Final Presentation: Same-body Sensor Network Security

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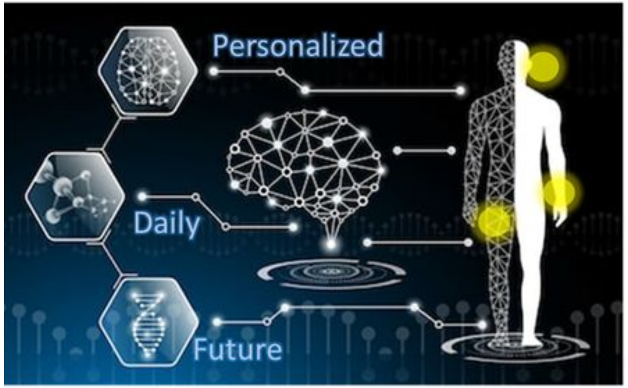
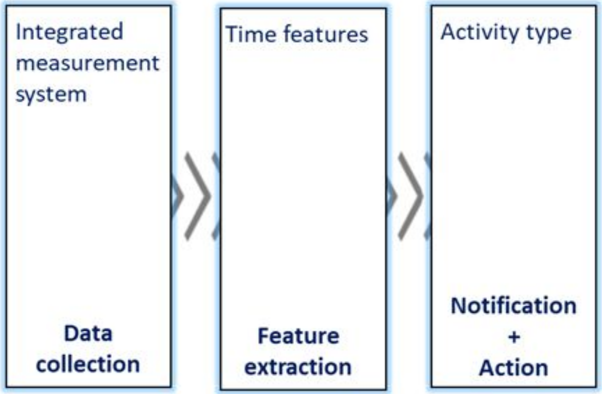
Overall Project Goals and Specific Aims

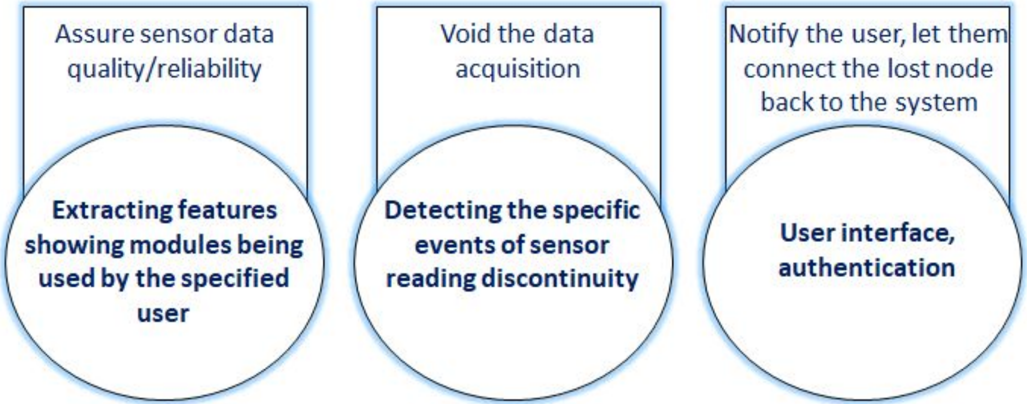
- The seamlessing pairings of off-the-shelf wearable sensors may lead to inaccurate sensor data collection and loss of devices due to the lack of user attentions.
- Our authentication system aims to secure and associate sensor readings of a user's body sensor network to that particular user.





Overall Project Goals and Specific Aims

- In addition, the system provides actionable feedback and on-board abnormality detection when verifying the integrity of a body sensor network.
- It notifies the user about the lost/stolen node in the body sensor network before that node loses its bluetooth connection.



Deliverables

- An Android app that authenticate and periodically verifies whether a three-device sensor network (phone, moto 360 watch, and eSense earable) is on the same body
- Data analysis plots of collected sensor data from some of these devices' accelerometers and gyroscopes
- Codes and scripts that authenticate phone and wearables, periodically check body sensor network integrity, record the sensor data, and analyze the correlations among the sensor data
- Video demo that illustrates the uses of our Android app in recognizing lost/stolen devices and notifying user to recover them.

