

H²AI—The Human Health and Activity Laboratory [†]

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Abstract: The Human Health and Activity Laboratory (H²AI) is a new research facility at Luleå University of Technology implemented during 2018 as a smart home environment in an educational training apartment for nurses and therapists at the Luleå campus. This paper presents the design and implementation of the lab together with a discussion on potential impact. The aim is to identify and overcome economical, technical and social barriers to achieve an envisioned good and equal health and welfare within and from home environments. The lab is equipped with multiple sensor and actuator systems in the environment, worn by persons and based on digital information. The systems will allow for advanced capture, filtering, analysis and visualization of research data such as A/V, EEG, ECG, EMG, GSR, respiration and location while being able to detect falls, sleep apnea and other critical health and wellbeing issues. The resulting studies will be aimed towards supporting and equipping future home environments and care facilities, spanning from temporary care to primary care at hospitals, with technologies for activity and critical health and wellness issue detection. The work will be conducted at an International level and within a European context, based on a collaboration with other smart labs, such that experiments can be replicated at multiple sites. This paper presents some initial lessons learnt including design, setup and configuration for comparison of sensor placements and configurations as well as analytical methods.

Keywords: smart home environment lab; pervasive computing; ehealth; ambient assisted living

1. Introduction

The undergoing demographic change is a well-known trend which points at an increasing amount of the general population consisting of elderly persons, with physical or cognitive impairments. This leads to great challenges for societies, due to resource demanding care of these persons by both formal (public sector) and informal carers (spouses, relatives, etc.) [1]. It is also clearly affecting the quality of life for the elderly persons and their families.

Sweden, similarly to other European countries such as the UK, plan to harness the opportunities offered by digitalization to strengthen the long-term development of health, medical care and social services. The Swedish Government has together with the Swedish Association of Local Authorities agreed on a Vision for eHealth 2025 [2]:

“Sweden will be best in the world at using the opportunities offered by digitalization and eHealth to make it easier for people to achieve good and equal health and welfare, and to develop and strengthen their own resources for increased independence and participation in the life of society.”

There are several strong trends concerning the digitization of care and support of digital tools in care. For example, there are several care organizations that now offer patients doctor or therapist consultations and training using online tools, such that patients can avoid cumbersome and time-consuming visits to care facilities (in Sweden a first good example is kry.se). Patient journals and booking services are now also widely accessible online (through the national e-service 1177.se).

Nevertheless, the digitalization of care, or the use of digital tools in and for care, will need to expand beyond the borders of care facilities to achieve the increased independence and participation in the life of society that is being aimed for. A means to avoid hospitalization and to support active lifestyles in home environments is, for example, still an area that requires increased attention, in particular for persons diagnosed with cognitive or physical impairments, if the aforementioned vision is to be realized. There is still a long way to go in order to fully harness the opportunities offered by digitalization [3].

Even today, 2018, little consideration is given towards the digitalization or digitization of the home environment. For example, there are few, if any, care facilities and homes that are equipped with more advanced sensor and actuator systems supporting active lifestyles and preventing hospitalization. There could be several reasons for this, such as costs, complexity, acceptance and adoption in addition to the lack of regulations, knowledge, procedures and tools [4].

This paper describes the motivation and design for a new research facility, the Human Health and Activity Laboratory (H²AI). The smart lab, housed in an 86 m² apartment (see Figure 1 left) at the Luleå Campus at Luleå University of Technology, aims to identify and overcome economical, functional, technical and social barriers to help achieve the good and equal health and welfare within and from home environments. The H²AI studies will help guide the construction of new elder care facilities, such as Kronandalen in Luleå that will consists of four elder care homes plus one health center (see Figure 1 right). It is currently also planned to equip it with a selection of the technologies following evaluation in the H²AI. The focus is on identifying and monitoring the sequence of activities and activity patterns to support interventions and care systems. Two key conceptual scenarios are presented below.



Figure 1. The Human Health and Activity Lab (Left) and Kronandalen Elder Care Facility (Right).

1.1. Scenarios

Digital Home Visits

Sweden has a very low density of population in large regions of the country, such as in the region of Norrbotten. In the case where persons need to be visited to be tended to, such as during the night, the current method is no longer neither feasible nor sustainable. Care staff often need to travel long distances by car on dark, often icy or slippery, roads, which raises several work-related safety concerns. The person at home is then easily disrupted in their sleep when the care staff visits which may result in the person falling or wandering off in the middle of the night after a visit, which increases personal risks and reduces quality of life [5,6].

Home visits delivered digitally are corollary considered as a viable alternative to those delivered with the current care method. Digital home visits can be defined as when the care staff can monitor the person, in a non-invasive way using passive sensors in the home environment. There are naturally many ways to implement digital home visits, from pressure sensors in the bed to ultra-wideband sensors in the roof above the bed, that can track whether a person is safely in bed and sleeping.

