Smart Toys for Sensing and Soothing Distress in Pediatric Patients

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Contents

Background

Emotional and Mental Health in Children

- ·Interconnection of emotional well-being, mental health and physical health **[2]**
- ·Factors infuencing mental health and children’s emotions
- ·Importance of early intervention and emotional regulation-lead to issues
    - Detection+Monitoring+Therapy
- ·Limited therapists and availability

Abstract-Introduction

HealPet (Health and Emotional Assistance for Little ones through Plush Education and Therapy)

Need

- ~(20-30k) children with cancer
- ~40% have mental health issues (8-12k)
- ~20-25% of all children have chronic pain (6-7.5m)
- ~30% have mental health issues (2.25 m) [1]

Aim

- Introduction of HealPet: A toy for emotional monitoring support
- Bridge emotional and mental health with physical care
- Not designed to replace or diagnose but rather compliment therapy

Target Audience

Primarily for children aged 2-9 with cancer or chronic pain, but suitable for others

Challenges of Tracking Emotions in Children

- Difficulty in data collection and assessment
- No consensus on studies and methods [3]
  - Observational Assessments
  - Self-reports
- Limited self-awareness and communication skills, avoid
- Modern technological solutions [4]
  - Emotion recognition software
  - EEG’s
- Need for non-invasive, continuous monitoring

Illness and Mental Health

- Emotional and psychological effects of chronic illness [5]
- The effect of chronic pain and cancer on emotional well-being
- Role of social stigma in mental health issues
- Importance of addressing mental health alongside physical health
    - Anxiety, Depression, Constitutional Fatigue, Asthenia

- Types of therapy used for children with cancer or chronic pain
    - CBT: focus on changing - emotions to +
    - Family therapy
    - Child life specialists: Not always available; not continuous
    - Play Therapy

Impact of Play on Mental Health

- Cognitive, social, and emotional benefits of play
- Theories of play by Piaget and Bandura [6]
- Play as a tool for emotional expression and regulation
- The role of play in promoting well-being and mental health

Play Solutions

- Incorporate aspects of all solutions
  - Cognitive
  - Smart
  - Medical
  - Sensorial
  - Soft, Tangible
  - Comforting
  - Creative

Fidget Toys

Sensory Toys

Switch-Adapted Toys

Communication Aids

Virtual Reality Therapy

Digital Play Kits

Adaptive Art Supplies

Smart Toy Companions

Weighted Sensory Toys

Medical Distraction Tool

Therapeutic Board Games

Therapeutic Robots

State of the Art

Paro Therapeutic Robot

- Elderly people with dementia
- No monitoring

MoxieRobot

- Data privacy
- General cognitive monitoring
- Not for medical care

Joy for All

- Elderly
- No monitoring

LEKA

- Not soft and tangible
- More congitive
- General emotional monitoring

State of the Art

Paro Therapeutic Robot ($6,000)

MoxieRobot ($800)

Joy for All ($130)

LEKA ($750)

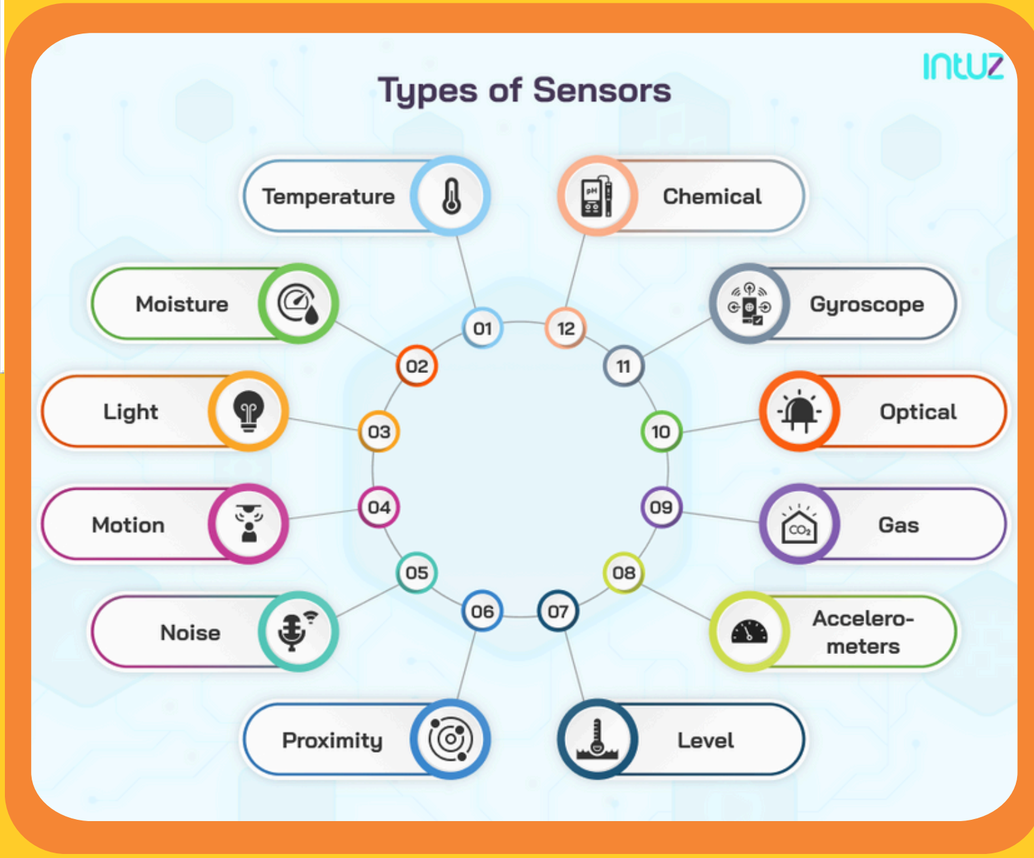
- Expensive
- Not warm, no watch or just app
- Animal creates empathy, soft companion
- Imagination
  - mythical

Criteria and Constraints

Criteria/Objective	Illustration	CTQ (Critical to Quality)	CTI (Critical to Innovation)
Customization for individual children		Must adapt to each child's unique physical and emotional profile	Develop AI/ML algorithms for personalized engagement
Customization for specific diseases		Tailored to the specific needs of children with different diseases	Adaptive functionality based on health status and treatment phase
Acceptability		User-friendly, engaging for children and parents. Aligned with therapist feedback	Intuitive interface and educational tools for optimal use
Affordability		Affordable and accessible across all socioeconomic backgrounds	Cost-effective materials and processes without compromising quality
Grounded in Scientific Approach		Clinically valuable data, complementing traditional monitoring methods	Innovative data analysis methods for predictive insights.
Safety and Comfort		Safe, hypoallergenic materials with comfortable sensor integration	Research and implement advanced materials and technologies
Emotional Engagement and Soothing		Effectively soothes and emotionally engages the child	Use of sensory feedback to create a responsive, "living" companion

Sensors Overview

Indicator	Detection Approach	Priority Level
Anxiety, Panic Attack	Heart rate, oxygen levels	High
Crying	Audio detection	High
Mood, Pain	Pressure	High
Frustration, Anxiety	Accelerometer-based, movement tracking, EMG, gait analysis	Medium
Stress	EDA (electrodermal) sensors	Medium



