ML Assisted Intermittent Gyroscope Utilization for Low-Power Sensing

ECE M202A/ CS M213A Final Project Presentation

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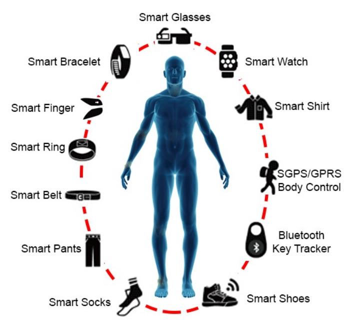
Motivation & Goals

- Importance of IMU(Inertial Measurement Unit)
  - Navigation: Measure velocity and orientation to determine the object's position and trajectory
  - Robotics: Provide real-time feedback about the movement
  - Virtual Reality: Integral to VR system to track the body movement
  - Motion Capture and Analysis: Used in sports science helping improve athletic performance
  - IOT and Healthcare



Motivation & Goals

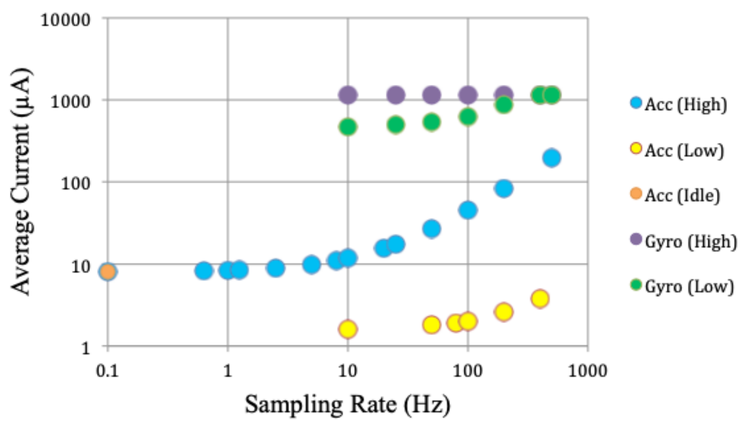


Fig. 1: Power consumption of MEMS IMU sensors: accelerometer, gyroscope, and low-power accelerometer currents are shown across frequency and operational mode.

HIGH POWER CONSUMPTION FOR GYRO!

- High Power consumption for IoT
  - Reduced battery life, which is essential for the functionality of the IoT devices
  - Poor user experience
- Gyro is more Power hungry
- IMU sensor data is redundant

Motivation & Goals

- Reduce Power consumption by using alternative sensors to mimic Gyro's functionality
  - Training a Machine learning model for Gyro emulation
  - Analyze the quality of the reconstruction
  - Implement the model on Arduino Nano 33 BLE Rev2
  - Visualize the reconstruction

Prior/Related work

- Accelerometer-only for body movement estimation[9](Physical model based)
  - Gyroscope free
  - 12 Sensors are required to determine the angular rate
  - Unscented Kalman Filter is applied to merge the angular acceleration and the angular rate

Fig. 3. The gyroscope-free IMU on the 3D rotation table.

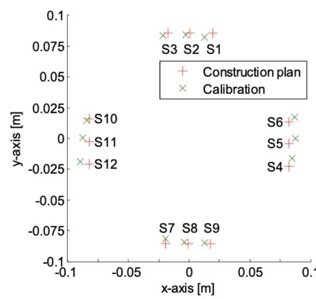


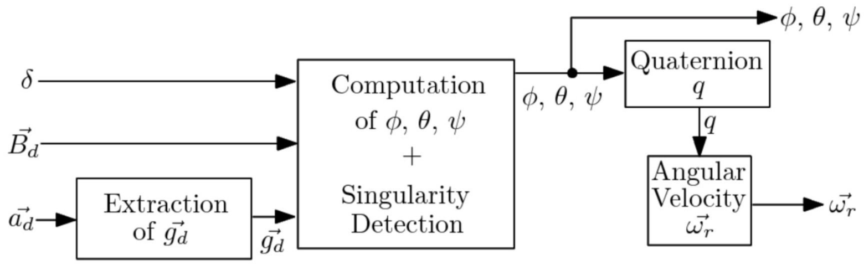
Fig. 6. The x-y positions of the 12 sensors (S1…S12) given in the construction plan and as determined by the calibration.

