Developing AI Toolkits for the Remote Monitoring of Patients with PD, MS and Stroke - The ALAMEDA Project

Smart Diaspora 2023

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Alameda

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No GA101017558

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Project Motivation and Description

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Why and what is ALAMEDA?

ALAMEDA - Bridging the Early Diagnosis and Treatment Gaps of Brain Diseases

- **Digital transformation**: a challenging necessity →rapid ageing of population; affects demands placed on the health care system
- Growing incidence of life-altering brain disorders →**increased expenditure on health and long-term care**

- **ALAMEDA Vision:** research and prototype the next generation of personalized **AI healthcare support systems** for people with brain diseases, specifically focusing on the needs of **patients with Parkinson's, Multiple Sclerosis and Stroke (PMSS)**.

Why and what is ALAMEDA?

Research organisations

ICCS

UNIC | Artificial Intelligence Lab

NTNU

POLITECNICA

CERTH
CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

iti Information Technologies Institute

Healthcare organisations

SCLEROSI MULTIPLA fondazione italiana
un mondo libero dalla SM

HELLENIC REPUBLIC
National and Kapodistrian University of Athens
EST. 1837

SMEs and corporates

catalink

wellics.

Pluribus One
seeing one in many

EY

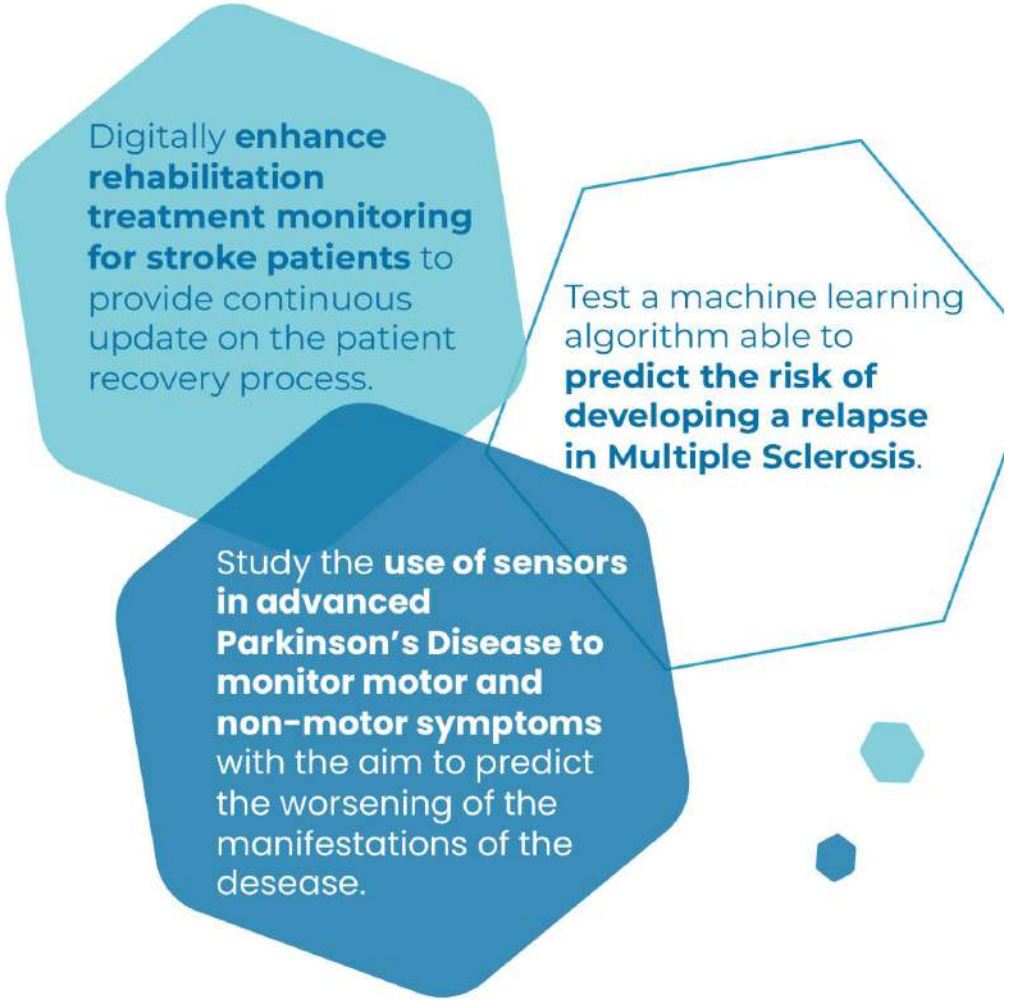
WISEANGLE

uni.systems

Why and what is ALAMEDA?