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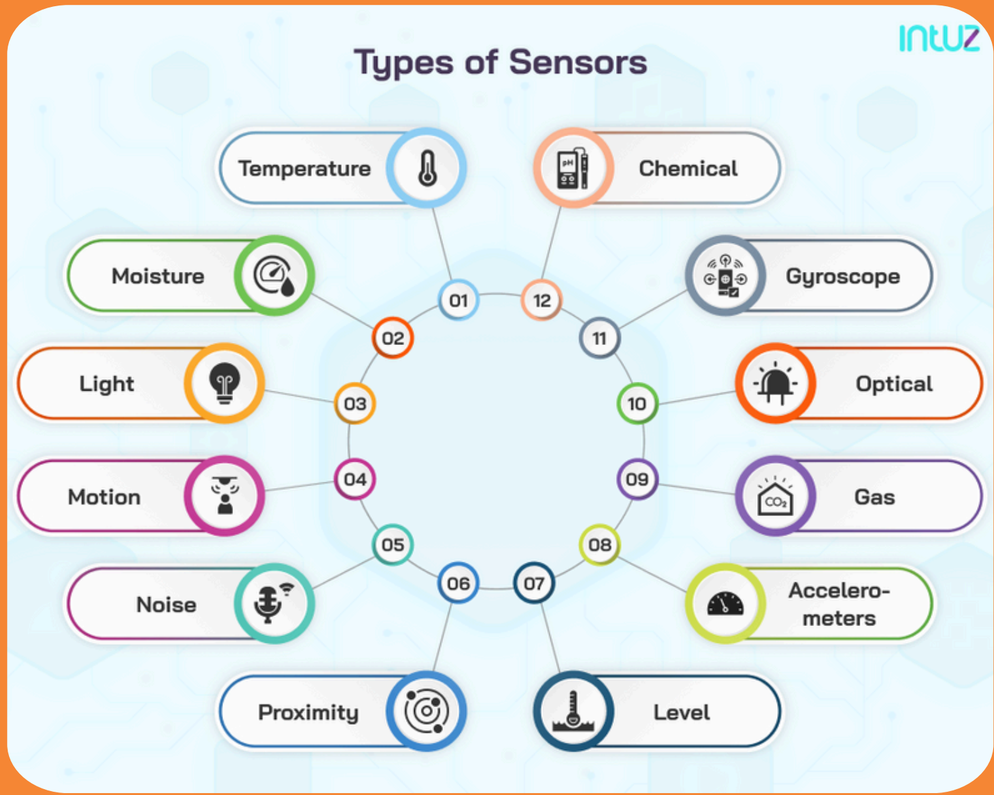
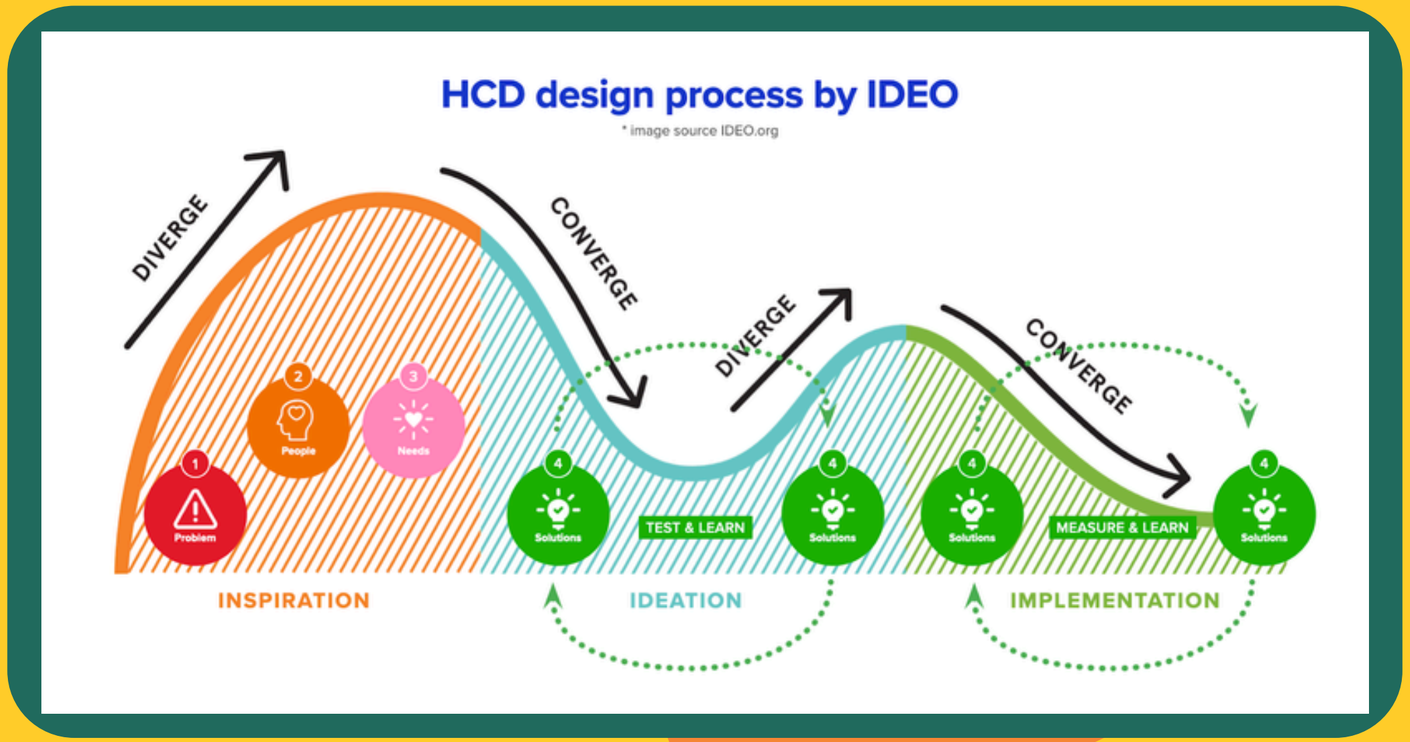
- Monitoring
  - Physiological
  - Behavioral
  - Psychological
- Soothing
- Cohesive, simple



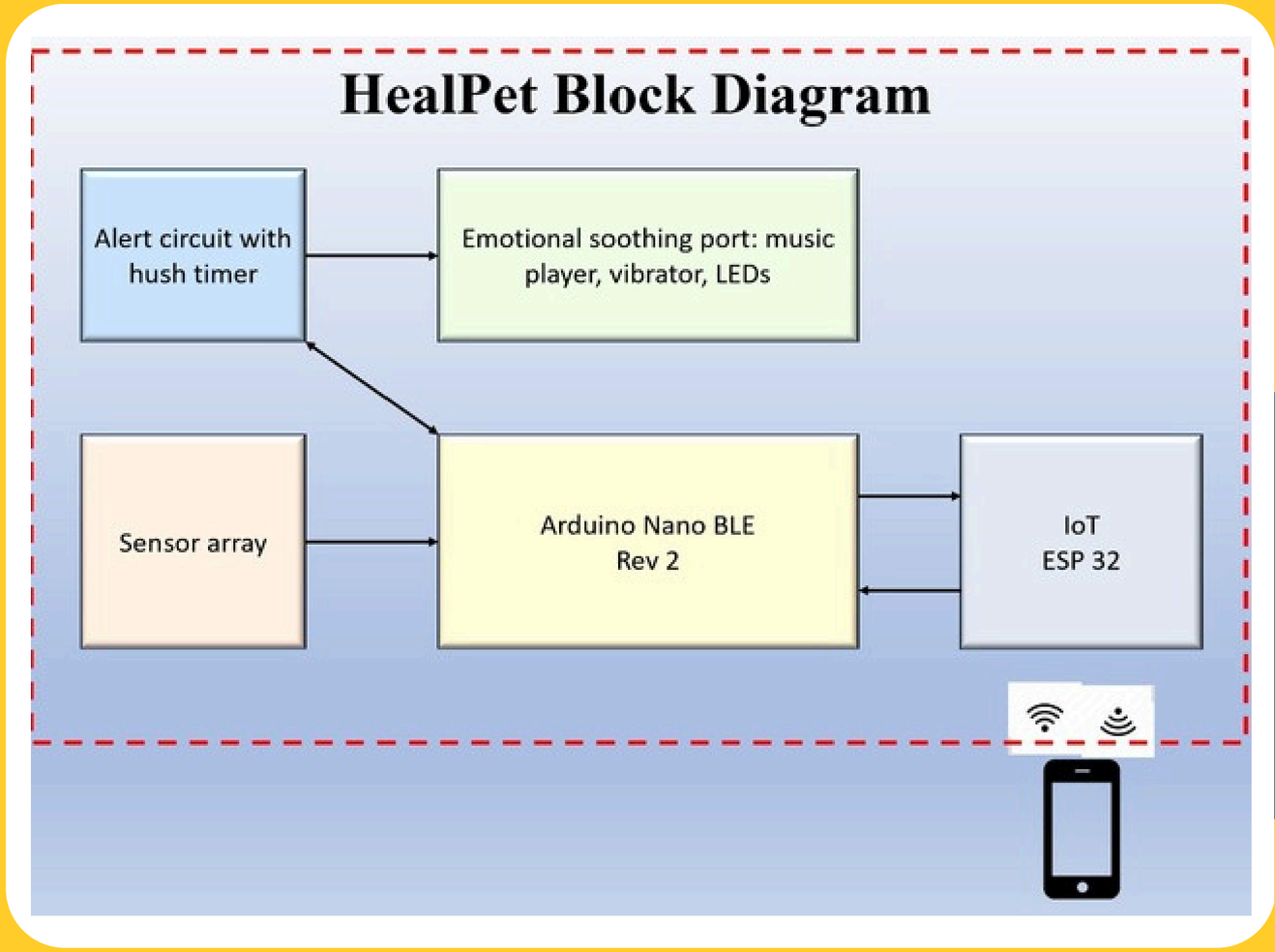
Human-Centered Design

- Insights from child life specialists and psychologists
- Observations from volunteering at DHMC
- Incorporation of user feedback into the design process
- Importance of user-centered design in developing the toy