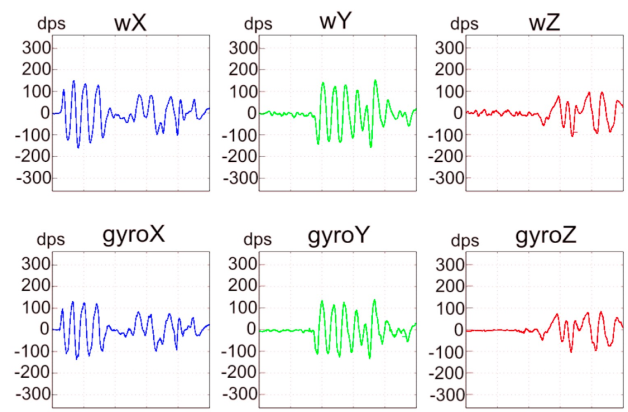
RMS Error:		Construction plan based	After calibration	Ideal Simulation
Body acceleration [m/s²] $\boldsymbol{a}_B$	x	0.14	0.03	0.02
	y	0.05	0.02	0.02
	z	0.07	0.05	0.02
Angular velocity [°/s] $\boldsymbol{\omega}_B$	x	17.75	8.53	1.18
	y	17.08	9.94	1.10
	z	18.17	6.54	0.92
Angular acceleration [°/s²] $\dot{\boldsymbol{\omega}}_B$	x	67.80	4.03	2.37
	y	30.07	4.18	2.12
	z	29.67	13.20	12.13

Tab. 1. Measured RMS error of the GF-IMU evaluated with offset adjusted sensor signals and parameters based on the construction plan, as well as after calibration. The simulation is based on ideal sensor position and orientation parameters.

Prior / Related work

- Accelerometer and Magnetometer based Virtual Gyro[3](physical model based)
  - Method1: Tait-Bryan angles and Quaternions
  - Method2: Rotation Matrix
  - Require Singularity Detection
  - Not accurate over time

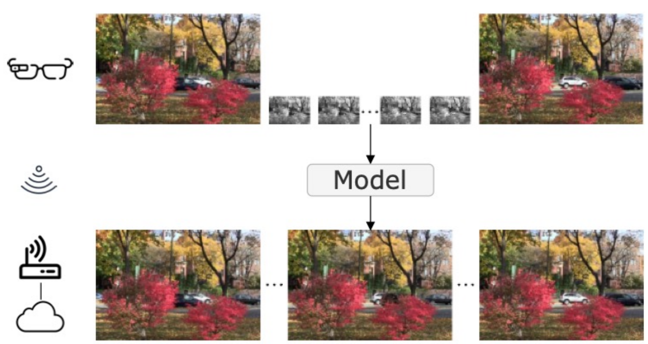


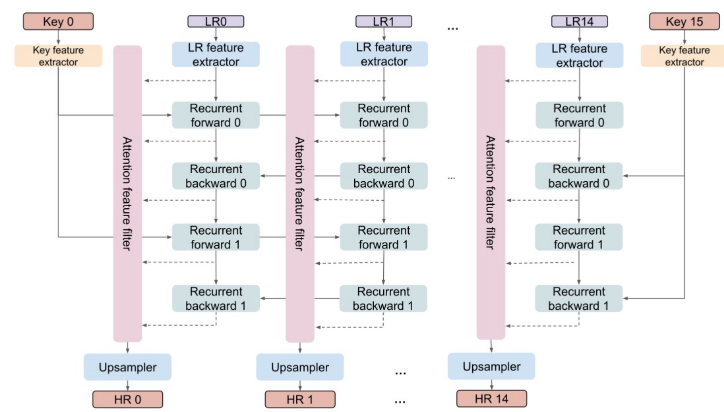


dps=degrees per second

Prior / Related work

- Key-Frame Video Super-Resolution and Colorization for IoT Cameras[1]
  - Use grey-scale, low resolution video frame to reconstruction high resolution colored video
  - High resolution of Key frame(lower sample rate) are used
  - An attention feature filter mechanism that assigns different weights to different features, based on the correlation between the feature map and the contents of the input frame at each spatial location is introduced