Use cases

ALAMEDA acknowledges that the care of patients with **brain disorders** is complex and manifestations of certain diseases could worsen over time and seriously impair the quality of life of patients and their caregivers: **regular rehabilitation treatment assessments are essential** to ensure that medical interventions are impactful and that the deterioration of state of health can be foreseen.



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Project Developments

This project has received funding from the European Union's Horizon 2020 research and
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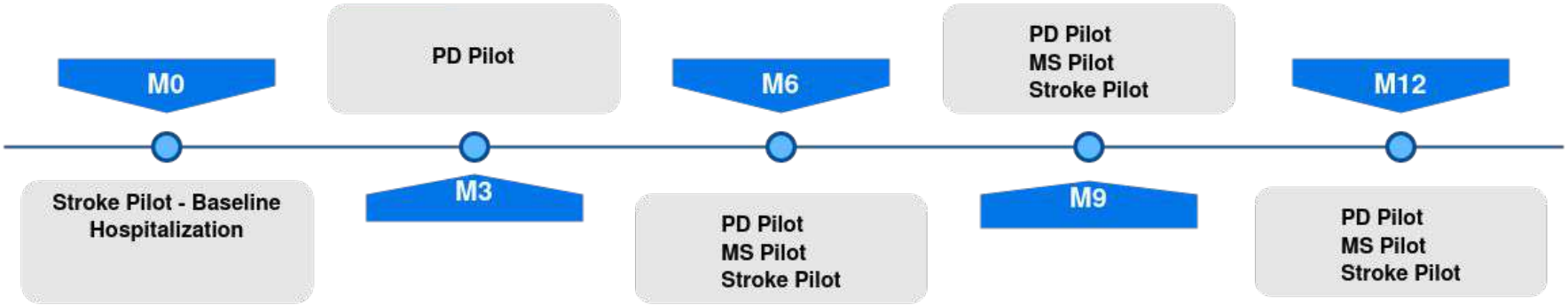
What we do in ALAMEDA - Patient Data Collection Journey

Continuous Monitoring

- Patient Reported Outcomes (PROs) - Questionnaires and Relevant Questions from 5 health domains:
  - (i) Mobility, general motor or physical function, (ii) Sleep, (iii) Mental and cognitive ability, (iv) Emotional status, (v) Quality of Life and Daily Living
- Fitbit Smart Watch - objectively monitored average activity and sleep metrics

Intense Monitoring
Wearables + Clinical Evaluation



What we do in ALAMEDA - Data Sources

The ALAMEDA technological ecosystem

Innovative data collection approach co-designed with patients, clinicians and caregivers

mHealth apps

The Digital Companion is ALAMEDA's application component that comprises of the **mobile applications** that the ALAMEDA patient users operate

WellMojo

The **WellMojo mobile application**, developed by **Wellics** and customised for the ALAMEDA brain diseases' use cases, **acts as a personal health coach, motivates, rewards** and **helps the users attain personal goals**.

Chatbot

The chatbot android application developed by **UNIC** will provide a user-friendly graphical interface for patients and caregivers **to interact with the ALAMEDA Conversational agent**. Our aim is to offer a conversational interface mimicking human communication to personalize the patients' journey.

Mood Estimation Android App

Catalink is developing **MEAA** responsible for monitoring the user while s/he is interacting with other ALAMEDA core modules. MEAA's goal is to analyze the **facial expressions of the users and assess their overall mood while they are conducting the related tasks**.

Virtual Keyboard

The software, developed by **CERTH**, **captures keystroke-related data** as well as typing metadata, i.e., **number of deletes, number of characters typed, typing session duration**, deliberate long-press events, and the application where the user typed, while the content of the typed text is not recorded.

Virtual Supermarket Test Application

The VST is an app designed by **CERTH** to assess older adults' cognition through a **simple task modeled** on an everyday activity. The latest version of the VST includes advanced navigation metrics with the virtual space divided into three zones that **represent different deviations.**

Line tracking test application

The LTT is an app designed to assess older adults' **hand dexterity**. Developed within the **NoTremor EU project**, the Line Tracking Test measures the **ability to follow a randomly moving target while ignoring the distracting target**.

