Motion Analysis of Football Kick Based on an IMU Sensor
基於六軸感測器信號之足球踢擊分析

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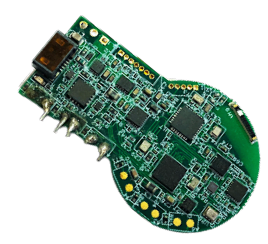
Abstract

A greater variety of technologies are being applied in the field of sports and health with the advancement of technology, but most image analysis systems have strict environmental restrictions and are usually costly. We introduce a motion analysis system based on a 6-axis inertial measurement unit (IMU) to reconstruct the motion trajectory of the football kick, in the meantime analyze the maximum speed and the highest point of the foot before getting in contact with the ball. We use MATLAB to integrate various functions into a complete measurement and analysis system and standardize the experimental process, allowing inexperienced users to reconstruct the trajectory and obtain other information about the motion within a short time.

Implementation

ICM-20649 consists of a three-axis accelerometer and a three-axis gyroscope, with a 16-bit ADC for each. We set the accelerometer range at ±30g and the gyroscope at ±4000 degree/s, then use the sphere regression model found by the least square method to calibrate the sensor deviation.



Data can be applied and analyzed only through attitude processing. We take the initial coordinate as the reference coordinate to obtain the rotation information of each sampling point through the angular velocity change during the motion, then do the further calculation with quaternion operations. The estimated attitude would then be applied to rotate the acceleration data from the sensor frame to the initial frame.

$$new\ orientation \mathrel{+}= 0.5 \times orientation \times angVel \times \Delta t$$

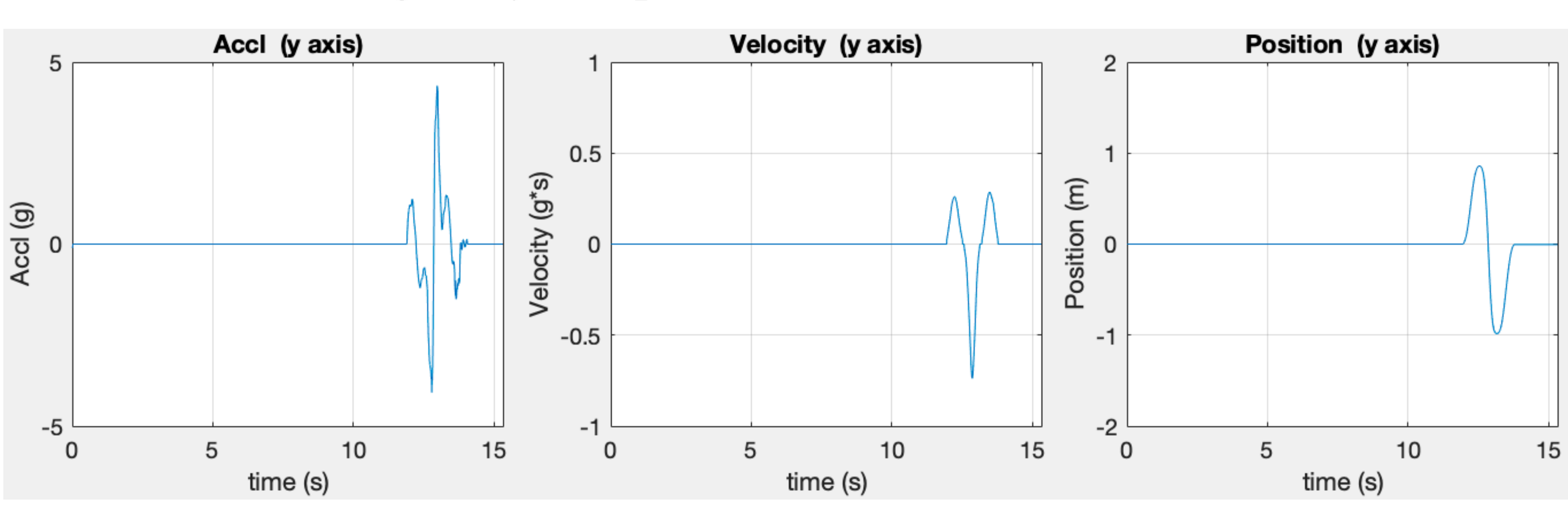
$$acc_{transformed} = Q \times acc \times Q_{conj}$$

