SMART INDIA HACKATHON 2023

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Problem Statement Title: Development of a prototype instrument (sensor based) for assessment and quantification of rasas (taste) in crude herbs.

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Theme Name: MedTech / BioTech / HealthTech

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Literature Review

1. ***"Spectroscopic and E-tongue evaluation of medicinal plants: A taste of how rasa can be studied."***
   Authors: Rama Jayasundar, Somenath Ghatak
   This study introduces a comprehensive approach to evaluating the taste properties of medicinal plants, known as "rasa," in the context of Ayurveda. It combines sensorial and chemical analyses using advanced techniques like NMR, FTIR, LIBS, and an E-tongue to gain insights into both the sensory and chemical aspects of these plants. Unlike previous research, this study focuses on whole plant extracts, aligning with Ayurvedic practices. The initial findings suggest that this combined approach enhances our understanding of rasa and offers promising avenues for further research in this field.
2. ***"E-Tongue: A Tool for Taste Evaluation"***
   Authors: Himanshu Gupta, Aarti Sharma , Suresh Kumar and Saroj K. Roy
   This study emphasizes the importance of taste in oral pharmaceuticals, especially for pediatric medicines, and its impact on market success. While human sensory evaluation is the traditional method for taste assessment, it's costly and impractical in early drug development. Electronic tongues (e-tongues) have become vital for taste analysis. They mimic human taste recognition at the receptor, circuit, and perceptual levels, offering a chemical fingerprint of the sample. E-tongues use sensor arrays to analyze samples quickly, with sensors correlating to taste attributes, often surpassing human detection thresholds.
3. ***"No ambiguity: Chemosensory based ayurvedic classification of medicinal plants can be fingerprinted using E-tongue coupled with multivariate statistical analysis"***
   Authors: Rama Jayasundar, Somenath Ghatak, Dushyant Kumar, Aruna Singh and Preeti Bhosle
   This study explores the use of an Electronic tongue (E-tongue) to classify medicinal plants in Ayurveda based on their chemosensory property, known as "rasa." Ayurveda categorizes medicinal plants into six taste groups: sweet, sour, saline, pungent, bitter, and astringent. The research analyzes 78 medicinal plants and reference taste standards using potentiometry-based E-tongue technology. Multivariate statistical analyses demonstrate the potential to fingerprint and classify medicinal plants according to their chemosensory properties.
4. "***Challenges in using electronic tongue to study rasa of plants."***
   Authors: Rama Jayasundar, Aruna Singh, Dushyant Kumar
   Ayurvedic medicines are characterized by their complex mixtures of natural products and multiple constituents, which pose challenges for quality assessment and standardization. Moreover Conventional methods like HPLC and GC/MS, designed for single-molecule analysis, may not be suitable for the complex and multi-ingredient nature of Ayurvedic formulations.

Introduction

Ayurveda is an ancient traditional system of medicine. The term "Rasa" finds a great significance in this system of medicine. It is a Sanskrit word which includes the six primary tastes that define the flavour of substances. These tastes are:

1. Madhura (Sweet)
2. Amla (Sour)
3. Katu (Pungent)
4. Tikta (Bitter)
5. Kashaya (Astringent)
6. Lavana (Salty)

They are vital to Ayurvedic principles. The harmony of these tastes in dietary and medicinal substances is believed to influence the balance of the three body humors, Vata, Pitta, and Kapha, as well as have profound effects on overall health and well-being.

The connection between taste and physiological effects is well-established. Consider these examples:

- Research in the Journal of Nutrition and Metabolism reveals that the taste receptors found in the gut can influence metabolic processes, indicating that taste goes beyond the palate.
- A study published in the Journal of Ayurveda and Integrative Medicine highlights the role of taste in identifying the medicinal properties of herbs. For instance, the Bitter taste is associated with anti-inflammatory and detoxifying effects.

Taste identification in herbs, a cornerstone of Ayurveda, often relies on subjective human judgment. To address this, we present the "Tongucometer," a sensor-based system that combines potentiometry sensors and machine learning to assess and quantify rasas in herbs with precision.

In our research we explore the Tongucometer's design, principles, and adaptability, offering a transformative tool for Ayurveda and beyond. It accelerates chemical analysis, offers a cost-effective solution, and opens new possibilities in various fields.