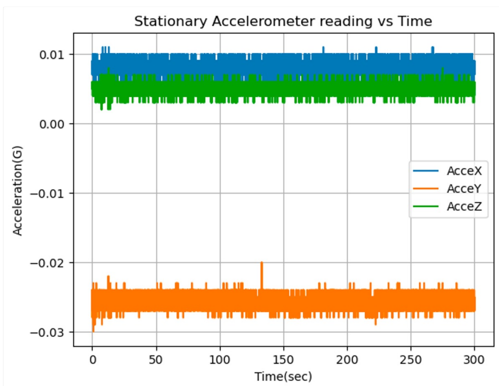


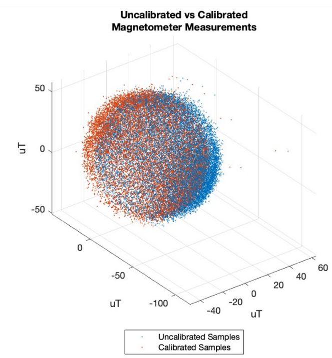
Novelty & Rationale

- Reduce Power consumption by using alternative sensors to mimic Gyro's functionality
    - Use accelerometer, magnetometer and gyro with much lower sample rate
    - A small set of gyroscope samples contributes to the overall robustness of the emulation process
    - Machine learning exhibits enhanced accuracy and resilience to noise compared to physical model-based algorithms

Technical Approach

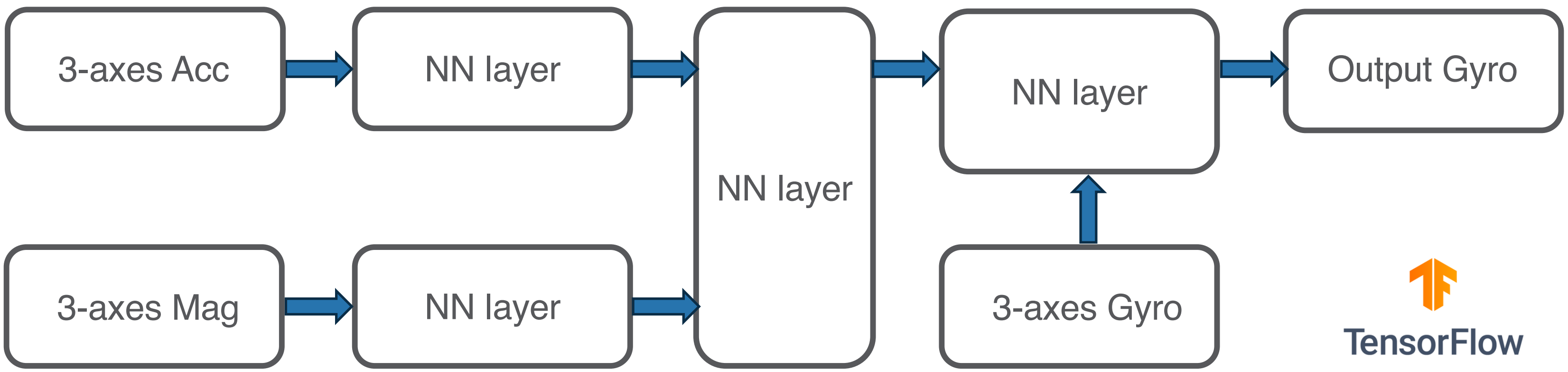
- Sensor Calibration and data collection
  - 2 separate datasets are collected for calibration and model training
  - Calibration dataset is collected while the IMU is in a static and stable position
  - Training dataset is collected, ensuring the IMU is randomly moving and rotating
  - 31494 samples are collected for further analysis