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Threat Model

- A user pairs up and wears the two wearables (eSense and watch) to perform personal sensor data collection

- Collected data can be messed up and/or the wearables can be stolen by the following two scenarios:
  - User forget one of the wearables on an stationary object such as table
    - An adversary can then take away the wearable
  - The adversary directly grabs one of the wearables from the user
    - Can apply man-in-the-middle attack (MITM) to steal the device in stealth

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Technical Approach

- In this three-device body sensor network, we implement two same-body checking mechanisms.
  - Accelerometer and gyroscope correlation sensing for same-body checking between phone and eSense
  - Heart rate sensing for same-body checking between phone and watch

- We ensure proper device placements and pairings on a selected user before authenticate this person’s sensor data collection

- The phone app continuously checks for sensor signatures from this same user and terminates data acquisition upon any of the two mentioned scenarios is met (see next slide).

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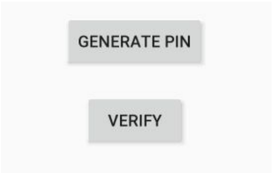
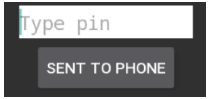
Implementation

- First Phase: Build initial authentication module that applies across the paired phone, eSense, and watch
  - User generates a pin on the phone (NO visual display)
  - The eSense speaks out the pin to user via text-to-speech
  - The user receives the pin from eSense
  - The user then types the pin on watch then send it to the phone
  - The phone enables sensor data collection upon confirming the received typed pin is the same as the one that generated earlier.
- This cyclic authentication through all devices ensures that the same person is using the sensor array





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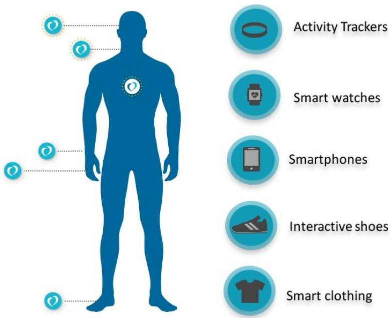
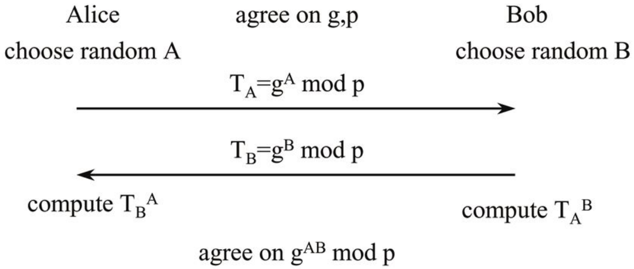
Implementation





- Second Phase: Digest literature Reviews of continuous validation/authentication based on shared context for designing our detection algorithm
  - Use time series to implicitly authenticate/communicate a secure channel[1,2]
  - Use anonymous key agreement like Diffie-Hellman[3] (not robust with attack models)
  - Reviewed methods introduced in body area network device-to-device authentication paper and continues pairing methods papers[4, 5]
  - We extract unique accelerometer, displacement, velocity, gyroscopic and heart rate data for more devices and ensure data is collected from the intended user by observing the contextual behaviours.
  - We introduce more details in the following slide

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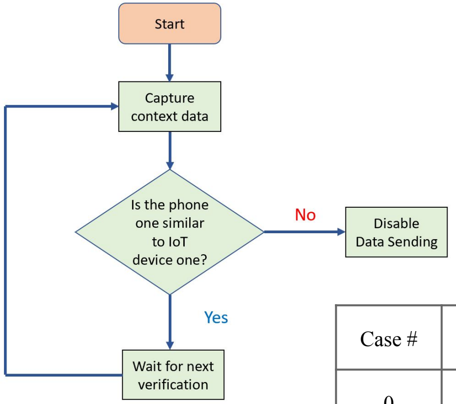
Implementation



