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3D Description of knee movements with a two IMU based wearable device: CHAKAMO

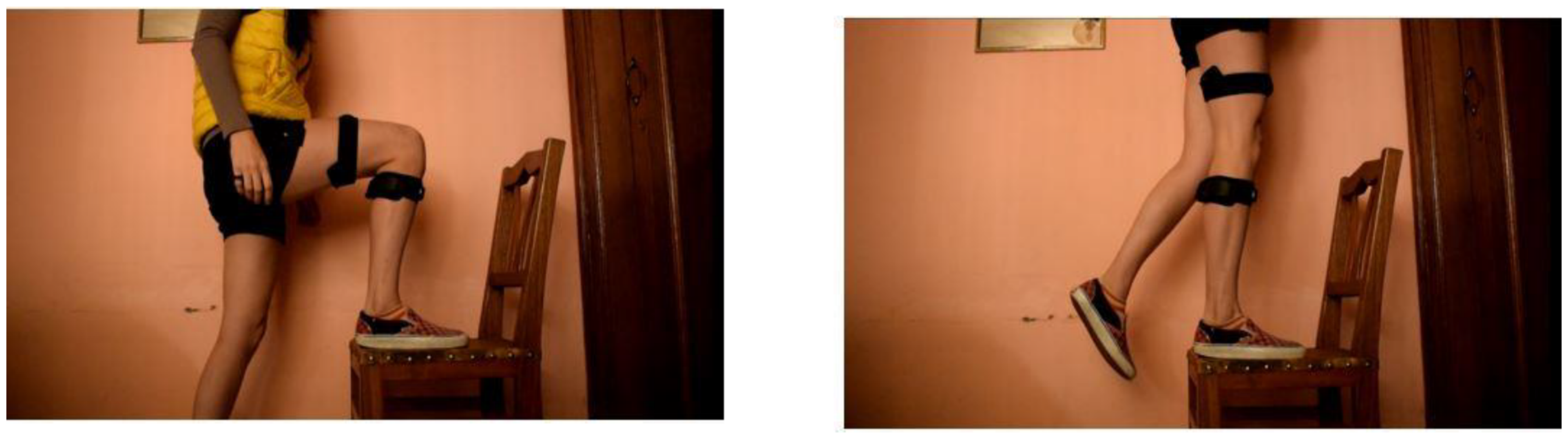
Maria Rene Ledezma [1], Darío Santos [1,2], Franco Simini [1]

1 Núcleo de Ingeniería Biomédica de las Facultades de Medicina e Ingeniería - Universidad de la República - Uruguay

2 Departamento de Rehabilitación, Biomecánica Clínica, Hospital de Clínicas - Universidad de la República - Uruguay

INTRODUCTION

After a knee injury, rehabilitation is important because it will determine the evolution of the knee joint and its continuous improvement. For this evaluation, the physiotherapist acts subjectively and uses tools such as goniometers to estimate ranges of knee angles. With these manual tools, the correctness of measurements depends on the instrument in use and on the physiotherapist's experience and ability.



(a) (b)

Figure 1. Motor task (a) Start of the cycle with 90° knee flexion. (b) Full knee extension, half cycle.

OBJECTIVE

To design and implement a device for clinical use with two inertial sensors, one on the shank, one on the thigh, to estimate knee joint kinematics. Inertial sensors were selected because they allow for natural movement and therefore measurements can be taken in any working environment.
The new instrument is called CHAKAMO, which produces time graphs to report flexion-extension as well as rotation of a person performing a simple motor task, such as climbing on a chair.