Data

S.No.	Botanical name of plants/part used	S.No	Botanical name of plants/part used
Sweet group		**Bitter group (contd.)**	
1	*Abutilon indicum* (L.) Sweet/root	34	*Solanum nigrum* L.*/wp
2	*Aconitum ferox* Wall/root	35	*Swertia chirata* Buch.-Ham.ex Wall**/wp
3	*Benincasa hispida* (Thunb.)/fruit	36	*Vernonia anthelmintica (L.)* Willd.*/root
4	*Borassus flabellifer* L./fruit	**Pungent group**	
5	*Cissus quadrangularis* L./stem	37	*Alpinia galanga* (L.) Willd/rhizome
6	*Cocos nucifera* L./flower	38	*Anacyclus pyrethrum* (L.) Lag./root
7	*Phoenix sylvestris* (L.) Roxb./fruit	39	*Baliospermum solanifolium* (Burm.) Suresh/root
8	*Cassia fistula* L./root bark	40	*Brassica juncea* (L.) Czern/seed
9	*Glycyrrhiza glabra* L./root	41	*Capsicum annum* L./fruit
10	*Musa paradisiaca* L./tuber	42	*Carum carvi* L./fruit
11	*Leptadenia reticulata* (Retz.) Wight & Arn./root	43	*Cassia tora* L.*/root
12	*Plantago ovata* Forssk./seed	44	*Croton tiglium* L./seed
13	*Phaseolus trilobus* Aiton*/wp	45	*Cuminum cyminum* L./fruit
14	*Prunus amygdalus* Stokes**/seed	46	*Erythrina indica* Lam.*/stem bark
15	*Pueraria tuberosa* (Willd.) DC./tuber	47	*Euphorbia neriifolia* L./leaf
16	*Sida cordifolia* L./root	48	*Ferula narthex* Boiss./resin
17	*Tribulus terrestris* L./fruit	49	*Gossypium herbaceum* L./seed
18	*Vitis vinifera* L./fruit	50	*Leucas cephalotes* (Roth) Spreng./wp
Bitter group		51	*Mentha x piperita* L./leaf
19	*Andrographis paniculata* (Burm.f.) Nees./wp	52	*Piper chaba* Hunter*/root
20	*Aristolochia bracteolata* Lam./leaf	53	*Piper longum* L./fruit
21	*Centella asiatica* (L.) Urb./wp	54	*Piper longum* L./root
22	*Cissampelos pareira* L./root	55	*Piper nigrum* L./fruit
23	*Citrullus colocynthis* (L.) Schrad./root	56	*Plumbago zeylanica* L./root bark
24	*Coccinia grandis* (L.) Voigt/root	57	*Trigonella foenum-graecum* L./seed
25	*Euphorbia thomsoniana* Boiss./root	58	*Zingiber officinale* Roscoe/rhizome
26	*Gymnema sylvestre* (Retz.) R.Br.ex Sm./leaf		
27	*Indigofera tinctoria* L./wp		
28	*Luffa acutangula* (L.) Roxb./fruit		
29	*Momordica charantia* L./wp		
30	*Nyctanthes arbor-tristis* L./leaf		
31	*Picrorhiza kurroa* Royle ex Benth.**/root		
32	*Rauwolfia serpentina* (L.) Benth. ex Kurz/root		
33	*Smilax glabra* Roxb./rhizome		

Table 1: Medicinal plants categorized under the rasas. Observation table taken from the research paper “ambiguity: Chemosensorybased ayurvedic classification of medicinal plants can be fingerprinted using E-tongue coupled with multivariate statistical analysis” by Rama Jayasundar, Somenath Ghata , Dushyant Kumar, Aruna Singh and Preeti Bhosle

S.No.	Botanical name of plants/part used
Astringent group	
1	*Acacia nilotica* (L.) Delile/stem bark
2	*Bauhinia purpurea* L./stem bark
3	*Dolichos biflorus* L.*/seed
4	*Ficus benghalensis* L./stem bark
5	*Ficus lacor* Buch.-Ham/stem
6	*Ficus racemosa* L./stem bark
7	*Ficus religiosa* L./stem bark
8	*Gossypium herbaceum* L./root bark
9	*Mangifera indica* L./seed
10	*Ougeinia dalbergioides* Benth.*/stem
11	*Salmalia malabarica* (DC.) Schott and Endl.*/stem bark
12	*Symplocos racemosa* Roxb./stem bark
13	*Terminalia arjuna* (Roxb. ex DC.) Wight and Arn./stem
14	*Terminalia bellirica* (Gaertn.) Roxb./fruit rind
15	*Thespesia populnea* (L.) Sol. ex Correa/stem bark
16	*Woodfordia floribunda* Salisb.**/flower
Sour group	
17	*Citrus medica* L./fruit
18	*Garcinia indica* (Thouars) Choisy/fruit
19	*Tamarindus indica* L./seed
20	*Thespesia populnea* (L.) Sol. ex Correa/fruit

Table 2: Medicinal plants categorized under the rasas. Observation table taken from the research paper “ambiguity: Chemosensorybased ayurvedic classification of medicinal plants can be fingerprinted using E-tongue coupled with multivariate statistical analysis” by Rama Jayasundar, Somenath Ghata , Dushyant Kumar, Aruna Singh and Preeti Bhosle

Use Cases and Business Prospect:

1. **Identification of rasa potency in a herb for better therapeutic research and clinical trials of ayurvedic medicine**:

   - The Tongucometer can be used to assess the quality of herbs and identify their potency. This ensures that only high-quality herbs with the desired rasas are employed in medicinal formulations.
   - Ayurvedic practitioners can utilize the Tongucometer to fine-tune herbal formulations by precisely measuring the rasas of individual herbs.