1.2. Intelligent Alarms

Many elderly persons today have safety alarms in their home environments, often worn or located close to the bed and in the restroom where falls are most common, which yield a large amount of false alarms that consume resources to check up on (such as by usage of pendants in the UK). Intelligent alarms would monitor the elderly person in their home environment to automatically send alarms and to filter out false alarms, to reduce resources used and unnecessary hospitalization as well as to help increase the quality of life and the capability to stay in the home for a longer period of time.

Related Work

There are many smart home research facilities that study healthy aging through assistive technologies [3,4,7,8]. The Aware Home Research Initiative at Georgia Tech [9], the MIT PlaceLab [10], the Ubiquitous Home [11], the HomeLab [12], the TigerPlace [13], the Toyota Dream House Papi [14] and the Drexel Smart House [15] are just a few research facilities that have been studied.

The H²AI will build on the results from these research facilities, as identified in a survey under review, while utilizing many of the recent technological advances. The H²AI will continuously scan published works for new innovations and state of the art solutions, which will be combined with information gained through collaborations between the labs as well as technology companies.

2. Design and Implementation

2.1. General Purpose

The general purpose of H²AI can be described as follows:

A person equipped with a wearable sensor kit, consisting of a mobile eye-tracker and sensors for EEG, ECG, EMG, GSR, respiration and other biometric data, conduct daily activities in the smart home environment. The person is continuously positioned using active and passive systems. The smart home environment is also equipped with video cameras and microphones which data is mixed and combined. Additional sensors, both worn and in the environment, will provide additional data, such as respiration, sleep apnea, status of objects and persons, etc. The data management system stores all data in synchronized (time-stamped) formats. An API is used to import and export data in real-time to additional systems. Data can also be imported and exported to and from the system in standardized formats. The data management system is then used to analyze the sequence of daily activities and activity patterns in the smart home using graphical and analytical tools.

The design and implementation of the H²AI thus aims to support a comparison of multiple sensor types to find the best possible configuration for residential homes and care facilities. We

strongly believe that the H²AI can contribute much to gaining knowledge about digitization of care and support of digital tools in care, together with companies such as Tieto and SkyResponse, municipalities such as Luleå and Kalix, and regions such as Norrbotten and Västerbotten.

The efforts also span multiple research disciplines, from both the technical and philosophical faculties. The general purpose of the H²AI will allow for cross-, inter- and multi-disciplinary research, between topics such as health and rehabilitation, nursing, medical sciences, pervasive and mobile computing, control engineering, signals and systems, information systems, technical design, engineering psychology and health economics.

The intention is to create an innovation cluster surrounding the H²AI that will develop technologies and processes for care through smart environments from primary care facilities, such as hospitals that may monitor a subject in a controlled environment before s/he returns home, secondary care facilities, such as temporary homes where persons reside for shorter periods and elder care homes, to normal residential homes. The new lab can enable studies of technologies and processes that spans all these types of environments.

Three types of sensing systems will be integrated into the aggregated system in the H²AI: sensors worn by the user, sensors placed in the environment and virtual sensors that track the user's usage of digital services. Figure 2 illustrates the systems of the H²AI, which are further explained in the following Section. (Note: UWB is ultra-wideband radio technologies.)

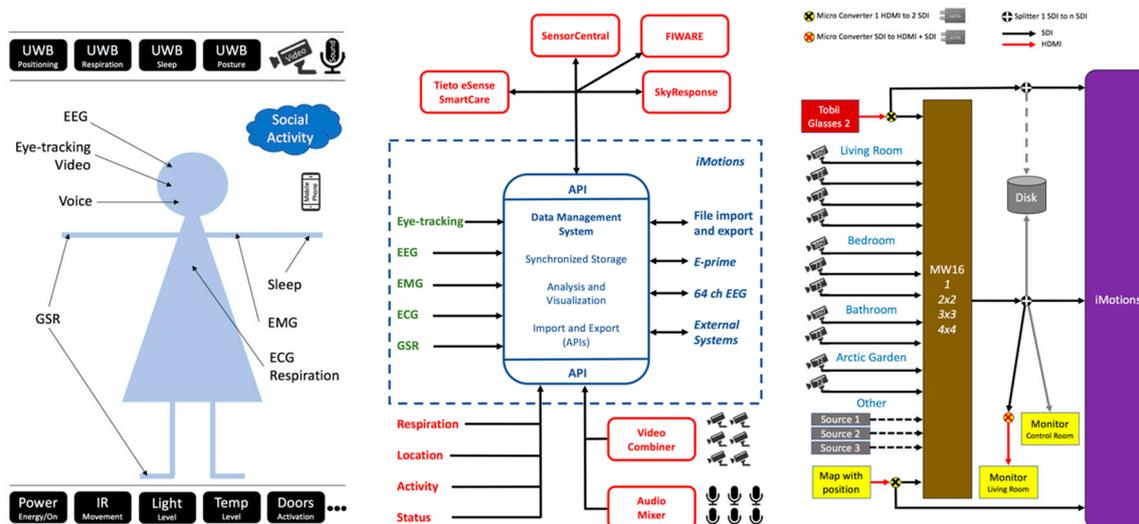


Figure 2. Systems in the H²AI: sensing (Left), data exchange (Middle) and AV (Right).

