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# A Semantic-based Collaborative Ambient-Assisted Working Framework

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**Abstract.** Over the last two decades an utmost interest has been shown to Ambient Intelligence (AmI), with most of the related applications focusing on home settings. However, considering the ever-increasing number of ageing people occupied in the workforce, the Ambient-Assisted Working (AAW) is arguably at the beginning of its development. For an effective development and integration of AAW systems, cooperation among and shared knowledge from different stakeholders are required. This work proposes an AmI framework leveraging on Semantic Web technologies to foster employees' wellbeing. The AAW framework makes use of a domain ontology, outcome of the cooperation between different stakeholders (employer, employees and environment) to adjust, modify and correct indoor comfort metrics in workplaces. In this paper, the proposed framework's architecture and its underlying ontology are described, along with a use case scenario that illustrates how collaboratively modelled data can actively support ageing workers.

**Keywords:** Ambient Intelligence, Ambient-Assisted Working, Collaborative design, Ontology-based decision support system, Society 5.0.

## 1 Introduction

The aging workforce is defined as “workers over 55 years old”, characterized by age-related impairments, such as in visual and/or hearing capabilities, muscular deterioration, and chronic diseases related to their cardiovascular, respiratory, endocrine, or cognitive systems; these impairments may hinder workers' harmony with the natural flow of daily work requirements [1]. This group of employees represents a relevant portion of the total workforce in EU, with an increase from 14% in 2004 to 20% in 2019 [2]. As this share is expected to raise significantly in the upcoming years, it is essential to take measures to foster the wellbeing of aging workforce in their workplaces. In order to adapt a workplace for such needs in an optimal manner, it is crucial to ensure an eminent level of collaboration between different stakeholders, namely the employer, the employees and the surrounding environment – i.e. the devices for the improvement or maintenance of employees' wellbeing, such as HVAC systems,

illumination sources, sensory equipment, etc. The essential factor for a successful collaboration is that all these devices can be clustered around an application that enables context-aware functionality and intercommunication, which can otherwise be connoted by the concept of Internet of Things (IoT). A promising solution to achieve this goal is Ambient Intelligence (AmI), that enables environment responsiveness to the needs of people in a non-invasive, adaptive, anticipatory and personalized fashion by means of embedded, unobtrusive, smart devices [3]. AmI is widely investigated for the care-taking of elderly population in their residences, generally referred as Ambient Assisted Living (AAL). On the other hand, Ambient Assisted Working (AAW) applications are still at the beginning and low in number compared to AAL studies. Therefore, this field is avid for novel and diverse approaches.

In this work, an AAW framework founded on an ontology-based Decision Support System (DSS) is introduced, which does not only aim for safer accommodation of aging workforce via avoiding exacerbation on their health conditions, but also for an increase in efficiency of the business via reducing sick leaves and injuries. This method leverages on the collaboration among different stakeholders, by representing the employees and their relevant characteristics, the partaking utilities and devices, the environmental metrics to be kept record of and controlled, and all of the interactions between these distinct elements. While providing this cooperation, it also contributes to the non-invasiveness principle of AmI by not constantly monitoring the workers but taking necessary actions according to their representations in the ontology. The AAW framework general approach leverages on previous AAL research projects [4-5] and introduces collaboration as a means to increase the system's scalability for multiple workers in the same workplace.

This paper is organized as follows: Section 2 surveys the previous works related to AAW; Section 3 illustrates the ontology underlying the DSS and its collaborative ontology engineering process; in Section 4, a use case scenario is depicted with preliminary results; lastly, in the conclusion and future works are addressed.

## 2 Related Work

Following the developments in fields like IoT and AmI, AAW solutions are investigated as a means for providing necessary attention to increasing number of ageing workers in workplaces.