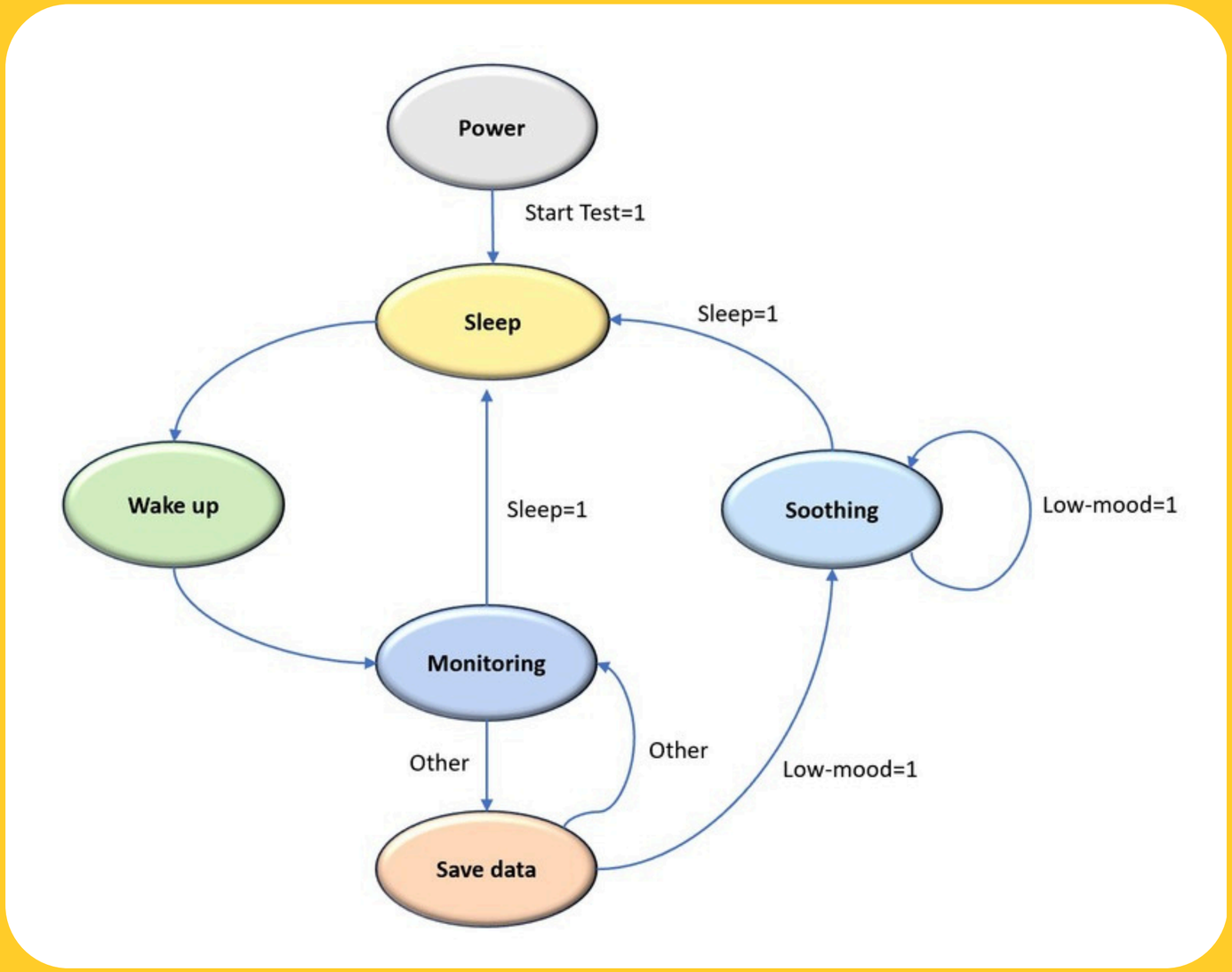


Design and Implementation

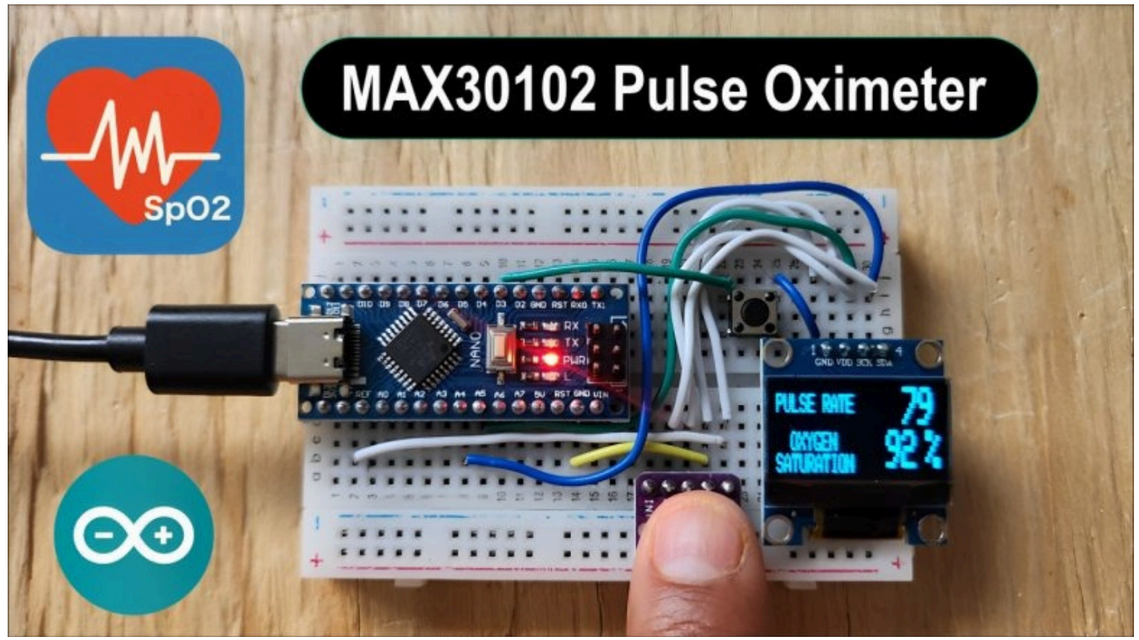
- Use of Arduino Nano and ESP32 boards
- Sensor integration: Heart rate, oximetry, accelerometers, voice detection
- Key design features



State Transition Diagram



Physiological-Biosensors



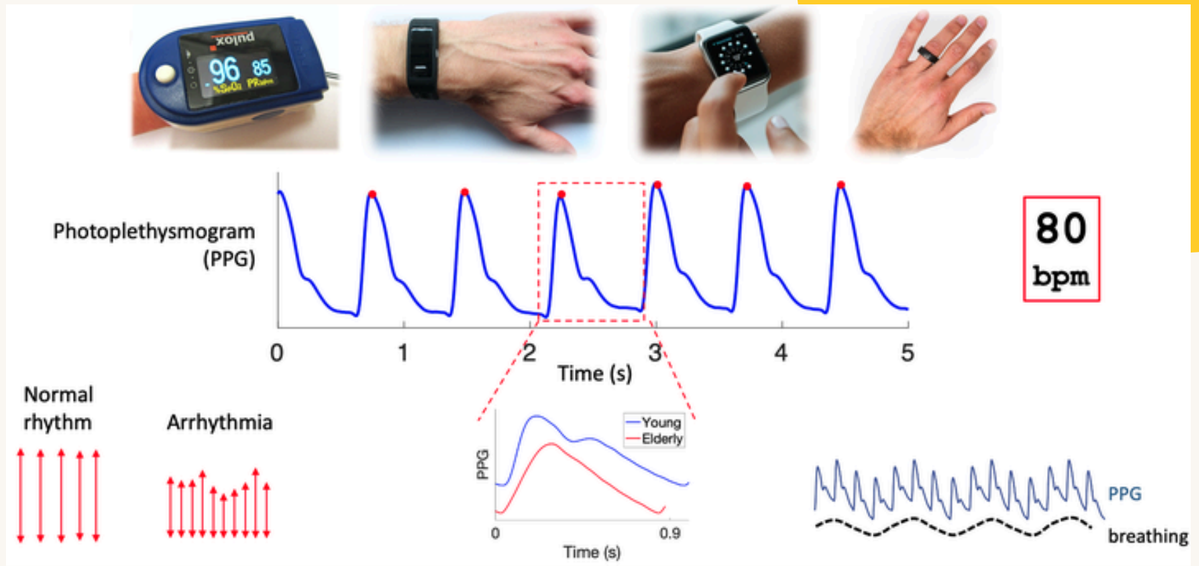
- MAX30102
  - Ideal for Biometric Monitoring: Compact, low-power sensor for HR and SpO_2.
  - Built-in algorithms and I^2C interface.
  - Accurate in low-perfusion with adjustable settings.
  - Ambient light, temperature and humidity cancellation for clear signals.
  - Widely used, affordable, and flexible for multiple health applications.
  - Sampling rate between 50-4000Hz. 100Hz