2.2. DEPICT—iMotions

The H²AI design is primarily influenced by the DEPICT Lab [16] for capturing, visualizing and analyzing human behavior and subconscious cognitive processes at Luleå University of Technology. The DEPICT Lab has a system from iMotions [17] that captures, filters, analyses and visualizes time-synchronized data from a wide range of biometric sensing systems. The main motivation to base the new labs system on DEPICT was to be able to share equipment and knowledge between the labs to save costs and make research training more effective. The iMotions platform supports synchronized logging, analysis and visualization of various sources and qualities of data (also see Figure 3):

1. Mobile eye-tracking as an output from mobile sensing of eye motion, gaze, etc.
2. EEG (Electroencephalography) is an electrophysiological monitoring method to record electrical activity of the brain.
3. ECG (Electrocardiogram) is the process of recording the electrical activity of the heart over a period of time using electrodes placed on the skin.
4. EMG (Electromyogram) is an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles.

5. GSR (Galvanic skin response) is the change in the electrical properties of the skin, used for capturing the autonomic nerve responses (by the sweat gland function).
6. Respiration as a metric of breathing performance and variation.
7. A/V (audio and video) from multiple sources in the lab.
8. Real-time import and export of data to/from other systems and sensor modules (API).

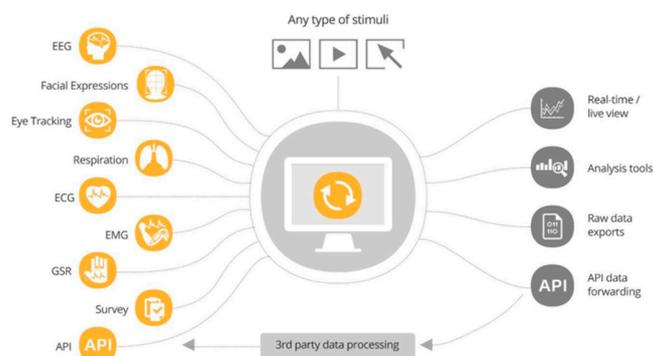


Figure 3. The iMotions platform for analysis of eye movements, GSR, EEG, EMG and ECG together with imported data through an API [Source: iMotions].

2.3. REMIND—SensorCentral

The H²AI design was also influenced by systems used in other similar smart home environments that focus on research on activity recognition and support of daily activities for persons with cognitive or physical impairments, such as the SERG lab at Ulster University (UK) [18], the Halmstad Intelligent Home at Halmstad University (Sweden) [19] and the Smart Home Lab at University of Jaen (Spain) [20]. These labs collaborate in a European Marie Skłodowska Curie Action named Remind (The use of computational techniques to Improve compliance to reminders within smart environments) that aims at ultimately setting up experiments across multiple labs [21].

The SensorCentral platform [22] has been implemented by Ulster University and will, similarly to the iMotions system, support advanced capture, storage, filtering, analysis and visualisation of research data. Both platforms will be used in parallel, where the primary platform will be selected based on the research criteria for individual studies. The parallel use of the two platforms can also verify them in comparison to each other, such as potential machine learning strategies and algorithms. University of Ulster may also provide a new IR-system integrated into SensorCentral.

2.4. Platform Integration

The iMotions and SensorCentral platforms will be complimented and integrated with other platforms and systems. The H²AI is part of a collaboration project with industry, municipalities and regions, such that research activities can be connected with both real problems and real commercial solutions to achieve impact. Figure 2 (right) illustrates integration of platforms for data exchange.

The Tieto SmartCare platform and eSense solutions [23] are being rolled out in Norway, Finland and Sweden. It will be of clear importance to bridge research with industrial interest and to achieve impact together with municipalities and regions using that platform. Technology from the H²AI aims to be modularised for commercial use in the Tieto SmartCare platform and for eSense solutions.

SkyResponse [24] is also participating in setting up the H²AI and they provide a flexible event handling system for alarms and other exceptions with an architecture based on cloud computing and mobile communication. The SkyResponse system registers complete traces of all alarms, making it possible to track how every alarm has been handled. H²AI solutions will benefit from the flexibility of SkyResponse, as they can easily be adopted for or integrated with numerous existing IoT applications and IT systems, such as trouble ticket systems in response service centers.

FIWARE [25] is a European open-source platform, which supports combining components that enable connection between IoT, Context Information Management and Big Data services in the Cloud. It provides standard APIs for data management and exchange, in addition to harmonized

data models. It supports automation of processes across value chains and enables easy plug&play integration with other solutions and services. The adoption of FIWARE enables H²AI modules to become part of a well-established European marketplace of portable and interoperable solutions.