Several studies are mainly focused on continuous monitoring of workers via a variety of smart devices: Sun et al. [6] introduced Healthy Operator 4.0, where an ontology-based DSS drives a health management scheme, withdrawing the required data through smart wearables. Pancardo et al. [7] used a wristband along with an accelerometer for keeping track of workers' stress levels and cardiac status against the effects of heat, while Rick et al. [8] exploited the information retrieved by facial recognition, movement tracking, EEG and ECG devices for observing the physical status and mood variations of employees. Kiyokawa [9] leveraged on worker's concentration and sleepiness monitoring to actuate lighting and speaker system housed on the worker's chair for optimizing his/her performance.

The above-mentioned works either aim at individuals' monitoring and adjustments, lacking non-invasiveness, or offer very generalized solutions that would not be sufficient to enhance the indoor comfort of a workplace; all works miss considering the cooperative nature of a working environment. On the contrary, this paper presents a framework that provides personalized settings without being invasive, leveraging on a cooperative approach for multiple workers working in the same area.

### **3 Collaborative AAW Framework**

In this section, the framework's architecture is explained. The framework is composed of a collaboratively-engineered ontology layer, which needs to determine essential health and environment-related information. Leveraging on sensors, fundamental comfort metrics are monitored and fed to the ontological model, so that reasoning processes can trigger the appropriate actuation to avoid any exacerbation on workers' health issues. In this way, the framework provides a less-invasive system that relies on the workers' location in the workplace and his/her characteristics to provide tailored services, without actively monitoring him/her.

#### **3.1 Ontology Layer**

The ontology needs to model the essential health information, used to represent the workers' conditions and to adapt the working environment for each worker, along with the relevant ambient measures. As foreseen in collaborative ontology engineering, stakeholders adopting the ontology and its results should be involved in its development [10]. The AAW framework foresees workers (with the cooperation of their clinicians, who determine the health condition), the employers and the working environment to identify relevant information with the aim of developing an ontology able to actuate the environment, so that it is possible to avoid any environmental condition that would result in an exacerbation of the worker's health issues. Together with the employer, this information is used to define the optimal metrics of the environment for the general wellbeing of all workers. Also, sensors placed in the working environment monitor the defined comfort metrics, while DL reasoning techniques [11] are adopted to detect risk situations and to trigger actuations.

The definition of worker's health condition is performed reusing the International Classification of Functioning, Disability and Health (ICF) and the International Classification of Diseases (ICD10) ontologies [12-13], since they describe the functional impairments of the worker and provide a common language to foster cooperation among different health stakeholders [14]. Environmental metrics are identified reusing ComfOnt [5], which provides the means to represent measures like CO<sub>2</sub> concentration, humidity rate, temperature, and indoor illuminance – indoor comfort metrics that can act as risk factors for many chronic health conditions [15-18]. The thresholds for each indoor comfort metric and for each specific condition (asthma,

COPD, cataract, low vision acuity, etc.) are also modelled in separate modules in guidance of healthcare professionals. Since ComfOnt reuses the Smart Appliance REference (SAREF) ontology [19] and parts of Sensor, Observation, Sample, and Actuator ontology (SOSA) [20], both models are reused to represent sensors, the measurements they perform in the working environment, and the actuators.

The resulting ontology is developed with Resource Description Framework (RDF) [21] and Ontology Web Language (OWL) [22], with rules in Semantic Web Rule Language, and hosted on a semantic repository – queryable with SPARQL [23]. As further illustrated in Section 4, workers – aware of their health conditions and supported by their clinicians – and employers – leveraging on their knowledge on the working environment – cooperate to define the relevant comfort metrics and actuations to enhance environmental metrics and conditions for aging workforce, thus selecting those concepts and relationships modelled in the ontology and necessary to provide the actuations.

### 3.2 Components of the Framework

As illustrated in Figure 1, the AAW Framework is completed with sensors and actuators, as well as a middleware accounted for receiving measurements from sensors, inserting them in the ontology, and triggering reasoning. The prototypical version of the AAW Framework relies on a thermo-hygrometric sensor (AM2320 Digital Temperature and Humidity Sensor), an illuminance sensor (TSL2561 Digital Luminosity/Lux/Light Sensor), a CO<sub>2</sub> reader (3709 Adafruit SGP30 Air Quality Sensor), with a RFID Reader to localize the worker.

