States measurement in a context of intelligent connected furnitures

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Abstract. The concept of intelligent connected furnitures opens new possibilities for the interaction between non animated objects. Actually intelligent connected furnitures are able to perceive their environment and can globally act as a measuring system. This paper presents how a community of objects acquire its own state. In this system, the measurement value is a weighted spatial ontology.

1. Introduction
The Internet of Thing is perceived as a pervasive presence around us of a variety of things or objects interacting between each other [1]. The given things are physical individuals, biological ones or virtual ones. The physical ones are mainly connected objects, the biological ones are connected humans or animals and virtual ones have no existence in the concrete world but are also able to propose services. A set of interacting things is designed as a community and a set of physical or biological interacting things is designed as a concrete community. The purpose of this paper is based on the principle that the elements of a community must know the potential and the concrete interactions between each other. This knowledge is mandatory inside a community in order to define the of services it can propose. Indeed, a community of objects may propose a set of services larger than the union of the sets of services proposed by its individual objects. More precisely, a subset of objects can propose services depending on the state of this subset. Such state is defined by the state of the objects and by the relations between objects. It is materialized by the relations inside this subset of objects and is represented by a physical ontology where the node entities are the physical objects or their parts, and the vertices are the relations [2].

The application field of our studies is defined by our partnership with a furniture manufacturer specifically concerned by a family of things that are the furnitures. In this context, the IoT community is made of smart furnitures like tables, chairs or sofa and of smart object already present in the furnitures environment: home automation devices that equip the house or the building, wearable devices and smart phones hold by the furniture users. The two main options to identify the state of an IoT community are : the acquisition of this information from an expert who is supposed to own it and who is able to transfer it, or the acquisition through a measuring system. In the specific context of
furniture, it is not possible to ask users to update the knowledge of smart furnitures each time he
moves a chair. Then the second option is to give perception capabilities to the furnitures. It has been
defined that the main need for perception for smart furnitures is the proprioception of the orientation.
Then all furnitures are equipped with at least a communication device a processor and a 3DoF
accelerometer. Due to cost limitations, the accelerometer is imposed.

To sum up, the goals of this study, is to embed a form of intelligence commonly named smartness
onto furnitures in order to promote them as smart connected objects in order to build a community of
object in a context of the IoT. This paper presents a solution to measure the situations, defined as the
states of a community of objects.

2. A model for the situations

As given in the introduction, the general model used for the representation of the community states is a
weighted spatial ontology, more precisely a mereotopology [3][4][5]. Ontologies are made of entities
and relations. In our concern, the entities are physical objects or physical parts of objects. The
relations are limited to the relations part_of and close_to. The part_of relation defines the link between
an object and his parts. This relation is a transitive and reflexive relation. The close_to relation is a
fuzzy version of the topological relation connected.

![Ontology representation including 2 instances of furnitures with their parts.](image)

The part_of relation is defined by the structure of objects that are supposed to be immutable during
their use. Then, as each element of the part_of relation links an object or a part with a part inside an
immutable structure, the part_of relation is also immutable.

Conversely, the close_to relation is able to change during the life of the object community. Indeed,
the objects can be added, removed, or moved. As the close_to relation leads to a closeness concept, we
chose to weigh the elements of the relation with a fuzzy closeness degree that represents the truth of
the assertion “instance a is close to instance b”.

Formally, a given ontology graph as shown in figure 1. is already a representative of the state of the
object community. In order to facilitate the use of the results, the global ontology graph is compared
with reference situations. Each reference situation is defined by a set of relations between objects and
represented by an ontology. When the ontology graph of a reference situation is a sub-graph of the
global ontology graph then the situation is realized. The state of the object community is then a set of
realised situations. As the general ontology graph is weighted with fuzzy degrees, the realisation itself
is also weighted by a fuzzy degree and the measurement result is a fuzzy subset of situations.
Practically, the degree of realisation of the situation “a chair close to a table” is the truthfulness of the
assertion “a table is close to a chair” that we represent by the weight of the close_to relation between a
table and a chair.
The goal of this paper is to propose a method to perform the measurement of the closeness between instances, i.e. objects or parts, on the base of incomplete and uncertain direct measurements of footsteps. Then to produce a result for measurement of the global state.

3. The seismic measurements

As the physical distance needs expensive measuring systems in the context of furnitures, we propose to define the closeness as an indirect measurement derived from near environmental measurements. One of these measurements is the seismic one. The idea is to perform the correlation between several measurements of a same vibration event produced by the environment of furnitures. Actually the smart furnitures already hold a 3DoF accelerometer ADLX345 associated to a small Arm7 plate-form with communication capabilities in order to get the 3 main respective functionalities: sensing, processing, and communicating. The goal of the study is then: is the embedded existing system of the smart furnitures enough to perceive the proximity of other furnitures?

Figure 2. presents an example of one of the seismic measurements performed by a table instrumented with an accelerometer. During this experiment, a chair is moved close to the smart table. In this example, 4 large events appear on the 3 axis. They are due to the direct contact of the chair with the table. We can remark also that smaller events appear only on the vertical axis (z). These last events are characteristic from seismic s-waves and fits with the impact of the chair on the floor.

![Accelerometer Measurements](image)

Figure 2. The accelerometer is sensitive on all axis to direct impacts like event A, and on the vertical axis only to indirect impacts like event B.

If we suppose that the objects doesn’t move during a long time, and that peoples are moving around the furnitures. The goal is to perceive the impact of shoes on the floor produced by human footseps in order to identify the correlation between impact events, then to estimate the closeness between smart furnitures. An other experiment where an impact of shoe is performed close to a smart table had been performed.