Photoplethysmography

- Blood hemoglobin absorbs light at different amounts depending on oxygenation.
- O2 blood absorbs + amounts of IR light and - red light, - 02 blood absorbs + red light and less IR light.
- Heart Rate: peaks (Max. blood vol.) $HR = \frac{60}{\Delta t}$
- Beer Lambert's Law: $A_\lambda = \log\left(\frac{I_0}{I_\lambda}\right) = \epsilon_\lambda \cdot C \cdot L$

$$R = \frac{\left(\frac{\text{AC component of red light}}{\text{DC component of red light}}\right)}{\left(\frac{\text{AC component of infrared light}}{\text{DC component of infrared light}}\right)}$$

  - DC : Baseline absorption from tissues, bones
  - AC : Pulsatile absorption from blood flow



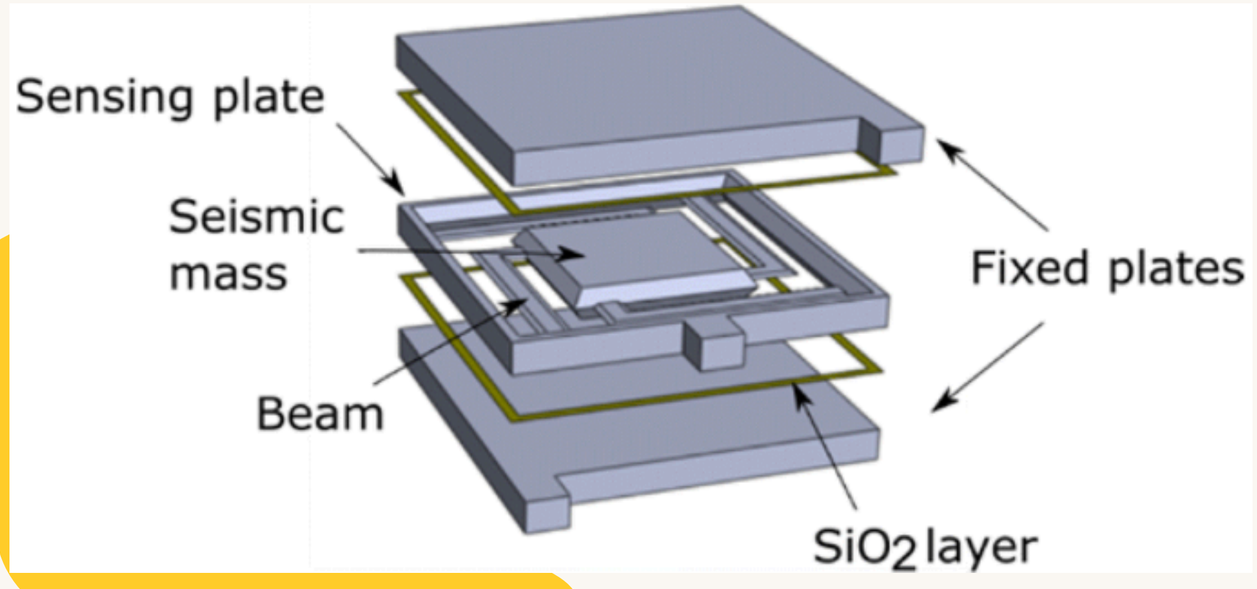
$$\mathrm{SpO_2} \approx A - B \times R$$

- Linear regression fitting obtained coefficients
- Reference to medical pulse oximeter, ABG sensor

Behavioral-Proprioceptive Sensors

- Importance of tracking movements
- Types of data that can be collected (e.g., gait, posture)
- ADXL335
  - Analog Output: Easy to interface with microcontrollers ADC (9.6kHz)
  - Low Power: Ideal for battery-powered devices.
  - Compact and Reliable: Proven performance in various applications.
  - Affordable

Capacitive Accelerometer



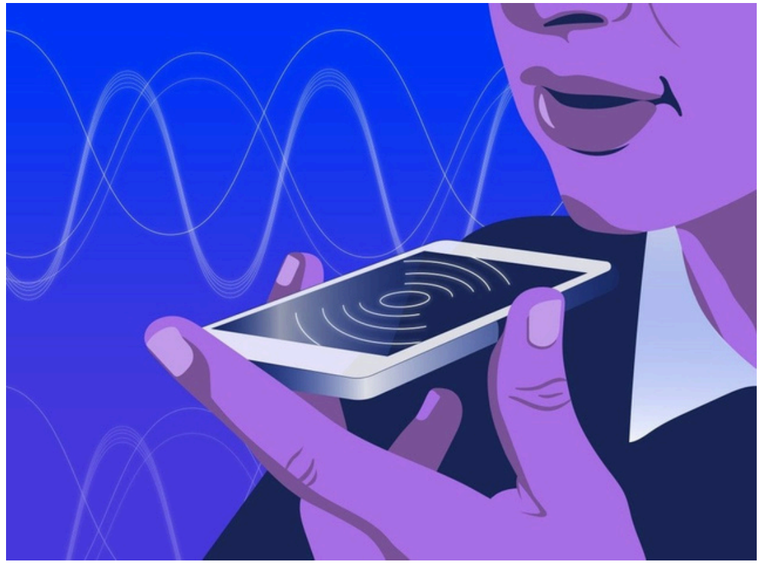
- Stable, less power, more sensitive to low frequencies and less costly
- When the system experiences acceleration, the inertia of the mass causes it to shift position
- Movement alters the distance between the plates to the movable mass. One side's capacitance increases while the other decreases.
- Analog voltage outputs for X, Y and Z pins.
- Subtract typical zero-g bias (drift): 1.5V for each axis, and it can vary by ±10%
- Divide by sensitivity 300 mV/g or 0.3V/g for each axis.

Psychological-Intelligent Piezoresistive Sensors

- Types of data collected (e.g., emotional state via voice analysis)
- Not large enough data pool
- Not enough SRAM

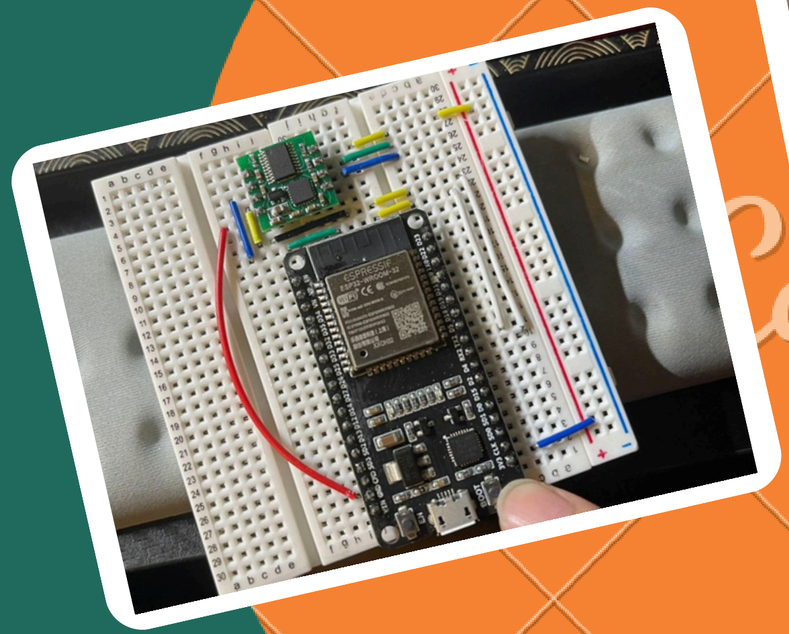
Voice Recognition Module V3

- Why Use It?
  - Hands-free operation.
  - Accessibility for users with disabilities
  - Provides a natural, intuitive user experience
  - Customization for specific applications
  - Easy integration with microcontrollers
- How It Works
  - Captures voice via a microphone
  - Filters and normalizes audio
  - Analyzes key audio features
  - Compares features with stored commands
  - Identifies and triggers actions
  - Sends command codes via UART
  - Allows learning of new voice commands