## 4 Use Case

The use case foresees a clothing retail company with operations taking place in different countries, where the environmental conditions are different. Two different sales offices in different clothing factories are populated with some ageing workers characterized by varying health conditions, to demonstrate how the level of collaboration between different modules of the ontology is implemented for different situations and to show how the cooperation among employer, employees and the AAW system can produce working conditions' enhancement for different workers.

The first office is situated in Novosibirsk, Russia, characterized by winter temperatures with peaks of -15° C / -20° C, with average humidity equal to 80%, and daylight is available only for limited periods [24]. The second sales office is in Doha, Qatar. In this city, temperature in summer ranges between 35° C and 40° C. Humidity rate is attested lower than 40% [25]. Company's management values its ageing workforce's expertise, therefore they implemented the AAW framework with the aim of improving the comfort of the employees and avoiding any exacerbation on their health conditions by providing them the most suitable environmental metrics. Both offices are equipped with a thermo-hygrometer, a CO<sub>2</sub> sensor, and an illuminance sensor. There exist a HVAC system that operates for the entire room, a number of general-purpose illumination sources and desks for each employee. Each desk is

equipped with an RFID reader, a workstation in which a software that sends the particular worker relative notifications is present, and a minor illumination source for personal use. The workers introduce their RFIDs to their desk-readers to identify themselves.

In Novosibirsk office there are 4 workers, with names and conditions as follow:

- Alex (male, 61 years-old), affected by COPD (ICD J44.9).
- Liza (female, 55 years-old), affected by adult-onset asthma with acute exacerbation (ICD J45. 901).
- Sergei (male, 53 years-old); affected by age-related incipient cataract (ICD H25.0), which causes impairments in glare sensitivity (ICF b21020 “Light sensitivity”)
- Nina (female, 26 years-old), no particular health condition.

On the other hand, in Doha office there are 5 workers, defined by following characteristics:

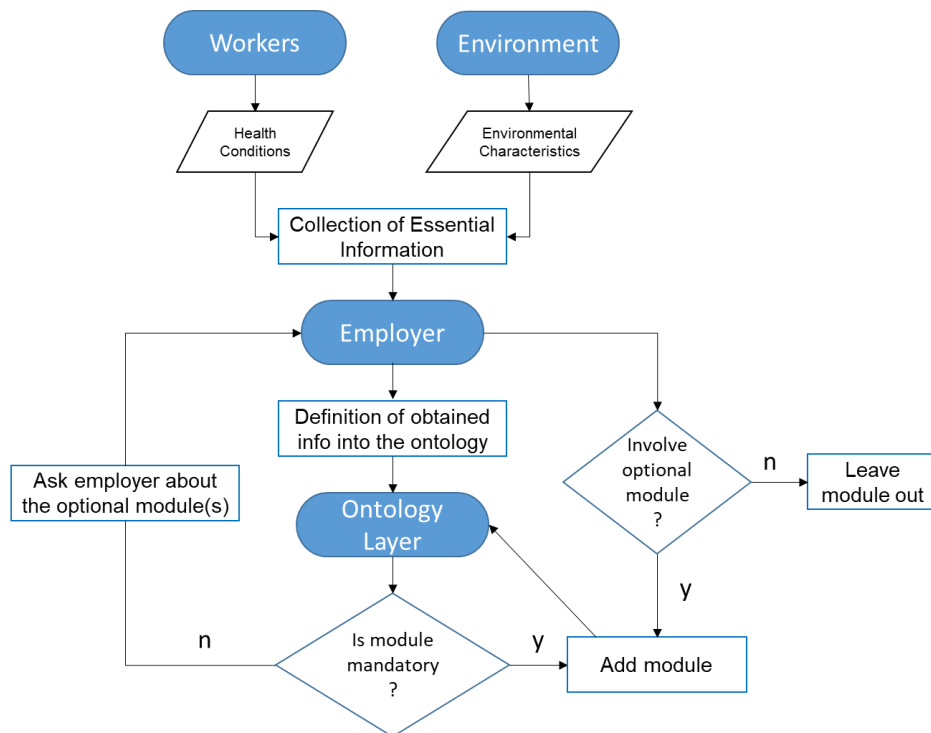
- Khalid (male, 61 years-old), affected by COPD (ICD J44.9).
- Mohamad (male, 57 years-old), affected by low visual acuity (ICF b21002 “Binocular acuity of near vision”); he wears corrective eyeglasses.
- Noora (female, 49 years-old); affected by adult-onset asthma with acute exacerbation (ICD J45. 901).
- Aisha (female, 34 years-old), no particular health condition.
- Nasser (male, 32 years-old), no particular health condition.

