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Resource-Aware Data Fusion Algorithms for Wireless Sensor Networks

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Preface

WSN (Wireless Sensors Networks) is intended to be deployed in environments where sensors can be exposed to circumstances that might interfere with measurements provided. Such circumstances include strong variations of pressure, temperature, radiation, and electromagnetic noise. Thus, measurements may be imprecise in such scenarios. Data fusion is used to overcome sensor failures, technological limitations, and spatial and temporal coverage problems.

Not many books addressed the real life problem in WSN applications. In this book, we are proposing real implementation of data fusion algorithms; taking into consideration the resource constrains of WSN. In addition, we are introducing some real applications, as case study, in the industry.

The data fusion can be implemented in both centralized and distributed systems. In the centralized fusion case, we propose four algorithms to be implemented in WSN. As a case study, we propose a remote monitoring framework for sand production in pipelines. Our goal is to introduce a reliable and accurate sand monitoring system. The framework combines two modules: a Wireless Sensor Data Acquisition (WSDA) module and a Central Data Fusion (CDF) module. The CDF module is implemented using four different proposed fusion methods; Fuzzy Art (FA), Maximum Likelihood Estimator (MLE), Moving Average Filter (MAF), and Kalman Filter (KF). All the fusion methods are evaluated throughout simulation and experimental results. The results show that FA, MLE and MAF methods are very optimistic, to be implemented in WSN, but Kalman filter algorithm does not lend itself for easy implementation; this is because it involves many matrix multiplications, divisions, and inversions. The computational complexity of the centralized KF is not scalable in terms of the network size. Thus, we propose to implement the Kalman filter in a distributed fashion. The proposed DKF is based on a fast polynomial filter to accelerate distributed average consensus. The idea is to apply a polynomial filter on the network matrix that will shape its spectrum in order to increase the convergence rate by minimizing its second largest eigenvalue. Fast convergence can contribute to significant energy savings. In order to implement the DKF in WSN, more power saving is needed. Since multiplication is the atomic operation of Kalman filter, saving power at the multiplication level can significantly impact the energy consumption of the DKF. This work also proposes a novel light-weight and low-power multiplication algorithm. Experimental results show that the TelosB mote can run DKF with up to seven neighbors.

This book is based on Abdelgawad PHD dissertation. The work presented was carried out through a large scale research project titled UCoMS (Ubiquitous Computing and Monitoring System) supported by DoE and State of Louisiana.

We appreciate the support, the project team, and the working environment of UCoMS. The VLSI group infrastructure, stimulating and challenging environment, and the weakly presentation and discussion have been an asset to the presented work.

Abdelgawad offers all praise to the almighty God, Allah, the Most Gracious, and the Most Merciful for his blessings bestowed upon him and for giving him the strength to achieve what he has accomplished in his life. Abdelgawad dedicates this book to his family which has played an important role in his life and study. Their support and encouragement has made this book a reality. He would like to thank his mother for her prayers, love, and faith in him. Ahmed's deepest appreciation goes to his lovely wife, Dalia Aboelfadl, his precious daughter, Salma, his handsome son, Mohamed, and his little son, Ali for their unlimited encouragement, sacrifices, and for being by his side.

Bayoumi would like to dedicate this book to his smart, energetic, and dedicated students.

Lafayette, Louisiana

Ahmed Abdelgawad
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List of Abbreviations

ADC	Analog-to-digital converter
ASIC	Application specific integrated circuits
CCA	Clear channel assessment
CDF	Central data fusion
CKF	Central Kalman filters
CMOS	Complementary metal–oxide–semiconductor
CoD	Conditioning and digitizing
CPU	Central processing unit
CSMA	Carrier sense multiple access
CTS	Clear to send
DC	Direct current
DEM	Decentralized expectation maximization
DKF	Distributer Kalman filter
DoD	Department of Defense
DP	Differential pressure
DPM	Dynamic power management
DSP	Digital signal processors
DVS	Dynamic voltage scaling
EEPROM	Electrically erasable programmable read-only memory
FA	Fuzzy art
FIR	Finite impulse response
FPGA	Field programmable gate array
GUI	Graphical user interface
HCI	Human computer interaction
I/O	Input/output
IIR	Impulse response filter

IP	Internet protocol
ISM	Industrial scientific and medical
JDL	Joint directors of laboratories
KCF	Kalman-consensus filters
KF	Kalman filter
LAN	Local area network
LCD	Liquid crystal display
LMI	Linear matrix inequality
LPL	Low power listening
MaC	Management and control
MAC	Medium access control
MAC	Multiply accumulate unit
MAF	Moving average filter
Max	Maximum
MIMO	Multiple-input and multiple-output
ML	Maximum likelihood
MLE	Maximum likelihood estimator
NiCd	Nickel-cadmium
Nimh	Nickel metal hydride
NiZn	Nickel-zinc
NP	Nondeterministic polynomial
P2P	Peer-to-peer
QoS	Quality of service
RAM	Random-access memory
ReT	Receiving and transmission
RF	Radio frequency
RISC	Reduced instruction set computing
RTS	Request to send
SPI	Serial peripheral interface
TCP	Transmission control protocol
TDMA	Time division multiple access
UAV	Unmanned aerial vehicle
WSDA	Wireless sensor data acquisition
WSN	Wireless sensor network