Developing an Autonomous Fish Tracking System

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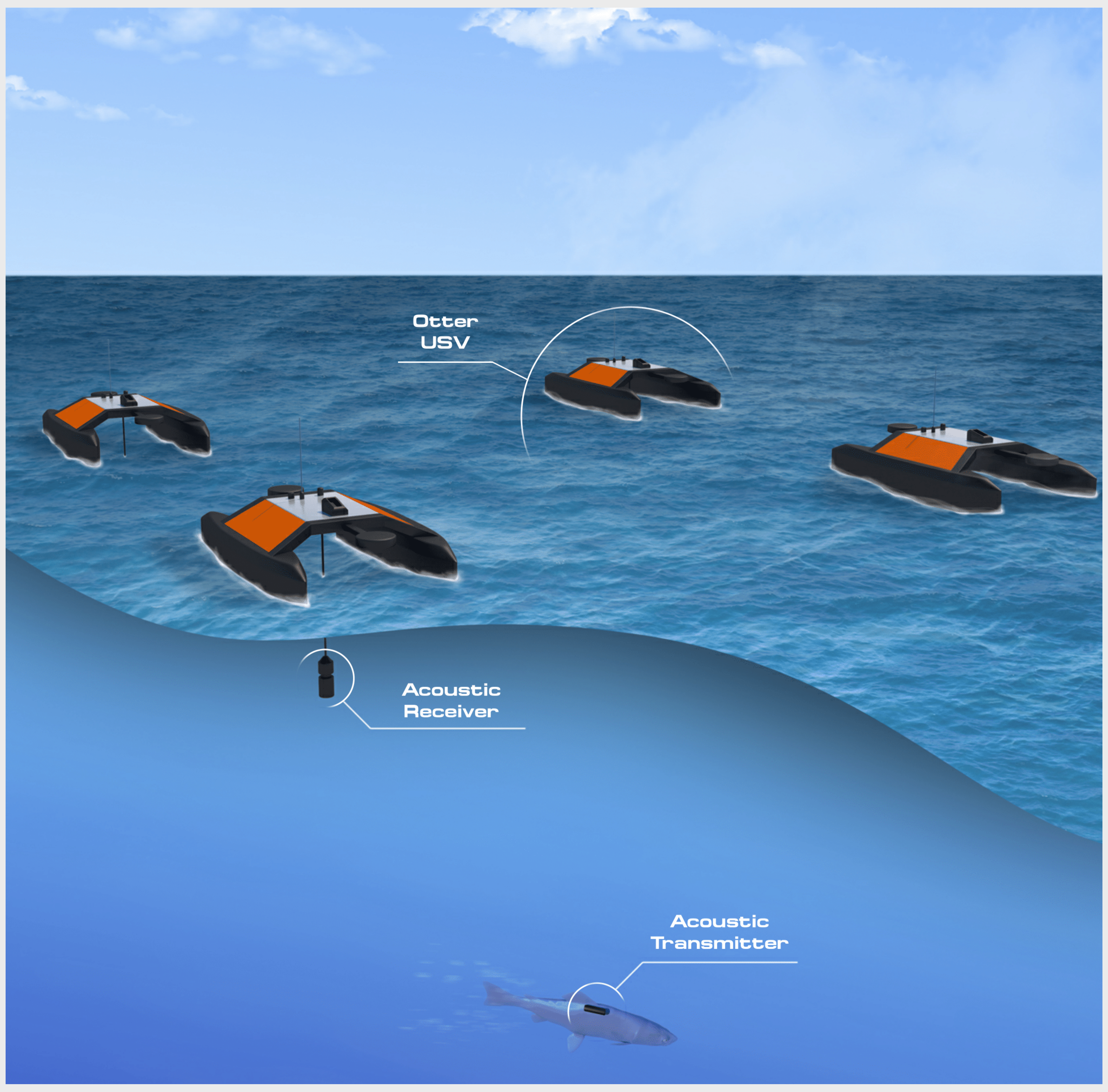
Background

The Department of Engineering Cybernetics at the Norwegian University of Science and Technology (NTNU) has recently received funding for a fish tracking project involving the Atlantic salmon *Salmo salar*. The current outline of the project is to track and obtain geospatial data of a fish, tagged with an acoustic transmitter, utilizing a formation of four Unmanned surface vehicles (Otter USVs). The ultimate goal is to conduct an experiment with a real salmon, likely in the Trondheimsfjord, with a field validation giving proof-of-concept. The number of conducted fish tracking experiments using a mobile receiver networks are few, and the project approach is therefore experimental. Data collection of migrating salmon in an open sea environment is hard with current technology, mainly consisting of fixed receiver arrays meant for closed areas such as fish pens or rivers. Better and more accurate data of migration patters and behavior of wild, restocked and escaped farmed salmon, will ultimately allow scientists to draw better conclusions regarding environmental impact of the aquaculture industry.