Employers in each factory acquire workers’ health condition and, by working together with them, leverage on the AAW ontology to identify the optimal indoor comfort metrics for each worker. Leveraging on reasoning and on workers’ ICF and ICD health models, each health condition mentioned above can be tackled specifically: Alex and Khalid’s statuses (COPD) require ideal indoor comfort to be specified as a CO<sub>2</sub> concentration lower than 800 ppm [26], temperature lower than 22 °C and the humidity rate up to 40% [27]. On the other hand, Noora and Liza – both suffering from asthma – can take advantage of a maximum CO<sub>2</sub> concentration of 700 ppm, a maximum temperature of 21.6° C and humidity rate no higher than 45% [28-29]. These comfort metrics are inferred in the ontology layer leveraging on both the health conditions and the best environmental conditions modelled in the semantic model. Considering the workers’ respiratory conditions, the ontology CO<sub>2</sub> module is required to be implemented for both locations, while the inferences regarding humidity rate for Doha and indoor temperature for Novosibirsk can be disregarded in the summer months, as the average values never exceed the defined thresholds to trigger exacerbation of health conditions of workers.

Regarding workers characterized by visual impairments, Sergei would benefit from working in a low illuminance area, whereas Mohamad needs a higher amount of illuminance to feel comfortable working. The ontology infers for Sergei a maximum illuminance of 650 lux, while the suggested illuminance for Mohammad is set to 750 lux. Under these circumstances, the employers can decide on not to include the module that is related to visual-aid adaptations. This is because the daylight levels in Novosibirsk is generally limited which is preferable for Sergei and they are always high

in Doha which is preferable for Mohamad. If the health conditions were the opposite, the use of visual-aid module would be inevitable in both locations.

In this scenario, employees and employers cooperate to define the ontology modules that can be adopted to actuate the tailored indoor comfort metrics. While temperature and humidity rate modules are active for most of the year in both regions, the adoption of other modules – tackling different health conditions – needs to be decided by all involved stakeholders.



**Fig. 1.** Flowchart of the collaborative process from the acquisition of information to selection of modules.

## 5 Conclusion

This paper introduced an ontology-based DSS for a healthier aging workforce by means of an AmI framework. It is shown how the collaborative ontology engineering allows a comprehensive yet personally tailored AAW framework for maintaining the wellbeing of each employee in a workplace. In addition, this is accomplished in a less-invasive and discrete manner thanks to the holistic functioning of the system. Leveraging on the interactions among employer, employees and environment, cooperative ontology-supported decisions are made to provide comfort for workers as required, without any implementation of an unnecessary measure.



Aprototypical testing on the use case given above is projected in STIIMA-Lecco, Smart Environments Laboratory. Through this application, it is planned to validate the applicability and scalability of the system, and to address privacy concerns, principally the data security as it is stored in the ontology. Among other future works there are the examination for further limits of expansion of collaborative ontologies with the target of comprising more comfort metrics, by inclusion of all the stakeholders that take part in the system and implementation of stress monitoring via providing workers and employers with blind data regarding stress, in order to provide further tailored suggestions (breaks, dedicated training on specific activities, etc.).

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