2.5. Wearable Sensor Kits

The sensors worn by the user are organized as a kit that supports capture of all data types natively supported by the iMotions platform or through its APIs, see Figure 3. The H²AI wearable sensor kits, see Figure 4, include biometric data from EEG equipment such as the 9 + 1 channel B-Alert X10. Note that the iMotions platform also support E-prime, a widely-used programming software for psychology experiment design, implementation, and analysis.



Figure 4. Top from the left: B-Alert X10, Shimmer 3 ECG/EMG/GSR and WideFind UWB-positioning tags. Bottom from the left: Tobii Glasses 2, Oura ring, Empatica E4 and Apple Watch with AliveCor KardiaBand.

The H²AI wearable sensor kits contains, in addition to EEG equipment, solutions for monitoring of accelerometry, EMG, ECG, GSR and respiration, such as the Shimmer 3 platform, the Empatica E4, the Oura ring, and Apple Watch with AliveCor KardiaBand. In addition, tracking of eye-movements and recording of video as seen by a user is conducted with the Tobii Pro Glasses 2.

Figure 2 (middle) also illustrates the time-synchronized data streamed from the wearable sensor kits into the iMotions and SensorCentral platforms (marked with green colors).

Finally, the location of persons and objects are monitored in H²AI using UWB-based tags from WideFind or Pozyx. These yield an accuracy of the data from about 10 cm to about 30 cm, depending on the line of sight, number and placement of anchors, and signal to noise ratios. The location can, in addition to being used to analyze activities, be used to steer the sensors in the environment.

2.6. Sensors in the Environment

The (active) sensors worn on the body, the wearable sensor kit, is complimented with (passive) sensors in the surrounding environment within the boundaries of the H²AI. These monitor some of the biometric data also captured by the wearable sensor kits, however, at different qualities and rates, such as respiration and location.

Location can also be monitored passively in H²AI using UWB (not using worn tags such as in the WideFind and Pozyx solutions), for example using technologies from Vayyar or EchoCare, while also being able to track posture and vital signs, such as respiration, as well as fall detection. Figure 5 is a screen shot from a Vayyar video illustrating location and posture tracking.

The H²AI also utilizes UWB sensors from Somnofy and Kardian, which will be ceiling-mounted above resting places such as the bed and an armchair to passively monitor resting heart rates, respiration and sleeping patterns, including sleep apnea, in addition to fall detection. Finally, a Z-Wave system will monitor opening/closing of doors and drawers, energy-consumption of power outlets and auxiliary data such as lighting conditions, air quality, room temperature and IR motion. Only Z-Wave Plus (generation 5) is used because of reach and stability (from Vera, Aeon Labs and Fibaro). Figure 6 (left) show an illustration of Z-Wave sensors in the H²AI kitchen.



Figure 5. Vayyar UWB-solution for tracking location, posture, etc. [Source: Vayyar].

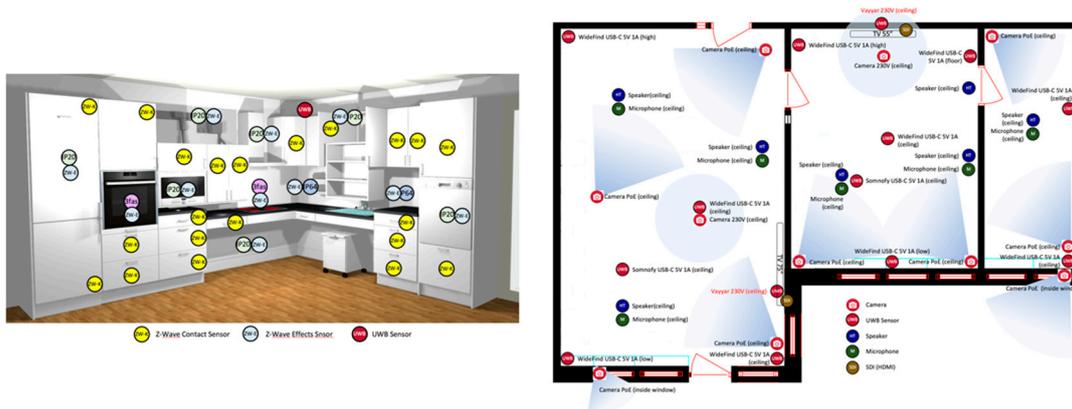


Figure 6. Sensor placement in the H²AI: kitchen (Left) and apartment (Right).

Figure 6 (right) illustrates the placement of cameras, speakers, microphones and UWB-sensors. Speakers and microphones are placed where users will likely reside: in the kitchen, near the sofa and armchair, the dinner table, the bed, the work desk and the washbasin.

UWB-sensors from WideFind are placed as much apart as possible and at different heights, to allow the best possible accuracy of the active positioning and to support active positioning in 3D (thus potentially also being able to track falls). UWB-sensor from Somnofy and Kardian are placed above the bed and above the armchair, to allow for detection of resting heart rate, respiration, sleep apnea and falls, potentially as well as in the bathroom to also detect falls there. UWB-sensors from Vayyar are placed in ceilings or at walls, at heights and angles to cover the H²AI best, such that up to four persons can be passively positioned and monitored for postures.

