HYBRID INTRINSIC–EXTRINSIC CALIBRATION OF MULTIPLE IMUS AND JOINT ENCODERS FOR ACCURATE END-EFFECTOR TRAJECTORY ESTIMATION OF AERIAL MANIPULATORS

Ilyar Asl Sabbaghian Hokmabadi[1], Mahdis Bisheban[1]
[1]Mechanical and Manufacturing Engineering, University of Calgary, Canada, Calgary.
Email: ilyar.aslsabbaghianh@ucalgary.com

INTRODUCTION

Pose, velocity and acceleration estimation are crucial for many robots. Traditionally, these parameters have been estimated using a plethora of sensors such as cameras and IMUs. For robotic manipulators, encoders are among the most ubiquitous sensors. With their help, the end-effector pose, and velocity can be estimated. However, encoders cannot accurately measure fast motion and suffer from quantization errors [1], they cannot sense vibrations along three axes and fail to account for joint or link deformation [2]. These restrictions and assumptions often result in reduced accuracy in estimating the end-effector pose. The proposed method aims to address these by fusing IMU and encoder data for manipulator state estimation. While IMUs have been used in the past, there is no prior work that simultaneously estimates the IMU intrinsic (e.g., bias, scale factor) calibration, IMU/joint extrinsic calibration (i.e., the transformation between the IMU and encoder frames), and the robot model parameters.

METHODS

In order to estimate the unknown calibration parameters, the proposed method leverages the known gravitational vector at a given position, static periods (when the arm is motionless), as well as the forward kinematics of the end-effector. The proposed method incorporates all the aforementioned information into an optimization problem. The parameters to be estimated include the intrinsic calibration parameters of the IMUs installed on each joint, and the extrinsic calibration parameters. Further, we also estimate the calibration parameters of the encoder, revolute joint rotation axes, and the joint-to-joint translation vector.

RESULTS AND DISCUSSION

The tests are performed using a robotic arm (JetCobot). This arm is equipped with absolute encoders that provide the rotation angle of each joint. The arm has 7 degrees of freedom with revolute joints, and IMUs are installed on each joint. These low-cost IMUs are developed by STMicroelectronics. In addition, the arm is mounted on a three-axis Cartesian test rig. A schematic of the arm with the IMUs is shown in Fig. 1. Table 1 illustrates the importance of both intrinsic and extrinsic calibration by measuring the angular rate error of four joints. The errors are computed as the difference between the forward kinematics estimated from the encoders and the gyroscope readings.

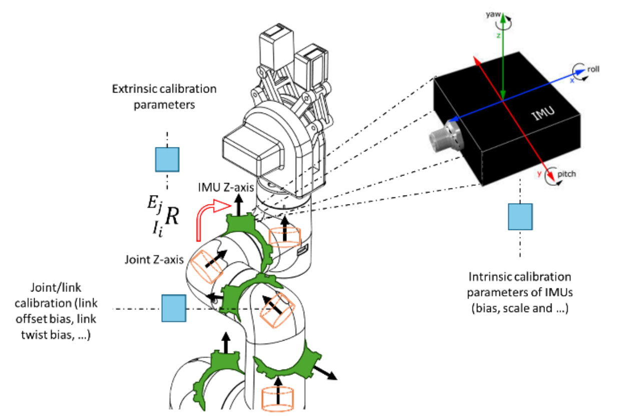

Fig 1 Illustration of the arm joints, IMUs and some of the unknown calibration parameters.

CONCLUSIONS

Robot manipulation is an important research area. To accurately estimate the pose, kinematics, and acceleration of an end-effector, an encoder–IMU fusion can be utilized. In this research, we propose an approach to estimate intrinsic, extrinsic, and robot model calibration parameters. The experiments are performed on a real-world robotic arm equipped with a low-cost IMU. The results demonstrate the importance of such calibration in achieving lower errors in the robot's forward kinematic model.

REFERENCES

[1] Moreira, J. et al., Applied Sciences, 2021.
[2] Axelsson, Linkopings Universitet (Sweden), 2011.

Table 1: The error comparison with and without intrinsic and extrinsic calibration

	IMU 1 (kinematic error)	**IMU 2 (kinematic error)**	**IMU 2 (kinematic error)**	**IMU 4 (kinematic error)**
W/O Extrinsic and intrinsic	51.53 ($°/s$)	62.63($°/s$)	67.52($°/s$)	73.18($°/s$)
W Extrinsic	4.06($°/s$)	5.23($°/s$)	5.84($°/s$)	6.91($°/s$)
W Intrinsic and Extrinsic	3.74($°/s$)	5.14($°/s$)	5.71($°/s$)	6.89($°/s$)