Underwater Optical Sensor Networks (UWOSNs) Localization with Limited Connectivity

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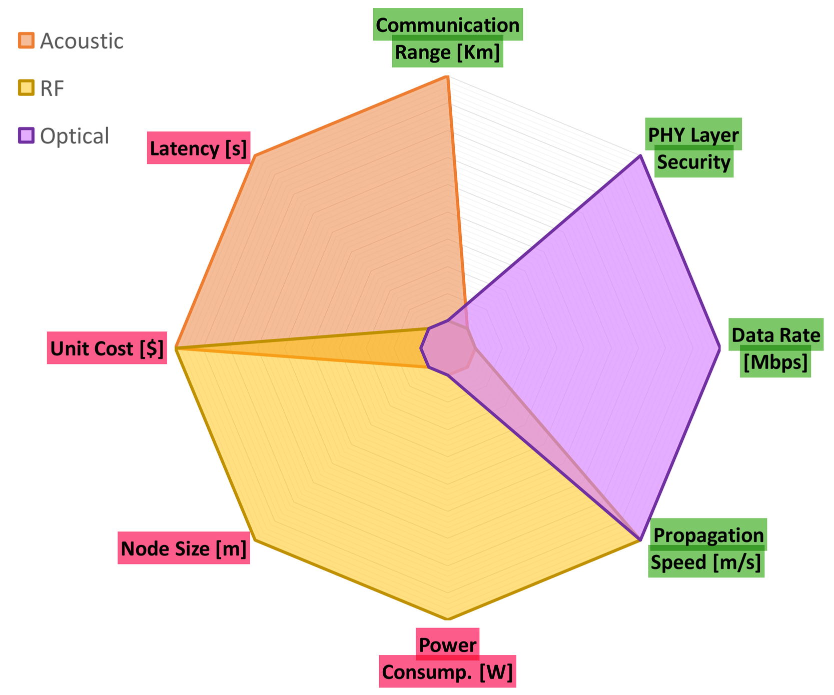
Problem Statement

1. The high quality of service demand for underwater exploration necessitates high data rate, low latency, and long-range networking solutions.



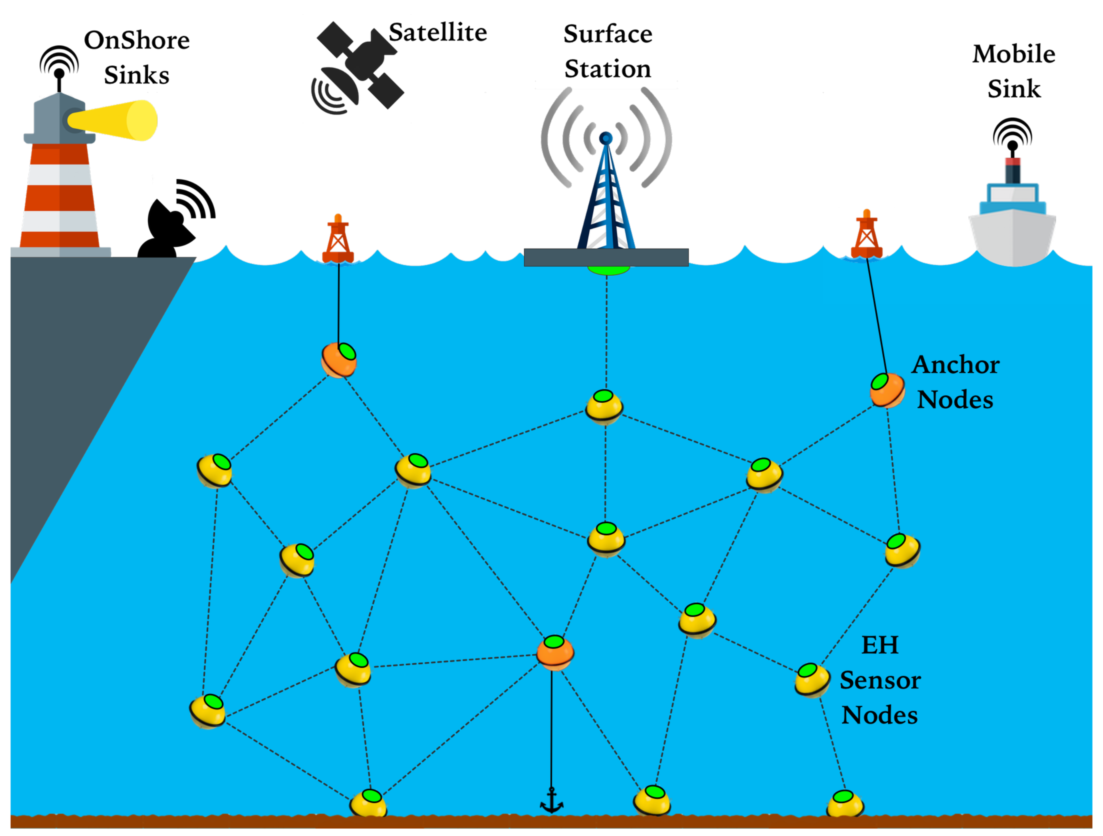
2. In particular, we are interested in the localization UWOSN nodes as the collected data is useful only if it refers to a particular location.

