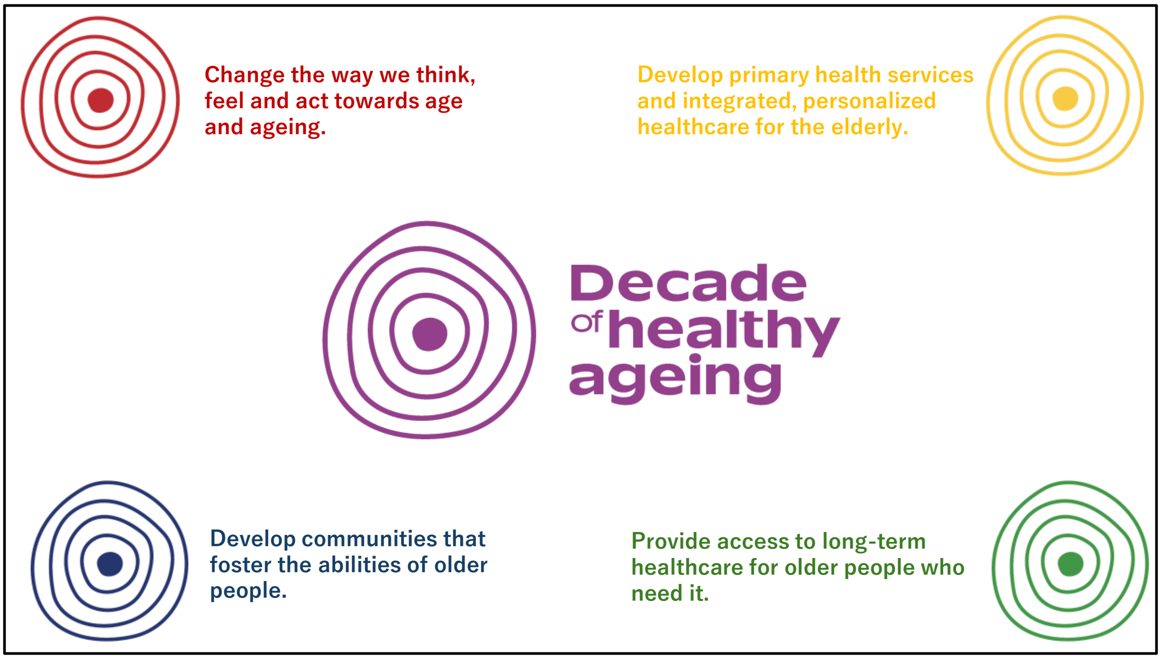
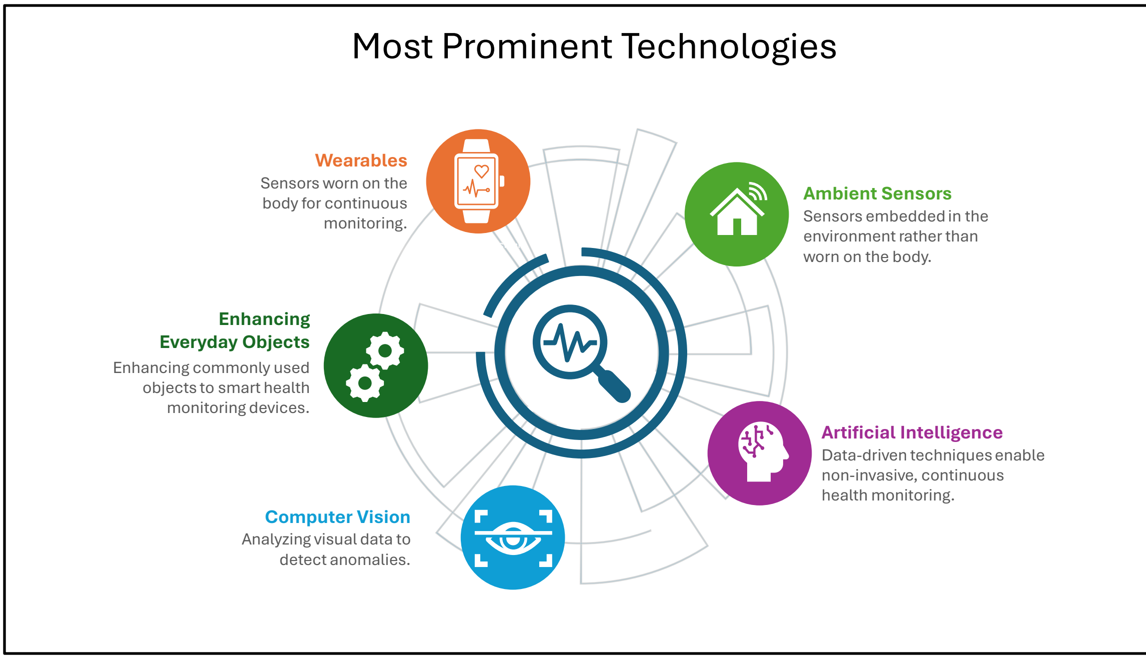

The World Health Organization in alignment with the United Nations launched an initiative in 2021 which is called the Decade of Health Ageing.




This global initiative focus on four key areas: Change the way we think, feel and act towards age and ageing. Develop communities that foster the abilities of older people. Develop primary health services and integrated, personalized healthcare for the elderly, which is also the main focus of this thesis. And to provide access to long-term healthcare for those who need it.




