RUHR-UNIVERSITÄT BOCHUM

RUS AUTOMATIC CONTROL AND SYSTEMS THEORY

RUB

ADVANCED FLOW RATE SOFT SENSOR FOR MARITIME PUMPS

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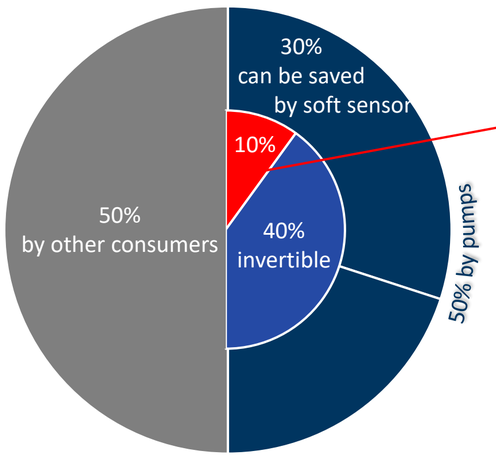
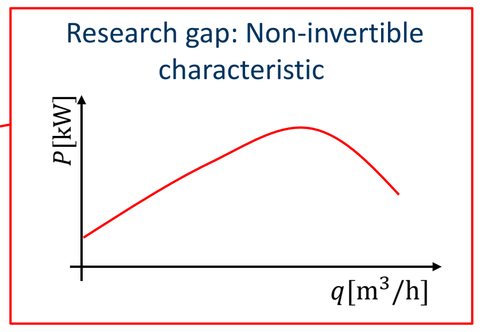
Motivation

- Pumps consume up to 50% of the electric energy used on ships.
- Flow rate soft sensors help to save up to 30% energy.
- Soft sensors can also reduce hardware costs, optimize performance, predict faults, and improve reliability.
- **Research gap:** Approximately 20% of maritime pumps exhibit non-invertible characteristics. State-of-the-art soft sensors cannot handle these.
- **Future goal:** Develop a flow rate soft sensor that also works for non-invertible characteristics.



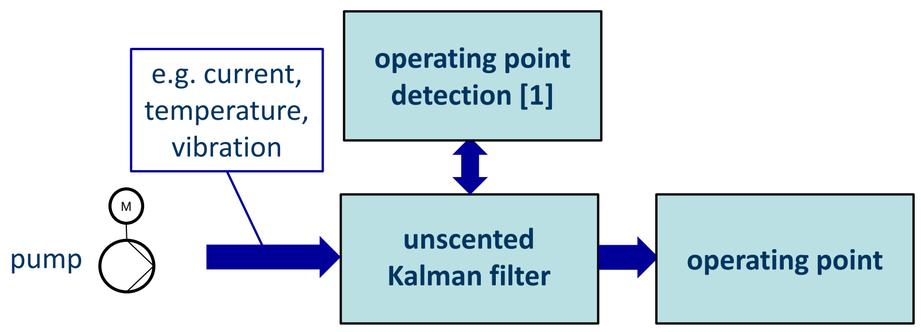
Energy consumption distribution on ships



- Invertible characteristic: one-to-one mapping
- Non-invertible characteristic: many-to-one mapping

State of the Art

Soft sensor



Modeling based on the boundary curve model [2]

current I → motor → pump → flow rate q

mechanical power P

Invertible characteristic:

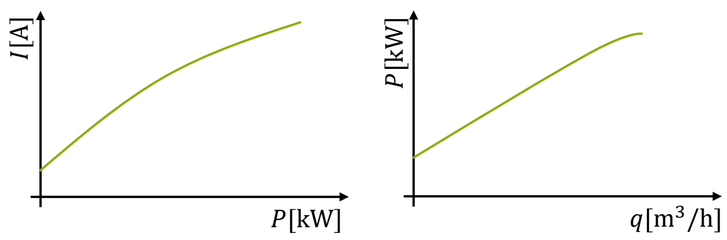


Fig. 1: Estimations based on the boundary curve model

$$I_{\mathrm{norm}}(f) = \frac{I - I_{\mathrm{min}}(f)}{I_{\mathrm{max}}(f) - I_{\mathrm{min}}(f)}$$

$$P_{\mathrm{norm}}(f, I) = g_1(I_{\mathrm{norm}}(f)) = \frac{P(f, I)}{P_{\mathrm{max}}(f)}$$

Power estimation: $\hat{P}(f, I) = P_{\mathrm{norm}}(f, I) \cdot P_{\mathrm{max}}(f)$

$$P_{\mathrm{norm}}(f) = \frac{P - P_{\mathrm{min}}(f)}{P_{\mathrm{max}}(f) - P_{\mathrm{min}}(f)}$$

$$q_{\mathrm{norm}}(f, P) = g_2\left(P_{\mathrm{norm}}(f)\right) = \frac{q(f, P)}{q_{\mathrm{max}}(f)}$$

Flow rate estimation: $\hat{q}(f, P) = q_{\mathrm{norm}}(f, P) \cdot q_{\mathrm{max}}(f)$

Results

- Test in real-time in the lab.
- Accurate and reliable estimations of flow rate and current in real-time applications.