- Third Phase: Add continuous verification module for eSense's and watch's same-body monitoring
    - Collect contextual modalities (accelerations, angular velocities, and heart rate) in time series from the two wearables
    - Extract signatures/features (*e.g.* peak values) from these modalities for same-body verification
    - Perform feature analysis by windowing the sensor data
    - Apply decision trees to check if a wearable is still on the same user's body via correlation across the features of these modalities
    - Based on the resulting decisions, disable data communication of a wearable if it is said to be detached from user's body

Case #	Action monitored
0	Sitting
1	Walking
2	Running
3	Put earable in from table
4	Take earphone out from ear
5	put earphone on table and get up
6	Earphone stolen and walk slowly
7	Earphone stolen thief running

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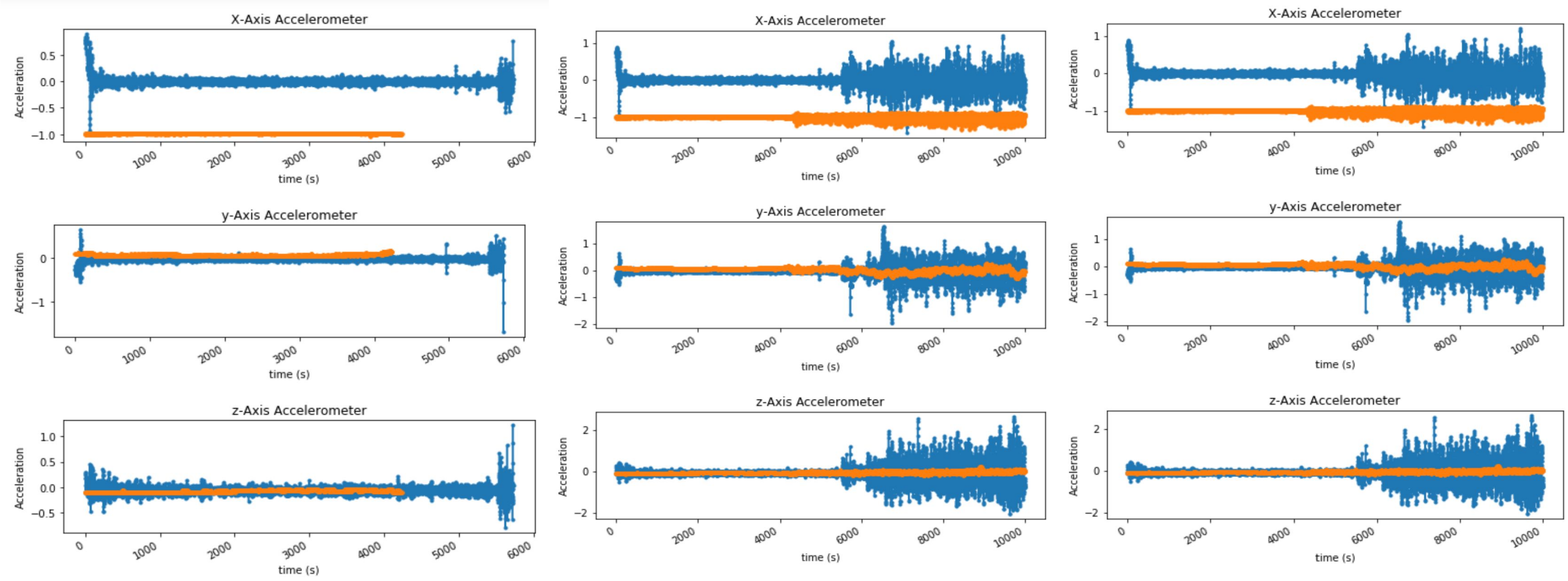
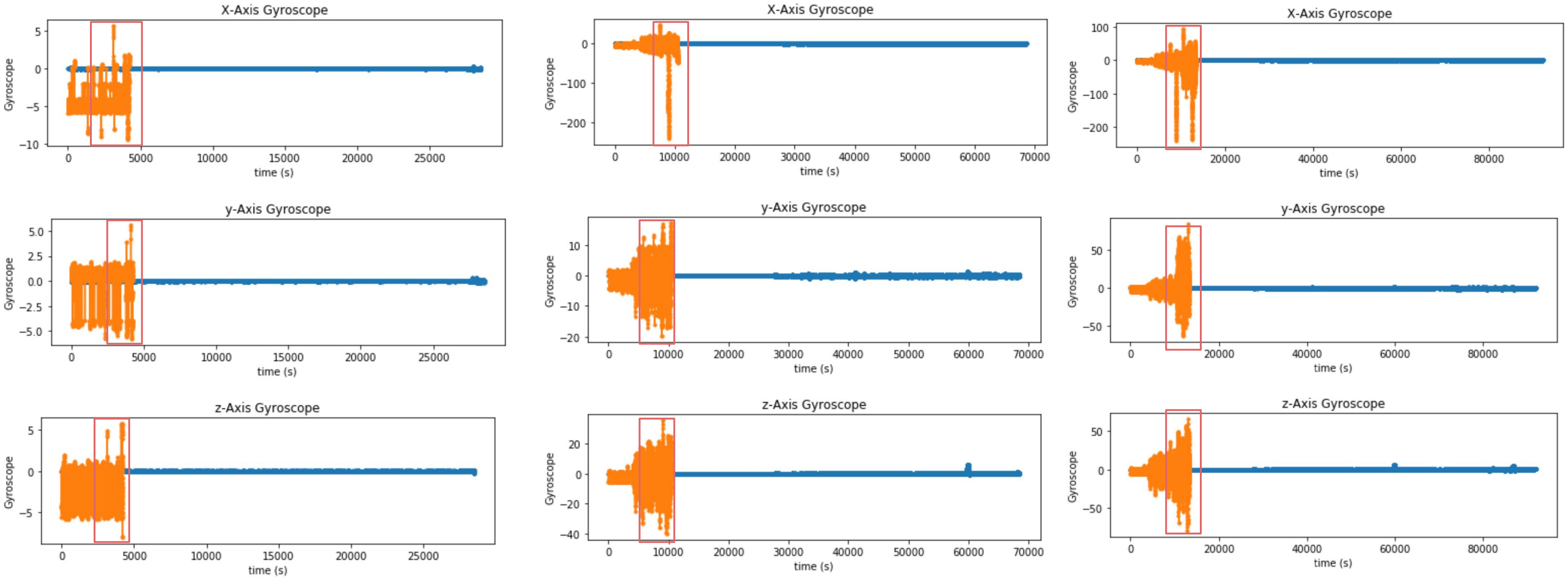
Experimental Results and Evaluations