Technical Approach

- Model Design and Training(TensorFlow)
  - Input data: 3-axes current accelerometer readings, 3-axes current magnetometer readings and 3-axes previous (estimated or measured) gyroscope readings
  - Output data: 3-axes current gyroscope readings

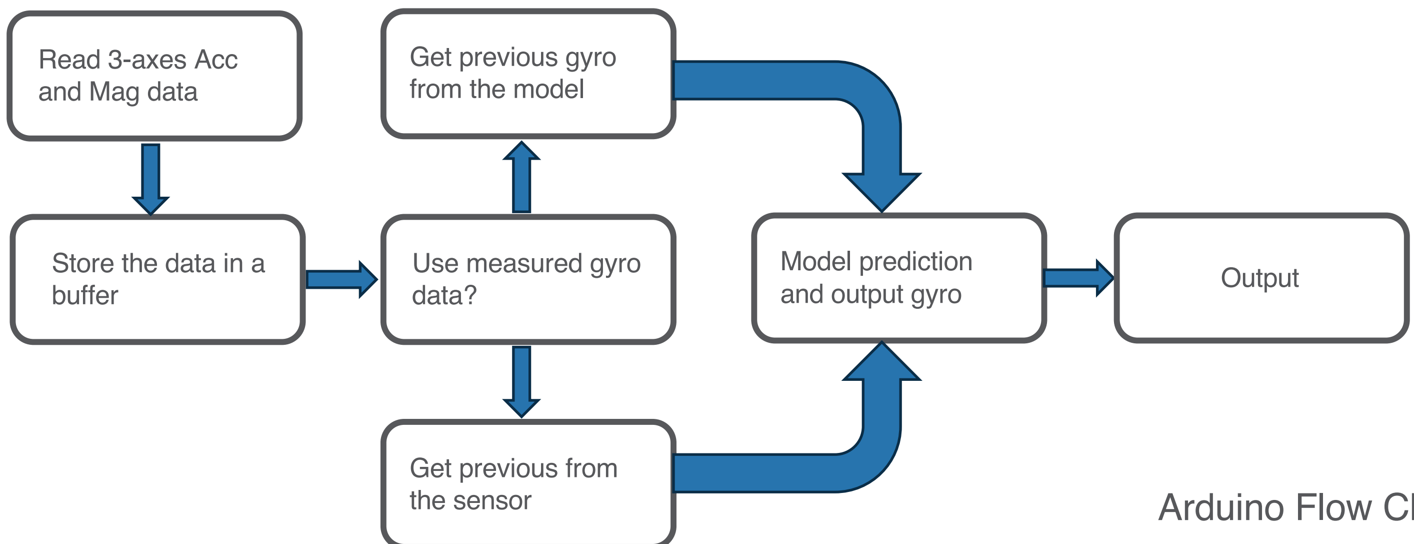


TensorFlow

Model design

Technical Approach

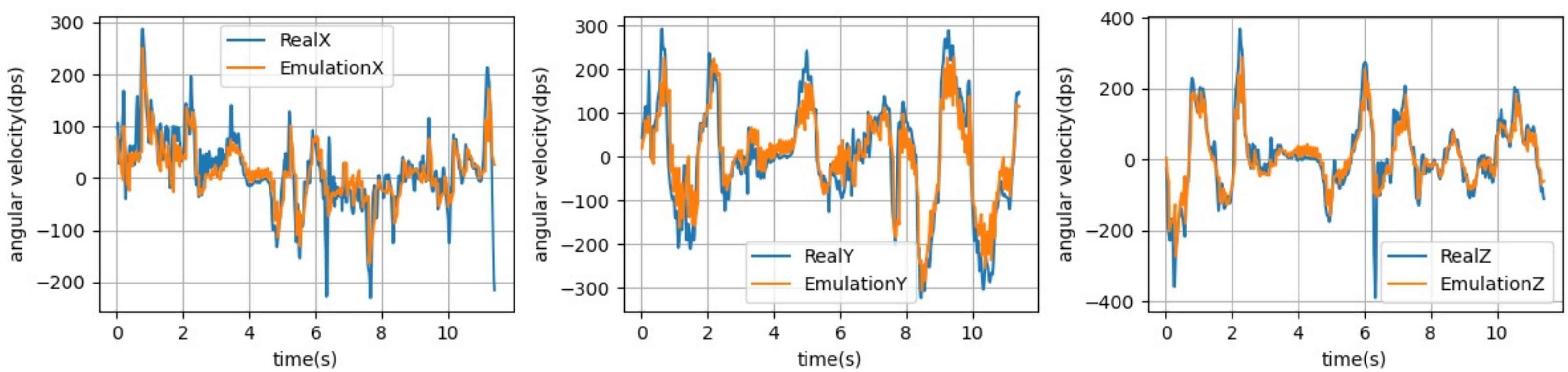
- Arduino Nano 33 BLE Rev2 and Visualization
  - Pretrained model is converted to TensorFlow Lite and then encoded the model in an Arduino header file.
  - The model is deployed on Nano 33 and use Processing for visualization