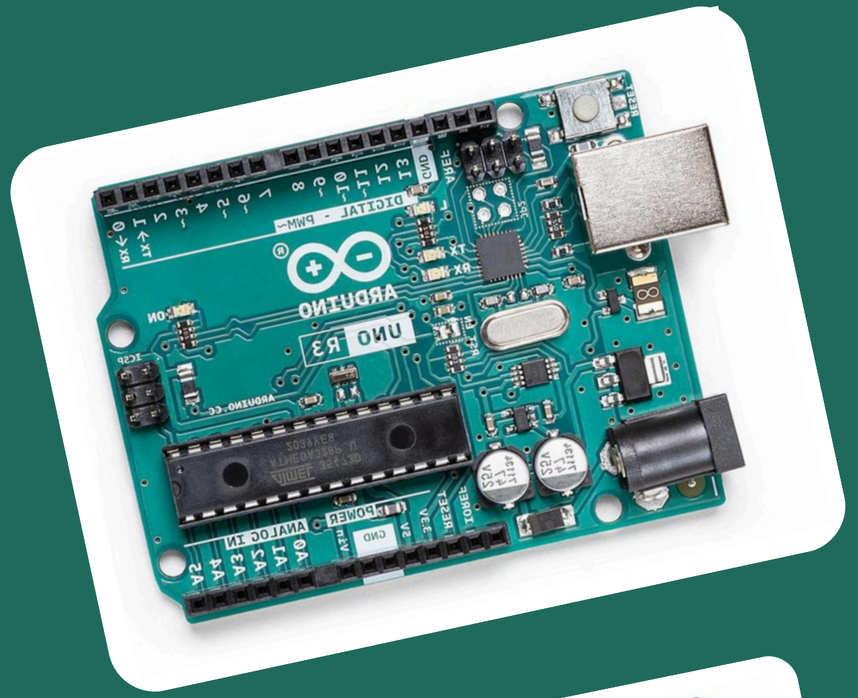
Prototype Iterations

- Overview of initial prototypes
- Key improvements
  - Sound improvement-speakers
  - Power and Data Frequency
  - Memory efficiency
  - Battery upgrade and efficiency
  - Data transmission
    - Not to IOS phone
    - Power Consumption
- Final prototype and its features



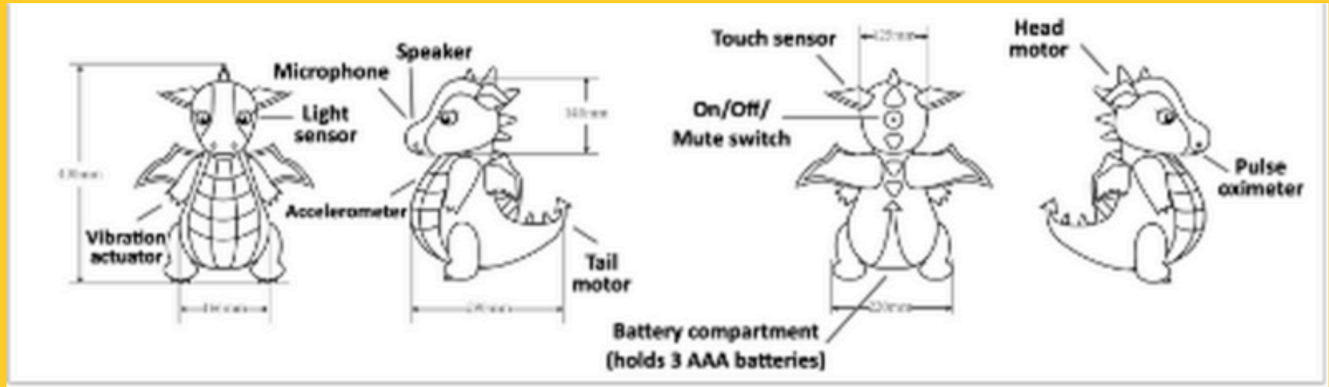
Processing, Memory and Programming

- Why Arduino UNO?
  - Multiple GPIO pins, higher processing capability
- Flash Memory: 32 KB sketch (program)
- Arduino Uno 2 KB SRAM (variables and computations)
- Main issue (no SRAM) - crashes or unwanted behavior
- float64’s to float32’s and float 32’s to int
  - SRAM use from 130% to 98%
- 32GB SD card module to store sensor data
- RTOS and event-driven architecture - real-time processing and responsiveness
- When sensor fails or data corruption - watchdog timers



Soothing JITAI Mechanisms

- JITAI [7]
- Integration of JITAI into toy
- Soothing features: Music, vibrations, LED lights
  - The Finetech FS90R Micro Continuous Rotation Servo Analog Motor
  - The HiLetgo GD3300 UART
- Alert to parents and caregivers if stress/pain persists (look over child)



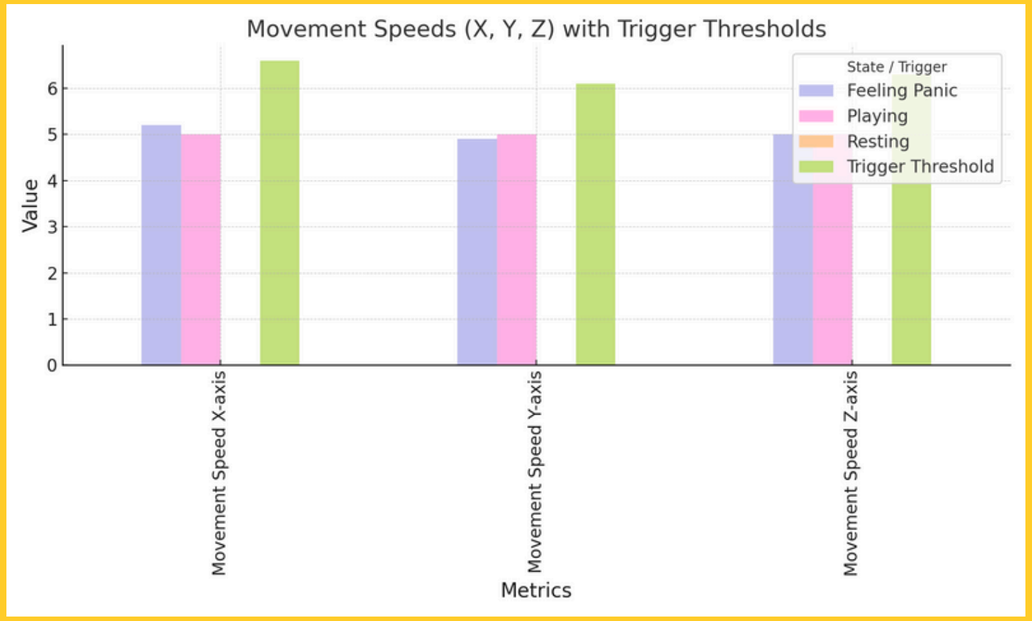
3D Modeling&Printing

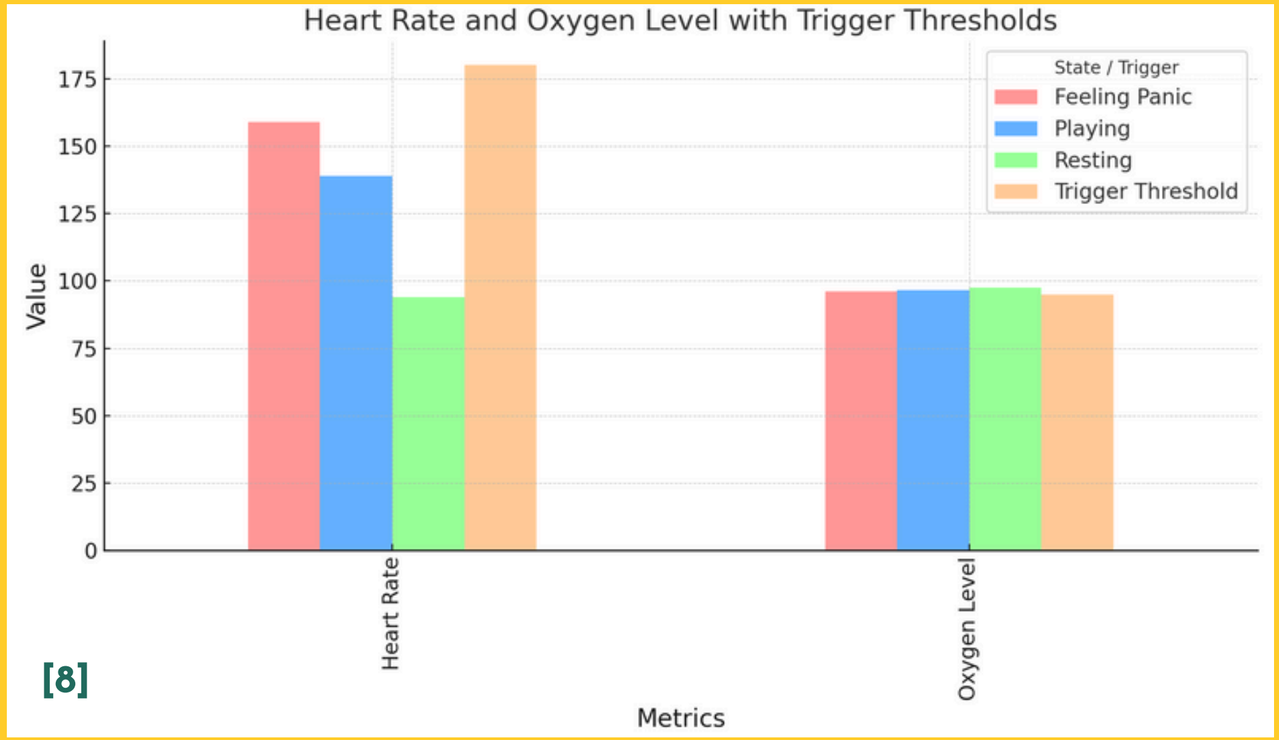
- Blender Models
- Materials used for 3D printing
  - PLA
  - TPU
- Challenges faced in the 3D printing process
  - Designs not suited for 3D printer
- Not safe or not great quality
  - Illustrative purposes
  - No testing