Smart devices

Multi-source data related to **ALAMEDA** use cases is collected from devices such as Fitbit, sleep mattress, smart insoles, smart bracelet and smart belt

Smart bracelet

This wearable allows to **collect high-resolution raw acceleration data** which are fused with raw data obtained from other specialized sensors to provide inputs for **ALAMEDA algorithms**. It also offers a **variety of activity and sleep metrics** using publicly available and validated algorithms.

Sensorised insoles

Shoe pressure sensors are used to gather data that **help assess the kinetics characteristics** and **fluctuations of ALAMEDA patients.** They accurately measure the plantar force detected inside the shoe during all static and dynamic activities.

Smart watch/FitBit

A smartwatch that monitors daily activities, **heart rate data** and **possibly raw acceleration signals**. The scope of this research is to enhance the provided **sleep assessment by Fitbit.** ICCS focuses on: sleep stages classification (Hypnograms creation), estimation of sleep quality, monitor/assess the sleep properties along time.

Smart belt

The smart belt sensor, designed by **NTNU**, is a wearable device that is used to record patient motion activity during the day. **One belt is composed of three motion tracking sensors** mounted on a wearable belt for a patient's (user's) motion identification.

Smart mattress

A **prototype mattress topper**, that uses pressure sensors to model the patient's movement on the bed and produce heatmaps of the movement, has been developed by **ENORA** and distributed to the 3 pilots along with a commercial sleep analysis sensor.

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What we do in ALAMEDA - Predictive Analysis Toolkits

- Semantic Knowledge Graph for Patient Status Modeling
- Movement and Mobility Analysis Toolkit
- Sentiment Analysis Toolkit
- Sleep Monitoring and Assessment Toolkit
- Predictor Variables Time Series Classification

What we do in ALAMEDA - Semantic Knowledge Graph

- Model collected data at a **semantic level - ALAMEDA Ontology**
- Enables efficient **querying** and **alert definitions**

Variable	Description	Pilot Study	Alert Conditions
Domain I - Mobility, general motor or physical function			
Step count, periods of relative immobility/slowness of movement	Continuously monitored step count and other features of general mobility in daily life	PD, MS, Stroke	Reduction of week average $\geq$20%
Self-assessed questionnaire for muscle tone	Self-assessed questionnaire to quantify the muscle tone variable	Stroke	Increase of $\geq$1 point compared to previous month
ACTIVLIM questionaire	Self-assessed questionnaire to examine both upper and lower limb muscle strength using daily living activities	Stroke	When answer to a question changes from "easy" to "difficult" or "impossible", compared to previous month
Dizziness and Balance questionnaire	Self-assessed questionnaire for the balance variable	Stroke	When a patient checks a symptom that was not checked in the previous month
Domain II - Sleep disorders			
Pittsburgh Sleep Quality Index (PSQI)	Self-administered questionnaire to assess sleep patterns	PD, MS, Stroke	Change in answer to item 5, marking an increase in occurrence frequency compared to previous month
Domain III - Mental and cognitive ability			
Virtual Supermarket Test	Self administered test based on a 3D serious game to assess cognitive decline	PD	Deterioration of performance by $\geq$20% compared to test 3 months ago
Domain IV - Emotional status			
PHQ-9	monitor the severity of depression and response to the treatment	MS, Stroke	Score increase of $\geq$1 point compared to previous month
Domain V - Quality of life and daily living			
MFIS	Assessment of the effects of fatigue in terms of physical, cognitive and psychosocial functioning	PD, MS, Stroke	Score increase of $\geq$16 points or $\geq$19% compared to previous month

