Radio-Frequency Signal Strength Based Localisation in Unstructured Outdoor Environments

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A thesis submitted in fulfillment
of the requirements for the degree of
Doctor of Philosophy

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August 2007

Declaration

This thesis is submitted to the University of Sydney in fulfillment of the requirements for the degree of Doctor of Philosophy. This thesis is entirely my own work, and except where otherwise stated, describes my own research.

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31st August, 2007

Reprinted with corrections and emendations 18th February, 2008

Abstract

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This thesis addresses the issues arising in range-only localisation and tracking using Radio Frequency Received Signal Strength Indicator measurements.

One of the key issues in Radio Frequency (RF) based localisation and tracking applications is to obtain an accurate sensor representation. Such a sensor model is one of the prerequisites to achieve high accuracy and precision in the localisation and tracking task. The sensor models used at present for this task are very simplistic, and as a consequence are unable to achieve highly accurate and precise localisation. While such an accurate sensor description is desirable it has not been presented for RF sensors.

This thesis addresses the task of obtaining an accurate sensor model for RF sensors. The major drawbacks of the most commonly used model, the nth power model, are demonstrated. A new model to satisfy the necessary requirements for high accuracy localisation is developed. This model is based on theoretical considerations and experimental data. It depicts the real occurring behaviour of RF sensors more closely than the models used so far for RF based range-only localisation. The use of this better sensor representation offers the possibility of achieving more accurate localisation.

The expected performance of the alternative sensor model is compared to the commonly used nth power model. Furthermore, the inherent properties of the new sensor model are presented and their ramifications with regards to the goal of achieving highly accurate localisation are discussed.

In addition to the sensor model development, the well-known probabilistic filtering techniques Kalman Filter, Particle Filter and Histogram Filter are compared and used to implement 1-dimensional and 2-dimensional range-only trackers. The filtering techniques are evaluated with respect to their suitability for appropriately handling the new multi-modal sensor model and the resulting multi-modal state distributions, and to provide correct and conclusive localisation and tracking results.

Results from experiments using real data obtained in outdoor environments with a prototype RF localisation system as well as results obtained from simulations are presented in this thesis to validate the theoretical findings and the newly developed sensor model.

Acknowledgements

I want to thank all the people that helped and supported me in any way during the four years of my research at the ACFR.

There are firstly my supervisors Eduardo Nebot and José Guivant. Eduardo, I want to thank you for giving me the opportunity to do my PhD at the ACFR, for supporting me in any possible way to achieve this goal and for the critical feedback you provided. Thank you José for all the discussions we had, related to my studies or not, for helping me out with the occasional SW issue, and for being my friend.

A big thank you goes to Stewart for keeping my spirits high, but also for helping me with the outdoor experiments. Juan, you helped me a lot with the hardware and were available for a discussion or just a chat. Gracias mi amigo. Tim, you introduced to me the concept of particle filtering in a private lesson, so that even I could understand it. Thank you for this and all the discussions we had. Also, thank you Graham for the help with the antenna pattern logging.

My thanks go to the technical staff, to Chris, Vijay, Allan and Jeremy for the hardware support they provided to me, but also to the Argentinean gang (all the Favios, Pedros and Juans) that developed the CPS hardware for my experiments. Special thanks to Favio Masson for his support and valuable feedback. Thanks also to the admin staff Christy and Ruth.

I would like to express my thanks to the CRC Mining for the financial support they provided to me.

Also a big thank you to my *social life*. You guys brought welcome distraction from work (too often according to the supervisors). Stewart, Marianne, Juan, Marina, José, Jürgen, Ute, Aléjandra, Connie, Ollie, Roman, Fabio, Andrew, Sharon, Piglet Lee and all the others, thank you, too.

To my best friend Peter, his wife Claudi and their kids Emily and Mia. Thank you for keeping in touch with us. Our weekly Skype session is always a highlight.

Most importantly I want to thank my family in Germany. Mum, Dad, Chris, Anita, Lea, Anne, Horst, Uschi and all the others. Thank you for all the encouragement and the support. I miss you all.

My biggest thanks go to my wife Cathérine for all the love she gives to me, for being my partner on the journey through life and for soon making us three in our home. You are the brightest star in my life.

To Cathérine & Amélie

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List of Acronyms and Abbreviations

APS Acoustic Parking System

BDT Bayesian Decision Theory

CDF Cumulative Distribution Function

CPS Close Proximity System

CRC Cooperative Research Council

DOL Department of Labor

EEG Electroencephalogram

GPS Global Positioning System

KF Kalman Filter

EKF Extended Kalman Filter

FFT Fast Fourier Transformation

GMM Gaussian Mixture Model

GPS Global Positioning System

HF Histogram Filter

IP Internet Protocol

IR Infrared

ISM Industrial, Scientific, and Medical

KL Kullback-Leibler

LCD Liquid Crystal Display

LOS Line-of-Sight

MAP Maximum A Posteriori

MCMC Monte Carlo Markov Chain

MHz Megahertz

ML Maximum Likelihood

MSHA Mine Safety and Health Administration

MMWR Millimeter Wavelength Radar

NIOSH National Institute for Occupational Safety and Health

OG Occupancy Grid

PDF Probability Density Function

PF Particle Filter

PTP Peer-To-Peer

RF Radio Frequency

RFID Radio Frequency Identification

RI Report of Investigations

RSSI Received Signal Strength Indicator

RTK Real Time Kinematic

SLAM Simultaneous Localisation and Mapping

SOG Sum of Gaussians

TCAS Traffic alert and Collision Avoidance System

TCP/IP Transmission Control Protocol/Internet Protocol

TDOA Time-Difference-of-Arrival

TOF Time-of-Flight

UDP User Datagram Protocol

UNS Universidad Nacional del Sur

U.S.A. United States of America

VW Volkswagen

WAF Wall Attenuation Factor

Notation

$\mathbf{x}$	state vector
z	a single measurement
$\mathbf{Z}_k$	measurements up to timestep k
$k \in \{1, 2, \dots\}$	discrete time step or index
t	continuous time
$\mathcal{U}$	Uniform distribution
$\lambda(.)$	likelihood function
w	weight
$\mathcal{P}(.)$	Probability mass
$p(.)$	Probability distribution of a variable
P	Covariance
μ	mean of a distribution
σ	standard deviation of a distribution
$\mathcal{E}$	Expectation operator
$g(x; \mu, \sigma)$	Gaussian distribution as a function of x with mean μ and variance σ
k(x, y, σ)	symmetrical Gaussian kernel as a function of x, y, and standard deviation σ
I	Intensity
E	Electric field
P	Power
G	Gain
PL	Path loss
λ	wavelength
ω	angular frequency
f	frequency
T	period duration
ϕ	azimuth angle
θ	elevation angle

i	imaginary unit
$\delta(.)$	delta function
$*$	convolution operator
$\mathbf{x}^T$	an arbitrary vector $\mathbf{x}$ transposed
$\mathcal{X}$	an arbitrary set
ε	an arbitrary threshold