Anticipated, Sensed and Relevant: a framework for designing sensing-based networks

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Abstract

Applications for sensor networks are diverse and include environmental, industrial and personal services. Design proposals remain largely specific to niches and most research is based on unverified sets of assumptions. The introduction of improved sensing coverage does not necessarily match current theoretical models. There are reasons to believe that current design proposals erroneously presume a complete understanding of the phenomenon or activity under observation. This short paper is proposing a framework for facilitating the design of wireless sensor networks by taking into consideration some of the fundamental limitations they face.

1. Introduction

Progress in wireless, computing, and manufacturing technology is facilitating the integration of ubiquitous wireless sensors for personal and environmental applications. Improved spatial and temporal resolution of sampling sets alongside the design choice for cheaper but reduced-accuracy sensing packages bring new challenges to the existing verified models of the phenomenon or activity under observation. Expectations of convenience and cost of the finished systems promote genuine interest from user communities. Consequently, there is great pressure to validate research against realistic scenarios and experiment on improved field tests.

However, validating these new proposals has so far proved to be slow and highly laborious. The origin and correlations of unforeseen features of the observed system and unexplained exceptional and occasional variations on the readings puzzle researchers. Slow progress in producing common learning experiences is also hindering the understanding of the problems, arguably because design proposals remain largely specific to their own niches. Recent research reports large differences between the modelling scenarios and simplified test trials. For instance, Cardell-Oliver, et al. report disappointing results in collecting data from wireless sensors in a multi-hop network with the purpose of soil-moisture monitoring [2]. They suggest that deploying an operational multi-hop sensor network for environmental monitoring requires progressive experimentation; they also report larger variations of network performance and sensing accuracy in phase with the presence of rainfall. Similarly, Yan argues in favour of improving realism when modelling data handling techniques [11].

Presuming a complete understanding of the variables involved in the system under observation and the pertinent sensed variables may be one of the most significant obstacles for achieving more better design and experimental stages. Interest in monitoring a system partially originates from the limitations of the current state of understanding. We are proposing a practical framework for assisting the design of sensor networks by facilitating the identification of the scope of the observing system. The proposed framework is based on previous work introduced by the project Equator in [1]; this is explained further in the next section.

2. Background research

Recent research proposes different models for architecture and management of sensor networks; Serri, et. al, surveys the recent work in architecture and data management in sensor networks [7]. Kochhal, et.al initially mention the importance of addressing sensing perspectives, however, their interest focuses on a new self-organising algorithm and not in a framework [6]. Strohbach, et al. propose a model for collaborative sensing devices [8] that is pertinent to this work. Strobach's model structures software components on collaborative sensors in three dependant layers named inference, knowledge-base, and perception; a copy of this model is presented in Figure 1. The model makes a clear distinction between what it calls different types of knowledge: a-priori (initial), semi-static (rules) and adaptive (dynamic) knowledge and consequently making provisions to collect and process unexpected trends.

Benford, et. al introduced a framework named "Expected, sensed and desired" for designing sensing-based interaction [1] – based on the authors' interest in designing pervasive interfaces for perceiving human activity – which can be extended and updated to suit our interests. The specific component of Benford's model that interests us is illustrated in Figure 2. This model suggests that the collection of sensors deployed for monitoring activity inherently produces readings that were not initially considered; it also suggests that it is possible that the produced readings do not provide enough data for characterising the observed activity.

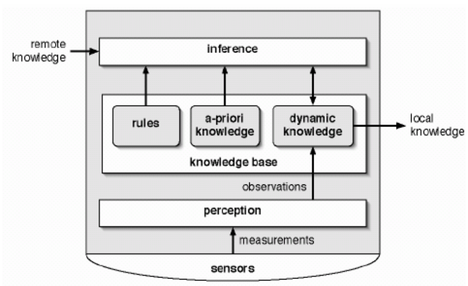

Figure 1 Perception model by Strohbach

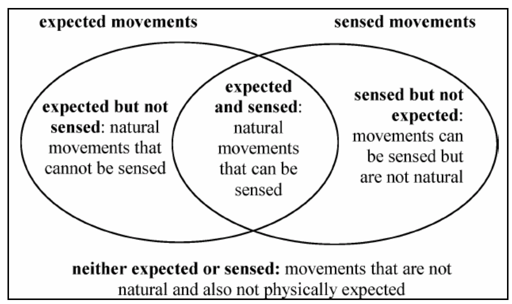

Figure 2 Benford's Framework

3. Anticipated, Sensed and Relevant

We believe that this framework can facilitate the design process in the early stages because its considerations for flexibility would provide benefit throughout the system's engineering cycle. Design specifications would reflect more accurately the degree of uncertainty the systems needs to handle and make appropriate provisions. It proposes two complementary sub-models: the "Anticipated vs. sensed" and the "Sensed vs. Relevant"; the schematic representations of these two models are shown in Figure 3 and Figure 4 respectively.