Arduino Flow Chart

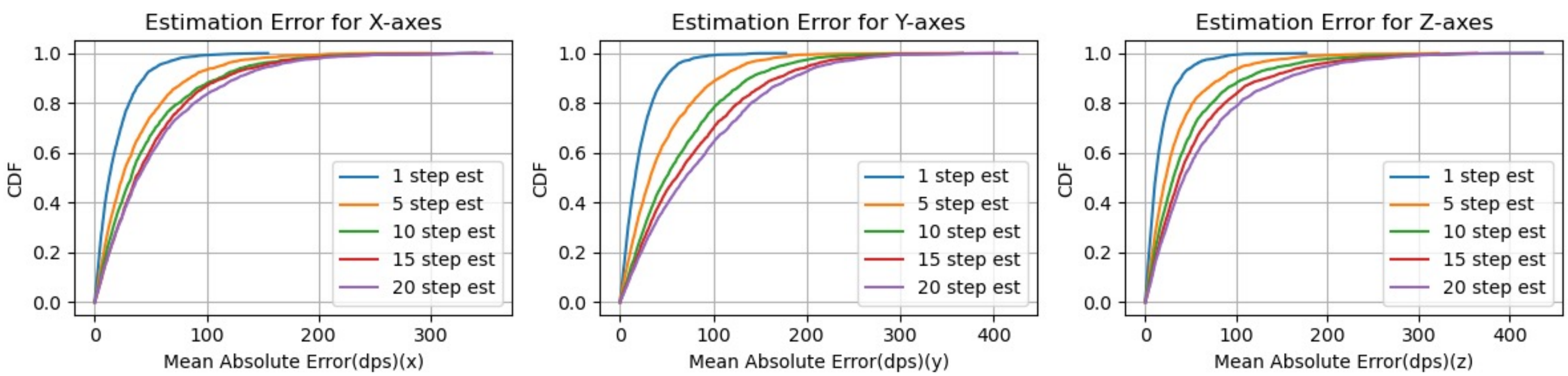
Experimental Evaluation

- Model Analysis
  - The model performance is evaluated given the previous gyro reading or estimation, current accelerometer and magnetometer readings