   Example: Ayurvedic practitioners use the Tongucometer to evaluate a batch of Neem leaves. It quantifies the Bitter (Tikta) taste, ensuring that the herb is of high quality for its intended medicinal use.

   In India, the Ayurveda market is expected to reach $10 billion by 2025, with increasing acceptance of traditional medicine. Also, the global Ayurvedic market is projected to grow at a CAGR of 16% from 2020 to 2025. The Tongucometer can tap into this market.

2. **Personalized Dietary Guidance and Consumer Wellness** :
   Individuals seeking personalized dietary plans can benefit from the Tongucometer's ability to assess taste profiles in foods to ensure that they get balanced diet.
   Companies in this sector can use the device to create supplements tailored to specific taste preferences and health requirements.

   The global dietary supplements market is predicted to reach $230.73 billion by 2027. Also, the global health and wellness app market is projected to grow at a CAGR of 11.5% from 2020 to 2028.

   For example, a nutritionist employs the Tongucometer to assess the taste preferences of a client. The data helps design a personalized diet that aligns with the individual's liking for Sweet (Madhura) flavours while maintaining health goals.

3. **Culinary and industrial purpose**:
   Chefs and culinary professionals can use the Tongucometer to explore and create unique flavour profiles for innovative and healthier dishes. It adds a new dimension to culinary arts by objectively measuring taste.
   Example 1: A chef explores the creation of a new dish that balances various tastes. The Tongucometer guides the chef in measuring and adjusting the Madhura, Katu, and Kashaya rasas to achieve the desired flavour without jeopardizing the health of the customers.
   Example 2: A beverage company wants to develop a unique, health-focused drink. The Tongucometer helps in creating a product with a perfect blend of Sour (Amla) and Sweet (Madhura) tastes for both taste and health benefits.

4. **Promotion of Ayurvedic medicines**:
   - The Tongucometer aids in the promotion of this traditional knowledge of Ayurveda as our app provides information and details about herbs based on the rasa as well as informs the user of its medicinal properties.
   - The Tongucometer can be used as an educational tool in Ayurvedic and herbal medicine schools where students can learn the about rasas and their applications in a hands-on and precise manner.

5. **Agricultural usage and herb adulteration prevention**:
    - Using ML, it can screen for important rasa(taste/flavor) compounds and help improve herb rasa(taste/flavor) based on their taste profiles, enabling the cultivation of herbs and produce with desired flavours..
6. **Disease prevention**:
   The Tongucometer helps maintain health and combat diseases by ensuring the selection of herbs and dietary components with the most suitable rasas for therapeutic purposes.

   For example, if someone has a digestive ailment, the Tongucometer can accurately measure the Amla (Sour) and Tikta (Bitter) rasas in herbs, allowing a healthcare practitioner to prescribe herbs with these tastes known for their digestive benefits. This precision enhances the effectiveness of treatments and supports overall health management

What makes our product Unique?

Our Tongucometer is a unique and innovative product in several ways:

- **Cross-Sensitive Sensor module:** The core of the Tongucometer is its cross-sensitive sensor module, which can distinguish between different tastes (Rasas) by leveraging electrochemical reactions.
- **Machine Learning Integration**: The integration of machine learning algorithms for taste classification sets the Tongucometer apart. It include the following features:
    i. It can predict the possible the herbs based on the rasas present
    ii. Give details of medicinal properties of the predicted herb.
    iii. Can also predict similar herbs according which contain the same rasa as the output.
- **Easy and Real-Time Analysis**: The Tongucometer provides real-time, quantitative results. As soon as a sample is introduced to the sensor module, it rapidly analyzes and quantifies the dominant Rasa, which is displayed on the smartphone interface. Also, it can be used in both traditional laboratory and non-traditional field settings.
- **Adaptability:** The Tongucometer's adaptability is a significant advantage. Its functionality is defined by software, making it easily reconfigurable for different tasks.
- **Mobile App Interface:** The smartphone interface, with a user-friendly mobile app, enables easy interaction and data visualization.
- **Multilingual Support:** The mobile app includes multilingual support, enhancing its usability for a broader user base.
- **Educational Content**: The app also offers educational information about Ayurvedic medicines, making it a valuable tool for those interested in traditional herbal medicine. It provide insights on maintaining harmony of the body through the herbs.

