Real-Time Fusion of Wireless Sensor Network Data for Wellness Determination of the Elderly in a Smart Home

A thesis presented in partial fulfilment of the

requirements for the degree of

Doctor of Philosophy

in

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New Zealand

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Abstract

In this research, I have explored a methodology for the development of efficient electronic real time data processing system to recognize the behaviour of an elderly person. The ability to determine the wellness of an elderly person living alone in their own home using a robust, flexible and data driven artificially intelligent system has been investigated. A framework integrating temporal and spatial contextual information for determining the wellness of an elderly person has been modelled. A novel behaviour detection process based on the observed sensor data in performing essential daily activities has been designed and developed. The model can update the behaviour knowledge base and simultaneously execute the tasks to explore the intricacies of the generated behaviour pattern. An initial decline or change in regular daily activities can suggest changes to the health and functional abilities of the elderly person.

The developed system is used to forecast the behaviour and quantitative wellness of the elderly by monitoring the daily usages of household appliances using smart sensors. Wellness determination models are tested at various elderly houses, and the experimental results related to the identification of daily activities and wellness determinations are encouraging. The wellness models are updated based on the time series analysis formulations. The integrated smart sensing system is capable of detecting human emotion and behaviour recognition based on the daily functional abilities simultaneously. The electronic data processing system can incorporate the Internet of Things framework for sensing different devices, understand and act according to the requirement of smart home environment.

Dedication

I dedicate this thesis to the elderly people living alone.

Acknowledgements

Firstly, I would like to express my sincere gratitude to my Guru: Prof. Subhas Chandra Mukhopadhyay, who has given me the opportunity to undergo my Ph.D. study under his excellent supervision. Prof. Subhas has taught me how to handle complex situations by inducing constructive concepts with fruitful cooperation and providing facilities in a timely manner. I also thank Dr. Ruili Wang and Dr. Ramesh Rayudu who have been my co-supervisors for providing me with valuable suggestions at different stages of my research.

I would particularly like to thank the elderly people (names and addresses are not mentioned due to privacy issues) for their immediate acceptance in deploying the developed home monitoring system at their houses and being tolerant to frequent visits/consultations during the troubleshooting phases of various tasks of the project.

I would like to also thank all my previous and present research scholars working in the School of Engineering and Advanced Technology, Massey University for their kindness and friendship. Many thanks also go to SEAT staff for being supportive in hard times. Financial support from Massey University Doctoral Scholarship program and the School of Engineering and Advanced Technology is also gratefully acknowledged.

I am extremely grateful to my parents, for their sacrifice and giving me the opportunity that they never had. I would also like to express my gratitude to my wife and children for their support in undertaking and sharing the family responsibilities in my absence.

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List of Publications, Contributions and Achievements during the PhD study (2011-2014)

Awards/Recognition:

1. Recipient of **Massey University doctoral scholarship** for three years (Aug-2011 to Jul-2014).
2. **Winner - Best Student Paper**-2013 for the paper titled: "A Smart Healthcare Monitoring System for Independent Living" presented at the HINZ Conference & Exhibition-27th Nov-2013, Rotorua, New Zealand.
3. Selected as one of the 10 finalists to the Best Student Poster Award of the IEEE - I2MTC 2013 held at Minneapolis, MN, USA, May 6-9, 2013.
4. Selected (as one of six papers) for the special issue as extended paper presented at International Conference on Intelligent Environments (IE'12), 2012, Guanajuato, Leon-Mexico.

Journal/Magazine Publications: (6)

1. **Suryadevara N.K**, Mukhopadhyay S.C, "Determination of Wellness of an Elderly in an Ambient Assisted Living Environment," Accepted for publication in IEEE Intelligent Systems-May 2014, (Acceptance rate for manuscripts is under 10%, **5 Yr Impact Factor: 2.538**) (Thomson Reuters(SCI)-World's leading journals Review)

2. **Suryadevara N.K,** Mukhopadhyay S.C, Wang R, Rayudu R.K, "Forecasting the behavior of an elderly using wireless sensors data in a smart home", **Elsevier: Engineering Applications of Artificial Intelligence**, Vol: 26, Issue: 10, Page(s): 2641-2652. **5 Yr Impact Factor : 1.947 (**Thomson Reuters(SCI)-World's leading journals Review)

