Orientation estimation for instrumented helmet using neural networks

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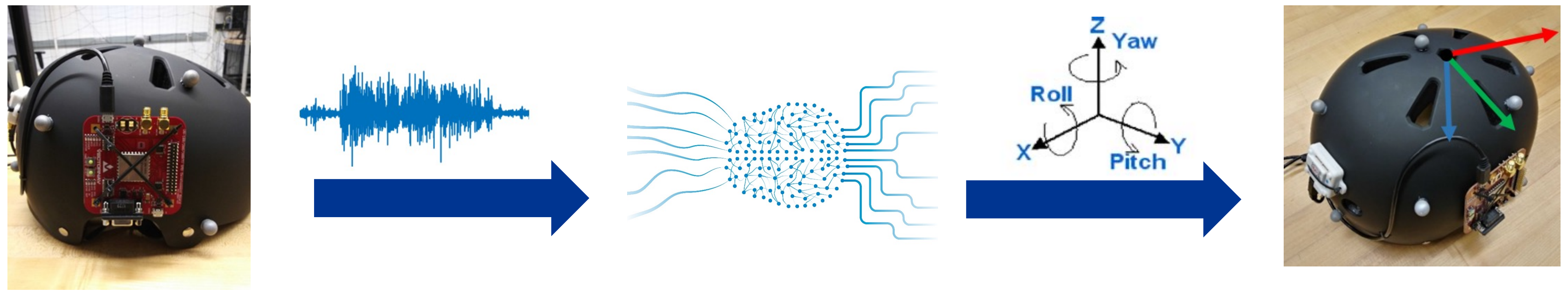

Problem

- Accurate head orientation estimation is important for applications of AR and VR with instrumented helmets
- Orientation is estimated by combining measurements from three sensors (accelerometer, gyroscope and magnetometer) packaged into an IMU module.
- Kalman Filter and Complementary Filter are the most widely used algorithms to estimate orientation by fusing measurements from these sensors.
- For best performance, parameters of these filters are tuned heuristically based on sensor noise, bias, calibration errors and acceleration/magnetic disturbances.
- Traditional filter parameter tuning is complex and time-consuming, thus there is a need to simplify and automate the filter design process.
- Limited benchmark results for works with instrumented helmets and head orientation estimation.

Goals

- Robust orientation estimation algorithm for instrumented helmet using CNN models and time series measurement data.
- Comprehensive study of estimation algorithm structure and CNN model hyper-parameters.
- Collection of training data for machine learning algorithms with motion profiles that are particular to head motion.
- Compare training data with head motion profiles, compared to training data used commonly used for orientation estimation.
- Demonstrate the effectiveness of the proposed CNN-based solution for head orientation estimation compared to existing learning-based solutions.
- Demonstrate the effectiveness of the proposed CNN-based solution for head orientation estimation compared to non-learning based methods like Error State Kalman Filter (ESKF) [1] and Complementary Filter (CF) [2].

Applications & Future Work

- Precise head orientation estimation is critical for developing robust Augmented and Virtual Reality Systems (AR/VR), develop wearable systems to monitor health and fatigue of users.
- Applications to head gears for first responders and other users that require fast updated information.
- Future work includes extending the proposed orientation estimation algorithms to perform in environments with high magnetic disturbance environments.
- Visual gyroscope may be incorporated to compensate for the increased magnetic disturbance.

References

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Sensor Fusion using Convolutional Neural Network

- The orientation estimation problem is formulated as determining the relation between the sensor measurements and the actual orientation,

$$q_t = f(q_{\omega,t}, \cdots, q_{\omega,t-T}, \tilde{u}_t, \cdots, \tilde{u}_{t-T})$$

- CNN-based network (Fig. 1) is used to estimate this unknown function.
- To train the CNN-based network we collect data from sensors attached to a helmet (Fig. 2) and use IR sensors to obtain the ground truth (Fig. 3).
- CNN-model is trained to determine estimation using the time series measurement data from the IMU on helmet. Estimation error is determined by comparing the model output to the ground truth collected data