Our Vision

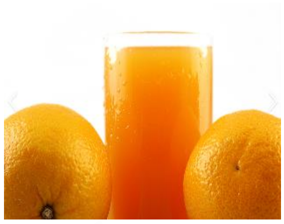
Our vision is to revolutionize the understanding and application of taste in holistic health and scientific research. We aim to bridge the gap between ancient wisdom and modern precision by making the assessment and quantification of rasas (tastes) in herbs and substances accessible to all. Our vision is to empower individuals, practitioners, researchers, and industries to harness the power of rasas for improved health, innovation, and quality control. We aspire to preserve and promote traditional knowledge while advancing it with the aid of cutting-edge technology. Our ultimate vision is to contribute to a healthier, tastier, and more sustainable world through the widespread adoption of the Tongucometer."

Proposed Solution

Introducing our solution, "The Tongucometer”. It is an innovative sensor-based instrument designed to quantify the rasas (tastes) in crude herbs used in Ayurveda. It combines a cross-sensitive sensor with machine learning, enabling the precise measurement of Madhura (Sweet), Amla (Sour), Katu (Pungent), Tikta (Bitter), and Kashaya (Astringent) tastes. By employing potentiometry and a microcontroller-based data acquisition system, it converts taste profiles into real-time, quantitative data which can be accessed by the mobile application. The Tongucometer offers adaptability through AI and mobile app deployment, making it a valuable tool for herb quality assessment, herbal medicine optimization, dietary guidance, and various applications where taste plays a pivotal role in health, research, and innovation.

Methodology

Step 1: Sample Preparation



Two types of samples are used:

1. Liquids
2. Dissolved solids

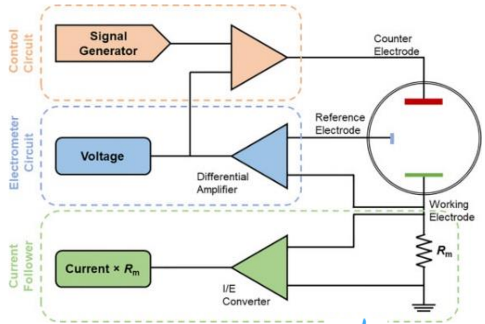
For dissolved solids, the sample is prepared like this:

1. Dry and powdered samples of medicinal plants are prepared and blended with distilled water to create a solution.
2. The solution is filtered to remove suspended particles.
3. The prepared solutions are left at room temperature for a few minutes before analysis.

Step 2: Sensor Module

1. Our 'Tongucometer' is a cross-sensitive sensor consisting of 5 thick film electrode. The thick film electrode has 3 electrodes:
   - working electrode
   - reference electrode
   - Auxiliary electrode.
2. Each of the thick film elecrtrodes has a coating of the pure samples on the working electrode representing the five primary Rasas:
   - Madhura (Sweet) Reference Sample
   - Amla (Sour) Reference Sample
   - Katu (Pungent) Reference Sample
   - Tikta (Bitter) Reference Sample
   - Kashaya (Astringent) Reference Sample

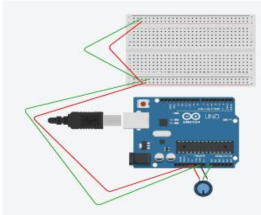
   The electrodes are designed in such way that they produce precision and reliability in taste detection.



3. We measure the voltage difference between the working electrodes and the reference electrode. The reference electrode voltage is constant. The voltage of the working electrode, on the other hand, depends on test sample. Here, the thick film electrode acts as both the sensor and the transducer.
4. When a drop of the test sample is introduced to the working electrode, a electrochemical reactions occurs which is unique to each rasa, resulting in different voltage potentials corresponding to each Rasa.
5. These potentials are measured using a potentiostat, providing data on the dominant Rasa in the test sample.

Step 3: Smartphone Interface

The following hard ware components are used:



1. A PCB module with several pins is placed below the the potentiostat along with the five thick film electrodes. Resistors, capacitors, differential amplifiers and potentiometers are used to build a potentiostat according to circuit diagram. All of these are housed in a miniature case which can be together called as a sensor module.
2. Analog-to-digital conversion: Arduino Uno microcontroller is used to convert potentiometric analog data into digital signals. The microcontroller is responsible for controlling the entire data acquisition process.
3. A graph of voltage versus current is obtained and from the graph, the presence of the most concentrated rasa in the sample is determined using an Arduino code and is sent to the app.
4. A HC-05 Bluetooth module is used to connect the Arduino Uno with the smartphone to transfer the data.
5. The Arduino is powered using a 12V Li-ion battery

Step 4: AI/ML Pipeline Integration

1. An ML-assisted and data-driven framework is introduced for supervised analysis of taste profiles. Commonly used ML methods like decision tree, random forest, k-nearest neighbours, artificial neural networks, and deep learning, are employed for prediction of a herb from the rasa(taste/flavour)s.
2. The ML algorithm classifies liquid samples using algorithms and models to analyze data related to rasa(taste/flavor) and display it in the smartphone.

