Moonlight Project

Development of a lightweight sports monitoring device - Application to cycling movement analysis

Context and objectives

The overall objective of Moonlight project is to design a new embedded system in order to analyze cyclists' movements in real conditions, i.e. outside of the laboratory. This requires to estimate reliable 3D joint angles, lower limb kinematics and pedals orientation. Usually, these parameters are evaluated using optoelectronical motion capture in laboratory conditions but marker-based solutions are not well set up for large volumes captures (such as velodromes) and may be cumbersome and time consuming. To overcome these limitations, inertial measurement units (IMU) seem promising. However, some challenges have to be addressed as regards to sensor-to-segment misalignment and drift. Indeed, a real time accurate orientation of the crank is necessary to get limb position. To acheive this goal, data fusion algorithms between IMU data and pedal orientation are implemented. A wireless sensor network with accurate time synchronisation mecanism is needed to process data fusion from all sensors nodes on a tablet. Finally, the system deals with size, energy consumption and ease-to-use constraints.

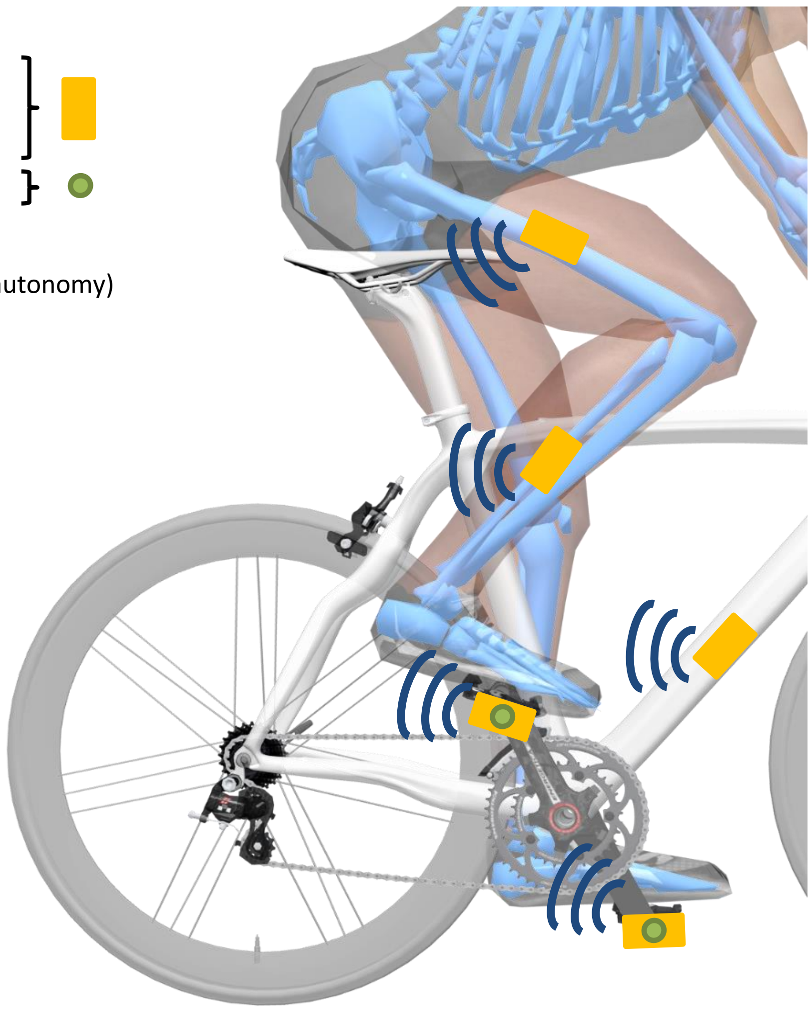
Monitoring system overview

Node architecture

- ULP Microcontroller
- Bluetooth communication
- 9DOF IMU (Inertial Measurement Unit)
- Magnetic coder (for pedal node)

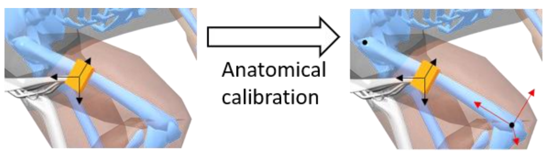
Features of the developed prototype

- Low energy consumption (up to 2h of autonomy)
- Small form factor (fit on a pedal)
- Embedded data logging
- Real time data exchanges with a tablet