Initially, a scoping review was conducted in order to identify the most prominent technologies used in health monitoring for the elderly over the past 15 years. The identified include wearable sensors, which are sensors worn on the body, ambient sensors, which are  embedded in the environment, artificial intelligence algorithms combined with sensor data, computer vision techniques such as image recognition, object detection, but also into exploring ways to enhance everyday objects used by the elderly in their everyday activities into smart, health monitoring devices. Wearable sensing technologies were identified as the most prominent technologies used, covering 50% of the records identified in the scoping review. Wearables enable long-term health tracking for chronic conditions like diabetes and sleep disorders, while also facilitating human activity recognition such as navigation, and fatigue detection. Clinically, they assist in disease detection, treatment alerts, and predicting health issues. While these technologies offer significant advancements, they also come with important implications.

*“Remote health monitoring of elderly through wearable sensors.”*
Al-Khafajiy, Mohammed, et al.

**Methodology**: Proposed a smart healthcare monitoring system utilizing smartphones and wearable sensors to monitor elderly individuals in real-time, focusing on processing and analyzing physiological data.

**Conclusions**:
- Pros: Enhances early detection of health issues; facilitates home-based monitoring.
- Cons: Reliance on smartphone usage may be challenging for some elderly users; data accuracy depends on sensor quality; Data privacy concerns.

*“Wearable Technology for Elderly Care: Integrating Health Monitoring and Emergency Alerts.”*
Hasan, Nowshad, and Mohammad Faisal Ahmed.

**Methodology**: Introduced a smart glove integrating sensors to monitor vital signs like heart rate and SpO2, detect falls, and send emergency alerts using IFTTT protocols.

**Conclusions**:
- Pros: Provides comprehensive health monitoring; facilitates prompt emergency responses.
- Cons: Wearing a glove continuously may not be comfortable for all users; potential issues with sensor calibration.

*“The Importance of Wearable Technology in Elderly Healthcare.”*
Ballaji, Hattan K.

**Methodology:** Discussed the role of wearable sensors in elderly healthcare, focusing on their ability to track health status remotely and send emergency alerts.

**Conclusions:**
- Pros: Supports independent living; enables timely interventions.
- Cons: Potential challenges include device maintenance and ensuring user comfort.

The technologies identified included wearable sensors like wristbands, smartwatches and wearable gloves, which combined with smartphones were used for enhancing early detection of health issues, monitoring conditions like diabetes and facilitating human activity recognition like navigation and fatigue detection.

*"HomeSense: Design of an ambient home health and wellness monitoring platform for older adults."*
VandeWeerd, C., et al.

**Methodology:** Described the design and deployment of HomeSense, an ambient home sensing project aimed at monitoring the health and wellness of older adults in a community setting.

**Conclusions:**
- Pros: Facilitates aging-in-place; potential to reduce healthcare costs.
- Cons: Limited research on benefits in private homes; user acceptance varies.

*"Evaluation of 1-year in-home monitoring technology by home-dwelling older adults, family caregivers, and nurses."*
Pais, Bruno, et al.

**Methodology:** Conducted a 12-month observational study assessing the usability and impact of an in-home monitoring system combining ambient and wearable sensors among older adults living independently.

**Conclusions:**
- Pros: Positive reception from older adults and caregivers; aids in staying at home and improving home care.
- Cons: Some concerns from nurses about potential weakening of relationships with older adults due to surveillance.

*"Ambient health sensing on passive surfaces using metamaterials."*
Nguyen, Dat T., et al.

**Methodology:** Presented a technique to transform passive surfaces into contactless health sensors capable of detecting vital signs, offering a non-invasive approach to health monitoring.

**Conclusions:**
- Pros: Enables hours-long cardiopulmonary monitoring with accuracy comparable to gold standards; unobtrusive and privacy-preserving.
- Cons: Technology is still emerging; real-world implementation challenges need to be addressed.

Ambient sensing technologies like RFID tags or proximity sensors embedded in the environment for detection of activities of daily living or monitoring of chronic conditions like cognitive decline and dementia.

*“Autocognisys: Iot assisted context-aware automatic cognitive health assessment.”*
Alam, Mohammad Arif Ul, et al.

**Methodology:** Introduced AutoCogniSys, a system combining wearable and ambient sensors with AI to assess cognitive health in older adults, demonstrating high accuracy in evaluations.

**Conclusions:**

- Pros: High accuracy in cognitive health assessment; combines multiple data sources for comprehensive analysis.
- Cons: Implementation in diverse home environments may present challenges; requires user training.

*“An AIoT-enabled autonomous dementia monitoring system.”*
Wu, Xingyu, and Jinyang Li.

**Methodology:** Presented an AIoT system for monitoring dementia patients, utilizing activity inference and trend prediction to detect abnormal behaviors and disease progression.

**Conclusions:**

- Pros: High accuracy in activity inference and abnormal activity detection; effective in forecasting disease-related activity trends.
- Cons: System complexity may affect scalability; data privacy considerations are paramount.