Step 5: Deployment as a Mobile App

The app is made using Kotlin language and for the front end XML is used. Python is used for the AI/ML which is integrated to the app.

- The Tongucometer is deployed as a mobile app, making it easily accessible outside traditional laboratory settings and also provides multilingual support so that language is not a barrier for those who wish to utilise the apps full potential.
- The app gets the information from the sensors and then displays rasa concentration of the sample and also the graph. Using ML, it then predicts the possible rasa and then displays the medicinal properties of the herbs based on the rasa and also finds similar herbs with the same rasa. It also gives other useful educational information. The educational information is stored in a database which is created using SQLite. There are scope for adding more additional features in the future.

Step 6: Results

The response of each sensor is assessed on a relative intensity scale of 1 to 10, representing the least to the most intense taste perception. Results are delivered in a matter of minutes, significantly reducing the time required compared to conventional methods.

Design & Prototype Development

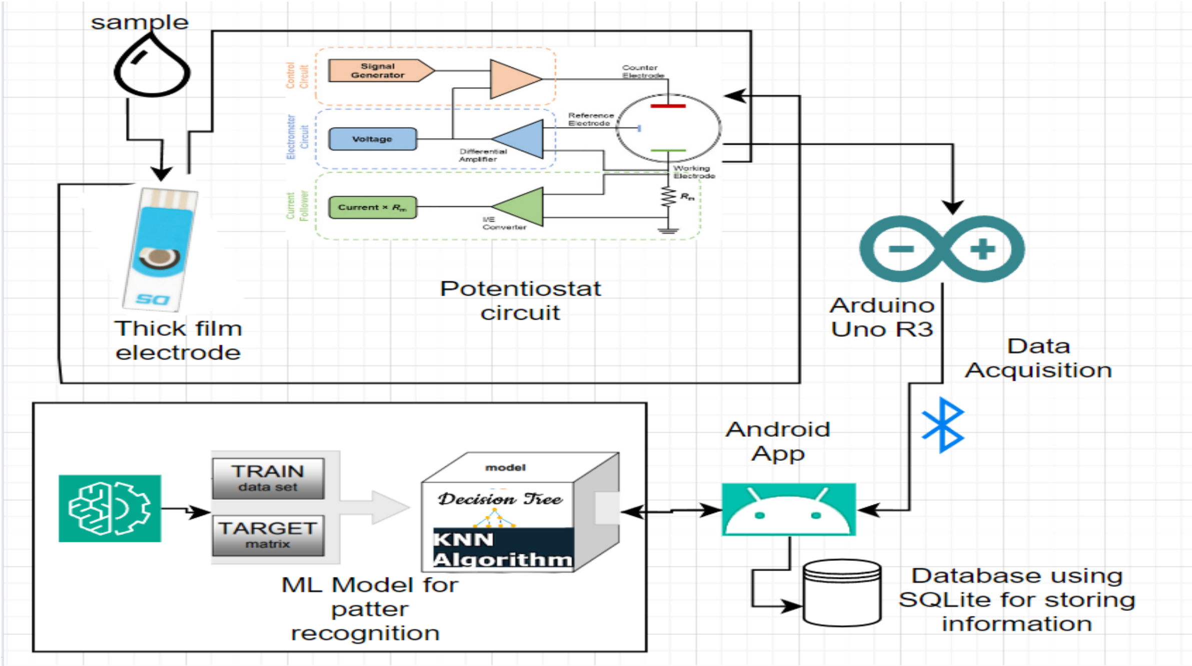


Fig: Simple diagram of the model

Fig: Thick film Electrodes

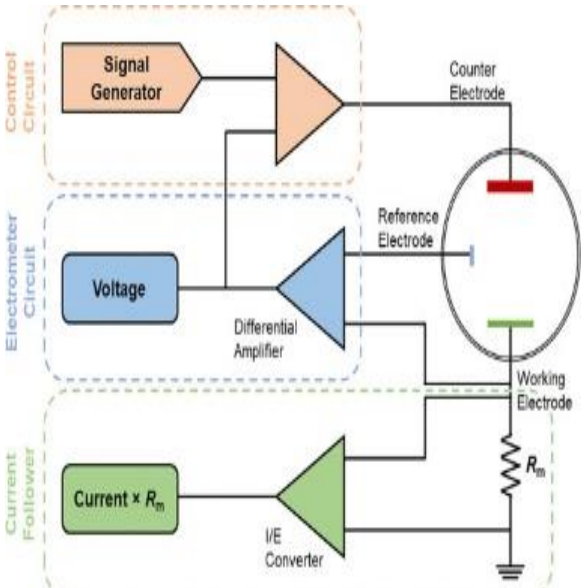
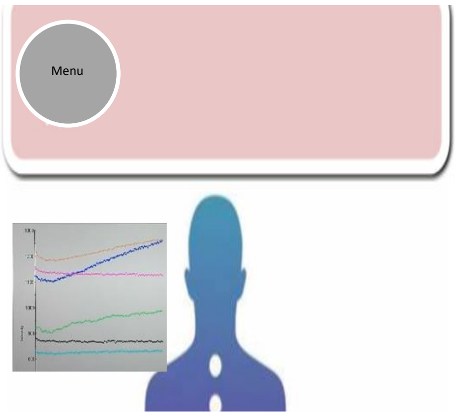