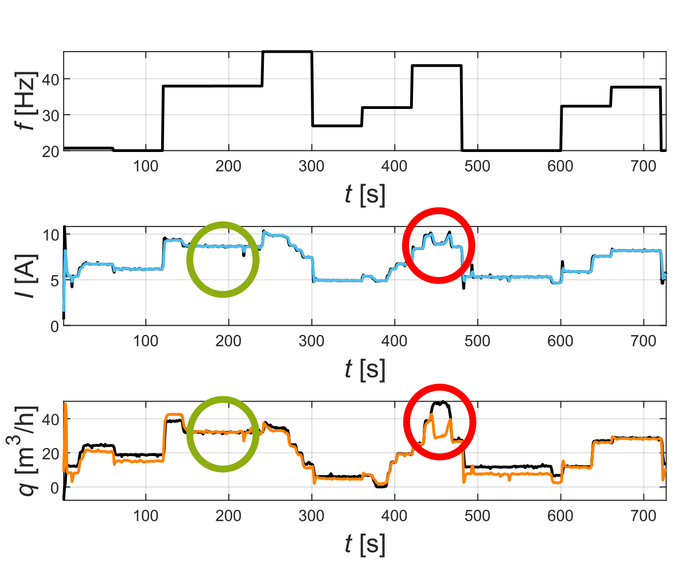


Fig. 2: Soft sensor performance evaluation

Estimations (orange, blue) follow the actual values (black) well.

The larger estimation error is caused by non-invertible characteristics.

These characteristics will not influence the estimation of I.

We need advanced algorithms to extend to non-invertible characteristics.

Challenge and Approach

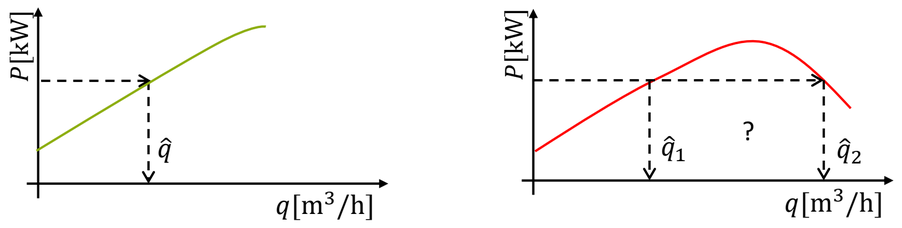
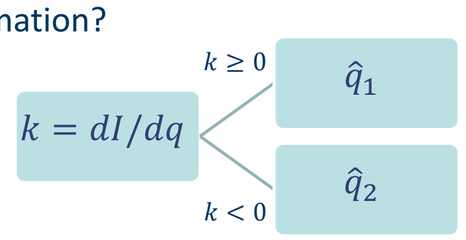


Fig. 3: Invertible and non-invertible characteristics

- Non-invertible characteristic leads to more than one estimation.
- Wrong selection may cause poor energy efficiency and damage.
- How to determine the proper estimation?
  - If slope magnitude $k \geq 0$, the flow rate estimation $\hat{q} = \hat{q}_1$.
  - If $k < 0$, $\hat{q} = \hat{q}_2$.



Conclusion and Outlook

- The soft sensor provides sufficient precision in real-time.
- Simplify the nonlinear model to reduce the number of required measurements.
- Extend the soft sensor to pumps with non-invertible characteristics.

24th International Conference on Process Control, Štrbské Pleso, Slovak Republic, 2023.

Acknowledgment

Funding by German Federal Ministry for Economic Affairs and Energy is gratefully acknowledged.

Federal Ministry for Economic Affairs and Energy

References

[1] S. Leonow and M. Mönnigmann, "Operating point estimation in hydraulic turbomachines with non-invertible characteristics", European Control Conference (ECC), 2016.

[2] S. Leonow and M. Mönnigmann, "Soft sensor based dynamic flow rate estimation in low speed radial pumps", European Control Conference (ECC), 2013.

Smart Pumps for Digitized Seafare

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