Testing

- IRB standards
  - Parental consent
- User studies were performed in the Empower Lab-controlled and in real world settings.
- Healthy children were tested during this phase of the study.
- 15 kids each handed a toy and allowed to play freely
- 30-45 minutes
- Compensation provided

Parameters/Trigger Values





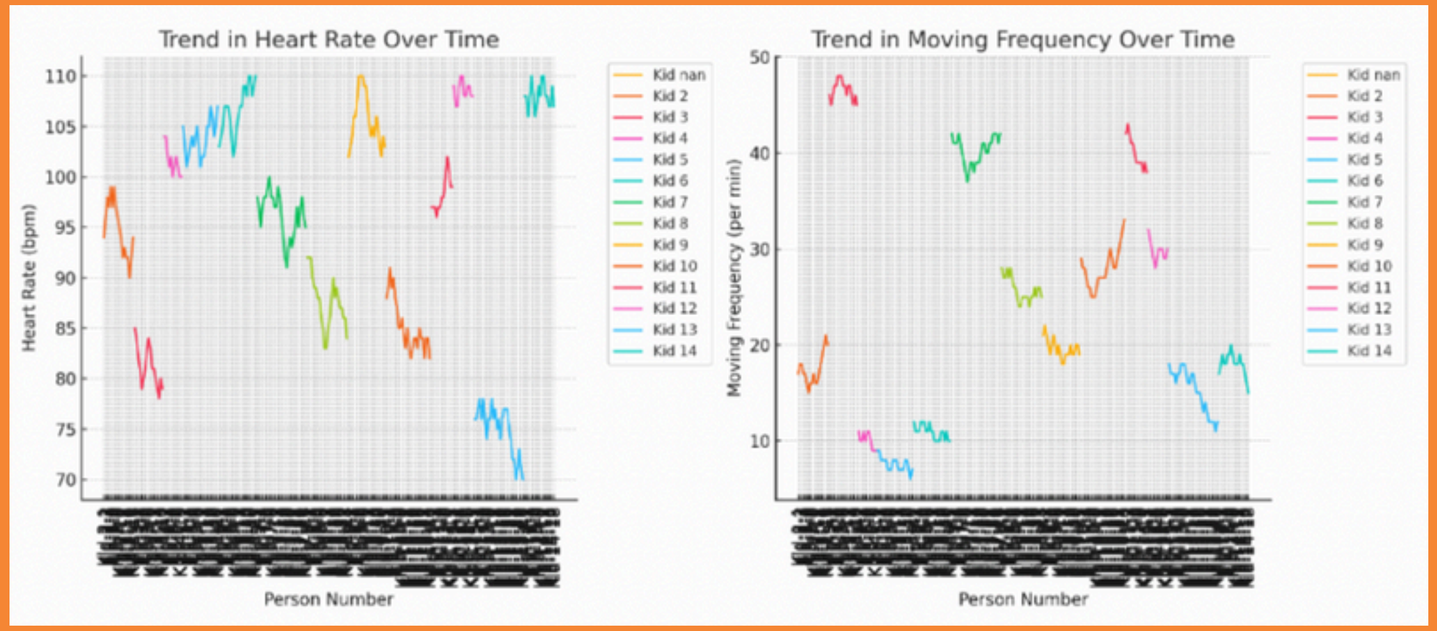
[8]

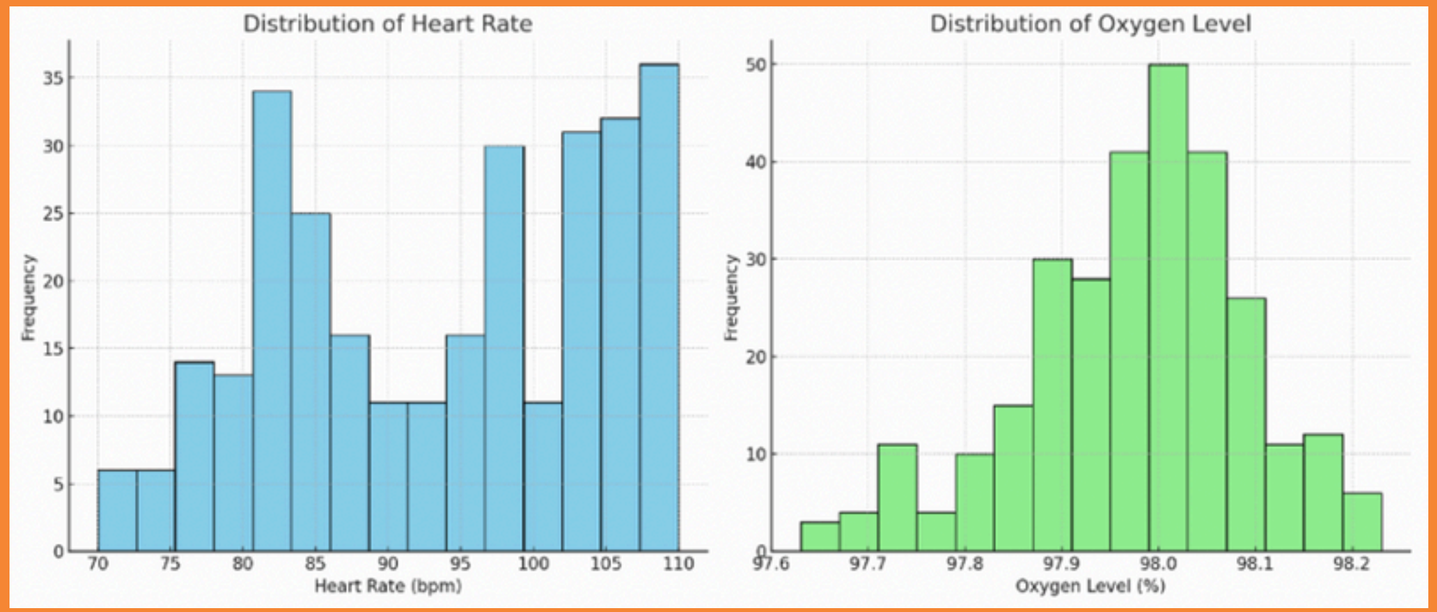
Metric	Panic	Playing	Resting	Trigger Threshold
Heart Rate	159	139	94	180.2
Oxygen Level	96.2	96.6	97.6	95
X Movement	5.2	5	0	6.6
Y Movement	4.9	5	0	6.1
Z Movement	5	5	0	6.3

Results

Testing Sensors Analytics

- Key results
  - 80 and 100 bpm-avg 93.6bpm
  - Stable oxygen levels-around 98%
  - Average mvt. freq. was 22.55 mvts. per min.
  - Higher for younger kids
- Key findings
  - Effective Monitoring
  - Need for tailored responses



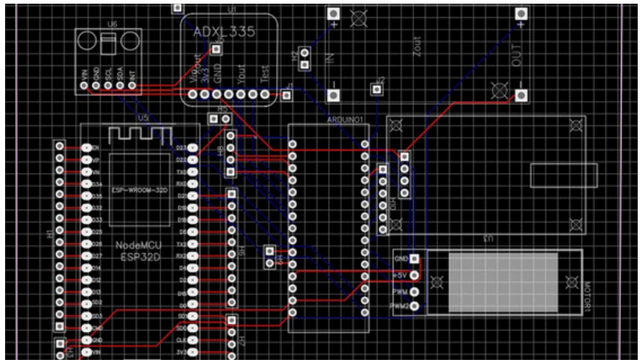


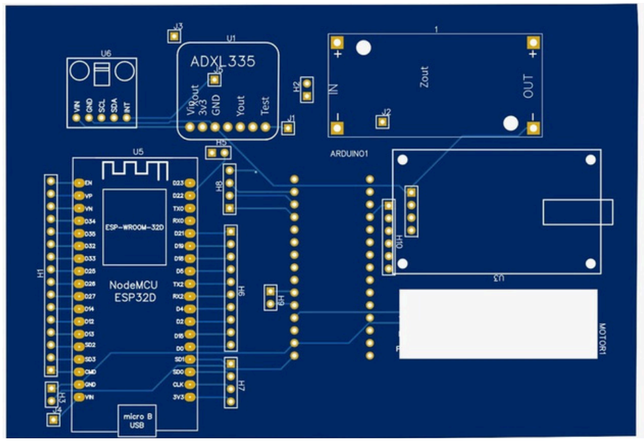
User Feedback

Surveys

11/15 of children feeling happy going into the test
13/15 of the children were happy
12/15 of the children and families reported that using the smart toy was easy
13/15 of children also reported wanting to play with the toy again
11/15 children reported that the JITAI were helpful

