

Human arm motion tracking using IMU measurements in a robotic environment

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Abstract. Human-robot interactions (HRI) is an emerging paradigm that aims at combining complementary skills of robot and human. The meaningful human arm motion represent an interesting way of communication to explore with robot. IMUs appear as a simple, lightweight, easy-to-use, technology for human motion tracking compared to other systems such as opto-electronic devices. However, IMUs require important data treatment to reconstruct human motion and are usually coupled with a magnetometer or even other sensors. This paper explores a method only based on IMUs (accelerometer and gyroscope) to track human motion in order to keep the simplicity and robustness of IMUs in an industrial environment with magnetic disturbances. The signal processing method presented here limit the well-known drift of the gyroscope by gravity measurement.

1 Introduction

Human-robot interactions (HRI) is a research field that aims at combining the accuracy and repeatability of a robot and the versatility of a human. One aspect of current robots is their skill-demanding programming methods. The survey [1] opposes manual to automatic programming methods. The first one involves the modification of the robot program directly by a skilled operator while, in the second one, the robot itself modifies its program according to external information. A branch of this emerging robot programming method exploits human ways of communication like upper limb motions. In this work, Inertial Measurement Units (IMUs) sensors are used to measure human arm motion. Among the available technologies, IMUs have the benefit of being easy to used, lightweight, wireless and cheap compared to light-sensitive and expensive vision-based technologies. Exoskeletons are also used but only enable to measure human joint parameters, making it difficult to map the human motion to the robot frame.

One largely used approach in human motion tracking consists in computing human joint parameters from the relative orientation of sensors attached to human segments before and after joints [2]. This method presents the same inconvenient as exoskeletons. Another approach is selected in the present work and described later.

In any case, the orientation of the IMU should be estimated based on the sensor raw data. Many different methods are reviewed in [3]. Most of them combine IMUs (accelerometer and gyroscope) with a magnetometer (noted MIMUs) measuring the Earth-magnetic north as in [4] and consist in solving the Wahba's problem. However, electromagnetic disturbances in an industrial environment may jeopardize the measurement of the Earth magnetic field. Some alternatives have been proposed which fuse the IMU's data with other sensors [2]. Other solutions with only two accelerometers is proposed in [5], for which the distance and orientation between the two sensors has to be perfectly known. But these sensors cannot be too close from each other making this technology rather bulky for a wearable device.

This work presents a new approach, suitable for an industrial context, to limit gyroscope drift with a gravity-based orientation estimation. This approach has been mentioned in a previous work [6] and is detailed here. First, the equipment is presented. Then, the strategy for arm motion tracking is shortly exposed, in order to introduce the new approach. Finally, some experimental results are given.

2 Equipment

The sensor modules used in this work have been developed by the Microsys lab from the University of Liège [7]. These wireless platforms are composed of a 3-axis IMU from Bosch (BMI160) and transmit data at the frequency

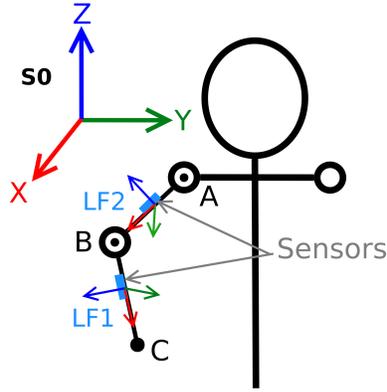


Fig. 1: Absolute segment orientation approach

of 100hz to a *Raspberry Pie 3*. The module measures 2 data sets with respect to local sensor frame (noted LF):

- The acceleration noted a^* :

$$a^* = a + g = \begin{bmatrix} a_x + g_x \\ a_y + g_y \\ a_z + g_z \end{bmatrix} \quad (1)$$

with a representing the linear acceleration of the sensor and g the Earth gravity field.

- The angular velocity ω^* :

$$\omega^* = \begin{bmatrix} \omega_x^* \\ \omega_y^* \\ \omega_z^* \end{bmatrix} \quad (2)$$

3 Trajectory computation

The problem addressed in this work is to measure the human motion in a robotic application. In a first step, the given objective is to compute the trajectory of the wrist with respect to the shoulder. The selected approach consists in computing directly the orientation of each segment of the human arm (arm and forearm) with respect to an inertial frame using two sensors as described in figure 1. The inertial lab frame noted S_0 has its Z-axis pointing vertically upwards. The sensors enable to compute the rotations ${}^{S_0}R_{LF_1}$ and ${}^{S_0}R_{LF_2}$. Thus, the trajectory $\vec{AC}_{S_0}(t)$ is computed as:

$$\vec{AC}_{S_0}(t) = {}^{S_0}R_{LF_1}(t)\vec{AB}_{LF_1} + {}^{S_0}R_{LF_2}(t)\vec{BC}_{LF_2}$$

The proposed method to compute the two rotations is based on an incremental quaternion-based estimation of the sensor orientation. At every time step n , the orientation of the local frame LF_n (either for sensor 1 or 2) with respect to the inertial frame S_0 is estimated from the previous quaternion q_{n-1} representing the rotation from the inertial frame S_0 to the local frame LF_{n-1} as follows :

$$q_n = q_{n-1} + h\left(\frac{1}{2}q_{n-1} \otimes \omega_{q_n}\right)$$

with h the time step value, ω_{q_n} is the quaternion representation of the angular velocity ω_n at time step n and ω_n is the gyroscope measurement (see Eq (2)):

$$\omega_n = \omega^*$$

After this operation, q_n is then normalized. This boils down to a direct quaternion based integration of the angular velocity, which is subject to a well-known drift over time usually overcome by extra sensors [3].