The difficulty of such measurement is given by the amplitude of the signal that is close to the quantization noise. Nevertheless, as it has been seen that the seismic s-waves signal produced by shoes impact has a low frequency under 100Hz. Then to extract the signal from quantization noise, the acquisition frequency had been fixed at 3200Hz that is the maximum available with the given accelerometer.

Considering footstep as seismic events they produce an elastic surface wave that can be detected an analysed respectively with sensors and algorithms devoted to the detection of seismic events [6][7]. The wavelet transformation is a privileged for that analysis of surface waves signals produced by
seismic events. We choose use the Morley wavelet transformation [8] to analyse the signal given by footstep events. indicates that seismic events can be extracted from the signal.

Figure 3. Wavelet coefficients power level computed with a Morley wavelet. 3 shoes impacts are measured. The vertical axis is the Fourier period and the horizontal axis is the translation coefficient.

The figure 3 shows the result of a Morley wavelet transformation of the signal produced by the vertical axis of the accelerometer during an experiment where a feet knock the floor close to the smart table. The Morley wavelet is defined by the complex function:
\[
\psi(t) = \pi^{-1/4} e^{i\omega t} e^{-t^2/2}
\]
And the wavelet coefficients \( W \) are computed by a convolution of the signal with a set of wavelet daughters obtained by dilatation and translation of the Morley wavelet.
\[
W(\tau, s) = \sum_t x_t \frac{1}{\sqrt{s}} \psi^*(\frac{t-\tau}{s})
\]
During this experiment, 3 events are produced every 2.5 seconds.

The wavelet transformation of a seismic wave packet indicates that it is made of 2 mono-frequency wave packets with frequencies respectively close to 24Hz and 40Hz and a third mono-frequency wave packet with frequencies between 100Hz and 130Hz (see figure 4). The second frequency of 40Hz fits with the results of the studies of Ekimov [9] on the vibration signature of the human footstep in buildings. The first one (24Hz) doesn’t appear in the same studies. It is possibly related to the material of the shoe. The third mono-frequency wave packet (between 100Hz and 130Hz) doesn’t appear in all events, as shown in figure 5, and is possibly related to the way the footstep is performed. These 2 hypothesis are not yet tested and are under study.

Figure 4: Details of the 1st event in the plane time/frequency (a). The wave packet is made of 3 mono-frequency wave packets as shown on the average of wavelet power on a 150ms window (b).
Figure 5. Details of the 3rd event in the plane time/frequency (a). The wave packet is made of 2 mono-frequency wave packets as shown on the average of wavelet power on a 150ms window (b).

At this step, the seismic events appear as wave packets with frequencies 24Hz and 40Hz. A threshold and a normalisation of the wavelet power for these 2 frequencies gives a fuzzy value that represent the truth that the event “footstep” occurred. The measurement result is a fuzzy value.

4. The closeness measurement

The definition of closeness needs another paper but is resumed below.

The closeness fuzzy value related to a \textit{close to} relation between 2 physical entities is supposed to value the truth of the assertion “entity 1 is close to entity 2” at a given time. We suppose that a period of time where the entities doesn’t move can be identified. We want then to reinforce our knowledge about the truth of this assertion during this period of time.

The closeness between objects is related the conflict between the measurement sources. Indeed, when the smart furnitures are close, they perceive similarly their environment, and the conflict between the information they produce is low. When they are far from each other, the conflict is also low for strong far events like a door slam but become high for small events like footsteps that are detected by one object but not by another one.

Within the field of uncertain information fusion approaches [10], the possibility theory and the evidence theory are potential candidates for the management of conflict.

The possibilistic approach qualifies an assertion with a measure of possibility and a measure of necessity. It is able to represent the impossibility, the lack of knowledge and the necessity. In the context of this study, the \textit{close to} relation is weighted by a couple possibility/necessity \((\Pi, N)\). At the beginning of the stable period, the couple is initialised with the couple \((1, 0)\) that represent the lack of knowledge. Each footstep event detected simultaneously by the 2 sources maintains a high possibility measure but a footstep event detected by one source but not the other improves the impossibility then reduces the possibility. This method is optimistic and doesn’t distinguish between the lack of knowledge and a totally possible \textit{close to} relation.

The evidence theory applied on the context of this study distributes a unitary amount of belief masses on the set \(\{\emptyset, \{a\}, \{\bar{a}\}, \Omega = \{a, \bar{a}\}\}\) where \(a\) is the assertion “entity 1 is close to entity 2”. This approach is more precise and distinguishes the full conflict (with belief masses on \(\emptyset\)) the certainty on the assertion or on the negation of the assertion, and the lack of knowledge (with belief masses on \(\Omega\)). At the beginning of the stable period all belief masses are on \(\Omega\). A footstep event detected simultaneously by the 2 sources transfers masses on \(\{a\}\). A footstep event detected by one source but not the other transfers masses on \(\emptyset\).
5. Conclusion

The measurement of the states of a community of connected smart furnitures is a challenge that must be faced to be able to propose a solution for the home-care support. This paper proposes a link from the higher level of modelling of object communities to the raw measurements. Despite the limited performance of the accelerometers embedded into smart furnitures, this study shown that the detection of small seismic events can be performed by the way of continuous wavelet transformation. The first results shown that the footstep can be recognized. This last point is important for the fusion process that will estimate the closeness. Indeed the smart furnitures must be able to distinguish small close seismic events that improve the belief into the closeness, from strong ones. The closeness is the pivot concept between the numerical measurement and the abstract representation of object communities. Its determination is the basic point to identify situations defined as states of object communities. The fusion at the higher level of imprecise information like the closeness is still under study.

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6. References

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