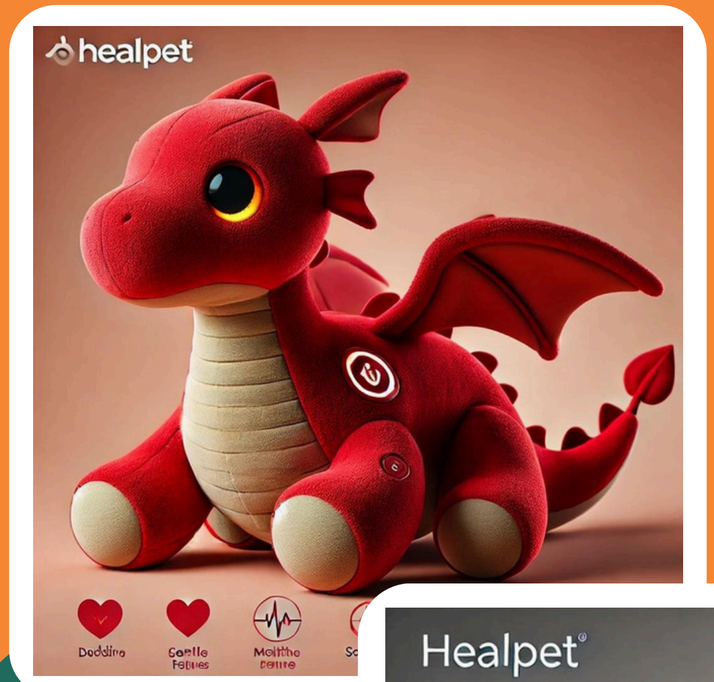
Higher Level Category	Details	Examples
Child Interaction and Engagement	• Children were generally happy before and even more so after the test. • Enjoyed specific features of the toy such as glitter, wings, texture, and pattern. • Found the toy easy to use. • Wanted to play with the toy again. • Found JITAI (music and vibrational stimulus) helpful.	"I felt happy playing with the toy." "I love the pink dragon's glitter! "I love the blue dragon's wings!" "It's easy to play with." "Can I play with it again?" "The music and vibrations helped me feel better."
Parental Observations and Feedback	• Parents observed positive interactions between their children and the toy. • Noted improvements in their children's mood and behavior.	"My child seemed more relaxed and happier." "It's great to see my child enjoying something."
Usability and User Experience	• Most found the toy easy to use. • Positive feedback on user experience from both children and parents.	"The toy is very fun to play with." "We playing with it together."
Impact on Well-Being	• Changes in children's behavior and mood noted after using the toy. • Toy has potential to enhance the well-being of children.	"He seems much happier after playing with it." "It's a helpful distraction."
Areas for Improvement	• Desire for more interactivity, such as the toy talking. • Suggestions for giving each pet a name. • Preference for ears instead of antlers on the dinosaur toy.	"It would be cool if the toy could talk to us." "Can we name the toy?" "I don't like the antlers; ears would be better."





Evaluations and Limitations

Criteria	Metrics/Benchmarks and Evaluation
Customization for individual children	**In Progress**: Initial settings developed, but full range not yet available (**2/5**) **Not Yet Started**: Machine learning adaptations in the planning phase (**1/5**)
Customization for specific diseases	**In Progress**: Disease-specific customizations require development (**2/5**) **Partially Met**: Positive therapist feedback but comprehensive disease-specific utility is not yet achieved (**3/5**) **Not Met**: Need to ensure responsiveness to different treatment phases (**1/5**)
Acceptability	**Exceeded**: User interface and engagement have high satisfaction scores (**5/5**) **Met**: Short learning curve (**4/5**) **Met**: Initial design aligns with IRB and privacy guidelines (**4/5**)
Affordability	**Met**: Production cost and affordability targets achieved (**4/5**) **Met**: Affordable expected retail pricing (**4/5**) **Partially Met**: Positive initial material assessments (**3/5**)
Grounded in Scientific Approach	**Partially Met**: Promising initial data correlation and clinician feedback; further validation needed (**3/5**) **Met**: Short-term data retention and accuracy have been achieved (**4/5**) **Not Yet Started**: Long-term monitoring models are in planning phase (**1/5**)
Safety and Comfort	**In Progress**: Passed initial IRB testing, safety testing pending (**2/5**) **In Progress**: Potentials materials identified, pending evaluations (**3/5**)
Emotional Engagement and Soothing	**Met**: Emotional engagement and soothing features are performing well in initial tests (**4/5**) **Met**: Preliminary user feedback shows anxiety levels decrease (**4/5**) **Partially Met**: Interactivity features require improvement (**3/5**)

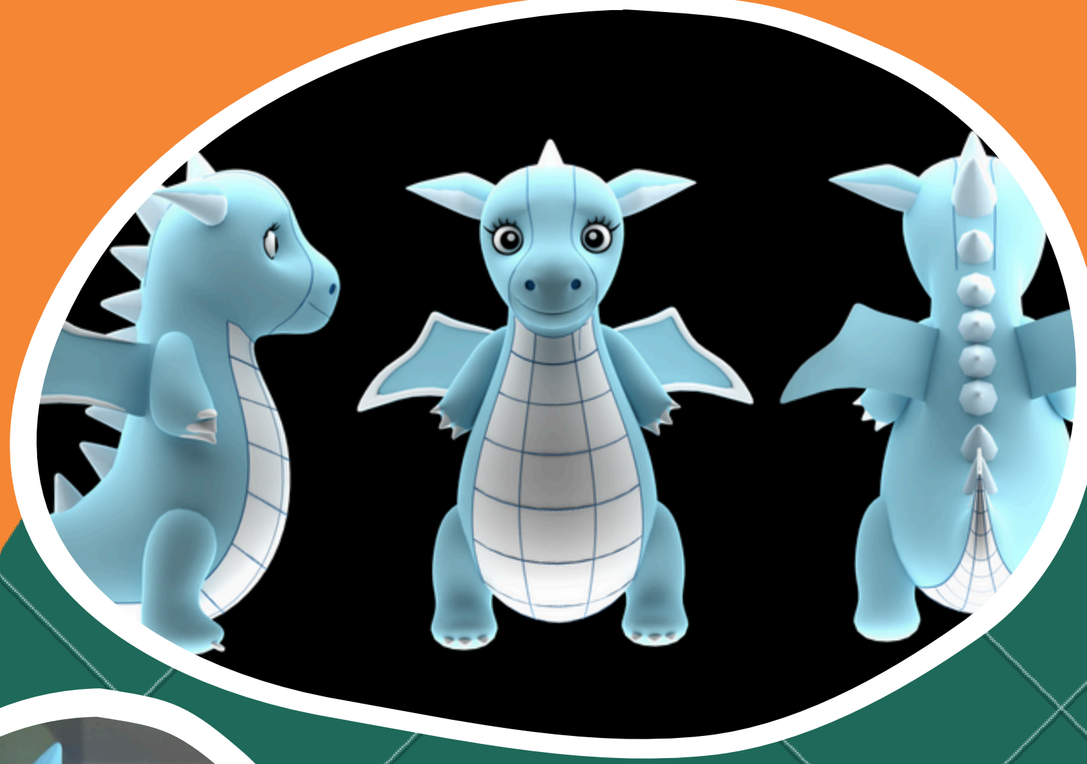


Future Work

- Optimization of sensor functions and machine learning algorithms
- Interactivity-as discovered in user feedback
- Continued research on emotional monitoring and support
- App development-parents and children
- Wifi connection for increased range
- Industrial manufacturing and market release
- Future research applications (other illnesses)
- Sell components separately or another product
- Longitudinal studies for the project

Conclusions

- Successfully tested a toy companion prototype
- Integration of Emotional Support with Physical Health Monitoring
- Development of an Affordable Monitoring Companion
- Encouragement of Play and Emotional Well-being
- User-Centered Design and Feedback
- Foundations for Future Technological Enhancements
- Potential for Market Expansion/Wider Adoption



Thank you

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References

Cancer Statistics
Chronic Pain Statistics

01

- American Cancer Society, "Key Statistics for Childhood Cancers," [Online]
- American Pain Society, "Prevalence and Impact of Pediatric Chronic Pain," [Online]

Interconnection of Emotions with Well-being

02

- F. J. Hagedoorn, P. C. Sanderman, A. E. Bolks, P. T. Tuinstra, and P. J. Coyne, “Distress in couples coping with cancer: A meta-analysis and critical review of role and gender effects,” Psychological Bulletin, vol. 134, no. 1, pp. 1-30, 2008.
- A. M. McCracken and L. M. Keeley, “The role of psychological flexibility in managing chronic pain,” Journal of Health Psychology, vol. 13, no. 8, pp. 1232-1246, 2008.

