COOPERATIVE CONSENSUS SIMULTANEOUS LOCALIZATION AND MAPPING FOR MULTI BLIMP SYSTEM

by

HERDAWATIE BINTI ABDUL KADIR

Thesis submitted in the fulfilment of the
requirements for the degree of
Doctor of Philosophy

March 2017

ACKNOWLEDGEMENTS

Alhamdulillah. Thank you Allah for blessing me with healthiness, strength and guidance in completing this research work and thesis. This thesis would not have been possible without the support of a number of people. First of all, my thanks go to my adviser, Professor Ir. Dr. Mohd. Rizal Arshad, for his constant encouragement and guidance, for the long hours of passing along his knowledge and experience, for pushing me beyond my own limitations, and for his seemingly endless supply of interesting research problems.

Thanks also go to my URRG labmates, Khalid Isa, Song Yoong Siang, Shariffah Shafinar Syed Zain, Mohd Norzaidi Mat Nawi, Khairul Izman Abdul Rahim, Siti Sarah Samsuri, Muhammad Faiz Abu Bakar, Mohd Hafiez Mohd Mokthar, Mad Helmi Ab. Majid, Mohd Faid Yahya and Noorazliza Sulaiman with all of whom I haveshared hours of discussion, cooperation, laughter, food, and play.

Most importantly, none of this would have been possible had it not been for the unwavering support and love of my family. Even though my studies limit my time from home, my family have always done everything for me to fullfield responsibility, and have never failed to believe in me, my husband, Sabran, my children, Farihin, Faheem and Nurul Iman has shared with me all the ups and downs of life as a student.

Lastly, I am also indebted to Universiti Sains Malaysia (USM), Universiti Tun Hussein Onn Malaysia (UTHM) and Malaysia Ministry of Science, Technology and Innovation (MOSTI), e-Science 305/PELECT/6013410 for funding this research, as well as allowances and living expenses. Thank you for supporting my study and this research.

TABLE OF CONTENTS

CHAPTER THREE : METHODOLOGY AND IMPLEMENTATION

CHAPTER FOUR : RESULTS AND DISCUSSIONS

CHAPTER FIVE : CONCLUSIONS AND FUTURE WORKS

APPENDICES

Appendix A: SIFT library
Appendix B: Analysis of motion behaviour for single hull blimp model
Appendix C: Matlab code
Appendix D: Feature detection method
Appendix E: Simulation of network formation

LIST OF PUBLICATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACK	Acknowledgement
AI	Artificial Intelligence
ANSYS	Analysis System
AoA	Angle of Arrival
AP	Access Point
API	Application Programming Interface
ASC	Autonomous Surface Craft
ATDB	AT command for Baud rate
ATNI	AT command for Node Identifier
BEC	Battery Eliminator Circuit
CAD	Computer-Aided Design
CAS	Centre of Excellence for Autonomous Systems
CCD	Charge Couple Device
CCW	Counter-Clockwise
CFD	Computational Fluid Dynamics
CMOS	Complementary Metal Oxide Silicon
CTD	Conductivity, Temperature, and Depth
DoG	Difference-of-Gaussian
DoH	Determinant-of-Hessian
EIF	Extended Information Filter
EKF	Extended Kalman Filter
EOM	Equation of Motion
ESC	Electronis speed controllers
FOV	Field of View

FS	Features selection
GDM	Group decision making
GPS	Global Positioning System
ICSP	In-Circuit Serial Programming
IDE	An Integrated Development Environment
IMU	Inertial Measurement Unit
IRRC	Intelligent Robotics Research Centre
ISM	Industrial, Scientific and Medical
KE	Klemm–eguílez
KF	Kalman Filters
LE	Local Estimates
Li-Po	Lithium polymer
LoG	Laplacian-of-Gaussian
LOS	Line-Of-Sight
LQG	Linear-Quadratic-Gaussian
LQR	Linear-Quadratic Regulator
LS	Least Square
LTA	Lighter-than-air vehicle
MAVs	Micro Aerial Vehicles
MIT	Massachusetts Institure of Technology
MRG	Marine Robotic Group
MSER	Maximally Stable Extremal Regions
NLOS	Non-Light-Of-Sight
NTSC	National television system committee
PAL	Phase Alternating Line
PC	Personal computer