To reconstruct the motion trajectory, we need to eliminate the gravity components from the acceleration data. By keeping the sensor stationary before the motion, we are able to do gravity compensation with the known attitude. Then by applying a 3-axis rotation matrix given below, the data would then be set to the Earth frame from the initial frame.

$$acc_{Earth} = T_{rotate} \times acc_{intial}$$

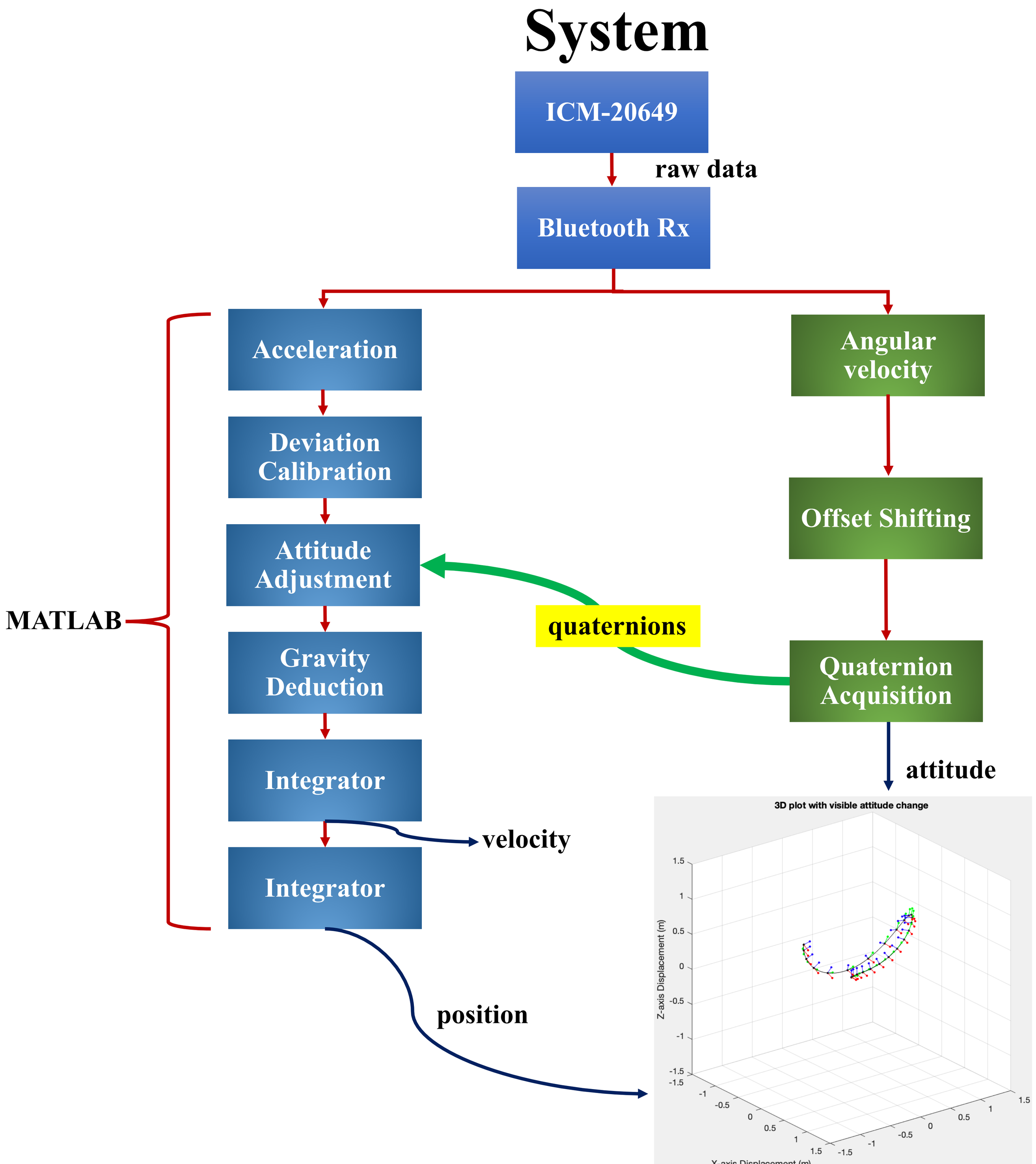
$$T_{rotate} = \begin{bmatrix} \cos(pitch)\cos(yaw) & \cos(yaw)\sin(pitch)\sin(roll) - \cos(roll)\sin(yaw) & \sin(roll)\sin(yaw) + \cos(roll)\cos(yaw)\sin(pitch) \\ \cos(pitch)\sin(yaw) & \cos(row)\cos(yaw) + \sin(pitch)\sin(roll)\sin(yaw) & \cos(roll)\sin(pitch)\sin(yaw) - \cos(yaw)\sin(roll) \\ -\sin(pitch) & \cos(pitch)\sin(roll) & \cos(pitch)\cos(roll) \end{bmatrix}$$

