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Privacy-Aware and Acceptable Video-Based Technologies and Services for Active and Assisted Living

ESR12. AI for Dementia Care

2nd Doctoral Seminar

Stockholm, Sweden

20.04.2023

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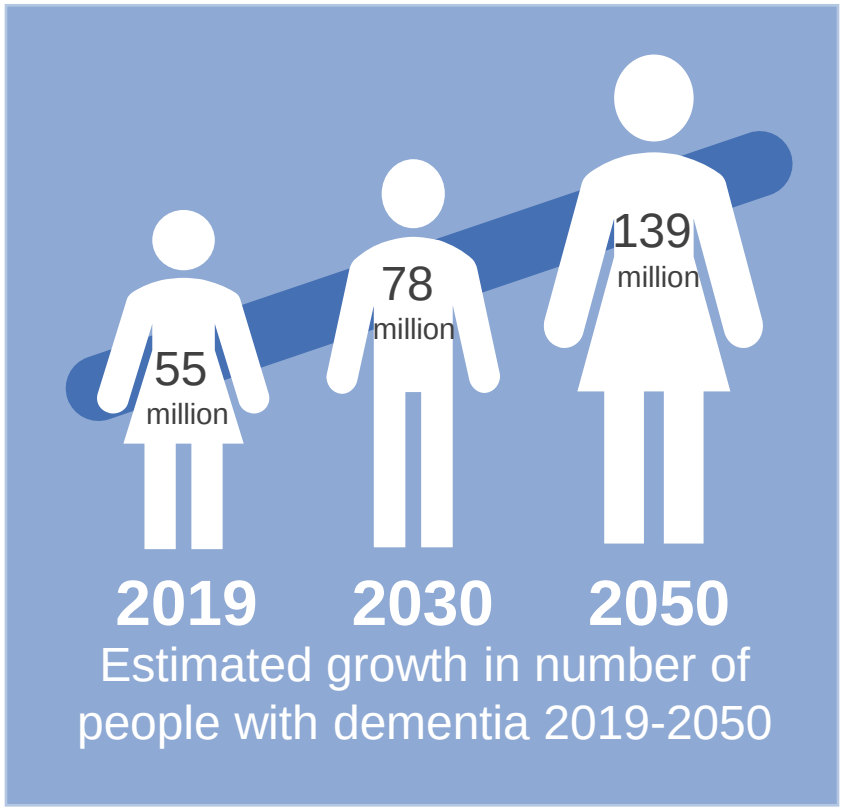
What's dementia?

- Syndrome in which there is a **deterioration in cognitive functioning beyond what might be expected from normal ageing** [1]

Why dementia?

- Behavioural changes **strongly correlated** with the degree of functional and cognitive impairment [2].
  Behavioral and Psychological Symptoms of Dementia (BPSD): agitation, aberrant motor behaviour, anxiety, irritability, depression, apathy, delusions, changes in sleep or appetite [2].
- One of the **major causes of dependency** among older people [3]



Data source: WHO [1]

[1] World Health Organization https://www.who.int/news-room/fact-sheets/detail/dementia (accessed April 25, 2022)
[2] Joaquim Cerejeira, Luısa Lagarto, and Elizabeta Blagoja Mukaetova-Ladinska. "Behavioral and psychological symptoms of dementia". In: *Frontiers in neurology 3 (2012)*, p. 73.
[3] **Global status report on the public health response to dementia**. World Health Organization (2021)

AI for behaviour analysis from unobtrusive sensor data

Goal: Development of AI methods for **measuring** the **behaviours** of care home residents with **dementia** using **unobtrusive sensors (depth maps)**

In order to:

1. Detect and **measure behavioural changes** indicative of dementia (BPSD) in the mid and long term *(weeks, months, years*)

2. Provide **assistance with ADLs** for people with dementia in the short term *(seconds, minutes)*

Thesis Overview: Research Questions

RQ1. How and what behaviours can be measured

RQ2. AI methods and data

RQ3. Measuring behaviour changes in the long term

RQ4. Providing assistance with ADLs in the short term

BPSDs taxonomy and measurement methods

BPSDs change detector

ToiletHelp

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ToiletHelp

Goal

Step-by-step guidance for people with mild dementia in the toilet using a depth camera

RQ4. Providing assistance with ADLs in the short term

1. How can the model be designed to **capture** the toilet procedure in such a way that it is possible to detect deviations indicative of the need for assistance?
2. How **interaction** with the user must be designed to be **effective** for people with dementia?
3. How can the effectiveness of the interaction be **measured** for the target group?

What was done until the last Doctoral Seminar in Aachen?

1. **Focus groups** with health professionals: *How the system should communicate with people with dementia?*

2. Prototype developed with hand-washing and acknowledgement module

3. Validation in the lab: functional testing
   - 98.5% avg. accuracy in action recognition
   - Interaction: 100% in fixed scenarios, 8/10 correct in open scenarios

4. New visualizations and audio

2 publications:

"**RITA: A privacy-aware toileting assistance designed for people with dementia**" by Irene Ballester, Tamar Mujirishvili and Martin Kampel, In *Proceedings of the 15th EAI International Conference on Pervasive Computing Technologies for Healthcare,* 2021