What we do in ALAMEDA - Semantic Knowledge Graph

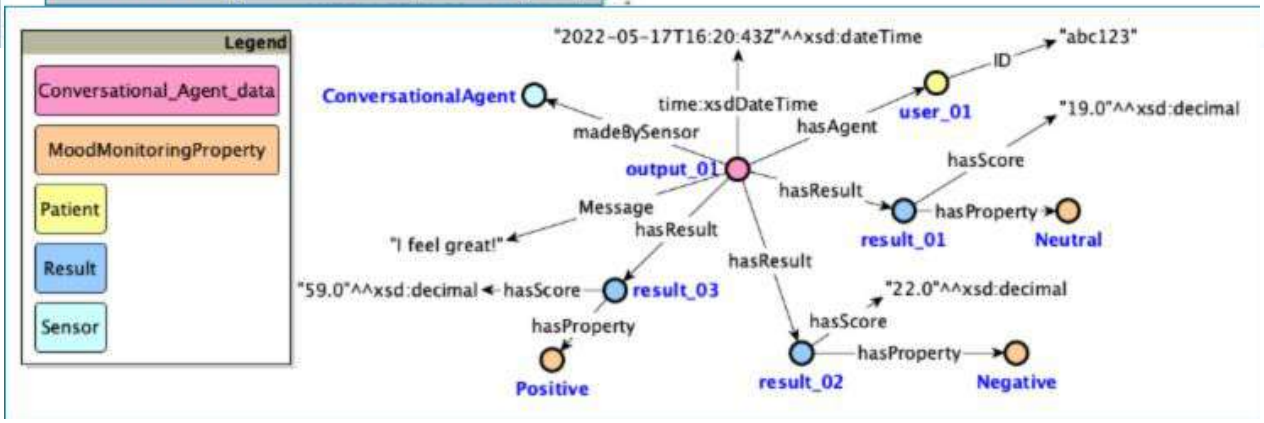
CA output (JSON)

```
{
  "user_id": "abc123",
  "source": "Conversational Agent",
  "observations": [
    {
      "sentiment_scores": [
        {
          "sentiment_class": "Positive",
          "sentiment_score": 87.0
        },
        {
          "sentiment_class": "Neutral",
          "sentiment_score": 2.0
        },
        {
          "sentiment_class": "Negative",
          "sentiment_score": 11.0
        }
      ],
      "timestamp": "2022-05-17T16:19:55Z",
      "explanation": "I feel great",
      "on_dashboard": "false"
    }
  ]
}
```

INSERT query (SPARQL)

```
INSERT DATA {
  :1ef7f22d-2337-4e5d-9f53-359d6f9714f0 rdf:type :Patient ;
          :ID "abc123"^^xsd:string .
  :373c2ee0-6c27-4d0b-91e1-7ed34211fa4e rdf:type :Conversational_Agent_data ;
          :madeBySensor :ConversationalAgent ;
          :hasAgent :1ef7f22d-2337-4e5d-9f53-359d6f9714f0 ;
          :Message "I feel great" ;
          time:xsdDateTime "2022-05-17T16:19:55Z"^^xsd:dateTime ;
          :on_dashboard "false"^^xsd:boolean .
  :373c2ee0-6c27-4d0b-91e1-7ed34211fa4e :hasResult :6836a00b-60bd-4501-b130-fca07bf76bac .
          :6836a00b-60bd-4501-b130-fca07bf76bac rdf:type :Result ;
                  :hasScore 87.0 ;
                  :hasProperty :Positive .
  :373c2ee0-6c27-4d0b-91e1-7ed34211fa4e :hasResult :31762ea5-ada0-47e1-aa41-b034ede75b3b .
          :31762ea5-ada0-47e1-aa41-b034ede75b3b rdf:type :Result ;
                  :hasScore 2.0 ;
                  :hasProperty :Neutral .
  :373c2ee0-6c27-4d0b-91e1-7ed34211fa4e :hasResult :262dc52b-af86-4dc4-b7bc-2b3b62e4fc33 .
          :262dc52b-af86-4dc4-b7bc-2b3b62e4fc33 rdf:type :Result ;
```

Semantic Representation (RDF triples)



What we do in ALAMEDA - Sentiment Analysis

- **Multimodal, multi-tool approach**
  - **On-device app**: Designed & implemented a simple mood estimation algorithm which **runs only locally, on the smartphone** →detect *positive, negative* and *neutral* mood

- **Emotion Recognition Service:**
  - Runs as a cloud-service and uses a custom ViT-based architecture
  - Fine-tuned for specific facial expression recognition per pilot study:
    - **PD**: Happy, sad, neutral, pain, surprise
    - **MS**: Happy, sad, fear, disgust
    - **Stroke**: happy, sad, neutral, pain

- **Text-based sentiment analysis service:**
  - Extract **mood of patient** based on free text interactions with the ALAMEDA Conversational Agent (classify utterances up to 150 tokens in length as *positive, negative* or *neutral*)