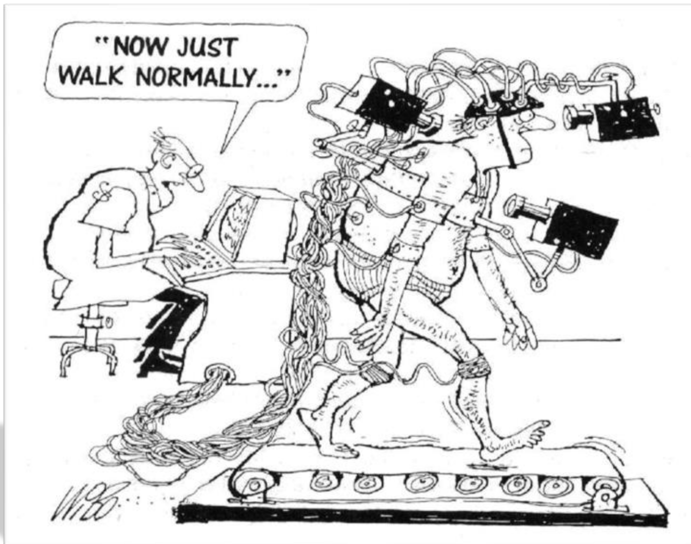
*“Artificial Intelligence–Powered Digital Health Platform and Wearable Devices Improve Outcomes for Older Adults in Assisted Living Communities: Pilot Intervention Study.”*
Wilmink, Gerald, et al.

**Methodology:** Analyzed how AI-powered digital health platforms, combined with wearable devices, can improve health outcomes for older adults in assisted living communities.

**Conclusions:**

- Pros: Provides actionable information for early intervention; contributes to improved health outcomes.
- Cons: Requires further validation in larger trials; integration with existing healthcare systems may be complex.

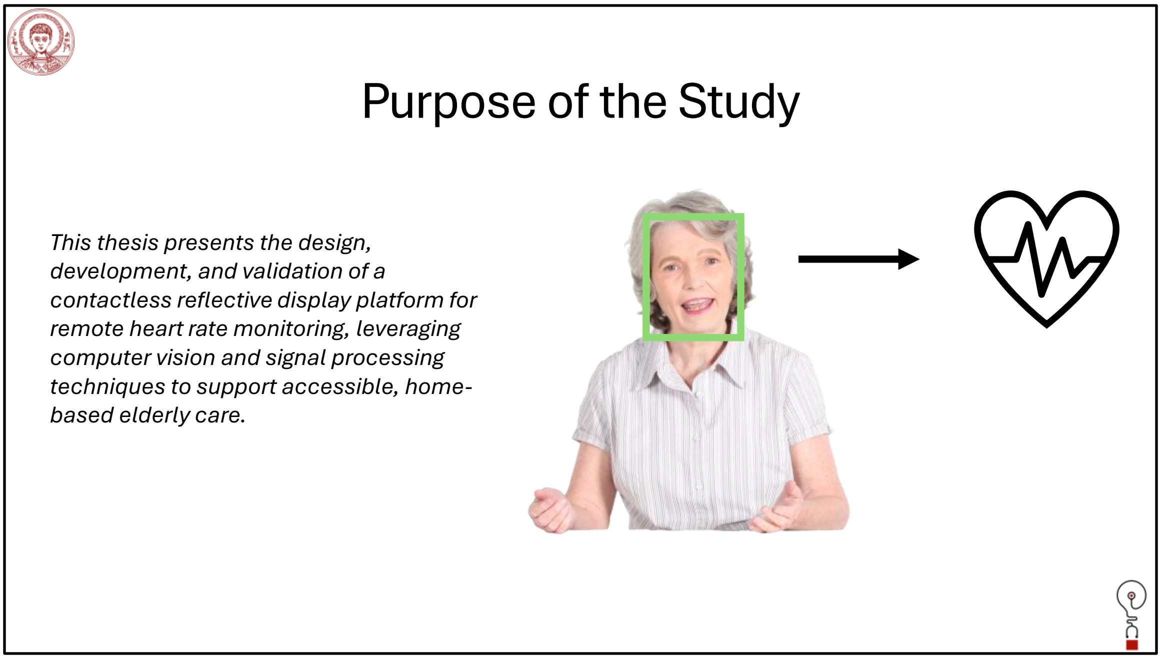
Moreover, Artificial intelligence algorithms were used combined with sensor data to improve accuracy and predict outcomes.



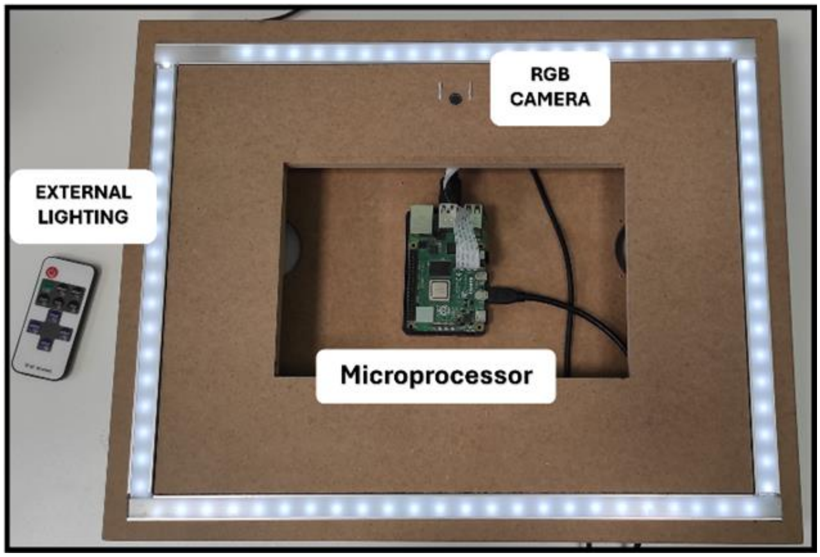

*Cartoon by Willem Louis Joseph Boost a.k.a. WiBo*

Willem Boost's illustration captures this reality effectively, showing how these technologies can often feel uncomfortable or overwhelming. Users are also required to follow strict protocols, such as daily data logging, which creates a heightened sense of obtrusiveness, ultimately compromising user engagement and data quality.