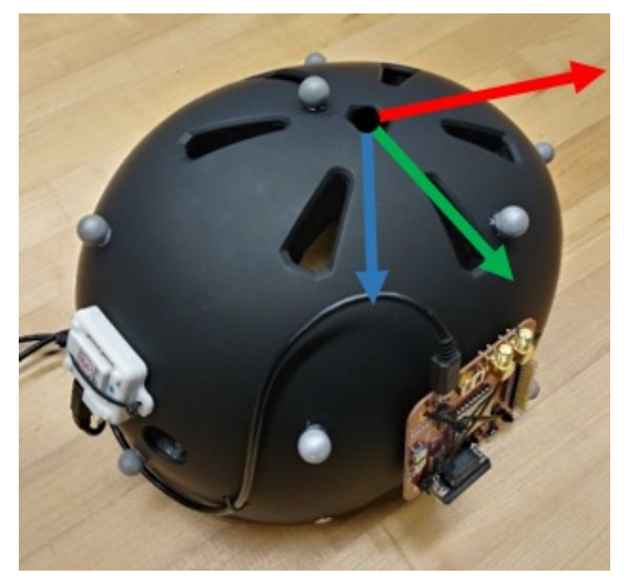
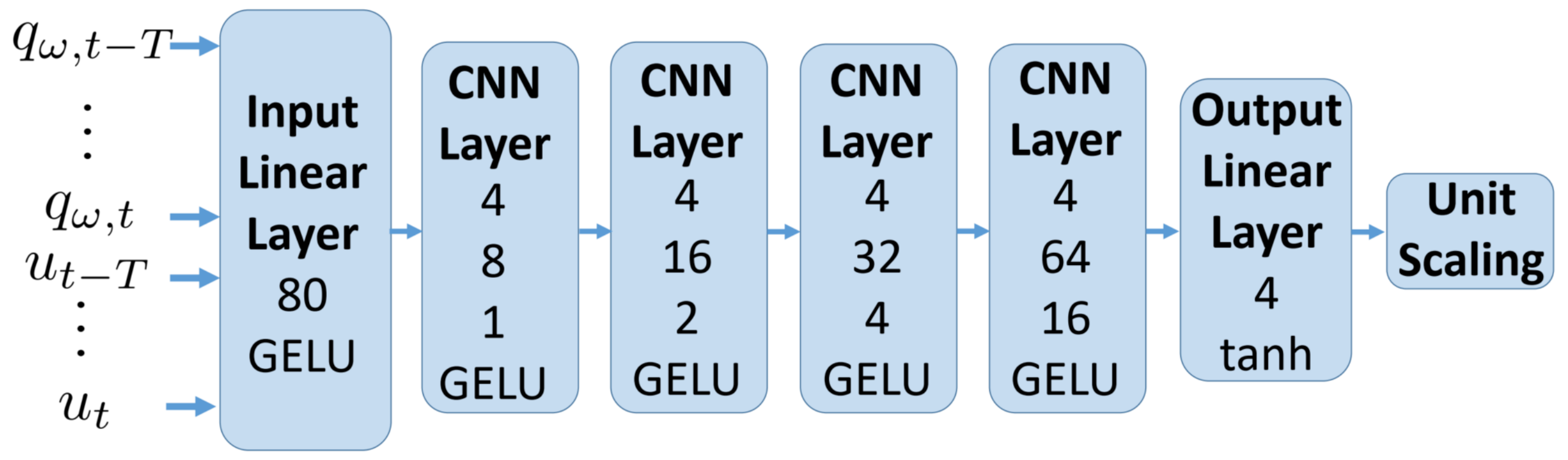


Fig. 2 Helmet with sensors



$q_{\omega,t-T}$
⋮
$q_{\omega,t}$
u_{t-T}
⋮
u_t

Input Linear Layer 80 GELU → **CNN Layer** 4 8 1 GELU → **CNN Layer** 4 16 2 GELU → **CNN Layer** 4 32 4 GELU → **CNN Layer** 4 64 16 GELU → **Output Linear Layer** 4 tanh → **Unit Scaling**