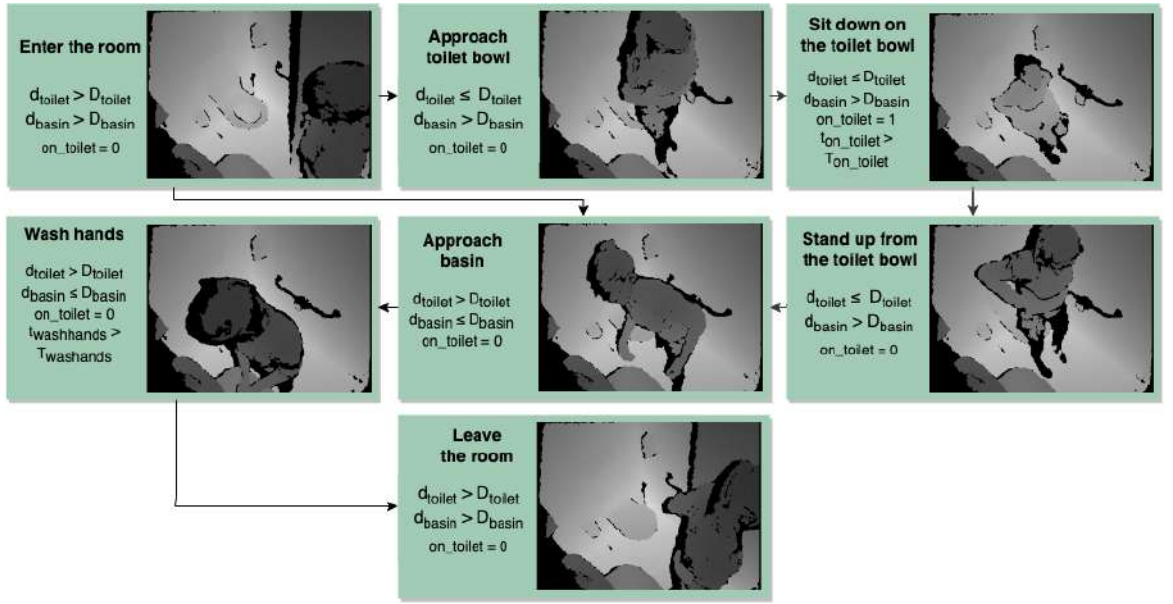
"**Automated vision-based toilet assistance for people with dementia**" by Irene Ballester and Martin Kampel, AHFE 2022 - *13th International Conference on Applied Human Factors and Ergonomics,* July 24-28, 2022, New York, USA

+ collaboration in the DIANA project

What has been done since then until now?

Further improvement of the prototype and evaluation of the system with **real data:**

1. Evaluation of the toilet **action recognition module** on 50 sequences with 20 people with dementia
2. Validation of the **interaction module** involving 30 older adults and 14 care staff members



All this work to be re-submitted:
Ballester I., Gall M. Brandstötter B., Kampel M. “ToiletHelp: an assistive technology to guide people with dementia in the toilet”, *ACM Journal on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT)*

Deadline: 15 May

Evaluation of the toilet action recognition module

Methodology

Action is detected correctly if:
H1 < fID_detected – fID_gt< H2

Results

Toilet Module evaluated against **human annotators** for action recognition with **20 people with dementia** and **50 sequences**, with 182 actions:

- Hospital group accuracy: **85%**
- Day center accuracy: **70%**
- **Overall accuracy: 81%**

Dataset	% of successfully recognized actions									
	Next to the toilet bowl		*Sat down on the toilet bowl*		*Stood up from the toilet bowl*		*Next to the basin*		**Total**	
	N actions	Acc.	N actions	Acc.	N actions	Acc	N actions	Acc.	N actions	Acc.
S1 (N=1)	6	33%	10	90%	10	90%	7	71%	33	**76%**
S2 (N=1)	10	70%	10	100%	10	90%	10	100%	40	**90%**
S3 (N=1)	10	100%	10	80%	10	100%	6	100%	36	**94%**
Hospital (N=3)	26	**73%**	30	**90%**	30	**93%**	23	**92%**	109	**87%**
Day center (N=17)	17	**59%**	19	**95%**	19	**68%**	18	**56%**	73	**70%**
All (N=20)	43	**67%**	49	**92%**	49	**84%**	41	**76%**	182	**80%**

Evaluation of the interaction module

Methodology

Install the prototype in a semi-public toilet and ask caregivers and older adults about their opinion via questionnaires

Conclusions

End-users (30 older adults,17 in DC1 and 13 in DC2)

- Increased **feeling of safety and independency** and not feeling feel afraid nor annoyed
- **Participants with dementia** affirm they **understand the instructions**
- Changes in rating as the user uses the system more times

Caregivers (14 professionals, 4 in DC1 and 10 in DC2)

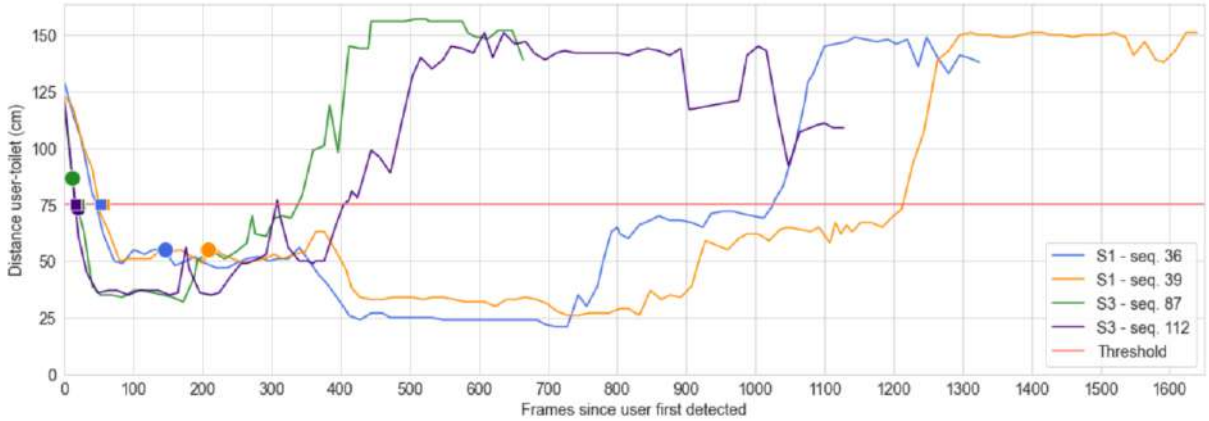
- Positive rating in terms of being **useful for end-users and reducing caregivers' workload**
- Positive **validation of the interaction modalities**

Poster accepted at: Ballester I., Gall M., Kampel M. "Design of a Toileting Assistive System for People with Dementia", WISH Symposium at the ACM CHI Conference on Human Factors in Computing Systems, April 2023

What's next?

- Rewrite IMWUT paper: add F1-score, improve clarity of explanations
- (Draft of) **next steps**
  1. **Improved action recognition module**
     - Enhancing the recognition accuracy of the actions "next to the toilet" and "next to the basin" by computing **orientation** towards the object of interest
     - Enabling **learning** to adapt to **individual rhythms**
  2. **Interaction effectiveness evaluation**

  Measure how effective the interaction is
- **Next paper**: CHI 2024 (Submission deadline: September 2023). IMWUT/UbiComp 2024? (Submission deadline: November 2023).