- Acceleration: (more in depth analysis results on github)
- 3 cases (sitting, running, walking)



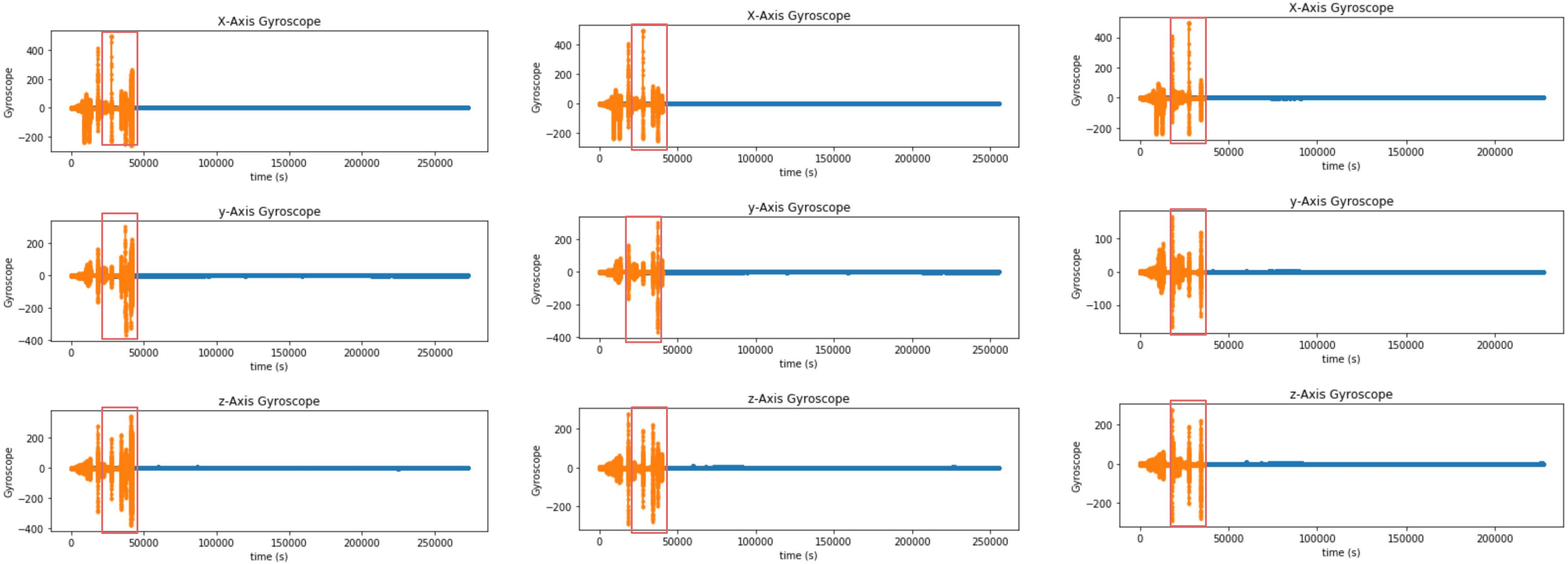
Experimental Results and Evaluations

- Gyroscope: (more in depth analysis results on github)
- 3 cases (sitting, running, walking)



Experimental Results and Evaluations

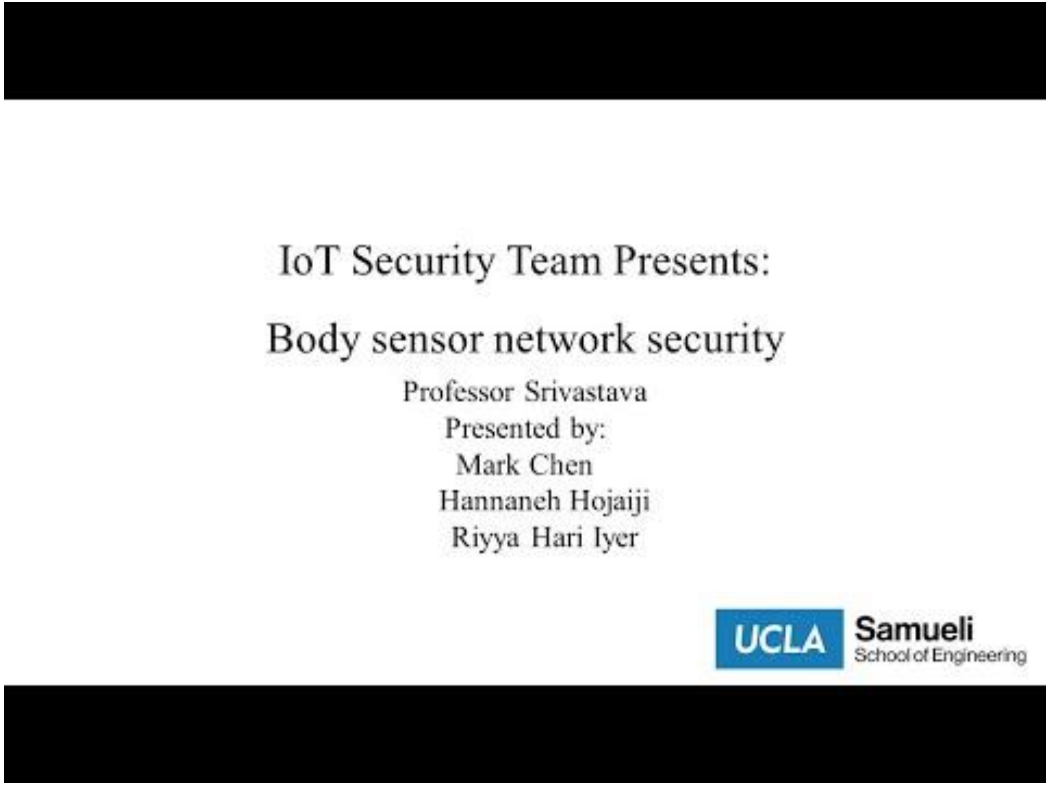
- Gyroscope :
- 3 cases (Adversary takes the device (running and with the same pace, the device is forgotten)