Fig. 1 CNN based Neural Network Structure

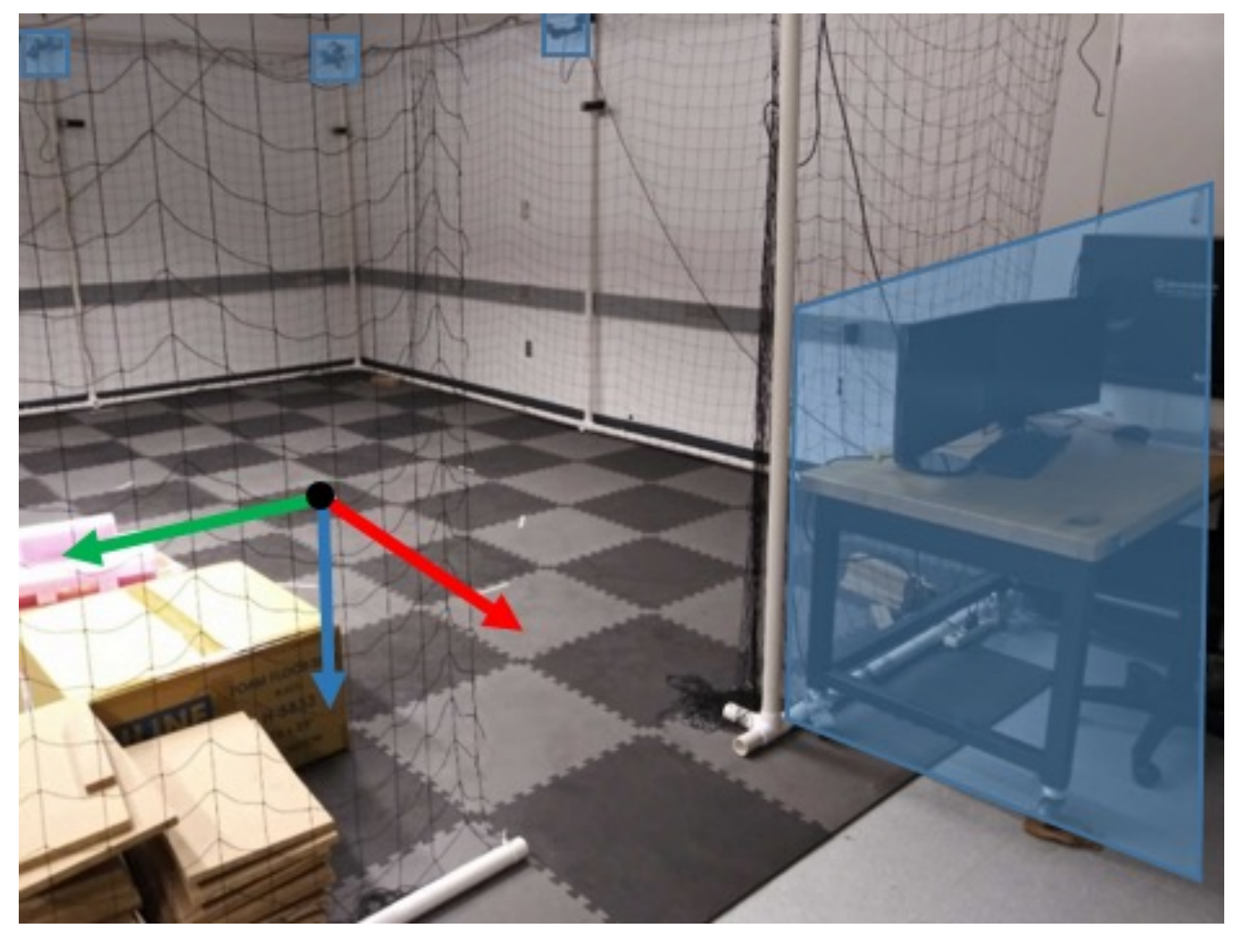


Fig. 3 Setup for obtaining ground truth

Results

- Performance comparison with ESKF and CF: Our method has significantly better performance when disturbances are high (Fig. 4)
- Estimation error of our method compared to CNN based denoising algorithm [3] on EUROC [4] dataset and HELMET [5] dataset: Our method has better performance on the HELMET dataset (Fig. 5)
- Study results also demonstrate that the proposed CNN model can be better trained for estimating orientation specific to head motion, compared to other learning-based solutions in the literature.