System Illustration



System

Target: Atlantic Salmon
Vessels: Otter USVs
Communication: CAN bus, UART and 4G LTE modem (Huawei E3382).
Computers: Raspberry Pi 3, Pi-CAN2 and Torqeedo Interface Board
Positioning: Garmin 18x-5Hz GPS, TBR700 (receiver) and fish tag
Software: LSTS toolchain

Objectives

Obtain formations in which the accuracy and resolution of geospacial data of a target fish is enhanced. Minimize geometric dilution of precision, stay within transmission range to target, and minimize distance traveled by USVs.

1. $\min_{\mathbf{x_R}\in\mathbb{R}^3} (\mathrm{Tr}(\mathbf{H}^T\mathbf{H})^{-1})$
2. $||\hat{\mathbf{x}}^E - \hat{\mathbf{x}}^E_{R_j}|| < \hat{\rho}_t$
3. $\min_{i1\neq i2\neq i3\neq i4} (\mathrm{sum}(\rho_{i1}+\rho_{i2}+\rho_{i3}+\rho_{i4}))$

$\mathbf{H}$ - receiver array geometry matrix, $\hat{\mathbf{x}}^E$ and $\hat{\mathbf{x}}^E_{R_j}$ - estimated fish and USV position, respectively, $\hat{\rho}_t$ - estimated transmission range and ρ_{ij} - path distances

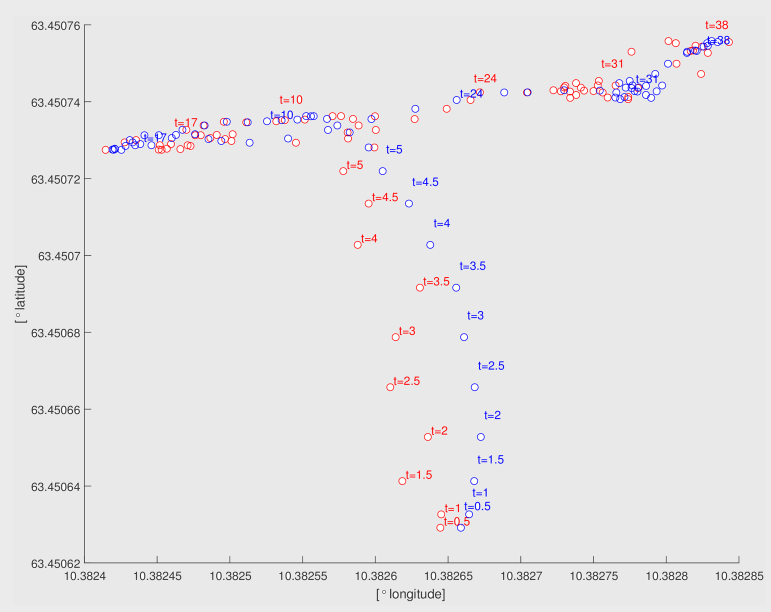
Target Localization

An extended Kalman filter for TDOA localization is implemented and tested in DUNE using fake TBR700 data messages dispatched in real-time - estimating fish position and velocities in $\mathbb{R}^3$.

$$\begin{cases} \hat{\mathbf{x}}_{k+1|k} &= \mathbf{F}\ \hat{\mathbf{x}}_k \\ \mathbf{P}_{k+1|k} &= \mathbf{F}\ \mathbf{P}_{k|k}\ \mathbf{F}^T + \mathbf{Q}_k \end{cases}$$