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BPSDs taxonomy and measurement methods

RQ3. Measuring behaviour changes in the long term

BPSDs change detector

RQ4. Providing assistance with ADLs in the short term

ToiletHelp

RQ1. How and what behaviours can be measured

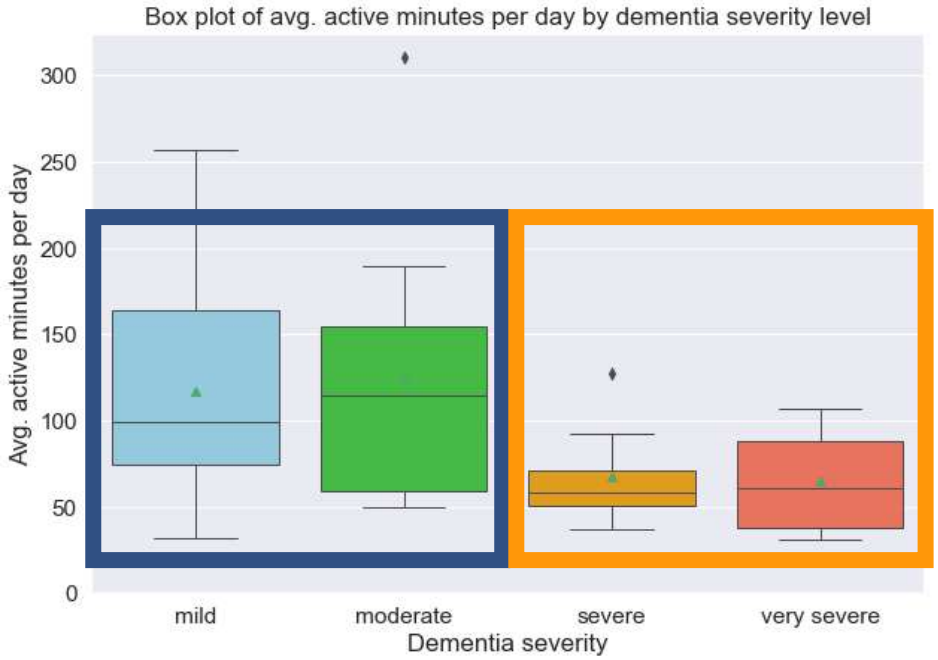
1. **Which BPSDs** can be measured from data collected continuously by unobtrusive sensors?
2. Which **metrics** (e.g., frequency, intensity and duration) can be used to quantify each of those behaviours?

RQ2. AI methods and data

1. Which **AI methods** are the most suited to model the different behaviours?
2. What **type of data** is best suited for modelling each behaviour?
3. How can AI methods for behaviour measuring be designed to allow **inter-resident variabilities** to be taken into account in the model to be able to generalize to other subjects?

What has been done?

Preliminary analysis



Literature research and draft of potential BPSDs

BSPDs	Metrics
Twisted day-night rhythm • Sundowning phenomenon • Daytime sleepiness • Sleep restlessness Decreased general activity level Increase in incident falling frequency Eloping attempts Wandering (?) …	Active time while being in the room • During day time • During night time Walking speed Time in the room • During day time • During night time Time on bed Number of falls Time sitting, laying, standing …

and mainly…. struggling with **DATA COLLECTION**

What's next? (I)

1. Ethical approval. Expected: May 2023
2. **Start of data collection in a care facility in Austria.** Planned: May 2023
   - 10 participants already accepted (with and without dementia)
   - Depth maps in single rooms, cognitive status (MMSE), medical and care documentation
3. **Measuring BPSD using depth maps.** (In collaboration with PD Dr. med. Thomas Münzer)
   Goal: Research whether BPSD can be measured to detect dementia in care facility residents
   - Develop pre-processing methods for false detections, lost tracking, > 1 person in the room
   - Develop taxonomy: behaviours (such as gait speed [4]) + metrics + measuring methods
   - Define and perform statistical analysis (cofounding factors [4], Poincaré Plot [5])

   Paper target deadline: Early-Mid 2024. e.g., Journal of Biomedical and Health Informatics, The Lancet Digital Health, Journals of Gerontology

[4] Liu, Y., Zhang, G., Tarolli, C. G., Hristov, R., Jensen-Roberts, S., Waddell, E. M., ... & Katabi, D. (2022). Monitoring gait at home with radio waves in Parkinson's disease: A marker of severity, progression, and medication response. *Science Translational Medicine*, *14*(663), eadc9669.
[5] Urwyler, P., Stucki, R., Rampa, L., Müri, R., Mosimann, U. P., & Nef, T. (2017). Cognitive impairment categorized in community-dwelling older adults with and without dementia using in-home sensors that recognise activities of daily living. *Scientific reports*, *7*(1), 1-9.

What's next? (II)

4. Video Anomaly Detection for Risky Behaviour of People with Dementia

Method: Apply and develop OCC [6,7] or/and unsupervised [8] autoencoders and/or GAN approaches

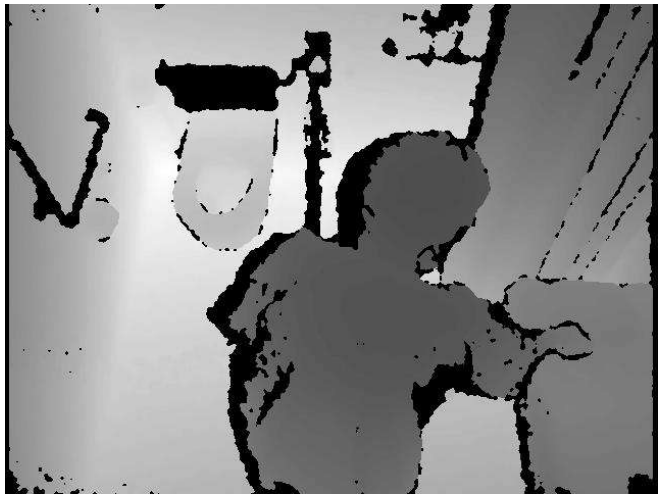
1. Behaviours of People with Dementia in the Toilet

- Challenge: large unlabelled data of people in the toilet
- Potential solution: use ToiletHelp to label normal sequences

2. Behaviours of Residents in their room *(TBD)*

- Abnormal behaviours "labelled" from care documentation

Paper target deadline: End 2023. ECCV2024? ICIP 2024?