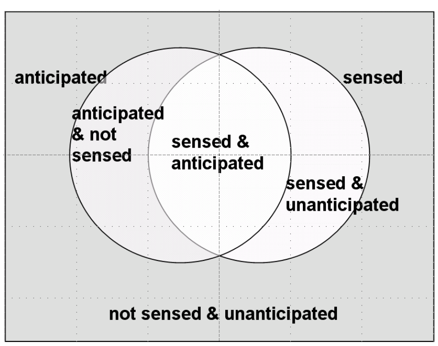

Figure 3 Anticipated vs. Sensed model

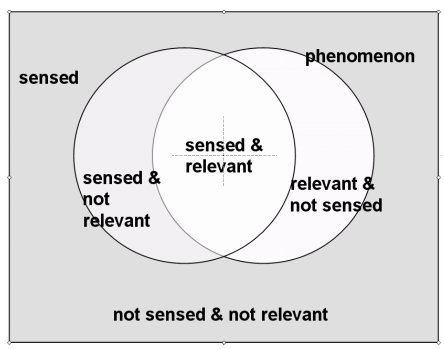

Figure 4 Sensed vs. Relevant model

The Sensed domain captures the capabilities of the deployment for obtaining information about the observed system; these capabilities are bound by the technological, resolution and stability constraints of the embodiment and placement of the sensing devices. The sensed domain captures readings which can be used to obtain a representation of the state or changes in the state of the system. The Anticipated domain encapsulates the list of requirements the observing system is expected to satisfy. This domain needs to list the methods for processing data as well as drafting the procedures for handling exceptional or unanticipated events. It is always the case that surprise events are of interest both for improving the design and exploring new research areas. The Relevant domain is a representation of the real events taking place that the observing system should usually capture. As with the other two domains, its borders are not hard delimited, and an adaptive system should provide mechanisms for redefining it. The space covered by the Relevant domain is as important as the space not covered by it. Recognising that other phenomenon occurring in the vicinity of the system might influence the sensing system plays an important role in designing adaptive systems.

3.1 Anticipated vs. sensed

Sensed & Anticipated. Designers will want to keep this region as comprehensive as possible; it provides a direct parameter for the current efficiency of the observing system. Consequently, the risk of over-providing resources on this region is very high.

Anticipated & not sensed. Initial expectations for detecting certain aspects of the target phenomenon are likely to be missed after initial tests. Providing early exploratory tests for evaluating this aspect will improve the quality of results in later stages. Reviewing the choice of sensing devices in regards to the natural compromise between cost and “fitness for purpose" is recommended. Some requirements may need to be downgraded or modified as a consequence. Under-sampling can be mentioned as the most common case in this respect; recent research on problems associated with placing sensors and wireless devices for assuring the level of coverage and availability has brought to light decisive conclusions. Huang in [5] surveys recent work addressing the problem, including Fanimokun in [3], who discusses issues of effects that natural scenarios produce on propagation patterns and consequently in the expected coverage. It can be deduced from the similarly raised conclusions which go against earlier belief, that sensor placement requires careful planning from the early stages of the sensor network design.

Sensed & Unanticipated. This region provides space for analysing the origin of signals that cannot be explained by conventional methods and avoid their consideration in the grounds of not being understood. Holman in [4] reports that information of shore activity can be gathered from off-shore video-monitoring – deduced after analysing collected data in earlier experiments and not originally intended in earlier designs. Van Laerhoven in [10] discusses accuracy and density issues of sensor array arrangements, including addressing issues related to the handling of unexpected readings.

Not anticipated & not sensed. The range of activity in this region has been probably left out due to lack of interest at the planning stages. Despite of the possibility for ignoring its contents, it is possible that adventurous changes in the sensing capabilities bring them to the region of Sensed & Unanticipated. Identifying the presence of factors that make certain variables unable to be economically sensed and/or non-informative for the purposes of the observing system will produce a more comprehensive and flexible specification.

3.2 Sensed vs. Relevant

Sensed & Relevant. This region fulfils a similar function to Sensed & Anticipated but with the specific purpose of highlighting how effective the sensing efforts are in capturing the phenomenon of interest. Clear relationships between sensed variables and their proportional contribution on the unequivocal characterisation of the phenomenon or activity are drawn here. Listed in a suitable format, this region should assist the identification of sensing regimes and devices that produce highest impact. This region actually provides a rich environment for discovering unusual and unexpected patterns

Sensed & not Relevant. Some of the collected data is likely to assist in the characterisation of a different phenomenon from the one originally intended and they represent a sub-product of deployment. Complementing the purpose of the Sensed & Relevant region, feeds information about the opportunities about the exploitation or restructuring of sensing regimes. Data originating from this region may not play an important role in characterising the phenomenon, however, it could provide temporal and spatial contextual information to support the detection of the phenomenon. Noise is naturally placed in the Sensed & not relevant region.

Relevant & not sensed. This region lists the range of variables – that regardless of their feasibility to be sensed – have being ignored – as consequence of an informed decision or lack of understanding of the phenomenon. This region's variables may correlate with already sensed variables; however, lower value of the information does not always justify the expense and/or does not contribute with the specific interest of the application. A conscious decision for providing additional redundancy may change the latter. For instance, Szewczyk identified unexpected patterns on sensing readings but it reported satisfactory identification of the target activities [9].

4. Conclusions and next steps

Recent experiences in deploying sensor networks suggest that exploratory topologies should be explored to establish best design; it has been suggested that the proposed framework can be a useful tool in this aspect. The framework raises awareness of unexpected factors when designing sensing-based applications; it also facilitates identifying the characterisation of the outcome of previous deployments, thereby improving the likelyhood of success for future ones. Designers using this model may find it useful for focusing their attentions on the key aspects that demand adaptive and intelligent capabilities. Additional practical work using the model is planned. We plan to extend the model to systematically address collaboration and adaptive capabilities in the near future.

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