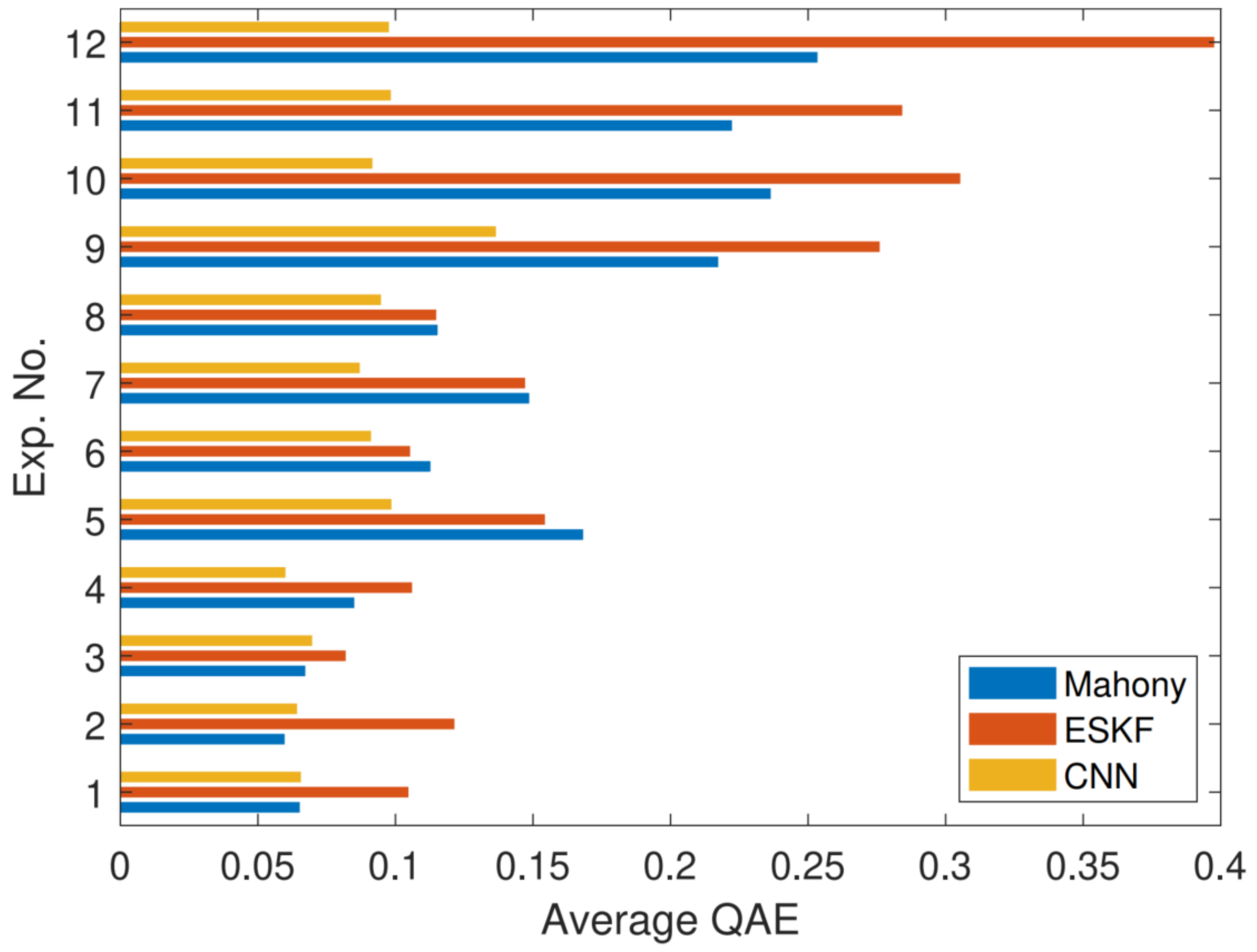


Fig. 4 CNN vs ESKF and CF (Mahony)