[6] Schneider, P., Rambach, J., Mirbach, B., & Stricker, D. (2022). Unsupervised anomaly detection from time-of-flight depth images. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition* (pp. 231-240).

[7] Mishra, P. K., Iaboni, A., Ye, B., Newman, K., Mihailidis, A., & Khan, S. S. (2023). Privacy-protecting behaviours of risk detection in people with dementia using videos. *BioMedical Engineering OnLine*, *22*(1), 1-17.

[8] Zaheer, M. Z., Mahmood, A., Khan, M. H., Segu, M., Yu, F., & Lee, S. I. (2022). Generative cooperative learning for unsupervised video anomaly detection. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition* (pp. 14744-14754).

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BPSDs change detector

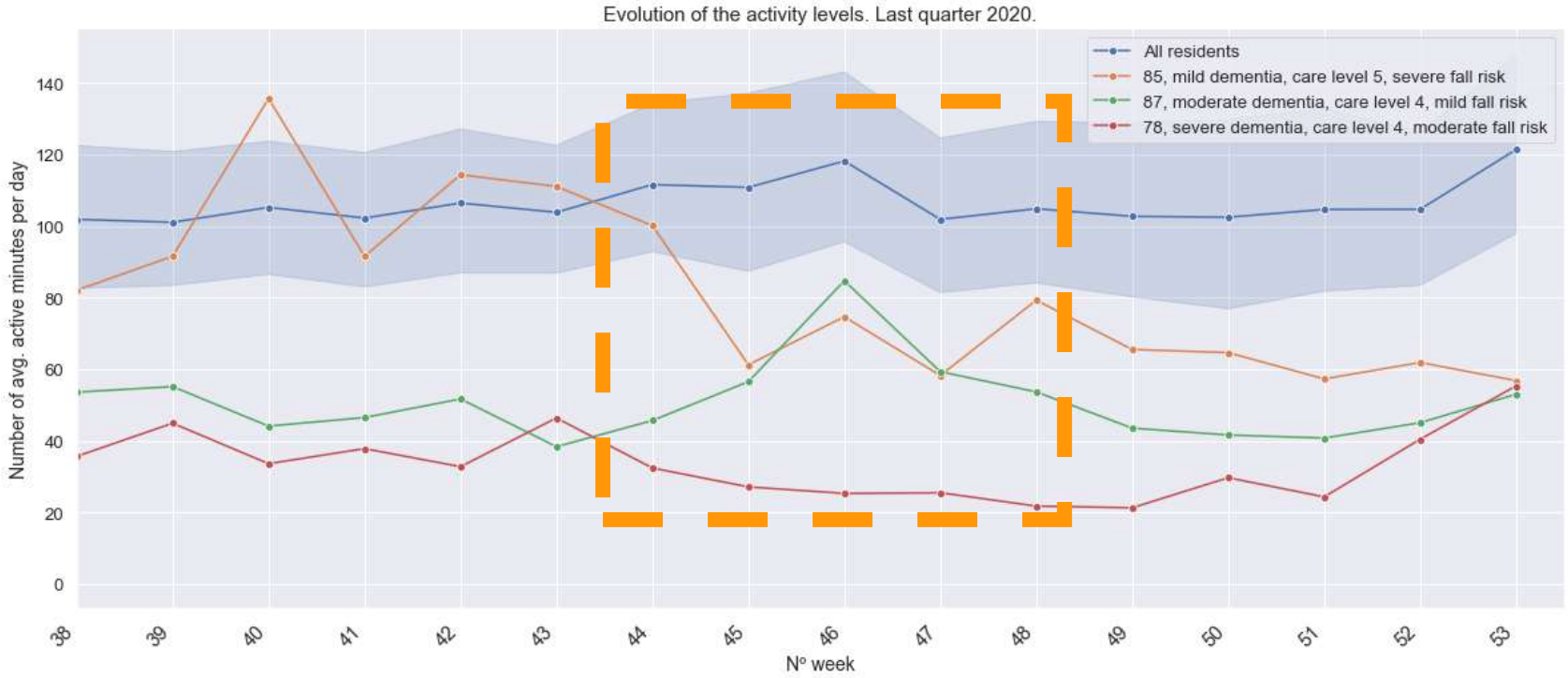
RQ4. Providing assistance with ADLs in the short term

ToiletHelp

BPSDs change detector

Goal

Detect and measure behavioural changes indicative of dementia in the mid and long term