3. **Suryadevara N.K**, Mukhopadhyay S.C, "Wireless Sensor Network Based Home Monitoring System for Wellness Determination of Elderly", **IEEE Sensors Journal**, Vol: 12, Issue: 06, Page(s):1965 – 1972. **5 Yr Impact Factor: 1.758 (**Thomson Reuters (SCI)-World's leading journals Review)

4. **Suryadevara N.K**, Gaddam A, Rayudu R.K, Mukhopadhyay S.C, "Wireless Sensors Network Based Safe Home to Care Elderly People: Behaviour Detection", **Elsevier: Sensors and Actuators: A Physical** (2012), Vol: 186, Page(s):277-283. **5 Yr Impact Factor: 2.084** - **(**Thomson Reuters (SCI)-World's leading journals Review)

5. **Suryadevara N.K**, Mukhopadhyay S.C, Kelly S.D.T, Gill S.P.S, "WSN-Based Smart Sensors and Actuator for Power Management in Intelligent Buildings", **IEEE Transactions on Mechatronics**, (Early Access Article) : doi: 10.1109 / TMECH . 2014. 2301716. **5 Yr Impact Factor: 3.39** (Thomson Reuters (SCI)-World's leading journals Review)

6. Kelly S.D.T, **Suryadevara N.K**, Mukhopadhyay S.C, "Towards the Implementation of IoT for Environmental Condition Monitoring in Homes", **IEEE Sensors Journal**, Vol: 13, Issue: 10, Page(s): 3846 – 3853. **5 Yr Impact Factor: 1.758 (**Thomson Reuters (SCI)-World's leading journals Review)

Conference Proceedings: (16)

1. **Suryadevara N.K**, Gaddam A, Rayudu R.K, Mukhopadhyay S.C, "Wireless Sensors Network Based Safe Home to Care Elderly People: Behaviour Detection", Elsevier Proceedings of the EuroSensors XXV-2011, Procedia Engineering: Vol25, Pages: 96-99.

2. **Suryadevara N.K**, Mukhopadhyay S.C, "Wireless sensors network based safe home to care elderly people: A realistic approach", Proceedings of the IEEE Recent Advances in Intelligent Computational Systems (RAICS)-2011, DoI: 10.1109/RAICS.2011.6069262, Page(s):001–005.

3. **Suryadevara N.K**, Quazi M.T and Mukhopadhyay S.C, "Intelligent Sensing Systems for measuring Wellness Indices of the Daily Activities for the Elderly", Proceedings of the Eighth International Conference on Intelligent Environments (IE'12)-Guanajuato-Mexico-2012, IEEE Computer Society, DOI 10.1109/IE.2012.49,Pages:-346-350.

4. **Suryadevara N.K**, Gaddam A, Mukhopadhyay S.C, Rayudu R.K, "Wellness determination of inhabitant based on daily activity behaviour in real-time monitoring using Sensor Networks", IEEE Proceedings of the Fifth International Conference on Sensing Technology (ICST), 2011, DoI: 10.1109 /ICSensT.2011.6137025, Page(s):474–481.

5. **Suryadevara N.K**, Mukhopadhyay S. C, Rayudu R.K., Huang Y.M, "Sensor data fusion to determine wellness of an elderly in intelligent home monitoring environment", Proceedings of IEEE International Conference Instrumentation and Measurement Technology (I2MTC)-Austria-2012, DoI:10.1109/I2MTC.2012.6229645,Page(s): 947 – 952

6. **Suryadevara N.K**, Mukhopadhyay S.C and Rayudu R.K, "Applying SARIMA Time Series to Forecast Sleeping Activity for Wellness Model of Elderly Monitoring in Smart Home" Proceedings of the IEEE 6th International Conference on Sensing Technology (ICST), India-2012,Page(s):157-162.

7. **Suryadevara N.K**, Mukhopadhyay S.C, Wang R, Rayudu R.K and Huang Y.M , "Reliable Measurement of Wireless Sensor Network Data for Forecasting Wellness of Elderly at Smart Home", Proceedings of the IEEE International Conference on Instrumentation and Measurement Technology (I2MTC)-Minneapolis-2013, Page(s):16-21.(Top 10 of the best student papers)

8. **Suryadevara N.K**, Chen C.P, Mukhopadhyay S.C, Rayudu R.K, "Ambient Assisted Living Framework for Elderly Wellness Determination through Wireless Sensor Scalar Data", Proceedings of the IEEE 7th International Conference on Sensing Technology (ICST), Wellington-NZ-2013, Page(s): 632-639.