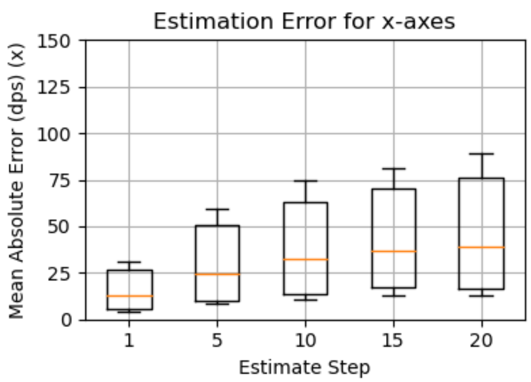
Experimental Evaluation

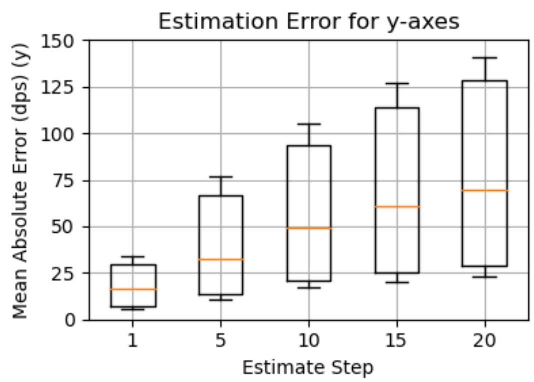
- Model Analysis(testing dataset based)
  - Multistep gyro estimation: Error Accumulation

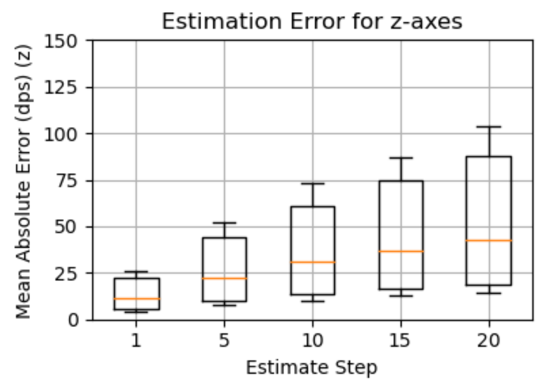


Experimental Evaluation

- Model Analysis(Experimental test)
  - Multistep gyro estimation: Error Accumulation
  - Estimation error is significantly greater along the Y-axe