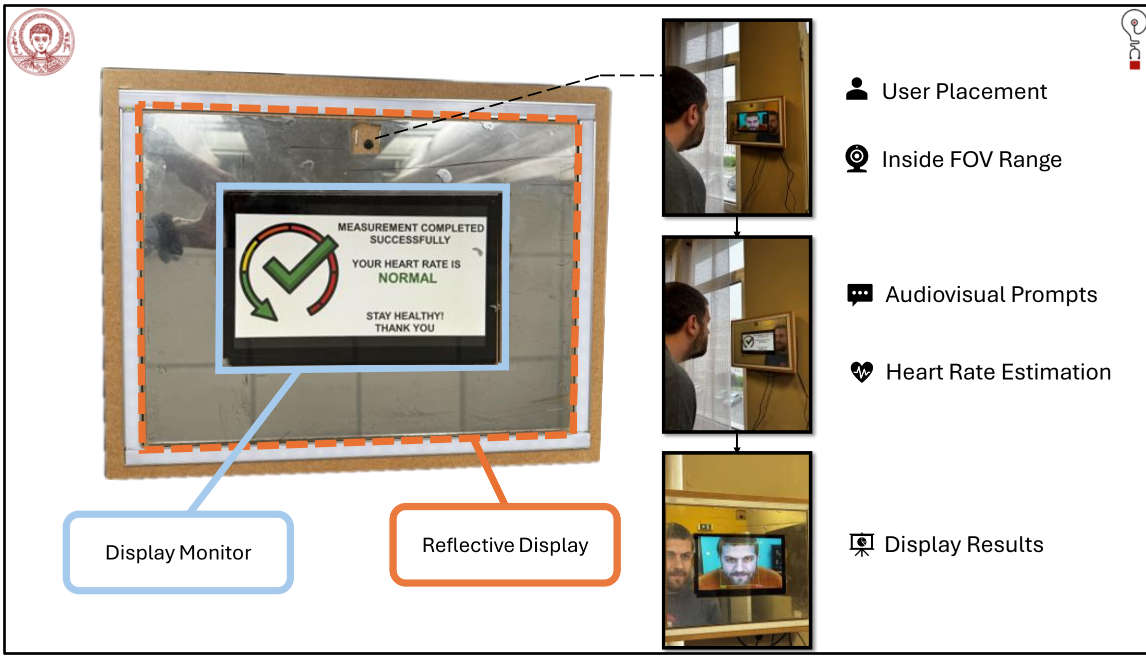

Focusing on the concept of enhancing everyday objects used by the elderly in their everyday activity, a use case was proposed. What if the bathroom mirror, a common object/furniture used daily by the general population could be enhanced into a smart, health monitoring device that could enable health monitoring without disrupting the user's routine? With smart mirror technology and computer vision, we could discreetly assess their general appearance and detect early signs of health issues, prompting timely alerts or interventions. Building on this concept, we developed an innovative reflective display platform that employs computer vision technologies to assist in remote health monitoring of the elderly in an unobtrusive manner.



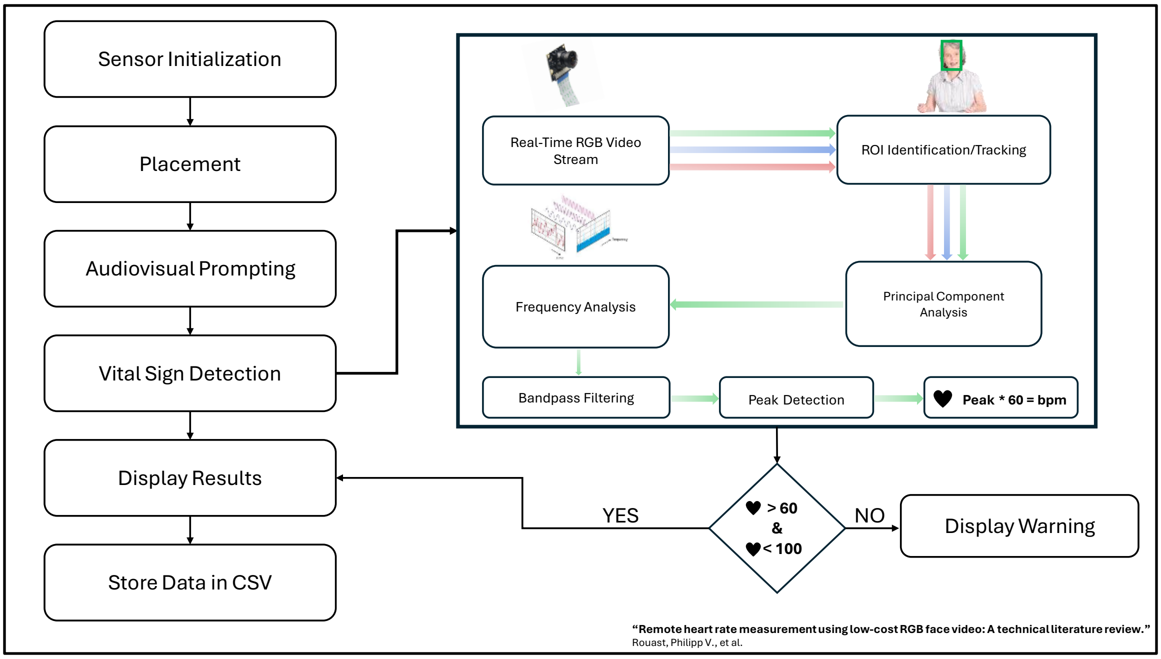

The purpose of this platform is to capture video frames from the user's face using a camera and extracting the user's heart rate from these frames enabling contactless heart monitoring. This thesis will present the development and validation of the proposed platform.