System Demo

- Please watch this brief demo on YouTube to see how critical parts of our platform work in action:

- https://youtu.be/Vbj39Gpa_f0



System Evaluation

- Key Findings:
  - Peak detection on collected sensor data gives good insights on user' actions/motions
  - Correlating multiple modalities (*i.e.* acceleration and angular velocities) provides better decisions on whether a wearable is detached from the user's body
  - Good control on sensors can be done through registering/unregistering sensor listeners inside the app

- Metrics of Success:
  - Properly collect wearables' sensor data through wireless transmission ✓
  - Implementation of decision trees based on sensor signatures to detect adversarial events ✓
  - Quick notification/toast to user about the detachment of a wearable ✓

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Prior work and our success

- There has been research in the domain of context sensing and ensuring that the devices are on the same person. WiFi-enabled authentication [5] is an example of the research work in this domain

- Shi, Liu and Chen's work talks about extracting Channel State Information (CSI) from the WiFi signals of IoT devices and use a deep learning based algorithm to identify individual users[6].

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Prior work and our success

- There have been some developments for continuous authentication and verification. F.Wang's[5] publication is one such paper discussing that.
- It talks about BodyPIN, a light-weight and robust technique that performs user authentication through computer execution and denies access when authentication fails
- Accelerometer data is a reliable sensor for extracting signatures for this purpose. Cornelius and Kotz's[7] research talks about the reliability and economical cost of accelerometer
- We built upon these methods choosing the best approaches utilizing the array of sensor signatures introduced. We also devised the initial authentication mechanism through random number generation

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Limitations

- Need to collect more data samples from more individuals to refine the decision trees.
- Wearable sensors' sensing accuracies affect the outcome of adversarial detection.
  - Accelerometer and gyroscope are okay, but heart rate sensor is not
  - Pedometer (step counting) ends up not working due to drifting in eSense.
- Must concatenate the sensor values collected from the watch in a package to synchronize better and more smoothly.
- Updates in Android packages and APIs cause unnecessary overheads when incorporating more sensors for adversarial detection
  - Frequent maintenance on the app's source code is required to ensure usability

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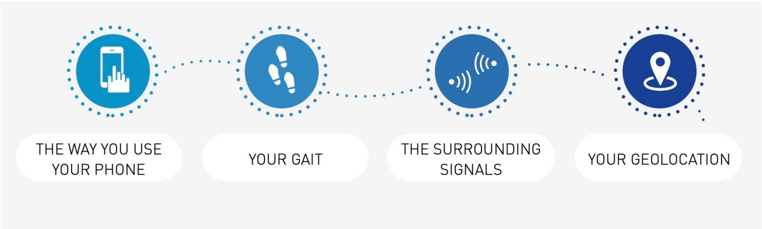
Future directions



- Train and use a machine learning algorithm/model that is resilient User-specific behavioural signatures.
- Add more sensor types and proper authentication/verification configurations to the system for enabling personalization on same-body sensor network.
- Search or develop more accurate sensing devices to improve the reliability of the system
- Apply this methods to healthcare platforms as was mentioned in Lin et al. paper[8].

