Improving the accuracy of orientation estimation from gyroscope data:

A data simulation study

Anne Haitjema[1,2], Frank J. Wouda[1,2], Kim Sunesen[2], Jasper Reenalda[1,3], Bert-Jan F. van Beijnum[1], Peter H. Veltink[1]

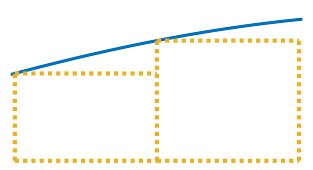
[1]University of Twente, The Netherlands, [2] Movella Technologies BV, The Netherlands, [3] Roessingh Research & Development, The Netherlands

Introduction

- Reducing the number of IMUs used in human movement analysis enables its widespread use, but is hindered by the limited accuracy of single sensor orientation estimation.
- **Our goal is to minimize errors in the orientation estimation from angular velocity data[1].**
- Orientation estimation could be improved by increasing the sampling frequency, or by including higher order terms in the often used[2,3] first order Taylor approximation.
- This is a first step towards sparse IMU setups in biomechanical applications in both the sport and health domain.

Methods

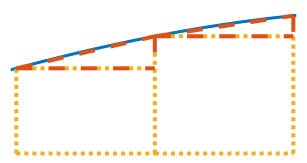
- Angular velocity signals with varying amplitudes and complexity (1D, 2D, 3D) are simulated.
- Orientation is estimated using a first and second order Taylor approximation at different sampling frequencies.
- First order Taylor approximation:



$$R(t+\tau) = R(t) + \dot{R}(t)\tau$$

Where R is the rotation matrix, τ is the timestep and $\dot{R}(t)$ is the first derivative of $R(t)$.

- Second order Taylor approximation:



$$R(t+\tau) = R(t) + \dot{R}(t)\tau + \ddot{R}(t)\frac{\tau^2}{2}$$

Where $\ddot{R}(t)$ is the second derivative of $R(t)$.

- The error angle is used to denote the shortest angle between the estimated and analytically derived orientation.

Results

Results shown are from a simulated 1D angular velocity signal: $(2\pi\cos(2\pi t) \quad 0 \quad 0)^T$ (see Figure 1). **Including the second order term in the Taylor approximation reduces the error and seems to have a larger effect than increasing the sampling frequency (see Figure 2).**

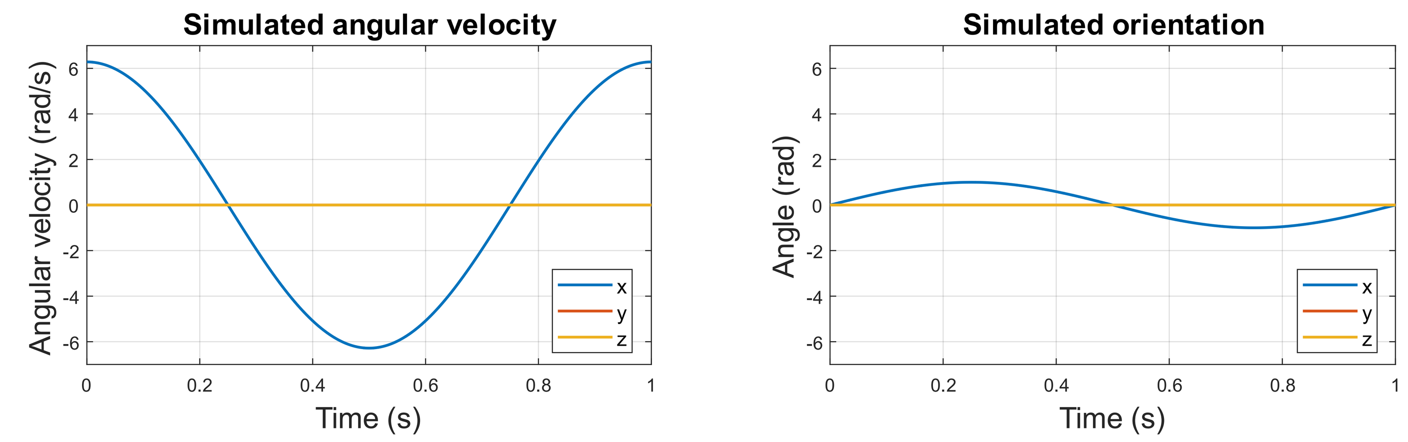


Figure 1: The simulated angular velocity and orientation signal.

