CHAPTER 8

CONCLUSIONS

In this chapter, work done in the thesis is summarized. Key contributions and aspects of future work have also been elaborated.

8.1 OVERALL SUMMARY OF WORK DONE

In second chapter, Wireless Sensor Network related literature was surveyed to understand related contemporary developments and existing research issues. An important finding was that from applications, assumptions, scale of deployment and protocol design point of views WSN can be divided into at least two categories. These have been termed as Large-scale homogeneous and Small-scale heterogeneous WSNs respectively. Issues related to handling and effective utilization of huge sensor streams was found to be of recent interest. So, this research considered sensor data related issues.

Given the difference in nature of emitted data, data dissemination issues were reviewed separately for both categories of sensor networks. Aggregation and fusion were found to be fundamental techniques for extraction of meaningful, reliable and timely information from the deployed network. These have to be supported by in situ processing on node being queried to reduce communication cost. It was also found that sensor fusion needs to be equipped to deal with sensor failures, corrupted data and compatibility of sensors. Data mining methods for sensor data should be adapted to do online mining in presence of sensor constraints and errors.

While investigating solutions to challenges posed in handling volumes of sensor data, context awareness was identified as useful abstraction of various data sources including sensors. Chapter 3 was devoted to this study. Human beings are understood to have implicit and clear understanding about background of interaction that is, “context”, and they adapt and behave accordingly. Identification and adaptation to context by certain sensor based devices without human intervention has been a research area since quite some time. However, these are limited to
very trivial context as data from single device only was used. The ideas of context abstraction has been leveraged and expanded for large scale sensor data management and abstraction.

For purpose of extracting and utilizing context, existing context models were surveyed. It gave rise to few major findings. Firstly, available models are more of meta-models and didn’t provide sensor specific methods of context extraction. There is no available approach for mapping data sources of specific contexts. Finally, most models don’t support hierarchical abstractions. Extracting only trivial contexts from data is not very useful for end user. Another higher level abstract concept of automated situation and situation models was then surveyed. Representation methods to identify, use and make context and situation available have been studied. Computational methods for real time determination of context values from sensors and situation values from contexts were also explored. As an outcome of knowledge acquired from related studies, a framework was designed to hierarchically compute situations from sensors via intermediate contexts. In subsequent chapters implementation of designed framework was described and evaluated.

In Chapter 4, first step of generic on-node processing of sensor data for efficient transmission and higher level abstraction was described. Processing steps were done to eliminate redundancies and at the same time preserving characteristics of original information. Exhaustive testing on different alternatives for all processing sub steps has been done to find most optimal combination of all parameters to be used in actual implementation. As a result of processing, sensor data was transformed to a low logical level as context attributes.

Chapter 5 describes context definition and extraction of multiple co-existing contexts. Mechanisms were worked out for sensor to context mapping and construction of Bayesian Belief Networks (BBN) based model for automated context extraction. Popular BBN learning algorithms were evaluated for choice of modelling algorithm. As no existing algorithm was found to be unanimously best, a novel algorithm was proposed. Proposed algorithm uses principles of evolutionary computing and provides better results than existing ones. Good results were obtained in terms of accuracy and computation time taken to predict the feature values.
Methods to detect higher level situations from extracted contexts have been described in Chapter 6. Lattice based model was proposed for this purpose. Proposed model was tested for inferring indoor activities of a person living alone in a house. Good recognition results were obtained across houses and persons. Further, to address the challenge of ambiguities in contextual composition of situation, lattice based model was improved to neutrosophic logic based model.

Widespread availability of sensor data and abstracted information was the subject matter of Chapter 7. A semantic web service framework to do so was proposed here. Implementation of the processes for the discovery of WSN Service, user registration and finally delivery of the requested information were described. These schemes and processes will make Sensing as a Service feasible.

### 8.2 CONTRIBUTIONS AND CONCLUDING REMARKS

In this work, methods of context and situation computation from sensor data were explored. The main contributions are:

- Investigation of contemporary research issues in WSNs and Data Handling
- Framework for hierarchical fusion of multi sensor multi rate data as Contexts and Situations
- Empirical study of methods of local sensor processing for low level abstraction
- Developed heuristics for online segmentation of sensor data and its evaluation
- Developed method for type and number of context identification from application data
- Development of bio-inspired meta heuristic based algorithm to obtain contexts from uncertain low level abstractions
- Developed a formal concept lattice based model to map and organize situations in terms of available Contextual Information (CI)
- Improved the lattice model to include neutrosophic membership concepts to quantize inherent indeterminism in situation description
- Develop soft inference process to reveal inadequacy of underlying contextual description in definition of target situations
• In the wider context of this problem, the use of fused sensor data as service to remote
users has been conceptualized.

The results obtained for context classification and situation recognition using techniques
proposed in this work were found to be better than some of the existing techniques evaluated.
The difference in performance was up to 10-15% in terms of recognition accuracy specifically on
noisy data.

8.3 SCOPE OF FURTHER WORK

In the data fusion framework, single situation calculating server may be undesirable due to lack
of fault tolerance and uneven loading. Depending upon application scale and budget, multiple
situation computation processors can be designated. The situation computation then can be
scheduled over all these by imposing some predefined or dynamic structure like trees to spread
the computation evenly and also achieve fault-tolerance.

In this thesis, Bayesian belief networks and concept lattice based methods have been developed
for extracting contexts and situations from sensor data. Virtual home setting environments of
various laboratories have been used for case studies due to free public availability of multi modal
sensors with ground truths in this domain. To demonstrate more generic applicability of these
methods, it would be interesting to evaluate in diverse environments like offices, factories and
outdoor field monitoring for climate or security monitoring. The methods have been tested with
only one user in the monitored environment. Performance testing of complicated environments
with presence of more people at a time can be done in future.

Besides type, the scale of monitoring can also be increased. For example, home monitoring
solutions can be scaled to monitoring of buildings having same scale. This work proved that the
lattice structure has a powerful expressive ability in representing the semantics of situation
information. Use of Neutrosophic lattice has demonstrated efficiency in handling ambiguities
and non-determinism in situation composition. Domain specific more effective functions for
determining indeterminism can be further explored.
One of the main bottlenecks in popularizing sensor based information systems is domain and instance dependence. There is a scope of working towards generic plug and play solutions valid for any scale and type of WSNs. Tools to help WSN designer setup customized sensor mappings, context attributes, context definitions etc. can also be developed as future work.

Current research has largely focused on datasets collected in research labs or by environments occupied by researchers. When real-world environments are used, more complexities appear, such as situation interruption, multi-tasking, multiple users, and unexpected user behaviour. It would be interesting to study performance of proposed methods in such scenarios.

This research and its outcomes will be beneficial in Tele-monitoring applications aimed at providing patient-centered, timely and location-independent healthcare, detection of abnormal situations and consequent appropriate action to arrest the abnormal situation etc.