9. **Suryadevara N.K**, and Mukhopadhyay S.C, "Smart Healthcare Monitoring System", *www.hinz,org.nz*. Health Informatics New Zealand, Pub: 20 Dec 2013. Retrieved on: Thu. 10 Apr 2014. <http://www.hinz.org.nz/uploads/file/2013conference/Smart Healthcare Monitoring System - Suryadevara.pdf>.

10. Mukhopadhyay S.C, **Suryadevara N.K**, "Homes for Assisted Living: Smart Sensors, Instrumentation, Energy, Control and Communication Perspective", Proceedings of IEEE International Conference on Control, Instrumentation, Energy & Communication (CIEC)-Kolkata-India, 2014, ISBN: 978-1-4799-2043-3, Page(s):9-14.

11. Kelly S.D.T, **Suryadevara N.K** and Mukhopadhyay S.C, "Integration of Zigbee-IPv6 Networks for Smart Home Sensor Data Transmission to Augment Internet of Things", IB2COM-Australia-2012, ISBN: 978-0-9872129-1-7, Page(s)-44-49.

12. Gill S.P.S, **Suryadevara N.K** and Mukhopadhyay S.C, "Smart Power Monitoring System Using Wireless Sensor Networks", Proceedings of the IEEE 6th International Conference on Sensing Technology (ICST), India- 2012, Page(s):444-449.

13. Kam M.H, **Suryadevara N.K**, Mukhopadhyay S.C, Gill S.P.S, "WSN Based Utility System for Effective Monitoring and Control of Household Power Consumption", Proceedings of IEEE I2MTC 2014 conference, IEEE Catalog number, CFP14IMT-USB, ISBN: 978-1-4673-6385-3, Page(s):1382 – 1387.

14. Quazi, M.T.; Mukhopadhyay, S.C.; **Suryadevara N.K**.; Huang, Y.M. "Towards the smart sensors based human emotion recognition", Proceedings of IEEE International Conference Instrumentation and Measurement Technology (I2MTC)-Austria-2012, DoI: 10.1109/I2MTC.2012.6229646, Page(s): 2365 – 2370.

15. Alabri, H. M, Mukhopadhyay S. C, Punchihewa G. A, **Suryadevara, N.K,** Huang Y.M, "Comparison of applying sleep mode function to the smart wireless environmental sensing stations for extending the life time", Proceedings of IEEE International Conference Instrumentation and Measurement Technology (I2MTC)-Austria-2012, DoI: 10.1109/I2MTC.2012.6229641, Page(s): 2634 – 2639.

16. Chen C.P, Jiang J A, Mukhopadhyay S.C, **Suryadevara N.K**, "Performance Measurement in Wireless Sensor Networks using Time-Frequency Analysis and Neural Networks", Proceedings of IEEE I2MTC 2014 conference, IEEE Catalog number, CFP14IMT-USB, ISBN: 978-1-4673-6385-3, Page(s):1197-1201.

Book Chapters: (5)

1. **Suryadevara N.K,** Quazi T, Mukhopadhyay S.C, "Smart Sensing System for Human Emotion and Behaviour Recognition", M.K.Kundu et al. (Eds): PerMIn 2012, Springer: Perception and Machine Intelligence, Verlag Berlin Heidelberg, Lecture Notes in Computer Science, 7143, pp: 11-22, 2012.

2. **Suryadevara N.K**, Kelly S.D.T, and Mukhopadhyay S.C, "Ambient Assisted Living Environment Towards Internet of Things Using Multifarious Sensors Integrated with XBee Platform", Smart Sensors, Measurement and Instrumentation, Vol. 9, Internet of Things: Challenges and Opportunities, ISBN 978-3-319-04222-0, Springer-Verlag, by S. C. Mukhopadhyay, 2014, pp. 217-236.

3. Mukhopadhyay S.C and **Suryadevara N.K**, "Internet of Things: Challenges and Opportunities", Smart Sensors, Measurement and Instrumentation, Vol. 9, Internet of Things: Challenges and Opportunities, ISBN 978-3-319-04222-0, Springer-Verlag, by S. C. Mukhopadhyay, 2014 pp. 1-18.

4. Mukhopadhyay S.C, **Suryadevara N.K** and Rayudu R.K, "Are Technologically Assisted Homes Safer for the Elderly", Smart Sensors, Measurement and Instrumentation, Vol. 2, Pervasive and Mobile Sensing and Computing for Healthcare: Technological and Social Issues, ISBN 978-3-642-32537-3, Springer-Verlag, by S. C. Mukhopadhyay, and O. Postolache, 2012, pp. 51-68.