What we do in ALAMEDA - Movement and Mobility Analysis

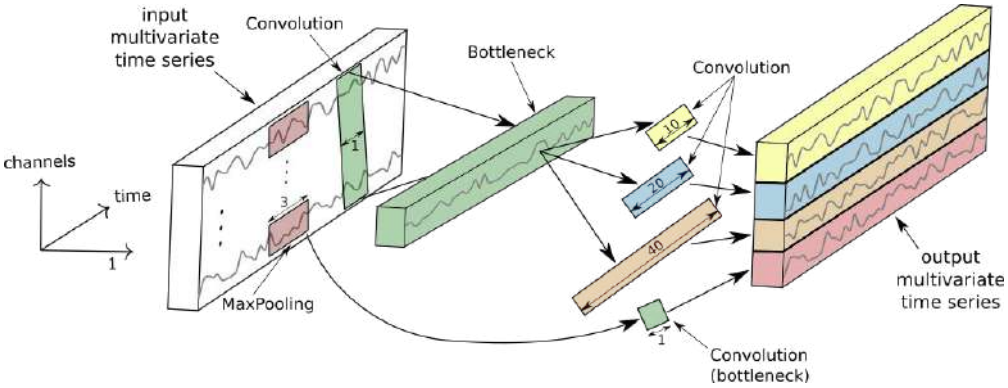
"Umbrella" term for services that use raw data from wearables (bracelet, IMU belt, insoles) to detect

Current Work	Partner
Detect simple ADLs (walk, sit, stand, walk up/downstairs)	NTNU
Detect tremor/dyskinesia/bradykinesia in PD - Current experiments on Levodopa Response Study dataset, EMA Dataset, mPower Dataset	ICCS, NTNU
Detect freezing of gait in PD - Current experiments on Gait in PD dataset	CERTH, NTNU
Detect execution of Stroke Rehabilitation Exercises based on accelerometer bracelet - Current experiments based on SPARS9X dataset for shoulder exercises	UPB

What we do in ALAMEDA - Movement and Mobility Analysis - Freezing of Gait in PD

- 1D-conv models based on custom *InceptionTime [1]* modules and Squeeze and Excitation Blocks

Daphnet Dataset	Sensitivity	Specificity	F1 Score
InSEption	91.2%	94.1%	0.862
LN-Inception	85%	98.4%	0.856
CNN-LSTM	33.8%	97.1%	0.363
LSTM	71.3%	97.0%	0.727
Bi-RNN	83.6%	98.1%	0.842
CNN	25.6%	99.4%	0.285

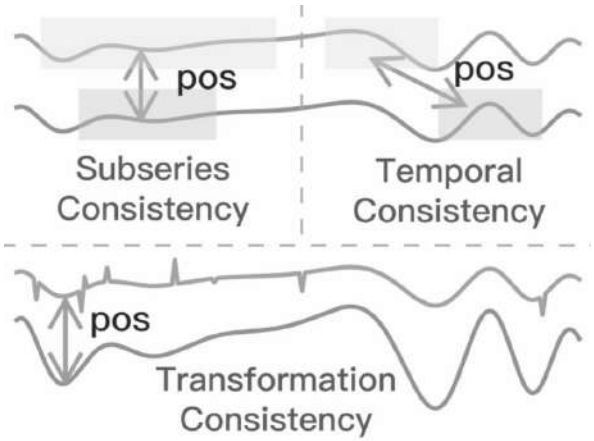


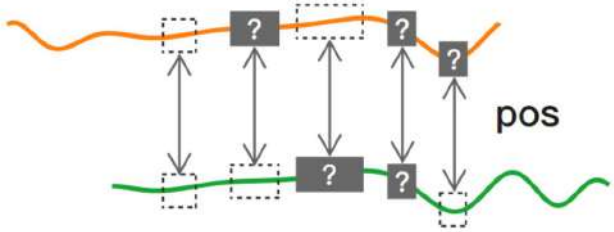
[1] Fawaz et al, 2019: InceptionTime: Finding AlexNet for Time Series Classification

IMU Dataset	Sensitivity	Specificity	Macro F1 Score
InSEption	98%	99%	0.972
LN-Inception	97%	99%	0.962

What we do in ALAMEDA - Movement and Mobility Analysis
- Timeseries representation Learning

- **Time series representation learning using contrastive learning techniques** → TS2Vec Model [1]
- Uses **contextual consistency:** representations at the same timestamp in two augmented contexts are positive pairs
- **Context** is generated by applying timestamp masking and random cropping on the input time series.
- Timestamp masking randomly masks the timestamps of an instance, and random cropping randomly samples two overlapping time segments.