The cameras are placed to primarily monitor activities in the areas where users are likely to be the most active: near the kitchen, the sofa, the bed and the bathroom. Fixed cameras are placed facing these areas and pan/tilt/zoom-cameras are placed to allow as much flexibility as possible.

Note the two fixed cameras facing out of the windows, towards the arctic garden outside, as cameras may not be placed outside due to Swedish and European privacy regulations and surveillance directives (such as GDPR). The cameras may later be complimented by mobile cameras, depending on identified needs and activities.

2.7. Audio and Video Monitoring

The H²AI utilizes 1080p HD-video sources from both worn eye-tracking glasses (such as the Tobii Pro Glasses 2) and cameras mounted in the ceiling (2 × Panasonic AW-HE40SW PTZ with pan/tilt/zoom and 9 × PTZ-Optics PTVL-ZCAM fixed 72-degree view) as well as auxiliary video from other sources, such as a PC with control software. Thermal vision is also an option but may be added as streams from Z-Wave units as additional sources (for example University of Ulster has a new thermal sensor that may be installed in the H²AI). The iMotions platform supports three simultaneous streams to be stored and analyzed.

Eye-tracking video: The first video stream is captured by the glasses and fed into the iMotions platform for video analytics, for example using heat maps for predefined areas in the H²AI.

Status video: The second video stream is captured from a computer and fed into the iMotions platform. This could be data visualized through the SensorCentral platform or a visualization similar to the Vayyar video as illustrated in Figure 5. This would allow researchers to also take position and posture into account when analyzing biometric data in iMotions.

Multiplexed video: The third video stream is multiplexed from all video sources. Figure 2 (right) depicts a schematic overview of how the video sources are mixed, stored and utilized. A mixer (Blackmagic MultiView 16, MW16) produces one video stream of 1, 2 × 2, 3 × 3 or 4 × 4 video sources, which then is fed into the iMotions platform for synchronized storage with all biometric data. The multiplexed video can also be streamed to the monitors in the H²AI living room and the control room.

2.8. Virtual Sensors

The H²AI will investigate virtual sensors in addition to the wearable sensor kits and the sensors in the environment. Such a virtual sensor acts on data available in other services. For example, the communication of a persons can be monitored to detect communication patterns over time [26,27]. These patterns represent a person's social network and can be seen as a social graph where each node carries a weight corresponding to the importance of that node (for example based on the richness and frequency of interactions).

Data from how a social graph evolves over time may indicate social isolation and can thus be used to establish interventions, especially if sedentary behavior also can be detected. The H²AI will thus also include virtual sensing, using data from smart phones and communication services.

3. Discussion

The H²AI aims to contribute to the study of human activity in a home setting. The scientific activities will be supported by both worn sensors and sensors in the environment as described above.

3.1. Why Multiple Sensors and Sensor Types?

A natural question is what can be achieved with such a large amount and wide variety of sensors, and the answer is that we are yet to find that out. The belief is that by monitoring the same type of data from multiple sensors and sensor types, we can find the most efficient and effective configuration for real use. That is, how should a smart home for elder care be setup based on the most recent findings and technologies. The prior work by the authors supports this conclusion [28–32].

Another key aspect is to bring multiple competences into the research, in our case to bring in experiences and solutions from the human interaction field (through the connection to the DEPICT lab), health economics, service innovation, and so on, as compliments to the technical research already being conducted through the REMIND and ACROSSING projects. This will open up new novel research connecting technical and philosophical aspects, in particular since solutions need to be very simple to use and manage both by carers and persons needing care. Pervasiveness and ubiquitous access is especially important in a field where care staff select their profession based on mainly other aspects than an interest for IT and often complex systems.

A key focal point is activity detection, analysis and visualization where both sequence of activities and more general activity patterns are central. The core challenge is to detect activities successfully using the least number of sensors possible.

3.2. International Collaboration

There are numerous collaborations at an International level that contribute to the H²AI. Foremost is the long connection through European projects with Ulster University, which have had a similar lab for more than a decade located at the Jordanstown campus outside of Belfast. Their SERG lab operates as a good example of how multi-disciplinary and international research collaborations can be conducted in collaboration with care facilities and companies. Their research on smart

environments and ambient assisted living incorporates networked environments (structure and sensors in buildings, clothing and personal devices) and intelligent processing (data mining, pattern recognition, decision support, context prediction, data fusion, and multimodal interaction). They have also created an innovation cluster that will work as an example for the H²AI environment.

Halmstad Intelligent Home (HINT) at Halmstad University, see Figure 7 (left), is a leading example in Sweden on an academic research facility with good connections with the surrounding region and companies. Their research on innovating care includes work on graphical interfaces for monitoring and analysis of the smart home facility, which are of importance to the H²AI environment.