Main Contributions

This work addresses the localization of UWOSNs with limited connectivity and noisy ranging measurements which are embedded in a higher dimensional space. Our main contributions can be summarized as follows:

1. A novel approach is developed to localize the sensor network in a lower dimensional space.
2. By completing the missing distances in the kernel matrix, we reduce the shortest path distance estimation error which is further reduced by fusing the output of proposed technique with the Helmert transformation.
3. Simulation results show that the root mean square positioning error (RMSPE) of the proposed technique is more robust and accurate compared to the baseline [1] and manifold regularization [2].

Network Model



We consider an UWOSN consisting of m sensor nodes and n anchor nodes which are assumed to be capable of sweeping the circular region around themselves. Therefore, the network is represented as a undirected graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ where $\mathcal{V}$ is the set of vertices and $\mathcal{E}$ is the associated links. A link exists between nodes i and j if they are in the communication range of each other. ***Given the location of anchor nodes and singlehop neighborhood distances, the problem of UWOSN localization is to find the location of m sensor nodes.***
Underwater channel is characterized by the extinction coefficient $e(\lambda) = a(\lambda) + b(\lambda)$ where $a(\lambda)$ and $b(\lambda)$ are the absorption and scattering coefficients at wavelength λ, respectively [3]. Thus, the propagation loss is given by $L_i^j = \exp\{-e(\lambda)d_i^j\}$ where d_i^j is the distance.

Proposed Localization Method

Our goal is to find the estimated locations of m nodes given the noisy range measurements matrix, $\mathbf{\Pi} = [\gamma_{ij}]_{m+n\times m+n}$. RSS measuremnts are obtained from the following reception power model [4],

$$P_r^j = P_t^i \eta_t^i \eta_r^j L_{ij} \frac{A_j \cos\theta_i^j}{2\pi d_{ij}^2 (1-\cos\theta_0)}, \quad (1)$$

where P_t^i is the optical power transmitted by node i, η_t^i and η_r^j are the optical efficiencies of node i and j, respectively, A_j is the aperture area of node j, θ_i^j is the angle between transmitter trajectory and receiver, and θ_0 is the divergence angle of transmitted signal.

The missing elements in the kernal matrix $\mathbf{\Pi}$ are approximated by $\gamma_{ij} = (\acute{R}_{min} + \acute{R}_{max})/2$ where $\acute{R}_{min}$ and $\acute{R}_{max}$ are the minimum and maximum achievable distances in the network, respectively. UWOSN localization requires to develop a non-linear projection technique from a noisy high dimensional space to the actual low dimensional space.

Exploiting the hidden information in the network, all the nodes are localized by employing the non-linear projection function $g: d_{ij} \longrightarrow \boldsymbol{C}$ which is defined as

$$g(d_{ij}|\boldsymbol{C}) = \sqrt{\sum_{i\neq j=1\ldots m+n} (\gamma_{ij} - d_{ij})^2 \, \mathrm{W}_{ij}}, \quad (2)$$

where $\mathrm{W}_{ij} = \frac{1}{\gamma_{ij}^2}$ are the associated weights for each link. Accordingly, coordinates relative to the anchor nodes is given as $\hat{\boldsymbol{C}} = \boldsymbol{E}_{(m+n)\times 2}\sqrt{\boldsymbol{Q}_{2\times 2}}$.

Thereafter, actual coordinates are obtained from relative coordinates $\hat{\boldsymbol{C}}$ by using the Helmert transformation as follows

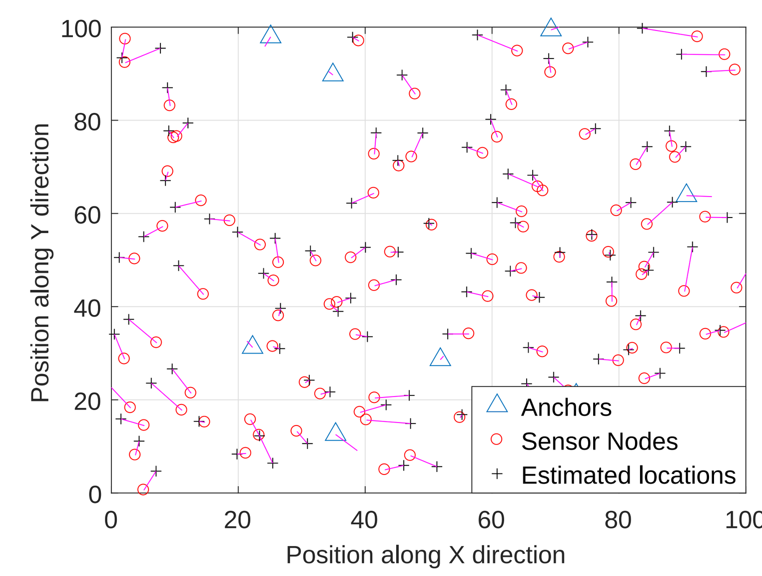
$$\tilde{\boldsymbol{C}} = \Phi\Omega^T(\hat{\boldsymbol{C}}) + \Psi. \quad (3)$$