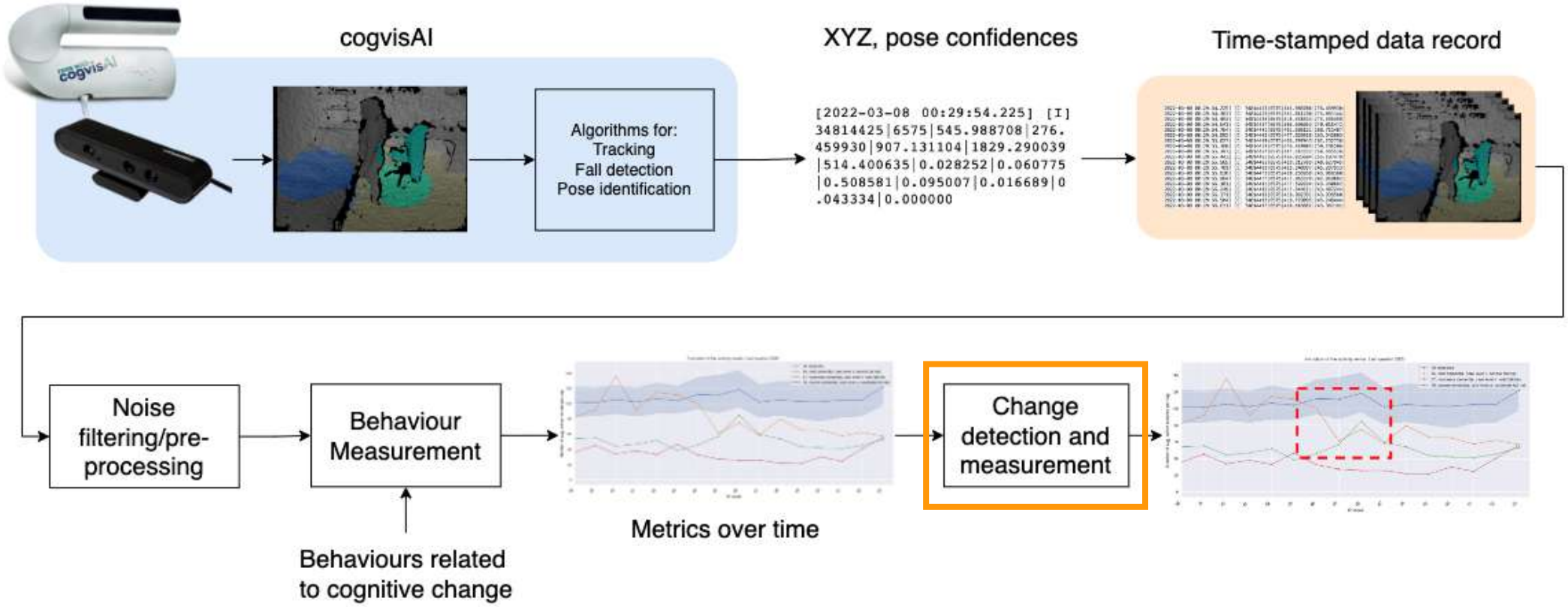


RQ3. Measuring behaviour changes in the long term

1. How can **changes** in behaviours be identified and measured?
2. How are **time horizons** defined for the detection of behavioural changes in the context of dementia through data collected by unobtrusive sensors?
    1. **How long** does an individual have to be observed for their statistically "**normal" behaviour** (routine) to be modelled?
    2. How long does a **trend have to be consistent over time** to be considered a change in behaviour statistically?
    3. How can the model be designed to account for **variability** that depends, for example, on the day of the week or the year's season?

BPSDs change detector

How?



BPSDs change detector

How?

- **Anomaly detection for time series data**

  Anomaly if (prediction – reality) > **ε**

- **Forecasting methods using RNNs (LSTM), Transformers**

Evaluation

Compare changes detected with changes in MMSE or events recorded in the care documentation

Paper target deadline: Summer 2024. ICML

2025? PerCom 2025?

LSTM Autoencoder

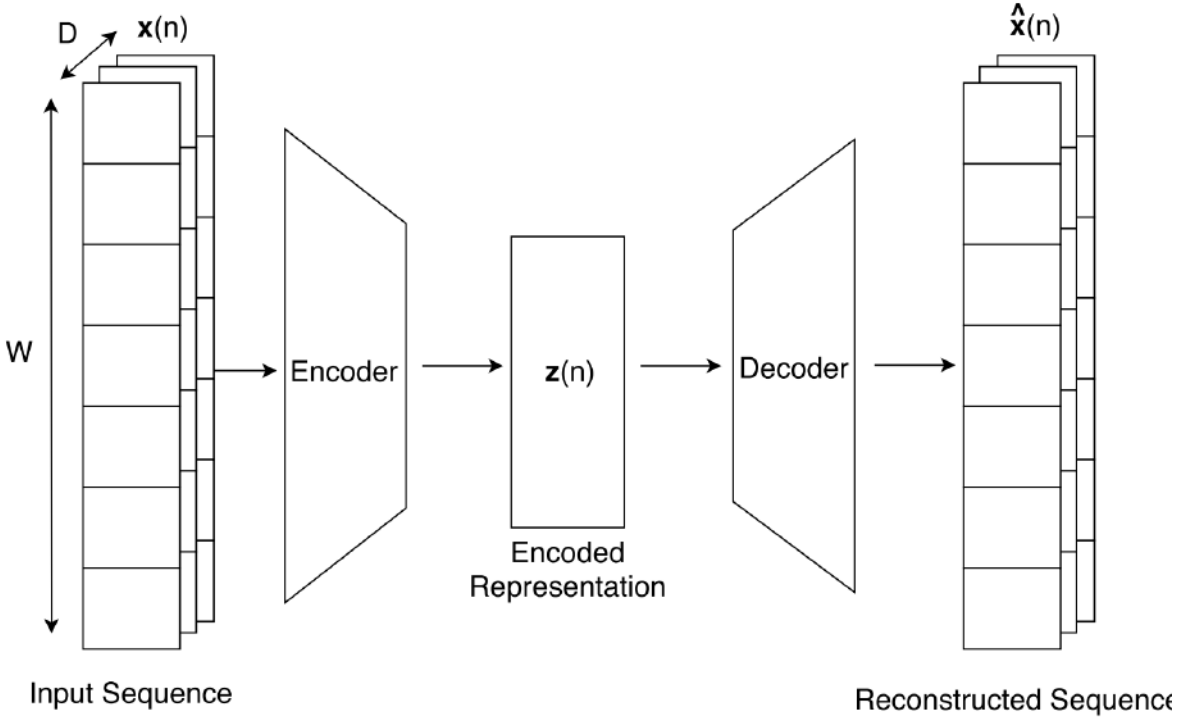


Figure extracted from Trinh, H. D., Zeydan, E., Giupponi, L., & Dini, P. (2019). Detecting mobile traffic anomalies through physical control channel fingerprinting: A deep semi-supervised approach. *IEEE Access*, *7*, 152187-152201.