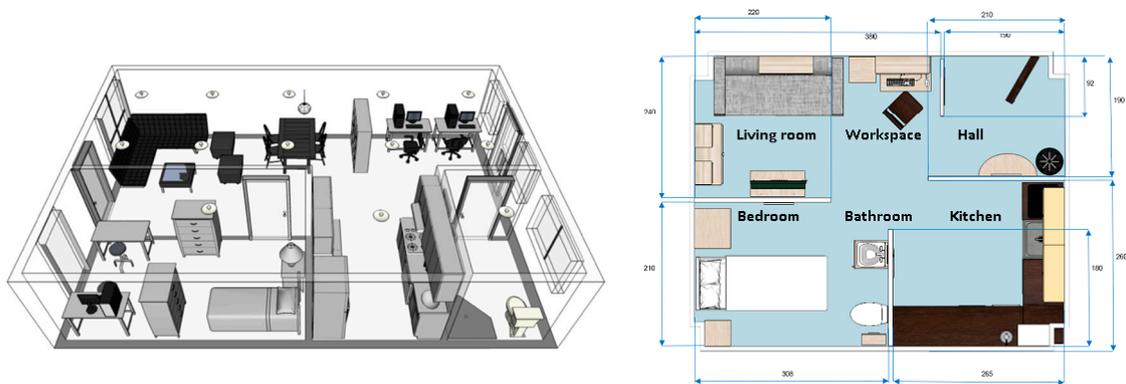


Figure 7. HINT—the Halmstad Intelligent Home (Left) and The UJAmI SmartLab (Right).

The Ambient Intelligence SmartLab at University of Jaén (UJAmI), see Figure 7 (right), is a smart apartment that has multiple and heterogeneous sensors and actuators that are connected to a unified middleware. The aim of the UJAmI SmartLab is to have a real apartment which was sensitive, adaptive, and responsive to human needs, habits, gestures, and emotions which subsequently underpinned assistive technology-based solutions in the home.

The three universities (Ulster University, Halmstad University and University of Jaén) are all part of the European Marie Skłodowska Curie Action (MSCA-RISE) project REMIND, that targets developments in reminding technologies for persons with dementia, together with Luleå University of Technology plus companies such as I+ from Italy, Swedish Adrenaline from Sweden and Karde from Norway. Experiences from the labs in Jaen, Halmstad and Ulster has significantly contributed to the design and implementation of the H²AI. For example, the high price and the poor performance of smart floor tiling made us avoid these technologies and instead utilize systems for UWB-sensing.

Another MSCA project is ACROSSING, that aims to develop advanced technologies and toolsets for smart home-based assisted living. The project is an International training network and early stage researchers will be able to take benefit from the H²AI for setting up experiments across multiple labs.

Overall, International collaboration is a key aspect for the H²AI and the collaborations mentioned above is just a few to highlight. There is also since several years an exchange of students with University of Limoges in France that now will be able to train in the H²AI. We will seek new collaborations, such as with Agder University in Norway and their new I4H innovation cluster.

Finally, the H²AI will allow us to potentially find the best configuration for a given need and deployment, but we also believe in the possibility of new services being enabled by different sensors or their combination. This opens up opportunities for reuse and redundancy as well as mobility of services. What matters is the continuity of services, regardless offered at H²AI, SERG lab, HINT or Smart Home Lab. Research across the labs is a key point, that will help establish such services in Europe, where partners will be offered to test, validate and evaluate technologies at H²AI.

3.3. Identified Research Areas and Challenges

A series of workshops was conducted, in parallel of the design and implementation of the H²AI, with participants from many research groups at Luleå University of Technology and together with the eHealth Innovation Centre and representatives from the Luleå municipality, the region of

Norrbotten and companies in the region. These workshops helped identify areas and challenges for research as well as what technologies and systems that were required for the lab. Each of these areas has their own challenges, but to mention a few identified in the workshops:

1. Loneliness may be one of the primary factors for a reduced quality of life among elder persons, which challenges care systems with declining resources for social interaction.
2. Distance to care facilities and qualified care is a great challenge foremost in the far north, but also in general, which needs to be overcome.
3. Frailty as a result of sedentary behavior and loneliness increases the risks for injuries and death, for which measures need to be taken.
4. Complexity acts as a barrier for the digitalization of care and up-take of new technologies.
5. Immediate feedback for (self-care) activities is very important, to sustain activities, for which gamification techniques may be important.
6. Designing homes to support digital interventions.
7. Identifying economical aspects related to quality of life and care involving family members.
8. Compare and recommend technologies and processes for wider adoption.

It is clear that the H²AI will help to bring researchers from different fields together in joint efforts to work on the areas, and to meet the challenges, as identified in the workshops. We believe we are now very well equipped to pursue research in the identified areas within a European community that fosters exchange and communication of results and ideas.

3.4. Rapid and Continuous Change

A final note is that the technological advances are rapid, quickly making old technologies obsolete or outdated. It is, however, favorable that new technologies that replace older are most commonly cheaper to purchase, deploy and maintain, otherwise keeping such a lab updated would be very hard. The H²AI will continuously monitor these advances, such that multiple solutions, both old and new, can be studied and evaluated in parallel. Close collaborations with companies that produce new technologies and with other labs are thus key to maintaining the lab up to date.