Quadratic integration for accelerations is required to obtain the velocity and the motion trajectory. A 0.04 (g) acceleration threshold and a 0.02 (g/s) velocity threshold are applied to avoid error accumulation of the integration caused by external factors such as vibration and the incomplete elimination of the gravity component.



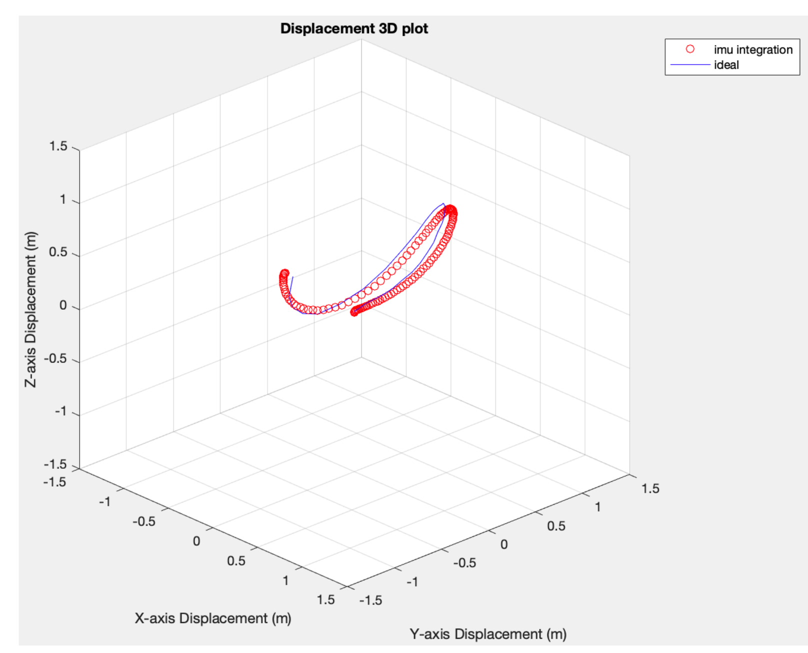
▲ Quadratic integration process

System



Results

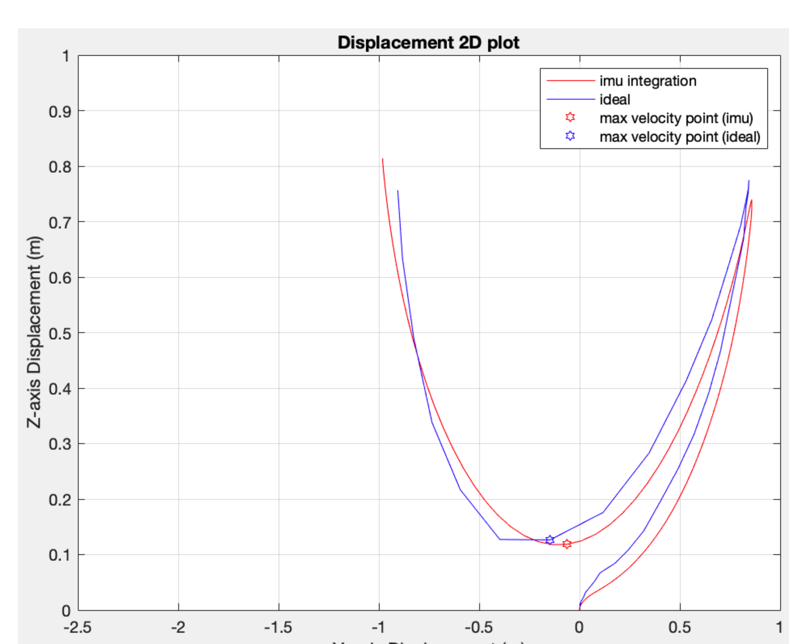
After the data is processed, the position information of each sampling point is obtained and a 3D trajectory diagram is drawn in MATLAB. We then calculate the average path length and the average Root Mean Square Error to the ideal path of repeated experiments to verify the accuracy of the trajectory reconstruction of the system.