PER	Packet error rate
PF	Particle Filters
RANS	Reynolds-Averaged Navier-Stokes
RF	Radio Frequency
RF-VSLAM	Radio Frequency Visual SLAM
ROV	Remotely Operated Vehicle
RSSI	Received Signal Strength Indicator
SCL	Serial Clock
SD	Secure Digital
SDA	Serial Data Signal
SDHC	Secure Digital High Capacity
SIFT	Scale Invariant Feature Transform
SLAM	Simultaneous Localization and Mapping
SMC	Sequential Monte-Carlo
SPI	Serial Peripharel Interface
SURF	Speeded Up Robust Features
SUSAN	Smallest Univalue Segment Assimilating Nucleus
SW	Small-World
TDoA	Time-Difference-of-Arrival
ToA	Time-of-Arrival
T_X	Transmit pin
UART	Universal asynchronous receiver/transmitter
UAV	Unmanned Aerial Vehicle
UBEC	Ultimate Battery Eliminator Circuit
USB	Universal Serial Bus
WSN	Wireless sensor network

LIST OF SYMBOLS

ρ_a	Air density
ε_{ij}	An arc of D
υ	Axial velocity perturbation
σ_0	Base scale
x_i	Blimp State Vector
P_i	Blimp State Vector Covariance Matrix
$\hat{x}_i^-$	Blimp state vector Mean estimated
P_{im}	Blimp i and map correlation
F_b	Body Fixed Reference Frame
S_{ix}	Center of the frame
u_0	Centre coordinates given in image
v_0	Centre coordinates given in image
p,q,r	Components of angular velocity
$m_{x,} m_{y\,,} m_z$	Components of apparent mass
X,Y,Z	Components of forces
L,M,N	Components of moment
U,V,W	Components of velocity
C_g	Centre of Gravity
C_v	Centre of Volume
u_k	Control input
S_{ia}	Coordinate matrix of camera
μ	Covariance of a Gaussian distribution
P_m	Covariance matrix of landmark states

$\mathbb{s}_{k,ij}^{T}$	Covariance matrix for the innovations
$\mathcal{X}^2$	Chi square value
$\mathcal{H}_k$	Data association
$d_k^{j,i}$	Distance between robot i and j
ε	Dissipation rate
D(x)	DoG scale space
C_b	Drag force on a body
Y_m	Dilatation fluctuation to the overall dissipation rate
Fe	Earth Fixed Reference Frame
E_{k}	Environment noise
P_{k+1}^{-}	Estimated error covariance
$\hat{x}$	Extremum
P_b	Effect of buoyancy
$\mathrm{K}_{\mathcal{H}_k}$	Filter gain
f	Focal length
α_v	Focal lights expressed in pixel units
u_j'	Fluctuation of velocity component
$\mathrm{o}_{\mathrm{min}}$	First octave index
U	Free-stream velocity
α_{u}	Focal lights expressed in pixel units
g_σ	Gaussian kernel
I_σ	Gaussian scale space
q_k	Gaussian white noise process
g_σ	Gaussian kernel
I_σ	Gaussian scale space

J	Gradient vector
$\mathrm{L_n}$	Helium unit lift
B	Identification of landmarks
o_x	Image centre
o_y	Image centre
$\mathrm{S_{is}}$	Image scale
ξ	Information matrix
$\nu_{k,ij}^T$	Innovation vector
$k-\varepsilon$	Kappa-epsilon
δ_{ij}	Kronecker delta
x_m	Landmark State Vector
$\mathrm{P_m}$	Landmark States Covariance Matrix
$\hat{\mathrm{x}}_{\mathrm{m}}$	Landmark States Mean Estimate
y	Lateral
ν	Lateral velocity perturbation
l	Length
x	Longitudinal
x_m	Landmark state vector
C_l	Lift coefficient
$L(t)$	Laplacian of the communication graph
$\hat{x}$	Location of extremum
d	Maximum body diameter
z_{k+1}	Measurement model
r_k	Measurement noise
$\mathrm{r_v}$	Measurement range limit

Σ	Means of a Gaussian distribution
$y_{i,k}^{j,i}$	Measurement data of agent j with respect to agent *i*
$y_{i,k}^{b,i}$	Measurement data of landmarks b with respect to agent *i*
$\hat{x}_i^-$	Mean estimated state vector
$\hat{x}_m$	Mean estimate of landmark states
$D_{k,ij}^2$	Mahalanobis distance
S_{ij}	Mean rate of strain tensor
C_D	Non dimensional drag coefficient of the body
w	Normal velocity perturbation
t_n	Number of maximum threshold interest key point value
t_m	Number of minimum threshold interest key point value
O	Number of octaves
S	Number of scales per octave
$\mathcal{N}_i$	Neighbour set of agent each at each instant time
$S_{i\theta}$	Orientation
F_b	Origin of Body Frame
z_{ik}	Observation taken from the vehicle of the location of the *i*-th landmark at time *k*
h_i	Observation function
t_p	Peak threshold
θ	Pitch attitude
q	Pitch rate
M	Pitching moment
t_p	Peak threshold
$I_{\sigma n}$	Pre-smoothed at nominal level I_σ

x_k	Process state vector at sampling k
A	Reference area
ϕ	Roll attitude
ρ	Roll rate
R	Rotation matrix
σ	Scales
$D(\hat{x})$	Scale space of the extrimum $\hat{x}$
x_i	State vector of the agent
$x_{b,k}$	States position of landmarks
γ	Skew coefficient
k	Time step
C_d	Total drag estimate coefficient
P	Total error covariance matrix
T	Translational matrix
P	Total error covariance matrix
Tz	Time stamp
N	Unique identification of agents
z	Vertical
Vol	Volume
m_i	Vector describing the location of the *i*th landmark
$\bar{u}_i$	Velocity component
V	Vertices of D
ψ	Yaw attitude
r	Yaw rate