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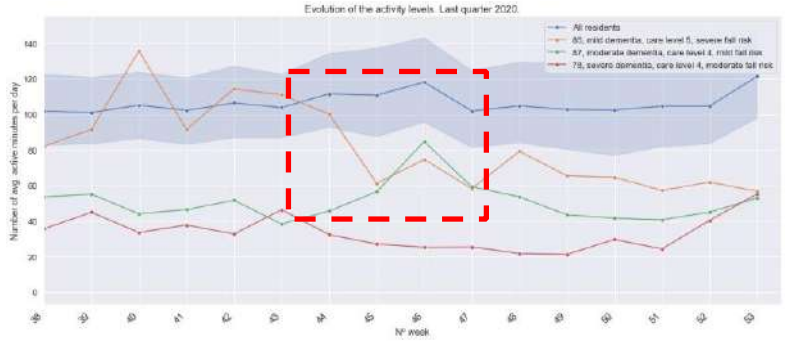
Thesis contribution

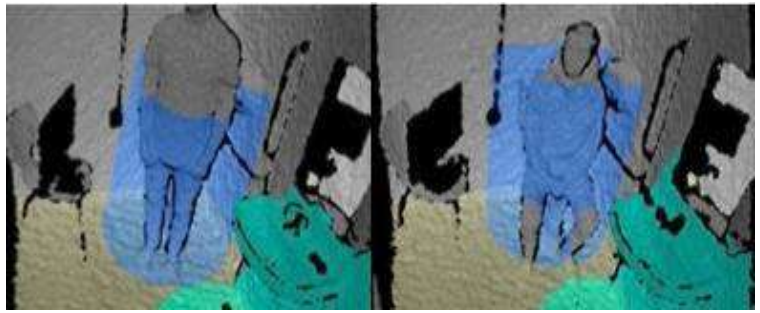
1. **Taxonomy of BPSDs** and **methods** to measure them via unobtrusive monitoring.

Behaviours related to cognitive impairment	Metrics
Twisted day-night rhythm • Sundowning phenomenon • Daytime sleepiness • Sleep restlessness Decreased general activity level Increase in incident falling frequency Eloping attempts Wandering (?) …	Active time while being in the room • During day time • During night time Walking speed Time in the room • During day time • During night time Time on bed Number of falls Time sitting, laying, standing ….

2. **Method** for the identification and **measurement of dementia-related behavioural changes.**



3. **Assistive system** to support people with dementia in using the toilet.



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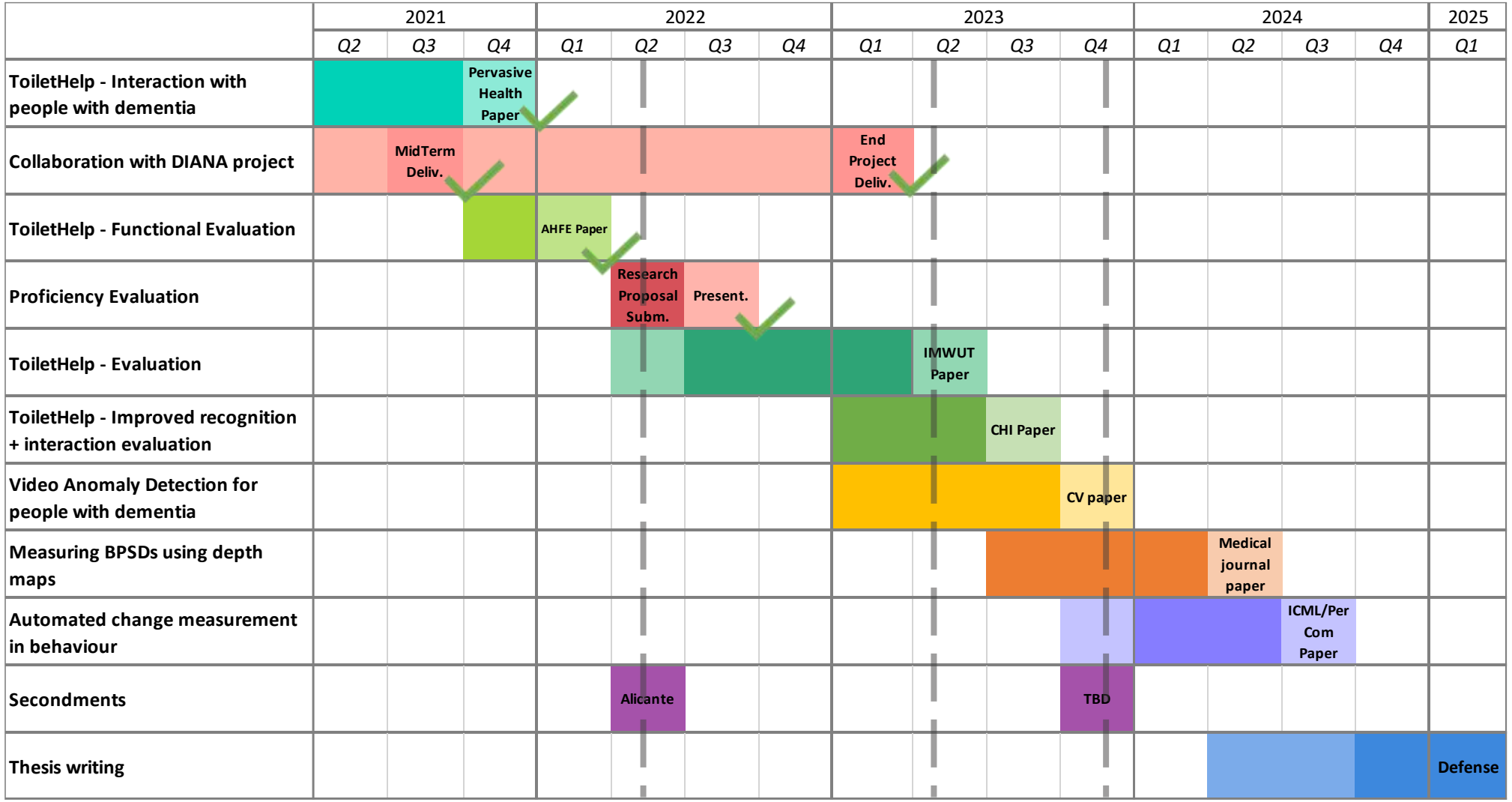
Estimated timeline



Thank you!