5. Significant contribution to the book chapters 5 and 6 for the book titled "Intelligent Sensing, Instrumentation and Measurements", Springer International Publishing, 2013, ISBN: 978-3-642-37027-4.

Google Scholar Citations:
http://scholar.google.co.nz/citations?hl=en&user=S28OdGMAAAAJ

Significant Contributions/achievements

IEEE Sensors Journal Top 25 Download

1. Article titled: "Wireless Sensor Network Based Home Monitoring System for Wellness Determination of Elderly", IEEE Sensors Journal, Vol. 12, No. 6, June 2012, has been one of the 25 most downloaded Sensors Journal papers for 8 out of 12 months in 2012 and Jan-2013.

2. Article titled: "Towards the Implementation of IoT for Environmental Condition Monitoring in Homes", IEEE Sensors Journal, Vol. 13, No. 10, October 2013, has been one of the 25 most downloaded Sensors Journal papers in the months of September, October 2013.

Elsevier: Most Downloaded Engineering Applications of Artificial Intelligence Articles

Article titled: "Forecasting the behavior of an elderly using wireless sensors data in a smart home" Elsevier: Engineering Applications of Artificial Intelligence, Vol: 26, Issue: 10, Page(s): 2641-2652, 2013, has been one of the most downloaded articles in the month of March-2014.

Tutorial Offered

1. Practical demonstrations on design and development of Wireless Sensing system and the Graphical User Interface system was delivered at 5th International Conference on Sensing Technology, Nov. 28th - Dec. 1st, 2011, Palmerston North, New Zealand.

2. Practical demonstrations on design and development of Wireless Sensing system Graphical User Interface system was delivered at 6th International Conference on Sensing Technology, Dec.18 - Dec.21, 2012, Kolkata, India.

3. Practical demonstration on the application of wireless sensor network was delivered at IEEE-I2MTC-2014 conference May 11-14, 2014 held at Montevideo, Uruguay.

Keynote Talk

On Behalf of Prof.S.C.Mukhopadhyay a Keynote talk was delivered at 4th International Conference on Signal and Image Processing (ICSIP) held at Coimbatore, Tamilnadu–India -13 to 15 December-2012. Title of the talk: "Are WSN Assisted Homes Safer for the Elderly? A Smart Signal Processing Perspective", Date: 13-Dec-2012.

News Letter Articles

Article titled "Internet of Things: A Review and Future Perspective" by N.K.Suryadevara and S.C.Mukhopadhyay was contributed in the May/June 2014 edition of The European Business Review.URL: http://www.europeanbusinessreview.com/?p=4431

Article titled: "An Intelligent Integrated Healthcare Platform for Wellbeing and Independent Living" by By Subhas Mukhopadhyay and Nagender Suryadevara was contributed in the IEEE Life sciences-March -2013 Issue. Url: http://lifesciences.ieee.org/publications/newsletter/march-2013/293-an-intelligent-integrated-healthcare-platform-for-wellbeing-and-independent-living

In News: (http://telecommunications.verticalnews.com/articles/7081324.html)
Date: 06-Jun2-2012, Vertical News: Telecommunication: Study Data from Massey University Update Knowledge of Sensor Research.

Seminars/Presentations

I have presented my research outcomes in the following occasions:

Special Presentations:

1. Title: Wellness determination of an elderly using Wireless Sensors Data in a Smart Home
Date: 03-May-2013
Venue: Electrical and Computer Engineering Department
College of Engineering, University of Missouri, Columbia, MO, USA

2. Title: Wireless Sensing System for Elderly Independent Living
Date: 01-May-2013
Venue: The Aware Home Research Initiative
479 10th st NW, Atlanta, GA 30318, USA

3. Title: Applying SARIMA Time Series to Forecast Sleeping Activity for Wellness-Model of Elderly Monitoring in Smart Home
Date: 18-Feb-2013.
Venue: IEEE-I&M Chapter-NZ
Workshop on Smart Sensors - Instrumentation and Measurement
University of Waikato, Hamilton-New Zealand

4. Title: Time Series Analysis of Sensing Data for Smart Home
Date: 11-April-2012.
Venue: IEEE-I&M Chapter-NZ
Workshop on Smart Sensors Measurements and Instrumentation: Applications to agricultural and environmental monitoring
Lincoln University, Christchurch-New Zealand

Conference Presentations: (Oral)

1. Title: Wellness determination of inhabitant based on daily activity behaviour in real-time monitoring using Sensor Networks
Date: 30-Nov-2011, Venue: IEEE-Fifth International Conference on Sensing Technology (ICST), 2011, Massey University-Palmerston North, New Zealand

2. Title: Intelligent Sensing Systems for measuring Wellness Indices of the Daily Activities for the Elderly (Doctoral Colloquium)
Date: 27-June-2012, Venue: IEEE-Computer Society-Eighth International Conference on Intelligent Environments (IE'12)-Guanajuato-Mexico.