From inertial measurements to joint angles

1) **« Sensor-to-segment » calibration procedure**



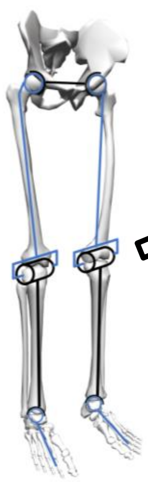
2) **Measures correction using kinematic chain based multi-body optimization**

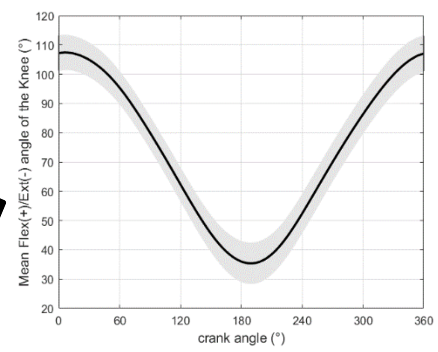
$$\min_{Q,\dot{Q},\ddot{Q}} f = \frac{1}{2}[\phi^m]^T W [\phi^m] + \frac{1}{2}\left(\begin{bmatrix}\dot{\phi}^k \\ \dot{\phi}^r\end{bmatrix}^T \dot{W} \begin{bmatrix}\dot{\phi}^k \\ \dot{\phi}^r\end{bmatrix} + \begin{bmatrix}\ddot{\phi}^k \\ \ddot{\phi}^r\end{bmatrix}^T \ddot{W} \begin{bmatrix}\ddot{\phi}^k \\ \ddot{\phi}^r\end{bmatrix}\right)$$

➔ Simultaneous correction of orientations, angular velocities and linear accelerations.

3) **Joint angles computation**

Computation of lower limb joint angles based on corrected anatomical orientations:

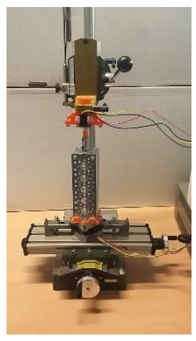


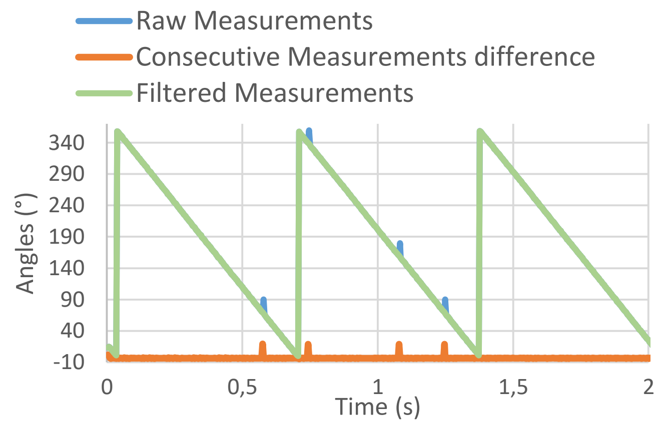


Flexion/Extension knee angle with respect to pedaling cycle (mean and SD)

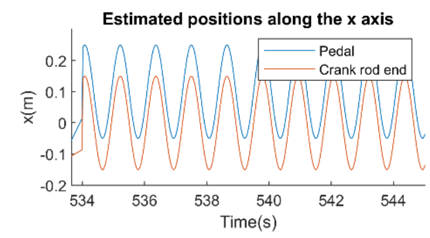
Prototype: tests & validation

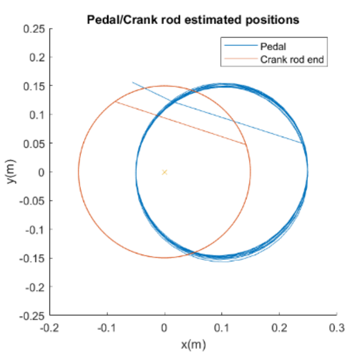
Magnetic coder evaluation: Test bench for proximity / misalignment characterizations



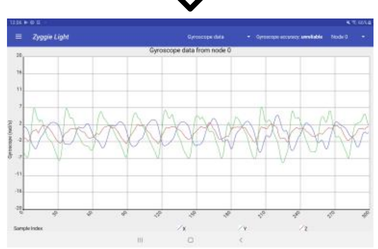


Simulator for prototype validation





Pedal prototype integration



Future works & validation

- Towards the development of a new embedded method for in situ biomechanical analysis of cycling
- Comparison of estimated values to those obtained with a reference optoelectronical system
- 3D real time rendering of motion & feedback for pedaling technique adjustments
- New miniaturized prototype