[1] Yue, Z. et al. Ts2vec: Towards universal representation of time series. AAAI 2022

What we do in ALAMEDA - Movement and Mobility Analysis - Timeseries representation Learning

- **Experimentation pipeline**
  - Use raw / filtered signal vs. pre-processed ENMO values
  - Use learned representations for **“anomaly” detection:**
    - Normal vs abnormal gait **(insoles)**
    - Daily Activities vs Rehabilitation Exercise sessions (accelerometer bracelets)
  - Study *generalization capability* of representations
    - How many samples from an activity or a specific exercise are required to discriminate between activity / exercise classes
    - What is the degree of **inter-subject** generalizability
      - Experiment with adversarial methods to discriminate the user who generated a time series

What we do in ALAMEDA - Sleep Monitoring and Assessment

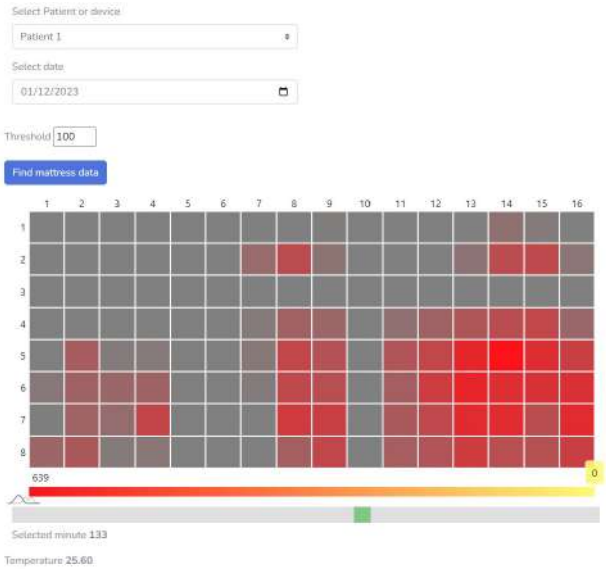
Current Work	Partner
Detect Sleep Stages (light, deep, REM, awake) based on Wearable data from Smart Watch and Withings Sleep Mattress - Experiments performed on Apple Watch[1], MESA[2] and SHHS2[3] datasets	ICCS
Sleep Quality Assessment - Prototype 8x16 pressure sensor mattress topper to record body posture during sleep - correlate with heart rate, wake up events, duration of sleep stages	ENORA

[1] Olivia Walch, Yitong Huang, Daniel Forger, Cathy Goldstein, Sleep stage prediction with raw acceleration and photoplethysmography heart rate data derived from a consumer wearable device, Sleep, Volume 42, Issue 12, December 2019, zsz180.

[2] Chen X, Wang R, Zee P, Lutsey PL, Javaheri S, Alcántara C, Jackson CL, Williams MA, Redline S. Racial/Ethnic Differences in Sleep Disturbances: The Multi-Ethnic Study of Atherosclerosis (MESA). Sleep. 2015 Jun 1;38(6):877-88. doi: 10.5665/sleep.4732. PMID: 25409106; PMCID: PMC4434554.

[3] Quan SF, Howard BV, Iber C, Kiley JP, Nieto FJ, O'Connor GT, Rapoport DM, Redline S, Robbins J, Samet JM, Wahl PW. The Sleep Heart Health Study: design, rationale, and methods. Sleep. 1997 Dec;20(12):1077-85. PMID: 9493915.