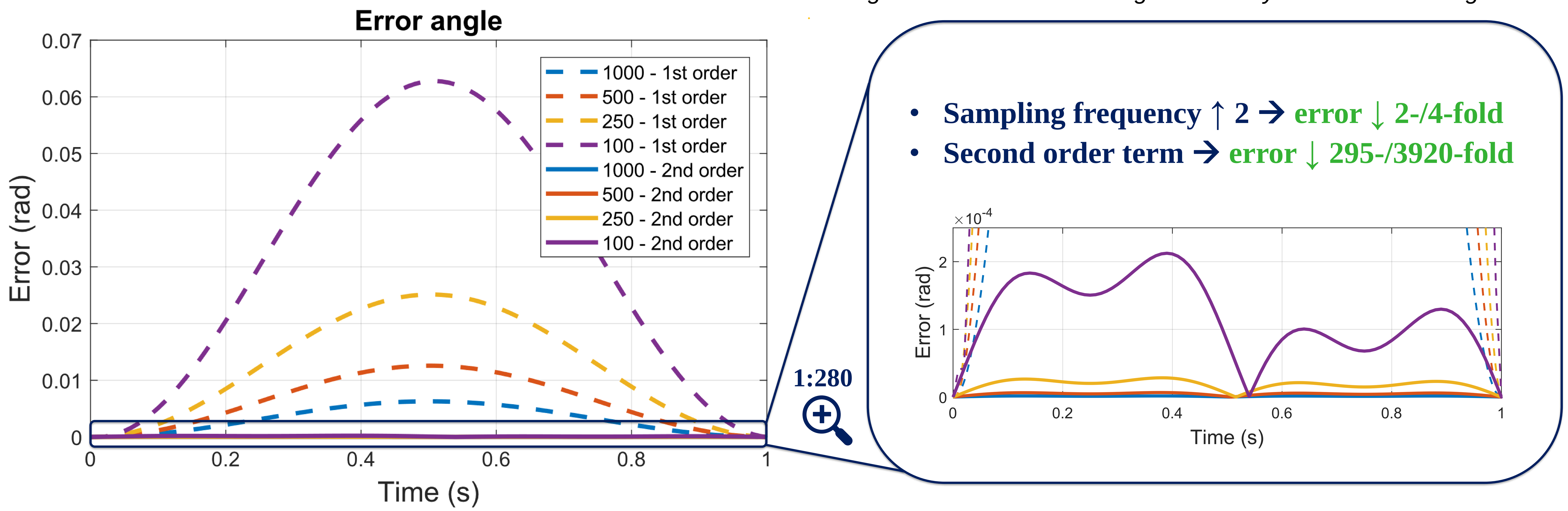


Figure 2: The error angle displayed for different sampling frequencies, and for a first and second order Taylor approximation.

Conclusions

Our initial results suggest that we can improve the orientation estimation by increasing the sampling frequency, or by including a second order term in the Taylor approximation. Inclusion of the second order term seems to have a larger effect, at limited computational cost (2.5x increase in runtime to 31 µs in MATLAB at 250 Hz). More complex simulated and experimentally obtained signals are currently being evaluated.

Significance

Minimization of errors in the orientation estimation could facilitate (near) real-time applications of sparse IMU setups in biomechanical sport-oriented applications such as single-IMU-based kinematic estimation in running[2]. Moreover, it could enable at-home monitoring of, for example, the foot progression angle of patients[3], thereby generating a more continuous patient profile that could allow for tailored care.

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This work is partially funded by TKI HTSM and Movella Technologies BV.

[1] Bortz (1971). *IEEE Trans Aerosp Electron Syst* 7(1): 61-66
[2] Zandbergen et al. (2022). *Sensors* 22: 956
[3] Wouda et al. (2021). *JNER* 18:37.

Anne Haitjema
a.haitjema@utwente.nl