Fig: Potentiostat circuit diagram



Click here to know more about the rasa
Click here to search identical herbs
More about Ayurveda

Fig: Prototype of the android app along with the graph representing the presence of each rasa

Process Flow

Fig: Thick film Electrode

Fig: Sample Droplet

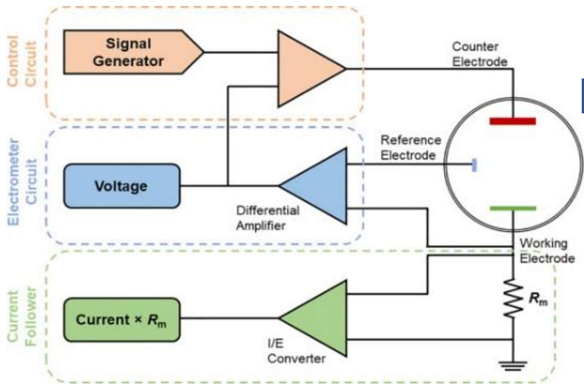


Fig: Potentiostat

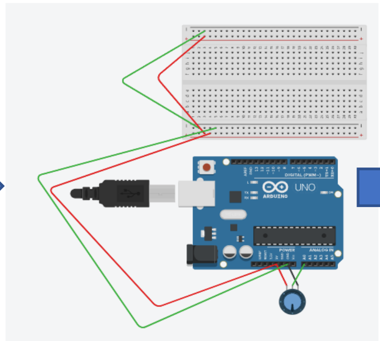


Fig: Arduino along with the PCB board. Note: This is just an image, the connections here are random

Fig: HC-05 Bluetooth to connect the Arduino with the smartphone

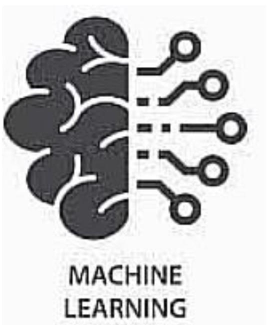


Fig: Machine leaning models are deployed

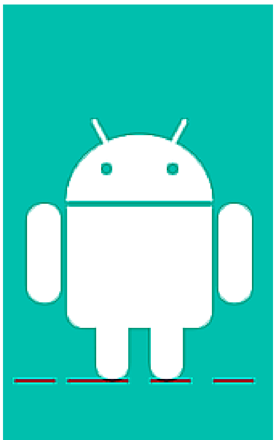
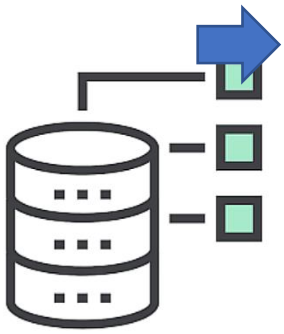
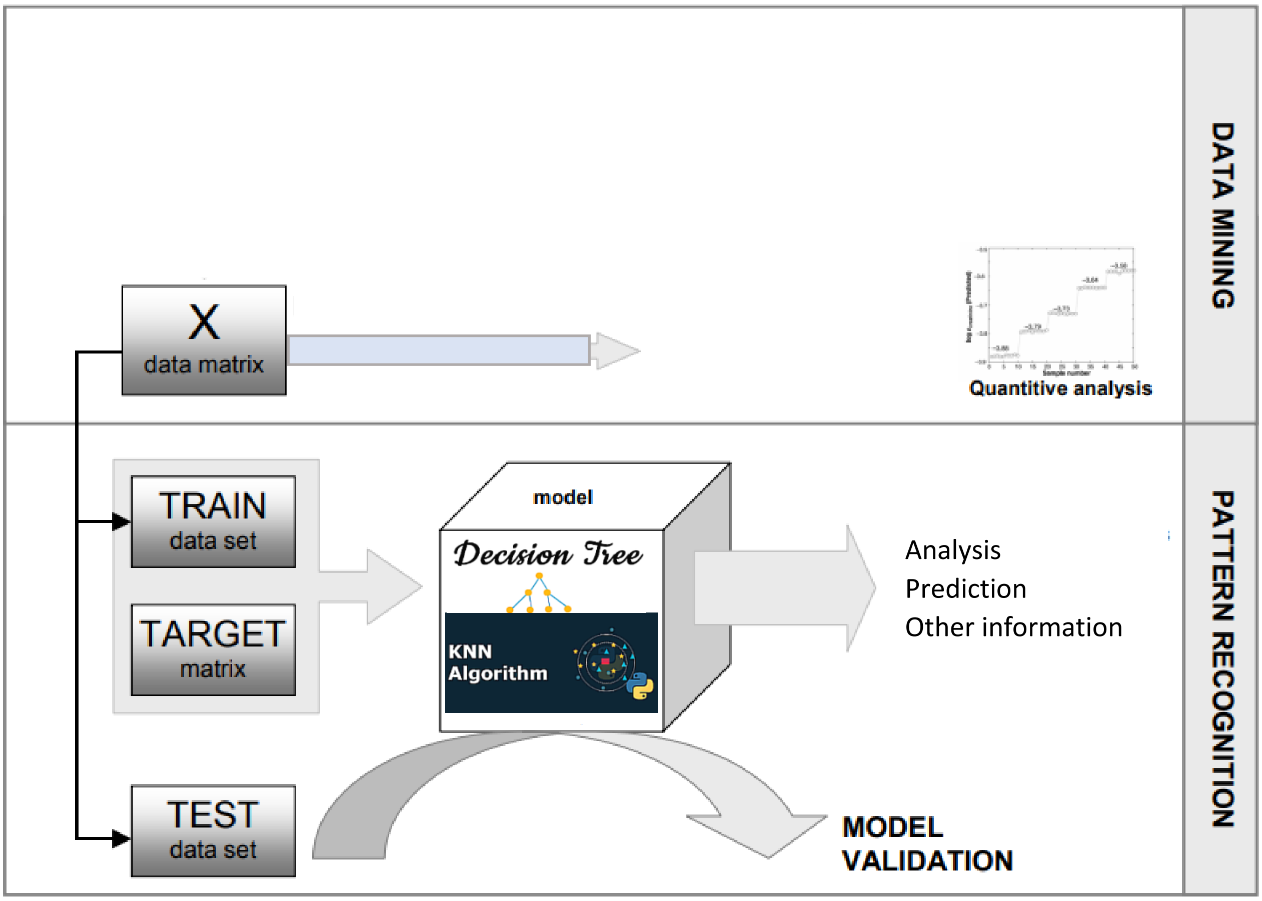