4. Conclusions

The Human Health and Activity Laboratory (H²AI) is a new research facility at Luleå University of Technology designed and implemented during 2018 as a smart home environment in a training apartment at the Luleå campus. The lab combines multiple systems for capturing, storing, analyzing and visualizing data. Platforms such as iMotions and SensorCentral will be key factors for processing data from wearable sensor kits and sensors in the environment as well as virtual sensors. The systems will allow for advanced capture, filtering, analysis and visualization of research data such as A/V, EEG, ECG, EMG, GSR, respiration and location while being able to detect falls, sleep apnea and other issues. A main focus is to detect and analyze the sequence of activities and activity patterns.

The resulting studies will be aimed towards supporting equipping future home environments and care facilities, spanning from temporary care to primary care at hospitals, with technologies for activity and issue detection. The work will be conducted at an International level and within a European context, based on a collaboration with other labs such that experiments can be conducted at multiple sites. The use of multiple platforms such as iMotions and SensorCentral will cater for research and training collaborations with other labs, with joint experiments as an end goal.

The aim is to identify and overcome economical, technical and social barriers to achieve an envisioned good and equal health and welfare within and away from home environments. We strongly believe that H²AI will contribute to this aim significantly, by studying new technologies and processes, as well as help establish them outside of the lab. We also hope that the design and implementation of the H²AI will enable other labs to be setup, such as at CUC in Colombia, so that knowledge of care in smart homes can be fostered Internationally.

5. Future Work

The areas and challenges listed above all represent future work to be conducted. One area not mentioned above is technologies not worn or placed in the environment but implanted. These types of devices may prove invaluable in providing pervasive and non-cumbersome biometric sensing, even if they are invasive. We see a clear potential in using implanted technologies in combination with worn devices, equipment in the surrounding environment and virtual sensors acting on available data resources. The key may be to allow seamless integration between all these services, breaking the common service silos currently predominating the markets.

Finally, the secure management of personal and maybe sensitive data is an important future work. The new European General Data Protection Regulation (GDPR) is central in this work. The balance between use and risk for users is important, for which new technologies such as distributed ledger technologies (blockchain solutions similar BitCoin and ‘tangled’ solutions like IOTA or Swirld) and the aforementioned NFC-chips maybe beneficial.

In conclusion, future work in this field is multi-disciplinary spanning from sensor development to user acceptance, including design, modeling and visualizations. We believe the H²AI will be a significant contributor to care in smart environments that focus on activities of daily living. The H²AI will also be important to establish an innovation cluster that can bring interventions into reality, from early design with and for users to wider trials and finally real implementation and usage.

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References

1. Harper, S. Economic and social implications of aging societies. *Science* **2014**, *346*, 587–591.
2. Action Plan for Cooperation on Implementing the Vision for eHealth 2025 (2017–2019), Approved by the Central Government in Sweden and the Swedish Association of Local Authorities and Regions on the 20th of January 2017. Article No. S2018.005. Available online: <https://ehalsa2025.se/wp-content/uploads/2018/03/Handlingsplan-e-h%C3%A4lsa-engelsk-version.pdf> (accessed on 23 May 2018).
3. Amiribesheli, M.; Benmansour, A.; Bouchachia, A. A review of smart homes in healthcare. *J. Ambient Intell. Humaniz. Comput.* **2015**, *6*, 495–517, doi:10.1007/s12652-015-0270-2.
4. Kaye, J. Making Pervasive Computing Technology Pervasive for Health & Wellness in Aging. *Public Policy Aging Rep.* **2017**, *27*, 53–61, doi:10.1093/ppar/prx005.
5. Malmberg, B.; Ernsth, M.; Larsson, B.; Zarit, S.H. Angels of the night: Evening and night patrols for homebound elders in Sweden. *Gerontol. J.* **2003**, *43*, 761–765.
6. Rashidi, P.; Mihailidis, A. A survey on ambient-assisted living tools for older adults. *IEEE J. Biomed. Health Inform.* **2013**, *17*, 579–590.
7. Poland, M.P.; Nugent, C.D.; Wang, H.; Chen, L. Smart home research: Projects and issues. *Int. J. Ambient Comput. Intell.* **2009**, *1*, 32–45.
8. Georgia Tech Aware Home Research Initiative. Available online: <http://www.awarehome.gatech.edu/> (accessed on 5 September 2018).