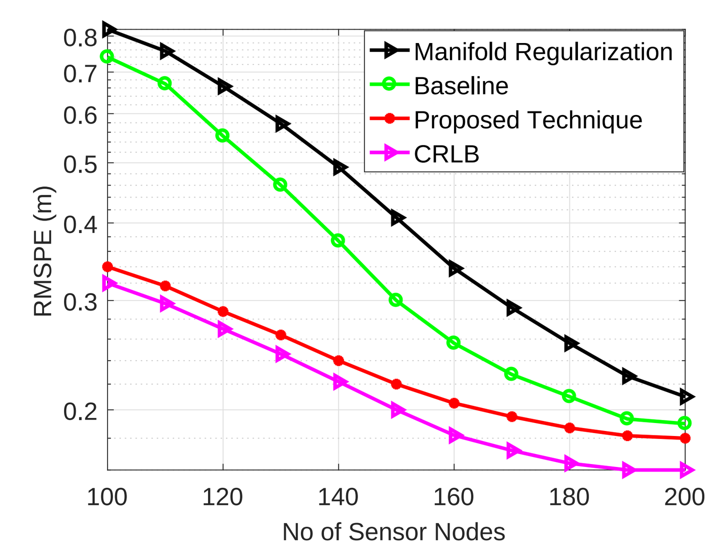
where Φ, Ψ and Ω represent the operations of scaling, shifting, and rotation, respectively. Finally, the Cramer-Rao lower bound (CRLB) is derived as

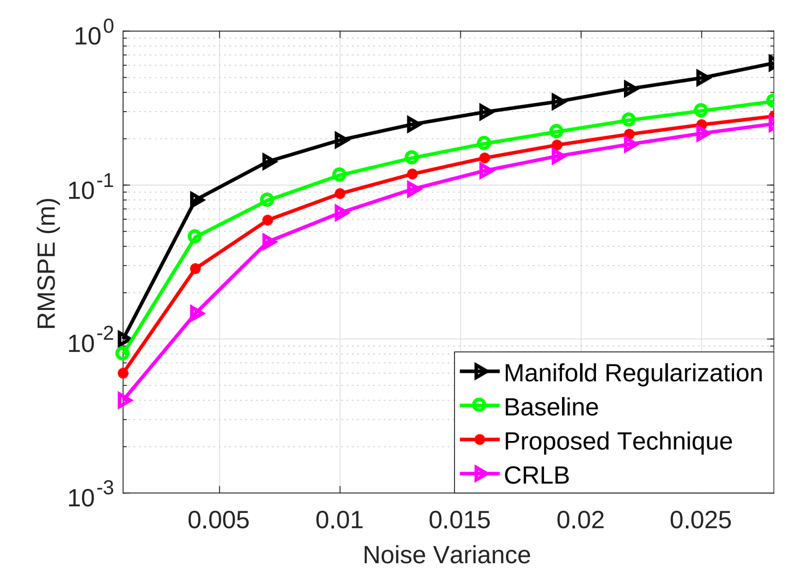
$$\mathrm{E}\left((\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2\right) \geq (\mathbf{F}_i^{-1})_{1,1} + (\mathbf{F}_i^{-1})_{2,2}, \quad (4)$$

where $(\mathbf{F}_i^{-1})_{1,1}$ and $(\mathbf{F}_i^{-1})_{2,2}$ are the diagonal elements of inverse Fisher information matrix, $(\mathrm{FIM})^{-1}$.

Results







Area: $100 \times 100\ m^2$, # Nodes: $100 - 200$, # Anchors: 10, Variance: $0.001 - 0.029$, and Range: $5 - 50$ m.

Conclusions and Future Research Directions

In this paper, a noisy RSS-measurement based localization technique is considered for UWOSNs. The proposed technique is robust to absorb the inaccuracies in the RSS measurement and provide better results. The proposed technique first collects the noisy RSS measurements and estimate the initial location of sensor nodes and then the final coordinate transformation is achieved by Helmert transformation. The CRLB is also been derived to analyze the performance of the proposed technique. Simulations show that the proposed technique provides enhanced localization performance to get more robust and accurate results. For the future work, we will investigate

References

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