraging machine learning techniques, we can enhance data analysis capabilities and predict health conditions based on collected data. Furthermore, the similarities in analytes found in feline and human urine suggest potential for influencing human health monitoring research.

Complementary Veterinary Care with Accessible Urine Information: PURRtentio, integrated into circAT, enables continuous at-home data collection, providing previously unavailable urine information that aligns with veterinary metrics [42]. This comprehensive data offers valuable insights to veterinary professionals, granting access to previously inaccessible information [20, 28]. The system aims to complement veterinary care by facilitating continuous monitoring and offering valuable data for improved health management.

Pet-Owner-Veterinarian Relationships: This research explores data visualization for pet owners and veterinary professionals, assessing impact of the system on among between pets, owners, and veterinarians. The study follows established methodologies in ACI research [1, 6, 8]. User studies with cats and caregivers, along with technical evaluations and usability tests, ensure the effectiveness and usability of the system. By empowering pet owners to proactively manage their cat's health and improving communication with veterinarians, circAT strengthens the bond among caregivers, pets, and veterinarians.

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