Assessment Methods
Self-Reports Reliability

03

- J. Smith, et al., "The Reliability of Self-Reported Data in Health Research," Journal of Health Studies, vol. 58, no. 3, pp. 123-130, 2023, doi: 10.1234/jhs.v58i3.1234.
- A. Brown, "Assessing Self-Report Measures in Clinical Trials," Clinical Trials Review, vol. 12, pp. 45-50, 2022. [Online]

Modern Technological Solutions and Their Limitations

04

- L. Jones, "The Challenges of Continuous Monitoring in Health Technology," Journal of Medical Devices, vol. 47, no. 1, pp. 22-30, 2024, doi: 10.5678/jmd.v47i1.5678.
- "Innovations in Monitoring Chronic Illness," Technology Review, 2024. [Online].

Mental Health Challenges in Chronic Pain and Cancer Patients

05

- National Institute of Mental Health, "Mental Health and Chronic Pain," [Online].
- K. Black, et al., "Mental Health Interventions in Cancer Patients," Psycho-Oncology, vol. 31, no. 4, pp. 150-158, 2024, doi: 10.1002/pon.5652.

Social Theories of Play: -Piaget -Bandura

06

- J. Piaget, Play, Dreams and Imitation in Childhood, Routledge, 1951.
- A. Bandura, Social Learning Theory, Prentice-Hall, 1977.

JITAI Interventions
Sensorial Stimuli Benefits

07

- R. Miller, "JITAI: A Novel Approach to Behavioral Interventions," Journal of Behavioral Medicine, vol. 33, no. 2, pp. 111-120, 2024, doi: 10.1007/s10865-024-9356-7.
- H. Green, "Sensorial Stimuli and Stress Reduction," International Journal of Psychology, vol. 52, no. 5, pp. 98-105, 2023, doi: 10.1016/j.ijpsycho.2023.07.004.

Normal Children Heartbeats and Oxygen Levels

08

- American Academy of Pediatrics, "Pediatric Vital Signs Reference Chart," [Online].
- National Institutes of Health, "Normal Oxygen Saturation Levels in Children," [Online]

Battery, Current and Power

- A typical AA battery has a capacity of about 2000 mAh.
- 4 AA batteries provide a total voltage of 6V (since each AA battery provides 1.5V).

$$C_{\text{total}} = 2000\,\text{mAh} \times 4 = 8000\,\text{mAh}$$

- Device lasts up to 40 hours of continuous use

$$I = \frac{8000\,\text{mAh}}{40\,\text{h}} = 200\,\text{mA}$$

$$V = 6\,\text{V}$$

$$I = 200\,\text{mA} = 0.2\,\text{A}$$

$$P = 6\,\text{V} \times 0.2 = 1.2\,\text{W}$$

Sponsorships

Hospitals/clinics

- Recommendations
- Testing

Therapists

- Pilot Program
- Training
- Feedback

Toy Companies

- Design/ Customized Versions
- Special Edition
- Collaborative Marketing

Cost Analysis

Item	Prototype	Manu (100-500)	Red. Manu. (1k-5k)	Manu+Sensors	Red. Manu. +Sensors
Arduino Nano	24	10	8	10	8
ESP-WROOM-32 ESP32)	15	5	4	5	4
MAX30102	10	3	2.5	3	2.5
Accelerometer	5	1.5	1.2	1.5	1.2
Voice Recognition	12	4	3.5	4	3.5
Vibration Motor	3	1	0.8	1	0.8
LED lights	2	0.5	0.4	0.5	0.4
Rechargeable Power Supply	15	6	5	6	5
Plush materials	20	5	4	5	4
MP3 Player Module	8	2	1.5	2	1.5
EDA	0	0	0	2	1.5
Touch	0	0	0	0.5	0.4
Pressure	0	0	0	1	0.8
Speakers	5	1	0.8	1	0.8
Misc. (wires, connectors, etc.)	5	1	0.8	1	0.8
Manufacturing Labor	0	2	1.5	2	1.5
Packaging	0	0.5	0.4	0.5	0.4
Shipping	0	1	0.8	1	0.8
Total (Materials +Manufacturing)	**120**	**43.5**	**36.4**	**53**	**46.4**
Manufacturing Costs	0	5	4	5	4
Company Gains (20%)	0	9.7	8.1	11.6	10.1
Total with Company Gains	**0**	**58.2**	**48.5**	**69.6**	**60.5**

Rating	Material	Hypo-allergenic	Softness	Cost/yd	Durability	Healpet Suitability	Overall Score
3	Microfiber	Yes	4	5 (~ $5)	5	5	4.75
2	Polyester Fleece	Treated	4	5 (~$4)	5	4	4.5
4	Lyocell (Tencel)	Yes	5	4 (~$7)	4	5	4.5
0	Organic Cotton	Yes	5	3 (~$8)	4	5	4.25
1	Bamboo Fabric	Yes	5	3 (~$7)	4	5	4.25
5	Minky Fabric	Yes	5	4 (~$6)	3	4	4
6	Silicone	Yes (medical-grade)	3	2 (~$15)	5	3	3.25

Material Analysis

Exterior:

- Organic Cotton/Bamboo Fabric: Soft, hypoallergenic for frequent skin contact
- Minky Fabric: Plush, comforting, but check for sensitivity

Interior:

- Microfiber/Polyester Fleece: Durable, soft, ideal for padding.

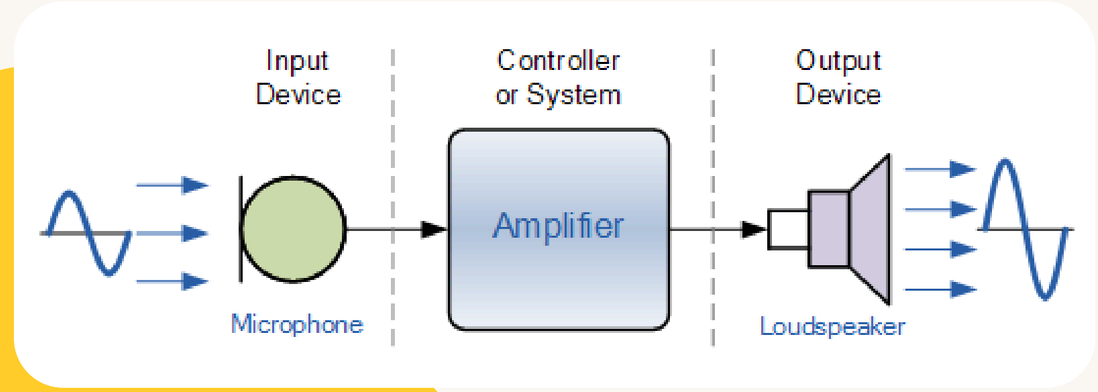
Special Components:

- Silicone: Flexible, durable, great for interactive parts

Safety

- Electrical: Low-voltage operation; insulated components; safe batteries (UL 2054)
- Mechanical/Material: Non-toxic, hypoallergenic, durable, no sharp edges (ASTM F963, EN 71)
- Fire: Fire-resistant materials; overheating protection (UL 94, IEC 60950)
- Ergonomic/Psychological: Comfortable, age-appropriate interactions (ASTM F963, EN 71)
- Radiation: Emissions within safe limits (FCC, CE).
- Hygiene: Washable parts; germ-resistant materials. (ASTM F963)
- Software: Safe shutdowns; regular updates (IEC 62304)
- Compliance: Meets all safety certifications; thorough testing (CPSC, CE marking)

Audio Detection



- Capture & Conversion: Microphone captures sound, converts it into electrical signals.
- Amplification & Filtering: Signals are amplified and filtered to remove noise.
- Digital Conversion: Signals converted to digital for processing.
- Signal Analysis: Detects sounds, pitch, volume. Extracts patterns