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ViBRANT

ViBRANT - Workshop on Video-Based Respectful Assistive Novel Technologies

Part of EICS 2023, the 15th ACM SIGCHI Symposium on Engineering Interactive Computing Systems at Computational Foundry, Swansea, Wales, UK - June 27–30, 2023

Important Dates

Submission deadline: **29.05.2023**

Notification of acceptance: 09.06.2023

Planned workshop day: **27.06.2023** (half-day)

Call for Papers

1. **(Out-of-proceedings) research highlights and work-in-progress** (2-page extended abstract)
2. **Archival original work (**published by Springer LNCS)

- video-based technology for health monitoring
- fair and privacy-aware systems
- integration of engineering issues in the design process of video-based AAL
- legal requirements and privacy issues for data collection and processing in care
- user acceptance criteria for video-based AAL
- GDPR requirements for video-based AAL solutions
- best practices of interdisciplinary collaborations between legal, technical, social, health sciences

visuAAL **+ info:** wiktor.mucha@tuwien.at.ac and https://www.visuaal-itn.eu/events (coming soon**)**

Evaluation of the toilet action recognition module

Actions evaluated

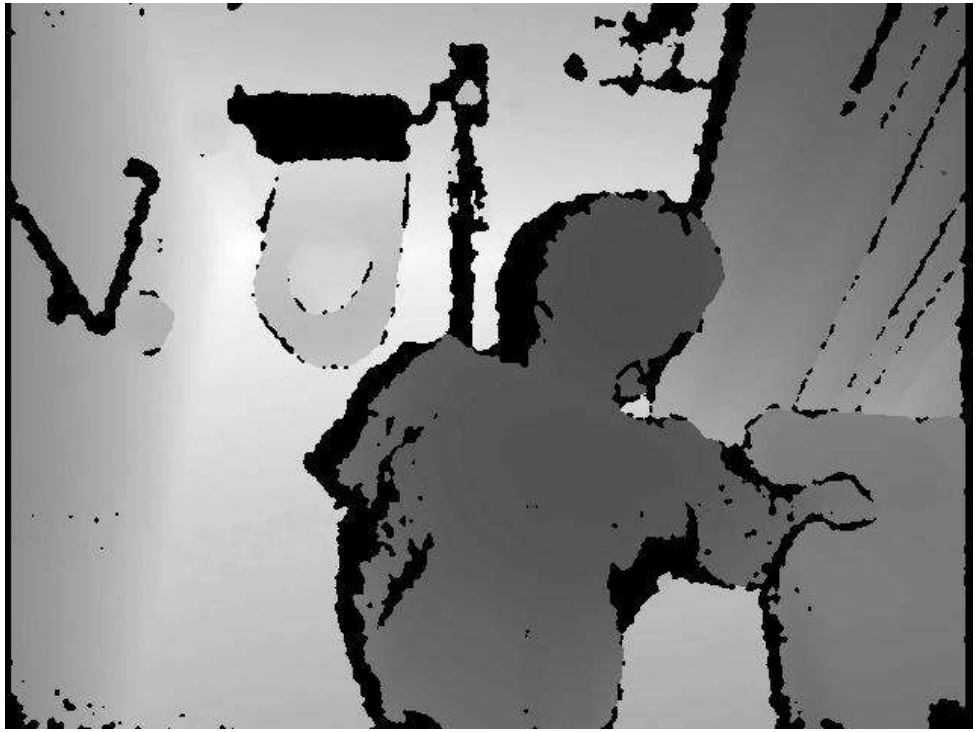
1. The person is about to sit
2. The person sat down
3. The person stood up
4. The person is about to wash their hands

Inclusion criteria:

- Participant sits on the toilet
- Only one person in the room
- The room is empty at the beginning and the end of the sequence

Description of participants:

- 6 male, 14 female
- Age range: 60-97
- 19 participants with dementia, 1 without
- 6 participants use walking aids



Evaluation of the toilet action recognition module

Action is detected correctly if:

$$H1 < fID\_detected - fID\_groundtruth < H2$$

- **fID_detected**: frame in which the system detects the action
- **fID_groundtruth**: mean of the frames labelled by 3 annotators: mean(An1, An2, An3)

How to calculate the thresholds H1, H2?

- **H1= - uncertainty_action + min_system_delay H2= uncertainty_action + max_system_delay**
  - Uncertainty_action = SD(An1, An2,An3) for each action-patient
  - System_delay = frames the system waits to ensure a robust recognition

Evaluation of the toilet action recognition module

Success assessment: Sensor *vs*. annotators

Example: S1 (Hosp), Action=Sitting down

H1 < fID_detected – fID_groundtruth < H2

	An1	An2	An3	Avrg = GT	Std Dev	Sensor	Sensor-GT	H2-H1	Success?
R 1	408	413	419	413.3	5.5	400	-13.3	35.0	
R 2	343	340	349	344.0	4.6	344	0.0	33.2	
R 3	455	453	458	455.3	2.5	400	-55.3	29.0	
R 4	436	433	437	435.3	2.1	440	4.7	28.2	
R 5	458	448	455	453.7	5.1	440	-13.7	34.3	
R 6	442	436	439	439.0	3.0	428	-11.0	30.0	
R 7	452	452	461	455.0	5.2	424	-31.0	34.4	
R 8	432	432	455	439.7	13.3	436	-3.7	50.6	
R 9	456	456	460	457.3	2.3	456	-1.3	28.6	
R 10	368	363	373	368.0	5.0	372	4.0	34.0	
Average	425.0	422.6	430.6	426.1	4.9	414.0	-12.1	33.7	
Std. Dev.	40	40.0	39.4	39.6		34.9	18.6	6.5	

Accuracy: 90%

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EXTRA: Toilet Module: What has been done since then until now?