Trajectory		
	Length (m)	RMSE (m)
exp1	3.48	0.076
exp2	3.76	0.064
exp3	3.65	0.057
exp4	3.66	0.079
exp5	3.61	0.078
Average	3.63	0.07

▲ 3D motion trajectory and table of results

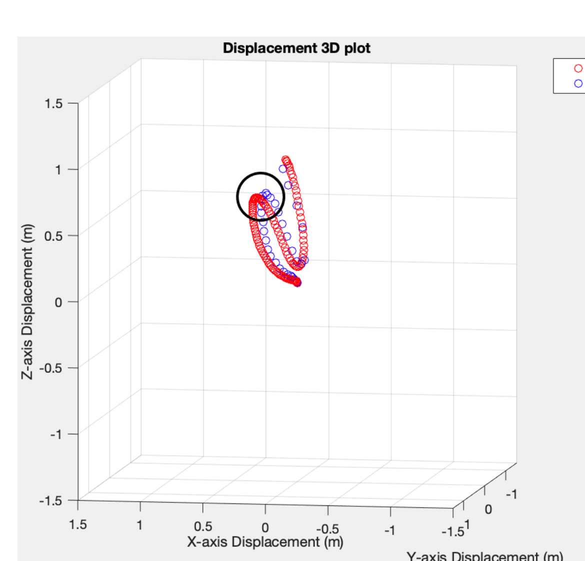
Through the analysis of the processed data, we can observe the maximum velocity of the athlete's foot swing as well as the position and timing where the maximum velocity appears. We verify the accuracy of the velocity estimation of the system by comparing its results with the velocity obtained from Tracker.

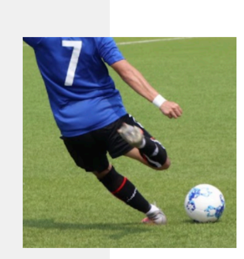


Maximum velocity (m/s)			
	Actual	Ideal	Error
exp1	7.448	7.154	4.1%
exp2	7.252	7.546	3.9%
exp3	7.252	7.546	3.9%
exp4	7.644	7.154	6.8%
exp5	7.742	7.644	1.3%
Average	7.468	7.409	4.0%

▲ 2D motion trajectory with maximum velocity position and table of results

When shooting, if the front knee is not bent enough to increase the height of the calf, the power of this shot will be significantly affected. Therefore, we'd like to observe the height of the highest point of the pull-back motion from the reconstructed trajectory. The accuracy of the highest point estimation is also verified by comparing the results with that from Tracker.





Highest point (m)			
	Actual	Ideal	Error
exp1	0.6552	0.6865	4.6%
exp2	0.8014	0.8104	1.1%
exp3	0.7396	0.7745	4.5%
exp4	0.725	0.7404	2.1%
exp5	0.7824	0.7686	1.8%
Average	0.741	0.756	2.8%

▲ 3D motion trajectory with pull back height and table of results

According to the experiment results, for the instep kicking motion of trajectory length around 3.63 meters, the root mean square error (RMSE) is about **7 centimeters** compared with the theoretical value obtained from high-speed cameras and image analysis software. For the maximum speed of the foot, the error is approximately **4%**. This physical quantity is related to the contact point with the ball and the timing of acceleration. The error for the highest point of the foot before hitting the ball is **2.8%**.

Reference:

[1] Wilmes, Erik, Cornelis J. de Ruiter, Bram J.C. Bastiaansen, Jasper F.J.A.v. Zon, Riemer J.K. Vegter, Michel S. Brink, Edwin A. Goedhart, Koen A.P.M. Lemmink, and Geert J.P. Savelsbergh, "Inertial Sensor-Based Motion Tracking in Football with Movement Intensity Quantification" Sensors 20, no.9: 2527, April 2020

[2] M. Roobeek, "Motion tracking in field sports using GPS and IMU", Master of Science Thesis, Delft University of Technology, 2017