9. MIT PlaceLab. Available online: http://web.mit.edu/cron/group/house_n/placelab.html (accessed on 5 September 2018).
10. Yamazaki, T. The ubiquitous home. *Int. J. Smart Home* **2007**, *1*, 17–22.
11. De Ruyter, B.; Aarts, E.; Markopoulos, P.; Ijsselsteijn, W. Ambient intelligence research in homelab: Engineering the user experience. In *Ambient Intelligence*; Springer: Berlin, Germany, 2005; pp. 49–61.
12. Skubic, M.; Alexander, G.; Popescu, M.; Rantz, M.; Keller, J. A smart home application to elder-care: Current status and lessons learned. *Technol. Health Care* **2009**, *17*, 183–201.
13. Toyota DreamHouse Papi. Available online: <http://tronweb.super-nova.co.jp/toyotadreamhousepapi.html> (accessed on 24 May 2018).
14. Drexel SmartHouse. Available online: <http://www.drexelsmarthouse.com/> (accessed on 24 May 2018).
15. Eriksson, H.; Isaksson, A. *Trygg om Natten: En studie av Kunders, Anhörigas och Personals Perspektiv på Införandet av ny Teknik Inom Nattpatrullens Arbete*; Högskolan i Halmstad: Halmstad, Sweden, 2011.
16. DEPICT. Available online: <https://www.ltu.se/org/ets/Verksamhet/Laboratorium-och-utrustning/Depict-Lab> (accessed on 24 May 2018).
17. iMotions. Available online: <https://imotions.com/> (accessed on 24 May 2018).
18. Nugent, C.D.; Mulvenna, M.; Hong, X.; Devlin, S. Experiences in the development of a Smart Lab. *Int. J. Biomed. Eng. Technol.* **2009**, *2*, 319–331.
19. Lundström, J.; De Moraes, W.O.; Menezes, M.; Gabrielli, C.; Bentes, J.; Sant’Anna, A.; Synnott, J.; Nugent, C. Halmstad Intelligent Home—Capabilities and Opportunities. In *Internet of Things Technologies for HealthCare*; Ahmed M., Begum, S., Raad, W., Eds, Springer: Cham, Switzerland, 2016; Volume 187.
20. Espinilla, M.; Martínez, L.; Medina, J.; Nugent, C. The experience in the development of the UJAmI Smart lab. *IEEE Access* **2018**, *6*, 34631–34642.
21. Remind. Available online: <https://www.remind-research.com/> (accessed on 24 May 2018).
22. Rafferty, J.; Synnott, J.; Ennis, A.; Nugent, C.; McChesney, I.; Cleland, I. SensorCentral: A Research Oriented, Device Agnostic, Sensor Data Platform. In Proceedings of the International Conference on Ubiquitous Computing and Ambient Intelligence UCAmI, Philadelphia, PA, USA, 7–10 November 2017; Springer: Berlin, Germany, 2017; pp. 97–108. doi:10.1007/978-3-319-67585-5_11.
23. Tieto White Paper on Challenges Facing Welfare Technology. Available online: <https://campaigns.tieto.com/sv/tietosmartcare#laddaner> (accessed on 24 May 2018).
24. SkyResponse. Available online: <https://skyresponse.com/> (accessed on 24 May 2018).
25. FIWARE. Available online: <https://www.fiware.org/> (accessed on 24 May 2018).
26. Rana, J.; Kristiansson, J.; Synnes, K. Enriching and simplifying communication by social prioritization. In Proceedings of the International Conference on Advances in Social Networks Analysis and Mining 2010 (ASONAM 2010), Odense, Denmark, 9–11 August 2010; pp. 336–340.
27. Rana, J.; Kristiansson, J.; Hallberg, J.; Synnes, K. An architecture for mobile social networking applications. In Proceedings of the International Conference on Computational Intelligence, Communication Systems and Networks 2009 (CICSYN’09), Indore, India, 23–25 July 2009; pp. 241–246.
28. Kikhia, B.; Gomez, M.; Jiménez, L.L.; Hallberg, J.; Karvonen, N.; Synnes, K. Analyzing body movements within the laban effort framework using a single accelerometer. *Sens. J.* **2014**, *14*, 5725–5741.
29. Kikhia, B.; Hallberg, J.; Synnes, K. Context-aware life-logging for persons with mild dementia. In Proceedings of the IEEE International Conference on Engineering in Medicine and Biology Society 2009 (EMBC 2009), Minneapolis, MN, USA, 3–6 September 2009; pp. 6183–6186.
30. Drugge, M.; Nilsson, M.; Liljedahl, U.; Synnes, K.; Parnes, P. Methods for interrupting a wearable computer user. *Int. Symp. Wearable Comput.* **2004**, *1*, 150–157.
31. Nugent, C.D.; Davies, R.J.; Hallberg, J.; Donnelly, M.P.; Synnes, K.; Poland, M.; Wallace, J.; Finlay, D.; Mulvenna, M.; Craig, D. HomeCI-A visual editor for healthcare professionals in the design of home based care. In Proceedings of the IEEE International Conference on Engineering in Medicine and Biology Society 2007 (EMBS 2007), Lyon, France, 22–26 August 2007; pp. 2787–2790.
32. Nugent, C.D.; Hong, X.; Hallberg, J.; Finlay, D.; Synnes, K. Assessing the impact of individual sensor reliability within smart living environments. In Proceedings of the IEEE International Conference on Automation Science and Engineering (CASE 2008), Arlington, VA, USA, 23–26 August 2008; pp. 685–690.