What we do in ALAMEDA - Sleep Monitoring and Assessment



Sleep Assessment using ENORA mattress topper

- Raw data acquired every 1 minute
- Posture results: Type, duration and rate of change of posture
- 13k readings so far

- End goal: define a *sleep quality* score and relate it to PD MDS-UPDRS scores

What we do in ALAMEDA - Variable Time Series Classification Service

"Umbrella" term for models that connect **all sources** to the **current** or **future patient health status,** expressed in terms of:

- **MDS-UPDRS** (for PD), **EDSS** (for MS), **mRC** (for Stroke)

Current Work	Partner
Wrapper service for model invocation	UPB
Estimate PD MDS-UPDRS scores from activity data - Current experiments on PPMI, LRRK2 and Fox Insight Datasets	CERTH
Estimate MS EDSS scores from PRO data - Current experiments on MSOAC and Performance of ADL in PwMS datasets	CERTH
Estimate MS EDSS scores from long term PRO data - Starting experiments with PROMOPRO-MS dataset	UPB, ICCS

ALAMEDA - Project Sustainability

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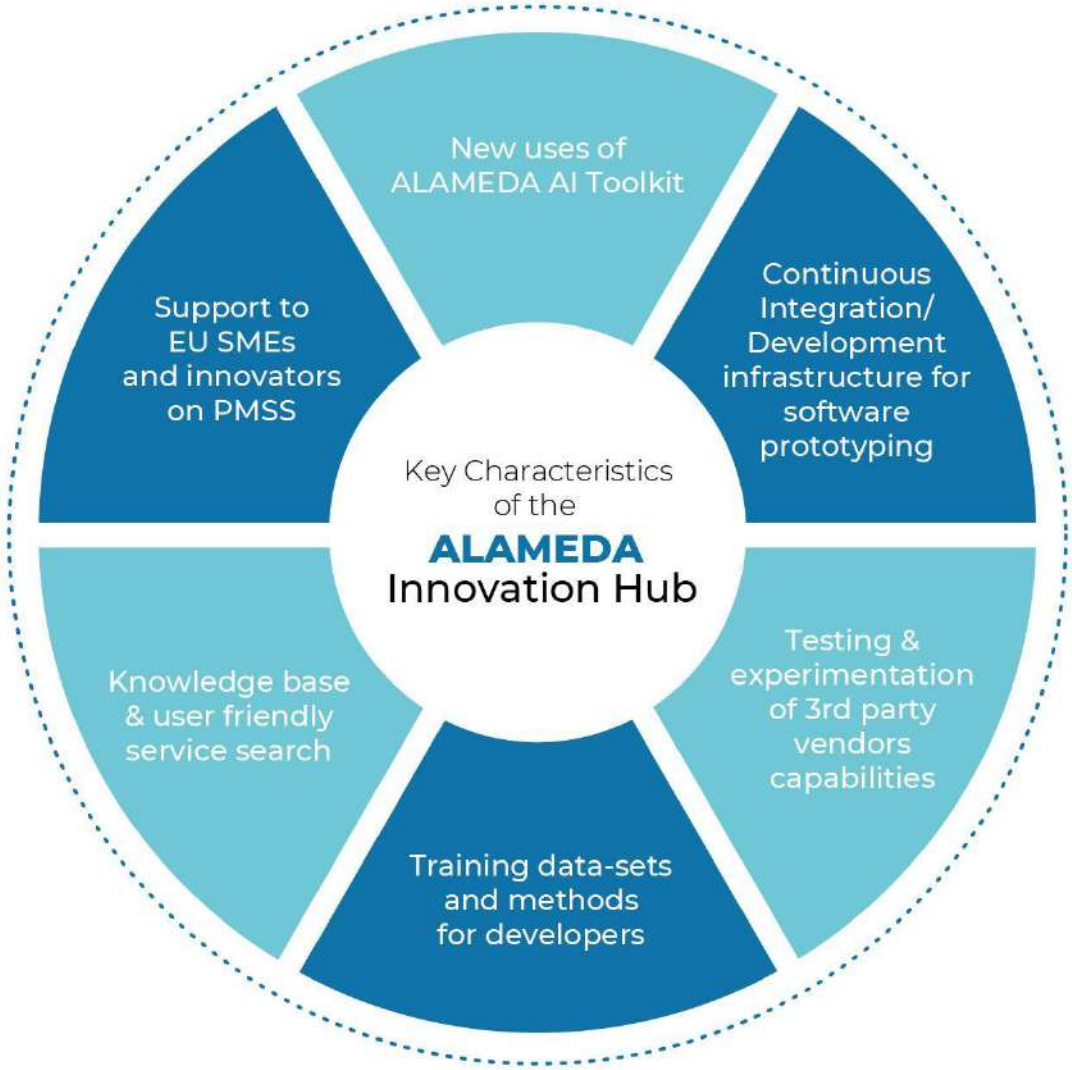
ALAMEDA - What Happens After



THANK YOU!