Fig: Android App



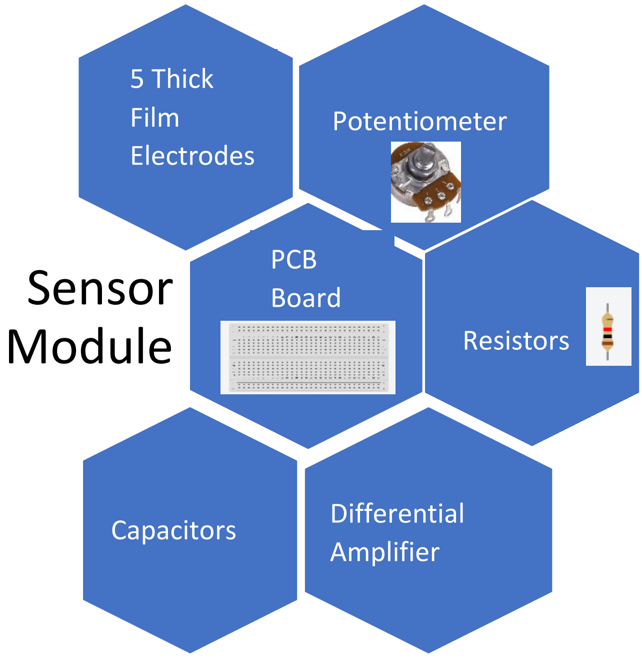
Database storage using SQLite for retrieving data

ML pattern recognition and analysis



Dependencies

1. <u>Hardware Components and Materials:</u>



The resistors, differential amplifiers, capacitors, potentiometers are together used for making the Potentiostat

Additional hardware required:

Fig: Arduino Uno R3

Fig: HC-05 bluetooth module

Fig: Li-ion battery(12V)

Fig: HC-05 bluetooth modue

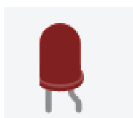


Fig: LED

2. <u>Software Development Tools:</u>

- Machine learning libraries and frameworks like vector machine, decision tree, random forest, k-nearest neighbours, artificial neural networks, and deep learning.
- AI/ML datasets for training data
- Kotlin for Android Development.
- XML for front end of the android app.
- SQLite for database systems for data storage and retrieval.
- External APIs and databases on ayurvedic rasas, herbs, medicine, etc.

3. Sample Collection and Calibration:
   A diverse collection of herbal and dietary samples representing various Rasas required for correct analysis.

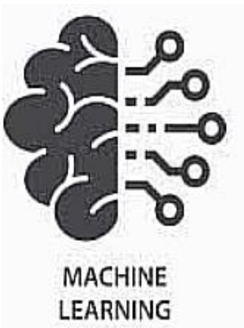
4. Collaborations with experts in Ayurveda and herbal medicine for knowledge and methodology validation.