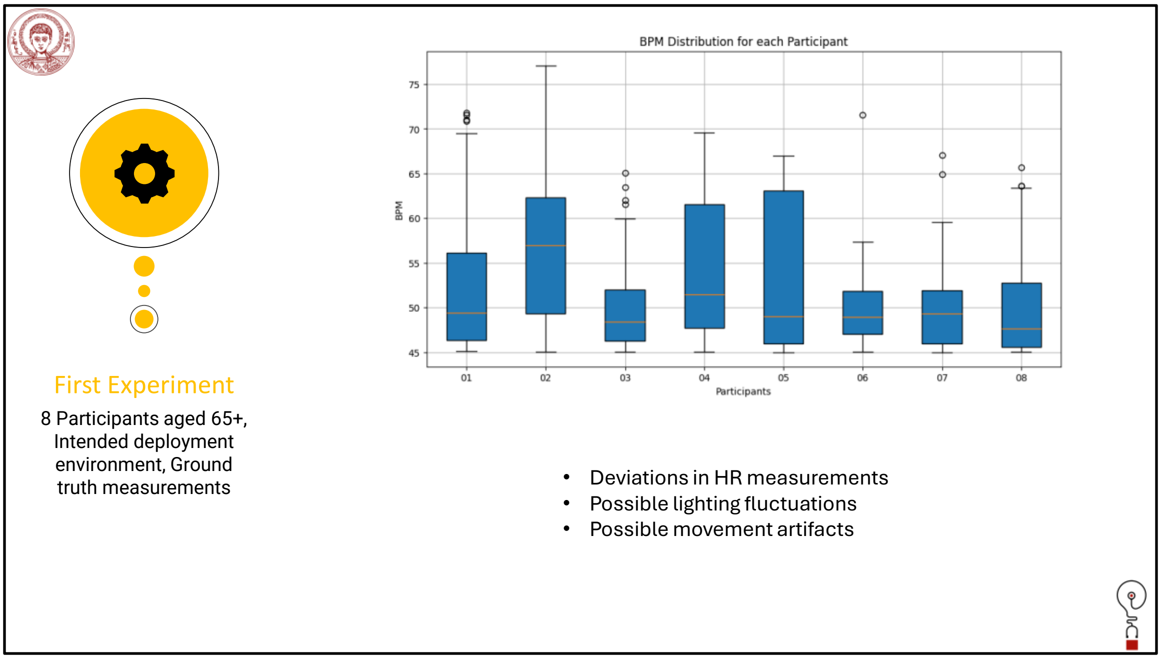

The system comprises of a Rpi microprocessor and an IMX219 RGB camera which acts as the main sensor, all encased inside a wooden frame to resemble a conventional household mirror furniture. A LED strip is also placed on the perimeter to provide external lighting when needed.




In the front, a display monitor serves as the user interface, delivering audiovisual prompts and feedback. A reflective surface is mounted over the monitor, allowing the device to function both as a standard mirror and an interactive health monitoring tool. The users are placed in front of the camera, ensuring their face is captured by the sensor's field of view and the system guides them through automated audiovisual prompts while assessing their heart rate. A heart rate estimation algorithm was implemented in python that is based on remote photoplethysmography, a non-contact technology that estimates heart rate by analyzing subtle color changes in a person's skin from video footage. After completion of the assessment, the results are displayed back to the user.



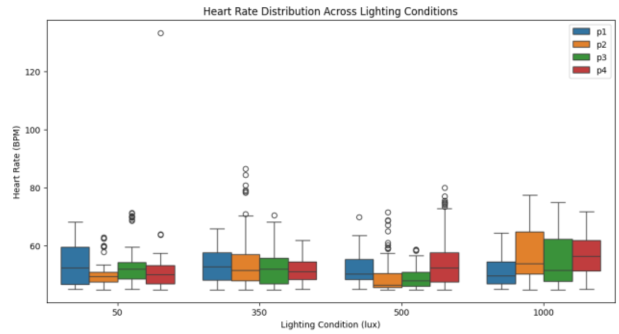

Digging deeper into the system and algorithm's process.. Faces are detected in the video stream using the Viola-Jones algorithm, and a region of interest is drawn around the face using OpenCV. For each frame, the mean RGB values within this region are extracted. To isolate physiological signals, principal component analysis is applied, which separates the RGB channels into three individual components. Based on current literature, the green channel contains the most feature-rich information related to cardiovascular activity, so it is separated and selected for further analysis. Subsequently, a Fast Fourier Transform is applied to convert the signal into the frequency domain and a bandpass filter is used between 0.75 and 4 Hz—corresponding to the range of actual heart rate values. Peak detection is performed on the filtered signal, and the dominant frequency is selected as HR estimation and is converted to beats per minute, or bpm. If the estimated heart rate falls within the normal range—between 60 and 100 bpm—it is displayed to the user. If the value is outside this range, the system responds accordingly. For example, if bradycardia is detected—below 60 bpm—the user is prompted to walk for 10 minutes and retry. If low heart rate persists, a warning is displayed. Similarly, if tachycardia is detected—above 100 bpm—the system instructs the user to sit and rest for 10 minutes before attempting another measurement. If the elevated rate continues, an additional warning is issued.