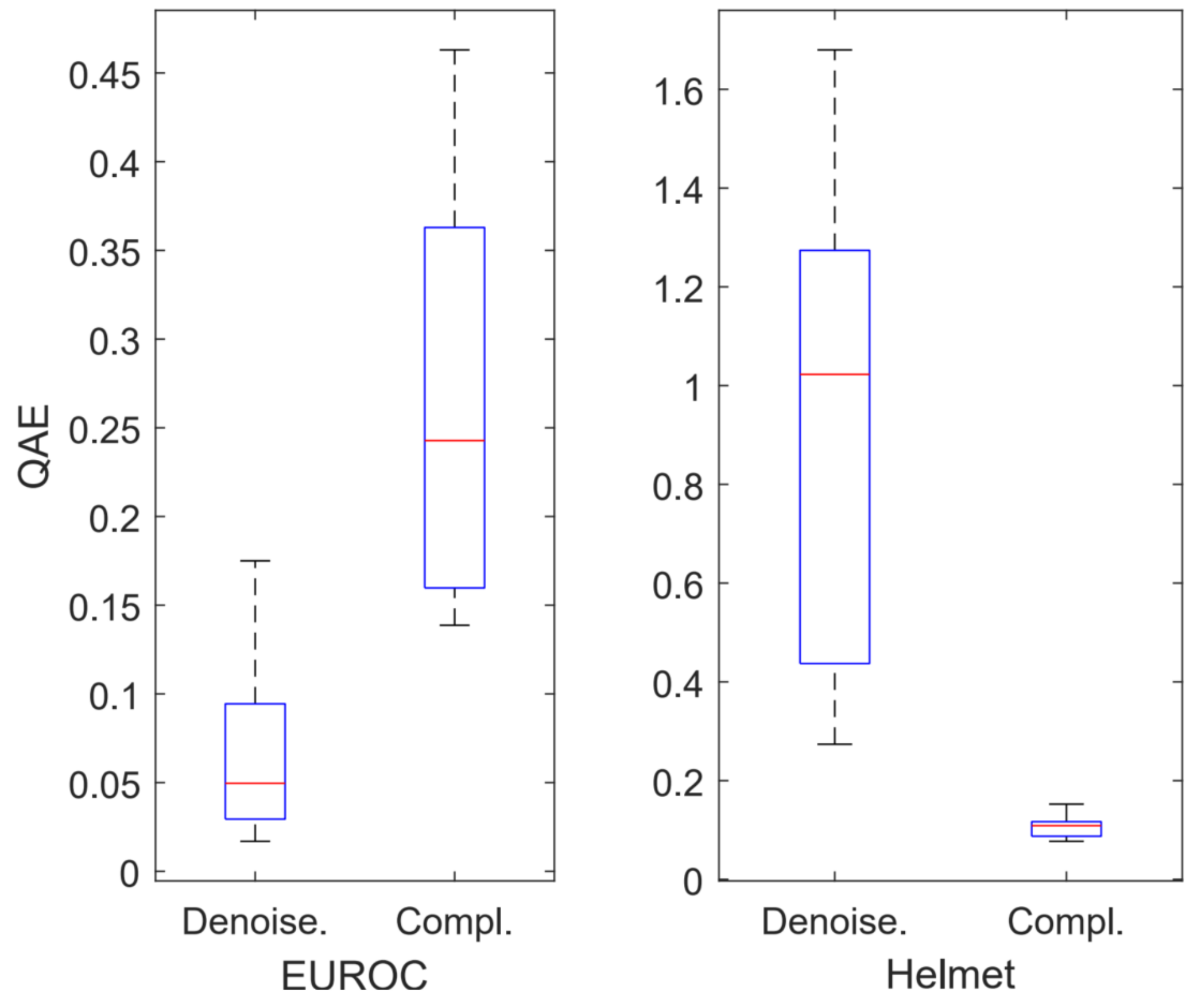


Fig. 5Performance evaluation on different datasets