

**COOPERATIVE CONSENSUS SIMULTANEOUS LOCALIZATION AND  
MAPPING FOR MULTI BLIMP SYSTEM**

**by**

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## 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 Institute 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 Peripheral Interface                     |
| SURF     | Speeded Up Robust Features                      |
| SUSAN    | Smallest Univalued Segment Assimilating Nucleus |
| SW       | Small-World                                     |
| TDoA     | Time-Difference-of-Arrival                      |
| ToA      | Time-of-Arrival                                 |
| Tx       | 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

|                    |                                       |
|--------------------|---------------------------------------|
| $\rho_a$           | Air density                           |
| $\varepsilon_{ij}$ | An arc of $D$                         |
| $v$                | Axial velocity perturbation           |
| $\sigma_0$         | 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           |
| $\mu$              | Covariance of a Gaussian distribution |
| $P_m$              | Covariance matrix of landmark states  |

|                       |  |
|-----------------------|--|
| $\mathbb{S}_{k,ij}^T$ | Covariance matrix for the innovations                  |
| $\chi^2$              | Chi square value                                       |
| $\mathcal{H}_k$       | Data association                                       |
| $d_k^{j,i}$           | Distance between robot i and j                         |
| $\varepsilon$         | 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                                     |
| $K_{\mathcal{H}_k}$   | Filter gain  |
| $f$                   | Focal length   |
| $\alpha_v$            | Focal lights expressed in pixel units                  |
| $u'_j$                | Fluctuation of velocity component                      |
| $O_{\min}$            | First octave index                                     |
| $U$                   | Free-stream velocity                                   |
| $\alpha_u$            | Focal lights expressed in pixel units                  |
| $g_\sigma$            | Gaussian kernel  |
| $I_\sigma$            | Gaussian scale space                                   |
| $q_k$                 | Gaussian white noise process                           |
| $g_\sigma$            | Gaussian kernel  |
| $I_\sigma$            | Gaussian scale space                                   |

|                   |                                      |
|-------------------|--------------------------------------|
| $J$               | Gradient vector                      |
| $L_n$             | Helium unit lift                     |
| $B$               | Identification of landmarks          |
| $o_x$             | Image centre                         |
| $o_y$             | Image centre                         |
| $S_{is}$          | Image scale                          |
| $\xi$             | Information matrix                   |
| $v_{k,ij}^T$      | Innovation vector                    |
| $k - \varepsilon$ | Kappa-epsilon                        |
| $\delta_{ij}$     | Kronecker delta                      |
| $x_m$             | Landmark State Vector                |
| $P_m$             | Landmark States Covariance Matrix    |
| $\hat{x}_m$       | Landmark States Mean Estimate        |
| $y$               | Lateral                              |
| $v$               | 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                    |
| $r_v$             | Measurement range limit              |

|                 |  |
|-----------------|--|
| $\Sigma$        | 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   |
| $D_{k,i,j}^2$   | 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   |
| $\theta$        | Pitch attitude   |
| $q$             | Pitch rate   |
| $M$             | Pitching moment  |
| $t_p$           | Peak threshold   |
| $I_{\sigma n}$  | Pre-smoothed at nominal level $I_{\sigma}$   |

|              |   |
|--------------|---|
| $x_k$        | Process state vector at sampling $k$                  |
| $A$          | Reference area  |
| $\phi$       | Roll attitude   |
| $\rho$       | Roll rate   |
| $R$          | Rotation matrix                                       |
| $\sigma$     | 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                          |
| $\gamma$     | Skew coefficient                                      |
| $k$          | Time step   |
| $C_d$        | Total drag estimate coefficient                       |
| $P$          | Total error covariance matrix                         |
| $T$          | Translational matrix                                  |
| $P$          | Total error covariance matrix                         |
| $T_z$        | 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 $D$                                       |
| $\psi$       | 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