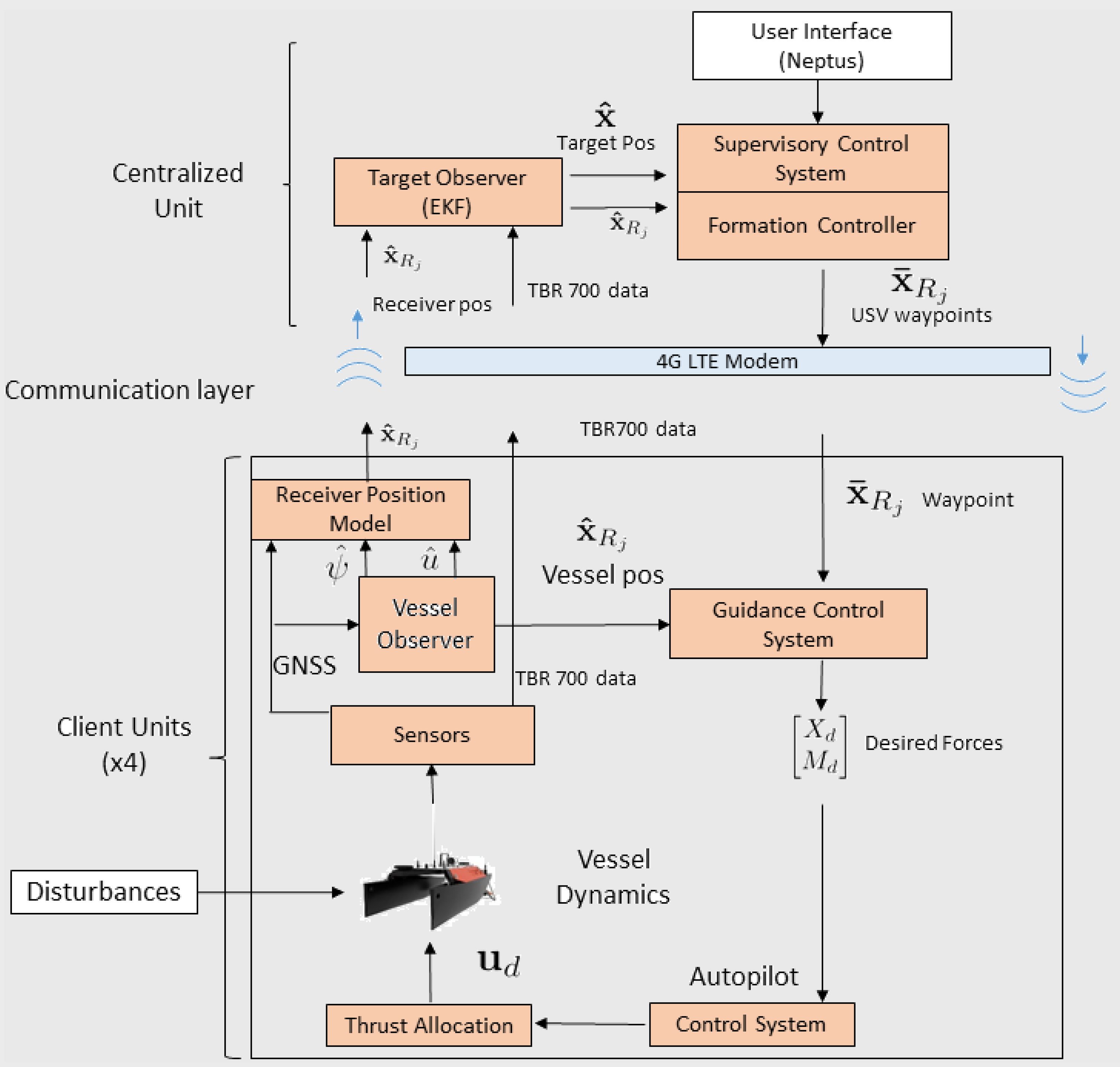
$$\begin{cases} \mathbf{K}_k &= \mathbf{P}_{k+1|k}\ \mathbf{H}^T\ (\mathbf{H}\ \mathbf{P}_{k+1|k}\ \mathbf{H}^T + \mathbf{R}_k) \\ \hat{\mathbf{x}}_{k|k} &= \hat{\mathbf{x}}_{k+1|k} + \mathbf{K}_k(\mathbf{y} - \mathbf{h}(\hat{\mathbf{x}}_{k+1|k})) \\ \mathbf{P}_{k|k} &= (\mathbf{I} - \mathbf{K}_k\ \mathbf{H}_k)\mathbf{P}_{k+1|k} \end{cases}$$

Results:



2D scatter plots of the true and estimated target trajectories in a North - East coordinate system, where red and blue color indicate the real and estimated position.

Control System



Receiver Positioning Model

$$\hat{\mathbf{x}}^E_a = \mathbf{x}^E_{\mathrm{GPS}} + \mathbf{R}^E_N(l,\mu)\mathbf{R}^N_b(\hat{\psi})\left(-\mathbf{x}^b_{\mathrm{GPS}} + \mathrm{LCF} + \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} + \begin{bmatrix} \cos(\tan^{-1}(-2.3671\hat{u}|\hat{u}|))(l+z_c) \\ 0 \\ \sin(\tan^{-1}(-2.3671\hat{u}|\hat{u}|))(l+z_c) \end{bmatrix}\right)$$

Implementations

Real-time GPS data acquisition in DUNE is successfully implemented and tested using a Raspberry Pi 3 and a Garmin GPS 18x-5Hz. A Torqeedo thruster with supplementary hardware and CAN interface is sucessfully integrated and tested in "forsøkshallen" experiment lab, elektrobygg D at NTNU Gløshaugen, Trondheim, Norway.

Error Sources

- Acoustic transmission speed variations
  - Salinity
  - Temperature
  - Pressure
- Multi-path interference
- Acoustic noise
- GPS error (UERE <15 m)
- Receiver positioning error

Conclusions

A Kalman filter implemented in DUNE converges and deliverers satisfactory position estimates of a target fish using generated TBR700 data. Formation control algorithms and receiver positioning model for a cable-connected receiver configuration are created in an attempt to enhance resolution of the geospatial positioning data. A Raspberry Pi 3 single-board computer was successfully integrated with a variety of hardware devices.