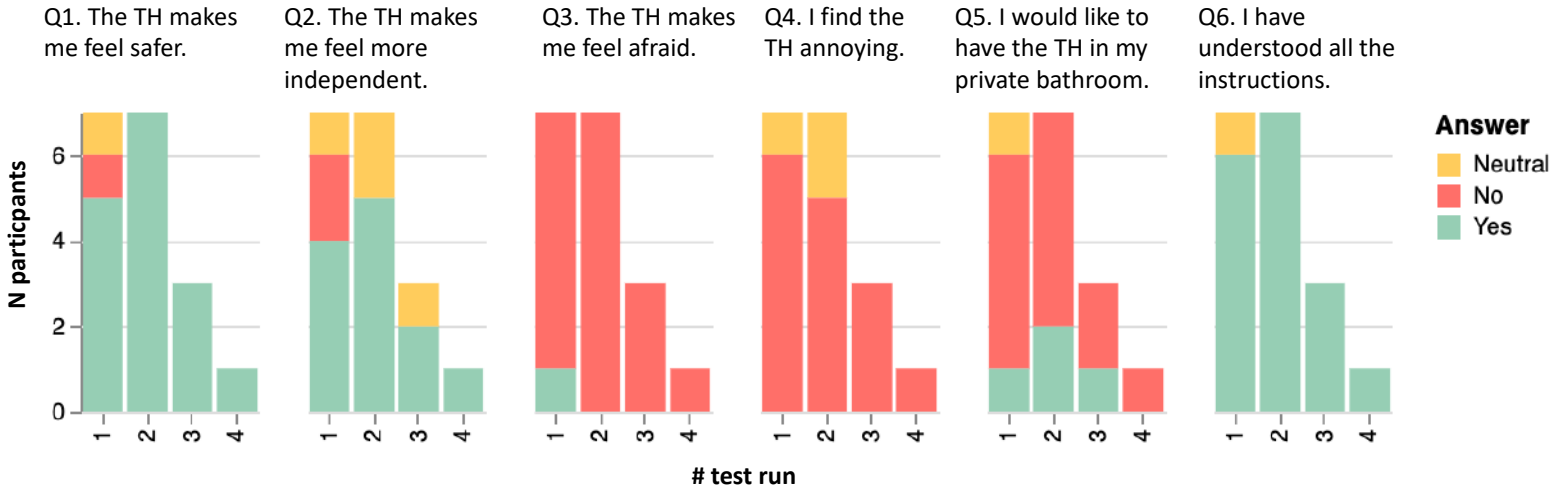
Evaluation of the interaction module

End-users in DC1 (St. Gallen, CH)

N = 17 older adults attending 1-2 days/week the day care centre

- 11 women, 6 men
- Dementia severity (6 measured by MMSE, 11 measured by MoCA) :
  - Mild: 11
  - Moderate: 5
  - Normal cognitive functioning: 1
- Mean age = 78,6. SD = 7.2, max. = 86, min. = 60
- Mean score of affinity for new technologies = 1.5 (0-2)

	1st time runs			All test runs		
	Yes	Neutral	No	Yes	Neutral	No
Q1. The TH makes me feel safer.	11	3	2	22	3	2
Q2. The TH makes me feel more independent.	11	0	5	19	3	5
Q3. The TH makes me feel afraid.	1	0	15	1	0	26
Q4. I find the TH annoying.	1	1	14	1	3	23
Q5. I would like to have the TH in my private bathroom.	2	1	13	5	1	21
Q6. I have understood all the instructions.	14	2	1	25	2	1



Times the participants tried the system: 1 time: 17, 2 times: 7, 3 times: 3, 4 times: 1

Evaluation of the interaction module

End-users in DC2 (Coimbra, PT)

N = 13 older adults attending the day centre daily

- 9 women, 4 men
- No cognitive status reported
- Age distribution
  - 71-80 years: 3 participants
  - 81-90 years: 6 participants
  - +90 years: 4 participants
- Mean score of affinity for new technologies = 4.2 (SD=0.9, scale=1-5)

(1=I do not agree at all, 10= Totally agree)

	1st time runs (N=13)		2-4 time runs (N=8)		All test runs (N=21)	
	Mean	SD	Mean	SD	Mean	SD
Q1. The TH would make me feel safer.	**8,5**	2,7	**9,3**	0,7	**8,8**	2,2
Q2. The TH would make me feel more independent.	**8,5**	4,2	**8,8**	0,9	**8,6**	3,3
Q3. The TH would make me feel comfortable.	**8,3**	2,5	**8,9**	0,8	**8,5**	2,0
Q4. The TH would make me feel afraid.	**2,2**	2,5	**1,3**	0,7	**1,8**	2,1
Q5. I find the TH annoying.	**1,4**	0,9	**1,3**	0,5	**1,3**	0,7
Q6. I would prefer to be assisted by the TH rather than by a caregiver.	**5,7**	3,5	**6,0**	3,6	**5,8**	3,5
Q7. I would like to have the TH in my private bathroom.	**7,9**	2,9	**8,5**	1,9	**8,1**	2,6

Evaluation of the interaction module

Care staff in DC1 and DC2

N=14 care staff (N=4 from DC1 and N=10 from DC2)

- All women
- Affinity for technology (scale: 1-5)
  - Total: mean=4.1, SD=0.9
  - DC1: mean=3.3, SD=0.8
  - DC2: mean=4.4, SD=0.7

DC1				DC2			
Aged		Work experience		Aged		Work experience	
21-30 y.	0	<5 y.	0	21-30 y.	4	<5 y.	3
31-40 y.	0	6 to 10 y.	0	31-40 y.	1	6 to 10 y.	1
41-50 y.	1	10 to 16 y.	0	41-50 y.	3	10 to 16 y.	0
51-60 y.	3	16 to 20 y.	1	51-60 y.	1	16 to 20 y.	2
61-70 y.	0	>20 y.	3	61-70 y.	1	>20 y.	4

	Total (N=14)		DC1 (N=4)		DC2 (N=10)	
	Mean	SD	Mean	SD	Mean	SD
Q1. How useful would you rate the use of the TH for older adults with cognitive impairment?	**8,1**	1,7	**7,5**	0,6	**8,4**	2,0
Q2. How useful would you rate the use of the TH for reducing the workload for healthcare workers?	**8,1**	1,9	**6,3**	1,3	**8,7**	1,6
Q3. How adequate do you find the interaction modalities used in the TH to guide the user?	**8,2**	1,3	**7,5**	1,3	**8,5**	1,3
Q4. Is the vocabulary in the TH adequate to guide the user?	**8,8**	1,3	**8,5**	1,9	**8,9**	1,0
Q5. Is the tone used in the TH adequate to guide the user?	**8,6**	1,2	**8,3**	1,7	**8,7**	1,1
Q6. Are the videos used in the TH adequate to guide the user?	**8,4**	0,9	**8,8**	1,0	**8,3**	0,9
Q7. How intrusive do you think the TH is compared to a caregiver guiding the person with dementia?	**4,9**	3,1	**7,7**	1,5	**4,1**	3,0