An initial validation experiment was designed to test the system on the intended population under the intended deployment environment. For this purpose, 8 participants were involved aged 65 or older and the experiment took place inside the A-HALL living lab of medical school. A conventional oximeter was employed to acquire ground truth measurements. Preliminary results from this experiment continued to show deviations in HR measurements.

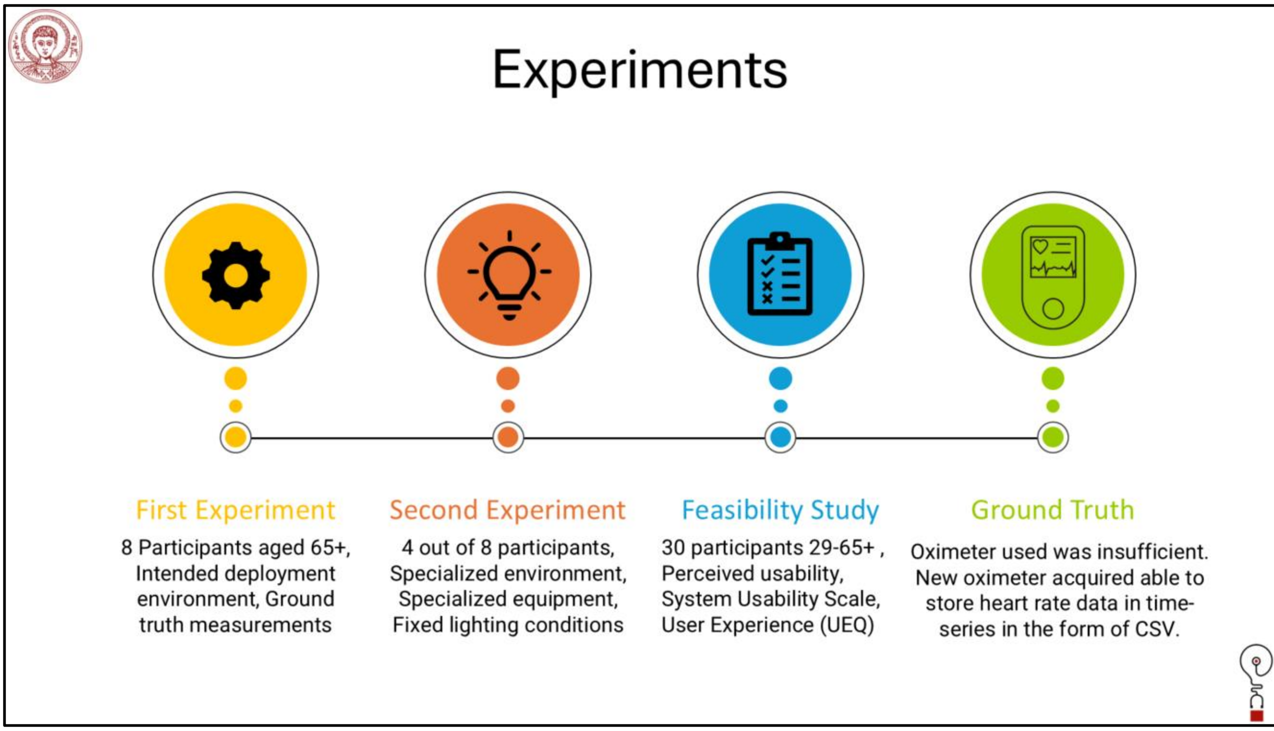
## Second Experiment

4 out of 8 participants,
Specialized environment,
Specialized equipment,
Fixed lighting conditions