KONSENSUS KERJASAMA PERSETEMPATAN DAN PEMETAAN SERENTAK UNTUK SISTEM BERBILANG KAPAL UDARA

ABSTRAK

Navigasi dalam persekitaran lautan dengan sedikit ciri-ciri statik dan menggunakan dinamik air sebagai latar belakang adalah bidang yang mencabar untuk diterokai oleh sistem berbilang ejen. Ini adalah kerana wujud pengukuran yang tidak seragam di permukaan lautan kerana pengagihan ciri spatial yang kerap berubah-ubah. Oleh itu, adalah wajar untuk mereka bentuk satu rangka kerja kerjasama persetempatan dan pemetaan yang mampu untuk mengendalikan pengukuran palsu, mengurangkan ketidaktentuan persetempatan ejen dan mampu mencapai keputusan yang cepat dan baik. Objektif utama kajian ini adalah untuk mereka bentuk satu keedah kerjasama persetempatan dan pemetaan serentak untuk berbilang kapal udara yang melibatkan permukaan air yang dinamik sebagai latar belakang dan konsensus kawanan kecil sebagai kaedah keputusan kumpulan. Rangka kerja koperasi yang baru bagi sistem berbilang kapal udara yang terdiri daripada tiga kapal udara dan pelampung isyarat telah dibangunkan dan direka bagi tujuan ini. Algoritma persetempatan dan pemetaan serentak telah direka dengan menyatupadukan tiga kaedah iaitu Penapis Kalman Lanjutan, Pengubah Ciri Peningkatan Skala dan Petunjuk Kekuatan Isyarat Penerima bagi meningkatkan proses pengurusan data. Persepsi arah dalam kumpulan berdasarkan konsensus kawanan haiwan kecil telah digunakan dalam proses pengurusan data. Konsensus kerjasama persetempatan dan pemetaan serentak ini, didapati telah berjaya mengurangkan bilangan dan mengesan ciri-ciri yang dikehendaki dalam persekitaran air jernih dan keruh. Di samping itu, berdasarkan penandaarasan konsensus kerjasama, kaedah ini telah berjaya mencapai persetujuan yang lebih cepat sehingga 8.3% dan 42% berbanding model skala bebas dan model klemm-eguilez. Selain itu, ketepatan arah telah ditemui bertambah baik sehingga 30% dan 76% daripada model skala bebas dan model klemm-eguilez. Secara keseluruhan, pendekatan yang dicadangkan telah mencapai keputusan yang baik dan terbukti boleh dipercayai dengan ketara dan boleh dilaksanakan di dalam sistem pemantauan pemerhatian lautan.

COOPERATIVE CONSENSUS SIMULTANEOUS LOCALIZATION AND MAPPING USING MULTI BLIMP SYSTEM

ABSTRACT

Navigation in an ocean environment with few static features and dynamic water background is an adventurous field to be explored by multi-agent system. This is because of its non-uniform availability of measurement on the ocean surface since the spatial feature distribution is greatly varied. Thus, it is desirable to design a cooperative localisation and mapping framework that is capable to handle spurious detection, reduce the localisation uncertainty of an agent and achieve fast and good decision. The main objective of this research is to design a cooperative simultaneous localisation and mapping method for multi blimp system involving the dynamic water surface as the background and small flock consensus as the group decision method. A new cooperative framework for the multi blimp system consisting of three blimps and buoys was developed and designed for this purpose. The simultaneous localisation and mapping were designed by integrating three methods which are the Extended Kalman Filter, the enhanced Scale Invariant Feature Transform and Received Signal Strength Indicator to improve the data association process. The group perception of direction based on small flock of animal consensus was taken into the data association process. It was discovered that this cooperative consensus simultaneous localisation and mapping was able to reduce the number of feature points and detect the desired features in clear and dark water environments. In addition, based on cooperative consensus benchmarking, this method was able to achieve faster consensus to up to 8.3 % and 42 % than the scale free model and klemm-eguilez model respectively. On top of these, its heading accuracy was found to be more accurate to up to 30 % and 76 % than the