A method has been implemented in order to limit this drift without extra sensor. This method, based on gravity measurement, can be used only during slow or no motion phases such that $a^* \approx g$. Thus, at time step n , the gravity

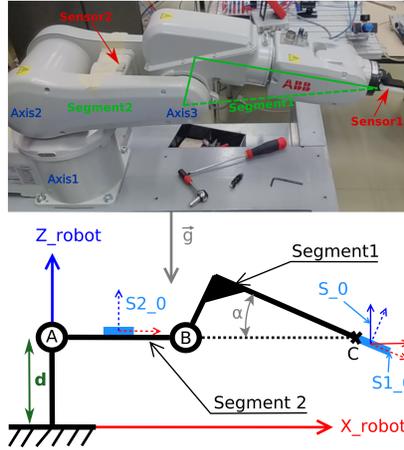


Fig. 2: Setup for comparison between robot trajectory and IMUs measured trajectory

vector g_n with respect to the local frame LF_n is close to the normalized accelerometer measurement : $g_n \approx \frac{a_n^*}{\|a_n^*\|}$. The angular velocity ω_n can be developed as follows:

$$\omega_n = (I - g_n g_n^T) \omega_n + g_n (g_n^T \omega_n) \quad (3)$$

with I is the 3-by-3 matrix identity. The first term of the equation (3) is the projection of ω_n in the plane perpendicular to g_n and approximated by:

$$(I - g_n g_n^T) \omega_n \approx \frac{1}{h} (g_n \wedge g_{n-1})$$

with h the time step value and g_{n-1} the gravity vector with respect to the sensor frame LF_{n-1} . The second term of the equation (3) is computed from the gyroscope measurement. The expression of ω_n become:

$$\underline{\omega}_n \approx \frac{1}{h} (g_n \wedge g_{n-1}) + g_n (g_n^T \omega^*)$$

In order to detect phases with negligible linear acceleration, the following criterion is implemented: if the acceleration norm is around 1 g-unit : $0,9 < \|a^*\| < 1,1$ and the norm of the gyroscope close to 0 degree/sec : $\|\omega^*\| < 1,1$ then the sensor is considered not undergoing any linear acceleration.

As the orientation along the path is computed incrementally the initial orientation q_{init} of each sensor frame with respect to the inertial common frame S_0 has to be determined. A procedure, relying on the measurement of the gravity field, was proposed and discussed in [6].

4 Results

This algorithm is tested on an *IRB 120* robot from ABB company. The robot simulates the motion of a human arm and the trajectory of its end-effector, recorded by its controller, is used as reference. Two IMU sensors have been mounted on the robot arm as described in the figure 2. The robot axes 1 and 2 represent the shoulder and the axis 3 the elbow, the segment 2 the arm and the segment 1 the forearm. The last 3 axes (4, 5 and 6) of the robot are not activated. The sensor 2 is set in a way its X-axis is aligned with the direction of the segment 2. The sensor 1 X-axis is not aligned with the direction of the segment 1, but still in the XZ-plane of the robot. This misalignment is managed by an initialization procedure. The S_0 frame, centered on A, has its Z-axis along gravity. It is assumed that the Z-axis of the robot is also aligned with the gravity vector. The X-axis of S_0 is along the \overrightarrow{AC} direction at the initial time step which is made to be parallel with the X-axis of the robot-base frame. That way, only an offset d has to be subtracted to the robot trajectory to express both trajectories with respect to the same frame. Figure 3 shows the good correlation between both trajectories of the robot end-effector measured by the robot itself and by the sensors.

3D representation of the same trajectory measured by the robot and by the sensors

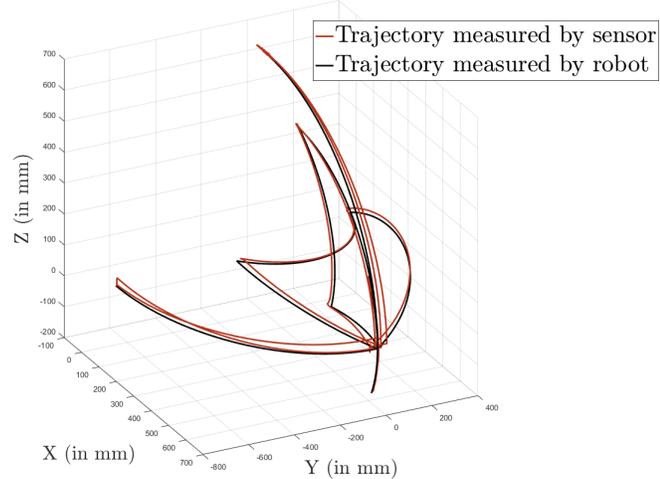


Fig. 3: Trajectory comparison between robot measurement and IMUs measurement

5 Conclusion

IMUs appear as an interesting way to measure human motion in an industrial environment. Many methods exist to compute human upper limb trajectory from IMU sensors but only a few are suitable for a robotic application. The proposed solution does not use magnetometers because of their sensitivity to electromagnetic disturbances. Only the gyroscope signal is used, completed by acceleration measurement to limit the drift from the gyroscope in slow or no motion phases. A consistent reconstruction of the trajectory is achieved but the accuracy of the measured trajectory could be further improved. The future work will consist in measuring the accuracy of the raw sensor data, of the orientation and finally of the complete trajectory in order to improve it.

Acknowledgements

This work was supported by the Interreg V programme of the Greater Region within the Robotix Academy project.

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