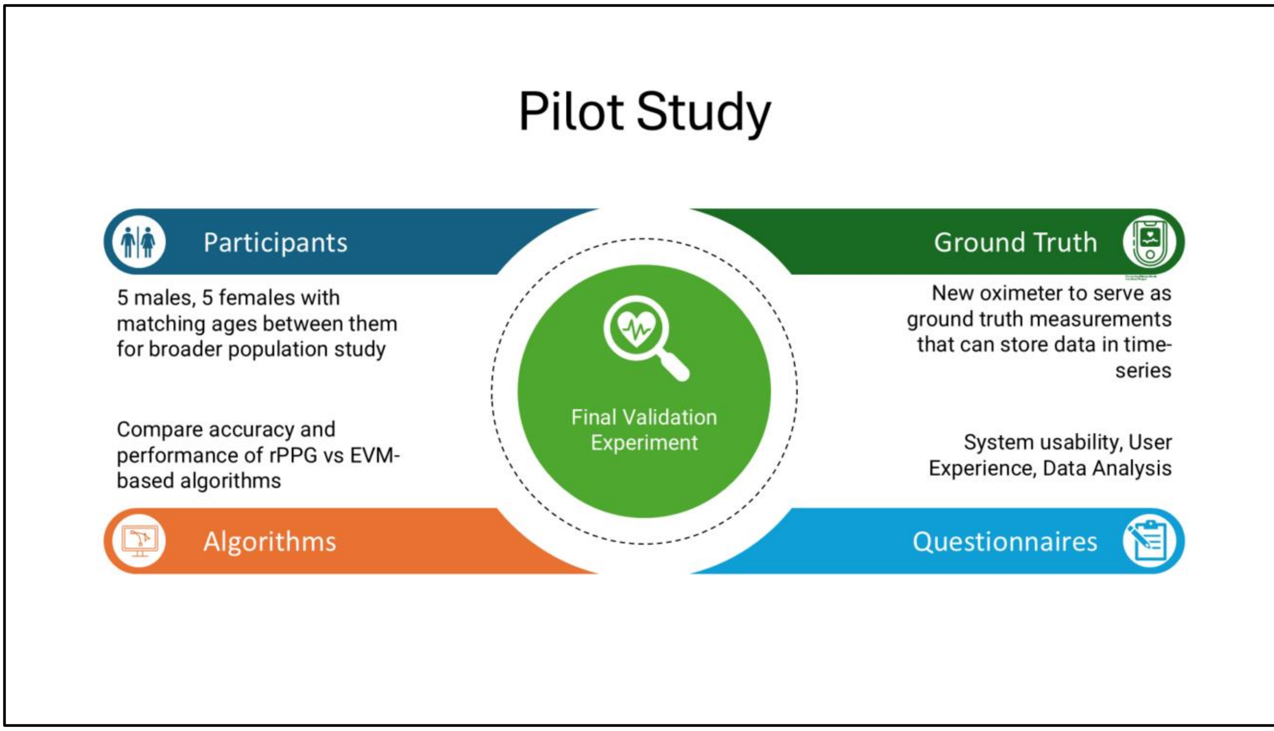



- 4 lighting conditions (50lx, 350lx, 500lx, 1000lx)
- Participant by color
- Deviations in HR measurements
- No correlation between light and error

This led to a second validation experiment under fixed lighting conditions in an attempt to quantify this introduced error. A photography studio with light isolation was used as well as specialized lighting equipment. Due to limited availability on the provided space and equipment, this experiment took place in short notice (a total of 5 hours) using 4 out of 8 participants used in the previous study. Data acquired from this experiment didn’t indicate any strong correlation between lighting and error.




Although the system was primarily designed for the elderly, it is also intended for use by the general population. To evaluate its broader applicability, a feasibility study was conducted alongside validation experiments, focusing on perceived usability, acceptability, and overall user experience. The study involved 30 participants ranging in age from 29 to 69, which also included the participant pool from previous experiments. For this purpose, standardized questionnaires were used including the System Usability Scale and User Experience Questionnaire. After reviewing the first two experiments and the feasibility study, a flaw was identified in the protocol: the current oximeter couldn’t provide time-synced data for a fair comparison. To address this, we acquired a more advanced oximeter capable of exporting time-series data in CSV form. In parallel, a second algorithm was implemented based on Eulerian Video Magnification—a video processing technique developed by MIT to enhance subtle color changes related to blood flow—in order to improve system performance.



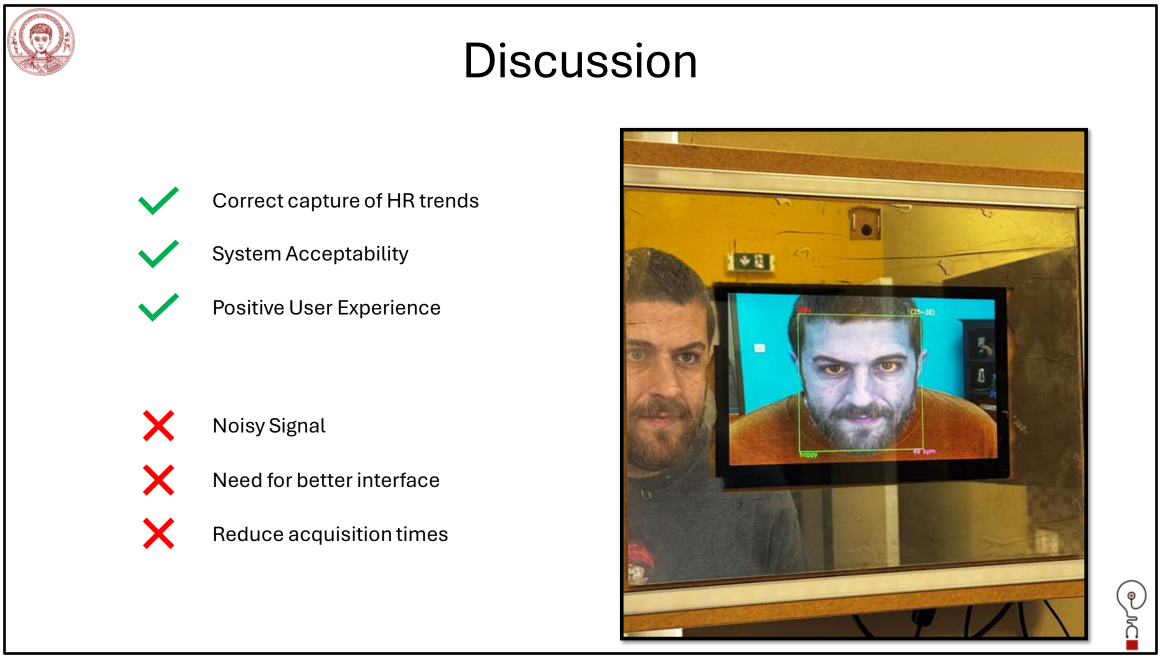

A third, final experiment was then conducted in a light-isolated room, at fixed lighting conditions involving 10 participants. The participants were assessed using both algorithms and each provided a total of 20 minutes of heart rate data. This time, synchronized oximeter data was captured each second for direct data comparison. The acquired data was scaled on oximeter's range and the performance was evaluated based on metrics identified in scientific studies that evaluated the performance of similar rPPG applications.