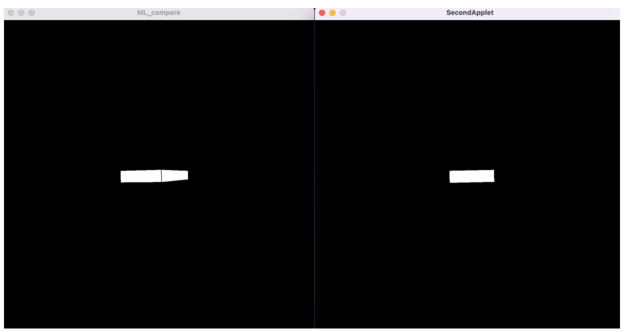




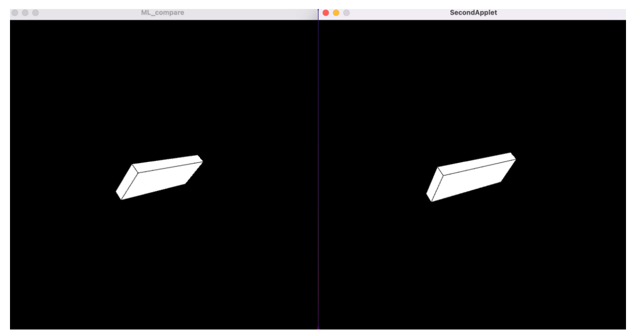
Experimental Evaluation

- Visualization for Real Gyro and Emulated Gyro

Start Point

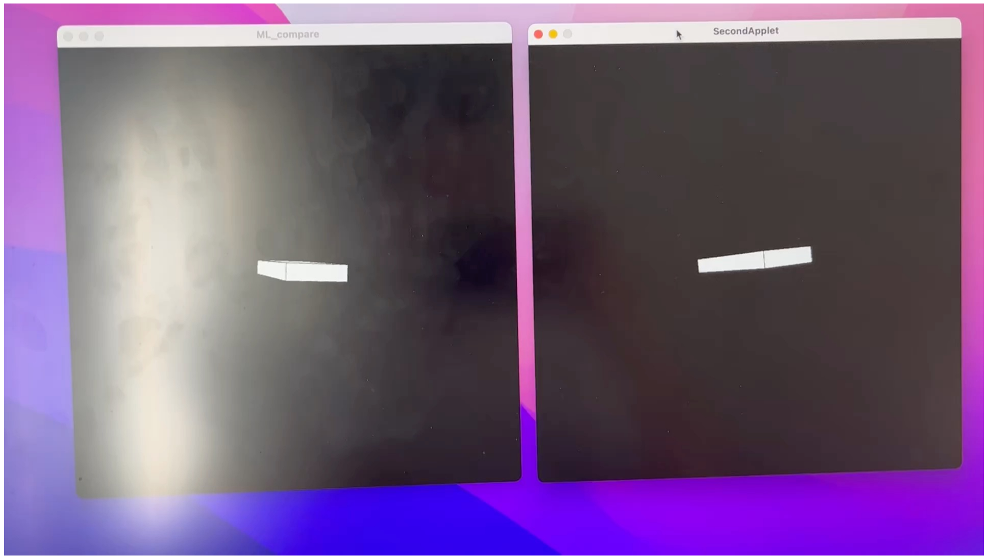


End Point



Experimental Evaluation

- Visualization for Real Gyro and Emulated Gyro



Conclusions & Future Directions

- Conclusions:
  - Proposed a machine learning model to emulate virtual gyro
  - Analyze the performance both on dataset and real-time scenario
  - Reconstruct the gyroscope with reasonable low-sample-rate

- Future Directions:
  - More complicated Model for gyro estimate
  - Power consumption analysis
  - Gyro-free reconstruction

Reference

[1]Bandhav Veluri, Collin Pernu, Ali Saffari, Joshua Smith, Michael Taylor, and Shyamnath Gollakota. 2023. NeuriCam: Key-Frame Video Super-Resolution and Colorization for IoT Cameras. In Proceedings of the 29th Annual International Conference on Mobile Computing and Networking (ACM MobiCom '23). Association for Computing Machinery, New York, NY, USA, Article 26, 1–17. https://doi.org/10.1145/3570361.3592523

[2]Zhang, Yifan, William W. Clark, Bryan Tillman, Young Jae Chun, Stephanie Liu, and Sung Kwon Cho. 2023. "A System to Track Stent Location in the Human Body by Fusing Magnetometer and Accelerometer Measurements" Sensors 23, no. 10: 4887. https://doi.org/10.3390/s23104887

[3]Baptiste Delporte, Laurent Perroton, Thierry Grandpierre, Jacques Trichet. Accelerometer and Magnetometer Based Gyroscope Emulation on Smart Sensor for a Virtual Reality Application. Sensors & Transducers., 2012, 14-1 (Special Issue ISSN 1726-5479), p32-p47. ⟨hal-00826243⟩

[4]Q. Liu et al., "Gazelle: Energy-Efficient Wearable Analysis for Running," in IEEE Transactions on Mobile Computing, vol. 16, no. 9, pp. 2531-2544, 1 Sept. 2017, doi: 10.1109/TMC.2016.2623304.

[5]Ludwig, Simone A., and Antonio R. Jiménez. "Optimization of gyroscope and accelerometer/magnetometer portion of basic attitude and heading reference system." 2018 IEEE International Symposium on Inertial Sensors and Systems (INERTIAL). IEEE, 2018.

[6]Wu, Yuanxin, and Ling Pei. "Gyroscope calibration via magnetometer." IEEE Sensors Journal 17.16 (2017): 5269-5275.

[7]Yu, Hongnian, Shuang Cang, and Yan Wang. "A review of sensor selection, sensor devices and sensor deployment for wearable sensor-based human activity recognition systems." 2016 10th international conference on software, knowledge, information management & applications (skima). IEEE, 2016.

[8]Liu, T., G. R. Zhao, and S. Pan. "New calculating method of angular velocity in gyroscope-free strapdown inertial navigation systems." Systems Engineering and Electronics 32.1 (2010): 162-165.

[9]Schopp, P., et al. "Sensor fusion algorithm and calibration for a gyroscope-free IMU." Procedia Chemistry 1.1 (2009): 1323-1326.

[10]Wang, C., et al. "Hybrid algorithm for angular velocity calculation in a gyroscope-free strapdown inertial navigation system." Journal of Chinese Inertial Technology 18.4 (2010): 401-404.

Thank You