3. Title: Applying SARIMA Time Series to Forecast Sleeping Activity for Wellness Model of Elderly Monitoring in Smart Home
Date: 18-Dec-2012, Venue: IEEE-6th International Conference on Sensing Technology (ICST), Kolkata, India- 2012

4. Title: Ambient Assisted Living Framework for Elderly Wellness Determination through Wireless Sensor Scalar Data
Date: 04-Dec-2013, Venue: IEEE-7th International Conference on Sensing Technology (ICST), Wellington-NZ-2013

5. Title: Performance Measurement in Wireless Sensor Networks using Time-Frequency Analysis and Neural Networks
Date: 15-May-2014,Venue: IEEE-I2MTC-2014,Montevideo,Uruguay

Poster presentation:
Title: Reliable Measurement of Wireless Sensor Network Data for Forecasting Wellness of Elderly at Smart Home
Date: 07-May-2013.
Venue: IEEE-International Conference on Instrumentation and Measurement Technology (I2MTC)-Minneapolis-USA-2013.

Contribution to the post graduate student thesis supervision's

I have contributed to the supervision of the following students while they were studying under Prof.S.C.Mukhopadhyay, SEAT, Manawatu Campus, Massey University-New Zealand.

Student Name	Degree, Year	Thesis Title
Anuroop Gaddam	Ph.D., 2012	Wireless Sensor Network Based Smart Home for Elder Care
Tauseef Qazi	Master, 2012	Sensors System for Emotion Recognition
Sean Kelly	Master, 2013	Design and Implementation of Internet of Things for Home Environment
Satinder Singh Gill	Master, 2013	Smart Power Monitoring Utility System Using Wireless Sensor Networks.
Vinok Verma	M.Eng. Studies, 2014	Data Fusion from two communication protocols
Mohammed Serhan Al Ghamdi	PG. Diploma, 2012	Medicine Dispenser for Eldercare
Hatim Al Abri	Bachelor Honours, 2012	Smart Wireless Environmental Sensing Station
MunHaw Kam	Bachelor Honours, 2013	WSN based Smart Grid for Utility System
Mohammad Anas	Bachelor Honours, 2014	Energy Harvesting Techniques for Sensor Node in Wireless Sensor Network (WSN)
Manaseh Togagi	Bachelor Honours, 2014	WSN and IoT in relation to a Tourist Perspective

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IEEE Sensors Council

March 11, 2013

TO:
Mr. Nagender Kumar Suryadevara, Massey University, New Zealand
Dr. Subhas Chandra Mukhopadhyay, Massey University, New Zealand

Dear Mr. Suryadevara and Dr. Mukhopadhyay:

On behalf of the IEEE Sensors Council I am pleased to congratulate you, the coauthors of the paper *Wireless Sensor Network Based Home Monitoring System for Wellness Determination of Elderly*, IEEE Sensors Journal, Vol. 12, No. 6, June 2012, for your paper being one of the 25 most downloaded Sensors Journal papers for 8 out of 12 months in 2012. It is exciting to note that included in this count are all Sensors Journal papers published since its foundation, about 1000 papers in total. You can view the latest Top 25 papers at:

http://ieeexplore.ieee.org/xpl/topAccessedArticles.jsp?punumber=7361

Thank you for your contribution to the IEEE Sensors Journal!

Best regards,

Vladimir Lumelsky

IEEE
Dr. Vladimir Lumelsky
President
IEEE Sensors Council

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Glossary

AAL	Ambient Assisted Living
ADL	(Basic) Activities of Daily Living
WSN	Wireless Sensor Network
IoT	Internet of Things
HMS	Home Monitoring System
SHMS	Smart Home Monitoring System
SAP	Sensor Activity Pattern
PSN	Pervasive Sensor Network
PAI	Predictive Ambient Intelligence
PIR	Passive-Infra Red
The Elderly/ An Elderly person	A person aged above 65 years