| Metrics | Definition | Analysis Metrics | rPPG | EVM | Comparison |
|---|---|---|---|---|---|
| Normalized Dynamic Time Warping (DTW) Distance | 0 = perfect<br>5 – 10 good<br>10 – 20 moderate<br>>20 weak | Median, IQR | 4.76, 3.97 to 6.51 | 6.43, 5.33 to 8.42 | U=25.00; p=0.059 |
| Spearman's Correlation Coefficient | +1 perfect<br>0.7 – 1 strong<br>0.4 – 0.7 moderate<br>0.1 – 0.4 weak<br>0 no correlation | Median, IQR | 0.72, 0.60 to 0.81 | 0.62, 0.60 to 0.69 | U=30.00; p=0.130 |
| Root Mean Square Error (RMSE) | 0 perfect<br>>0 increasing error | Median, IQR | 4.22, 4.05 to 6.01 | 5.65, 5.30 to 7.37 | U=22.00; p=0.034 |
| Signal to Noise Ratio (SNR) | ≥ 30 excellent<br>≥ 20 good<br>10 - 20 moderate<br>0 – 10 poor | Median, IQR | 18.32, 16.95 to 19.97 | 18.31, 14.77 to 19.09 | U=36.00; p=0.290 |

The metrics chosen are Dynamic Time Warping distance, Signal-to-noise-ratio (SNR), Root Mean Squared Error (RMSE), and Spearman's Correlation Coefficient. Dynamic Time Warping (DTW) is an algorithm that aligns two time-series to minimize the cumulative distance between their points. DTW distance represents the effort needed to align the two signals. The smaller the distance the better the alignment. Spearman's correlation coefficient measures how similarly two physiological signals change over time by comparing the rank order of their values. A value close to 1 shows perfect correlation while a value close to 0 shows no correlation. RMSE quantifies the average magnitude of error between two physiological signals by measuring the square root of the mean of their squared differences, making it sensitive to larger discrepancies and useful for evaluating overall signal accuracy. A typical accepted RMSE for physiological signals should be under 2. SNR quantifies how much stronger a signal is compared to background noise, with higher values indicating cleaner, more reliable signals. An SNR of 18.5 dB indicates a moderate-quality signal, meaning it's clearly distinguishable from noise, but still contains a noticeable level of interference; it's typically **acceptable** for non-critical physiological analysis, though **not ideal** for clinical-grade precision.


The evaluation of participant responses to the System Usability Scale (SUS) yielded an overall score of 87.5 out of 100, indicating strong positive feedback. The average SUS score places the system well within the range of acceptable and high usability.

Additional visualizations include a percentile plot comparing the system's performance to the online SUS benchmark database, which placed the system in the top 3%. The User Experience Questionnaire (UEQ) results suggest that the system delivers a generally positive user experience, particularly in terms of attractiveness and ease of use. Stimulation, Dependability and Efficiency received somewhat lower ratings, highlighting potential areas for enhancement in engagement and innovation. Oral feedback provided by the users focused on reducing acquisition times and developing a more interactive and engaging user interface.




In summary, despite challenges with variations in HR estimations and synchronization issues, the final experiment allowed for a more rigorous assessment of the platform. Both rPPG and EVM pipelines showed good promise in detecting HR trends, and user feedback was overwhelmingly positive. The most important limitations identified was the deviations in measurements due to noise in the signal, and based on feedback provided by the participants, the need for developing a more engaging user interface and reduce the acquisitioning times. The findings support further development of the platform, with a focus on reducing signal noise, improving system interface and exploring multi-parameter vital sign detection in future iterations.


Currently, we are working on age, gender and emotional state algorithms and explore ways of building a comprehensive dataset to enhance the classification models and algorithm performance. Further steps include exploration of additional modalities, such as extracting body temperature from video frames and estimating blood oxygen saturation, as well as equipment upgrades. This thesis presentation demonstrated the perceived usability and acceptability of the developed platform and gave insights to its potential for remote health monitoring in home environments. However, further research and development are required to enhance its accuracy and robustness, ensuring its suitability for medical applications.

# Publications

**“Empowering Ageing with Ingenuity: A Scoping Review on the Methods and Technologies Used into Elderly Health Monitoring.”**
Moraitopoulos A, Mpillis A, Bamidis P.

**“An Unobtrusive Health Monitoring System Using Reflective Display and Computer Vision Technologies to Assist Healthy Aging in Smart Health Environments”**
Moraitopoulos A, Mitsopoulos K, Athanasiou A, Mpillis A, Bamidis P.

**“Incorporating Computer Vision Technologies for Unobtrusive Elderly Care: A Concept for an Innovative Reflective Display System for Health Surveillance”**
Moraitopoulos A, Mitsopoulos K, Nizamis K, Bamidis P.

**“ENHANCING HOUSEHOLD OBJECTS INTO SMART HEALTH MONITORING DEVICES: AN UNOBTRUSIVE REMOTE HEALTH MONITORING SYSTEM TO ASSIST HEALTHY AGING”**
Moraitopoulos A, Pandria N, Mitsopoulos K, Bamidis P, Athanasiou A.

# References

**“The UN Decade of healthy ageing: strengthening measurement for monitoring health and wellbeing of older people.”**
Amuthavalli Thiyagarajan, Jotheeswaran, et al.

**“Monitoring physiological signals using nonintrusive sensors installed in daily life equipment.”**
Lim, Yong Gyu, et al.

**“Remote monitoring of vital signs in diverse non-clinical and clinical scenarios using computer vision systems: A review.”**
Khanam, Fatema-Tuz-Zohra, Ali Al-Naji, and Javaan Chahl.

**“Remote heart rate measurement using low-cost RGB face video: A technical literature review.”**
Rouast, Philipp V., et al.

**“Eulerian video magnification for revealing subtle changes in the world.”**
Wu, Hao-Yu, et al.