5. Compliance with healthcare and industry standards if applied in clinical or commercial settings.

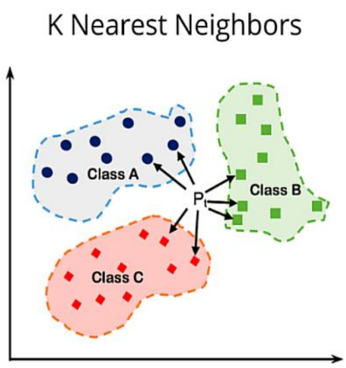
Tech Stack

HC-05 bluetooth module is used to connect the Arduino with the smartphone

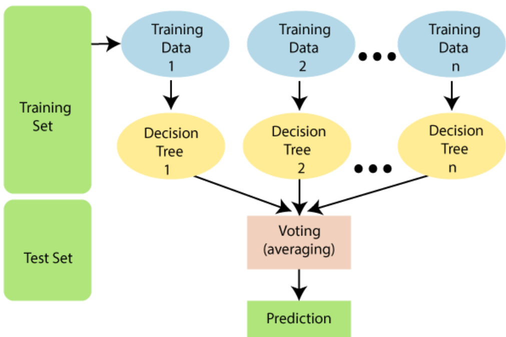
Arduino R3 Uno is a micro controller that has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. It can also be used as an ADC, ie, Analog to digital converter



The k-nearest neighbors algorithm, also known as KNN or k-NN, is a non-parametric, supervised learning classifier, which uses proximity to make classifications or predictions about the grouping of an individual data point.



A decision tree is a non-parametric supervised learning algorithm, which is utilized for both classification and regression tasks. It has a hierarchical, tree structure, which consists of a root node, branches, internal nodes and leaf nodes.



Database is stored in SQLite

Kotlin is a cross-platform, statically typed, general-purpose high-level programming language with type inference. Kotlin is used here to create the android app

Extensible Markup Language (XML) is a markup language that provides rules to define any data. XML is used here to create the front end of the app

The app is deployed in an Android development environment

Target Audience

1. Ayurvedic Students and Researchers
2. Alternative medicine healthcare Providers
3. Herbal supplement manufacturers
4. Food and Beverage Industry
5. Health-conscious Consumers
6. Culinary Professionals
7. Regulatory Bodies
8. Quality Control Labs
9. Government Health Programs

Potential sources of revenue

- Partnerships and Collaborations: Partnering with pharmaceutical companies, health institutions, and educational organizations for joint research projects and initiatives.
- Advertising and Promotions: Partnering with health and wellness brands for advertising and promotional opportunities within the mobile app and web platforms.
- Licensing: licensing the technology to other industries can be a source of income.
- Data Analytics: Selling aggregated and anonymized taste data to research institutions, pharmaceutical companies, and food and beverage manufacturers.

Show-Stoppers

1. Regulatory Challenges: Adhering to strict regulatory standards and obtaining approvals for a medical device can be a complex and time-consuming process.

2. Presently, the sensors cannot exactly identify the taste known as 'Umami' which is present in Ajinomoto. Also Umami, the meaty or the savoury taste, does not fall under the category of the 6 rasas in Ayurveda. However, it can be identified using a combination of some of this rasa but not to a great accuracy. So in the future we plan to add this 'taste' in the sensor also.

3. Excess temperature may cause fluctuation of voltage thereby causing fluctuation in results.

3. There are not enough datasets to train the AI/Ml models for rasas and herbs.

5. In the, excess moisture or pollutants in the air might produce deviated results.

Future Roadmap

Some of the plans and features we would like to add in the future are:

- Enhance of the taste sensor module to identify complex flavour profiles and also account for the Umami taste present in MSG/Ajinomoto.
- Connect users with Ayurveda practitioners for remote consultations.
- AI-driven Recommendations: Personalize diet plans and wellness suggestions based on taste data.
- Also improving the sensor for identifying the presence of any harmful substance in the sample.
- According to some researches, rasa/taste is not only influenced by the sensory organ of tongue but also depends a bit on the olfactory organ that is the nose. We would explore how taste can also be influenced by smell and improve the sensor accordingly, paving the way for a more comprehensive sensory analysis.
- Cloud-based AI/ML: Shift towards cloud storage and cloud computing for running AI/ML models, allowing seamless integration of new models without modifying the software.

Conclusion

The Tongucometer is not just a device; it's a bridge between ancient wisdom and modern science, offering a great solution for taste quantification with applications in healthcare, industry, and daily life. It is a blend of sensor coupled with AI/Ml deployed in a portable app for easy analysis. With the Ayurvedic and herbal markets experiencing substantial growth, the Tongucometer is poised to unlock new avenues for innovation, research, and business expansion, contributing to a healthier world.

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