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Contributions

- Mark:
  - Performed literature review
  - Performed data collection
  - Programmed Android application for sensor data collection from phone and earable
  - Programmed earphone data storage
  - Implemented sensor collection with the watch
  - Planned experiments
  - Debugged watch authentication interface and application connectivity
  - Integrated applications for the modules
  - Implemented Bluetooth connection and algorithm
  - Implemented the decision tree algorithm
  - Prepared final demo
  - Maintained and wrote github report
  - Developed and completed midterm and final reports

Contributions

- Hannaneh:
  - Performed literature review
  - Programmed Android application for sensor array data collection and plotting from phone
  - Programmed Android application for sensor array data collection and plotting from watch
  - Programmed data storage on the phone
  - Performed data collection
  - Developed data analysis algorithm in python
  - Devised and implemented the decision tree algorithm in the app
  - Implemented watch authentication interface
  - Planned out the experiments
  - Developed watch interface
  - Debugged the application package and API compatibility
  - Created and wrote github report and website
  - Took and made final demo
  - Developed and completed midterm and final reports

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Contributions

- Riyya:
  - Implemented text to speech conversion in the app
  - Implemented random number generator in the app
  - Created the initial authentication mechanism
  - Implemented earphone IMU data communication and storage
  - Helped with data storage of phone values in phone
  - Helped with accessing gyroscope values in phone
  - Reviewed data analysis in Python
  - Performed literature review
  - Helped with app integration
  - Helped with github repo
  - Prepared midterm and final report

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References and Resources

[1] Al Ameen, Moshaddique, Jingwei Liu, and Kyungsup Kwak. "Security and privacy issues in wireless sensor networks for healthcare applications." *Journal of medical systems* 36.1 (2012): 93-101.

[2] Stajano, Frank, et al., eds. *Security and Privacy in Ad-hoc and Sensor Networks: 4th European Workshop, ESAS 2007, Cambridge, UK, July 2-3, 2007, Proceedings*. Vol. 4572. Springer Science & Business Media, 2007.

[3] Huang, X., Wang, Q., Bangdao, C., Markham, A., Jäntti, R., & Roscoe, A. W. (2011, October). Body sensor network key distribution using human interactive channels. In Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (pp. 1-5).

[4] Schürmann, D., Brüsch, A., Sigg, S., & Wolf, L. (2017, March). BANDANA—Body area network device-to-device authentication using natural gAit. In *2017 IEEE International Conference on Pervasive Computing and Communications (PerCom)* (pp. 190-196). IEEE.

[5]Wang, F., Li, Z., & Han, J. (2019). Continuous user authentication by contactless wireless sensing. *IEEE Internet of Things Journal*, *6*(5), 8323-8331.

[6] Shi, C., Liu, J., Liu, H., & Chen, Y. (2017, July). Smart user authentication through actuation of daily activities leveraging WiFi-enabled IoT. In *Proceedings of the 18th ACM International Symposium on Mobile Ad Hoc Networking and Computing* (pp. 1-10).

[7] Cornelius, C. T., & Kotz, D. F. (2012). Recognizing whether sensors are on the same body. *Pervasive and Mobile Computing*, *8*(6), 822-836.

[8] Lin, S., *et al.* (2019). Natural Perspiration Sampling and in Situ Electrochemical Analysis with Hydrogel Micropatches for User-Identifiable and Wireless Chemo/Biosensing. *ACS sensors*.

Thank you for your time!

Report repository and website: https://hannahojaiji.github.io/HannaHojaiji209.github.io/