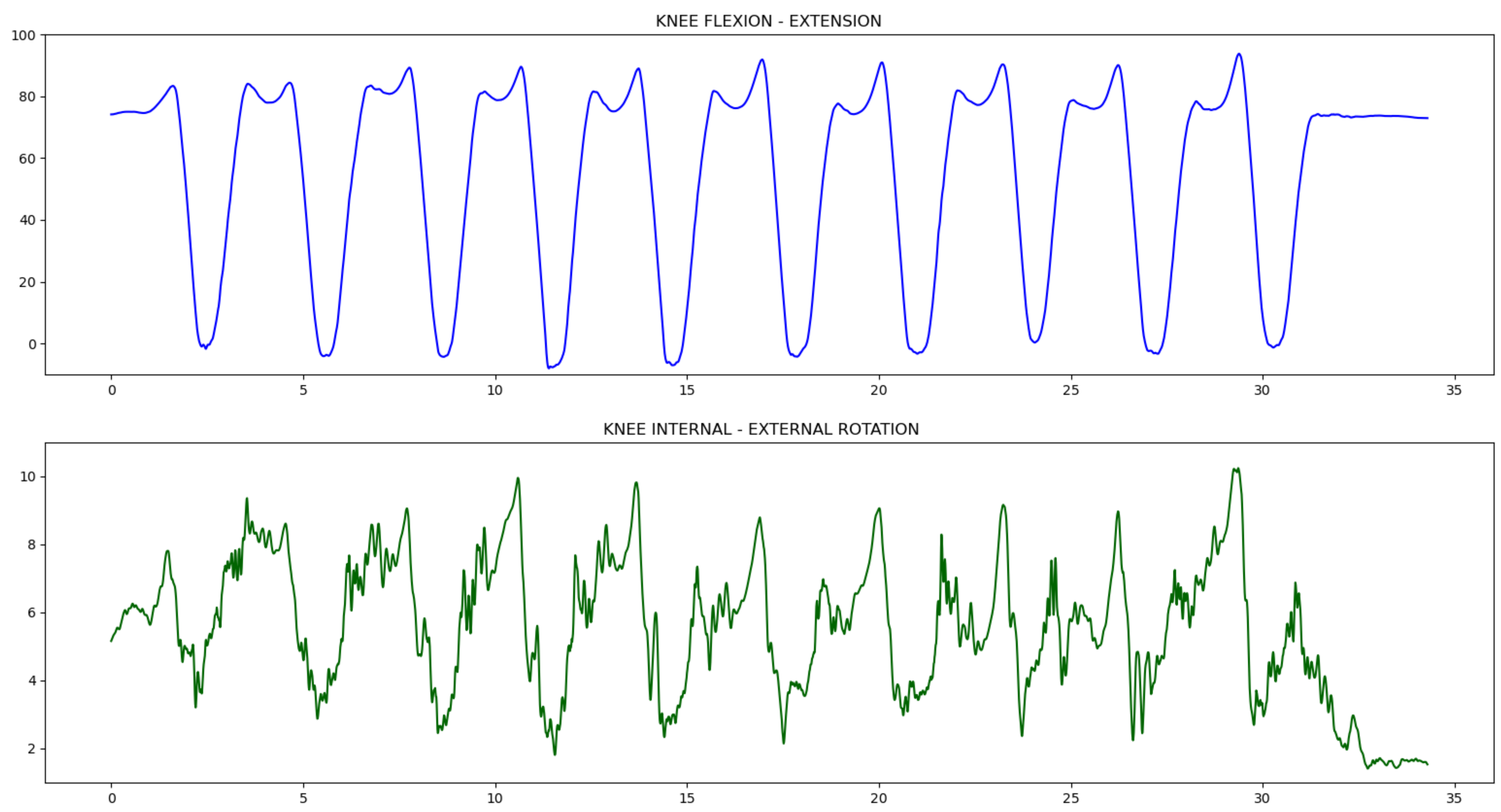


Figure. 2 Knee kinematics quantification during 10 cycles. Flexion-extension (blue) & rotation (green)

MATERIALS AND METHODS

1. Motor Task

The motor task consists of stepping up and down a step with one leg. Fig. 1 shows a chair taken as a high step (50 cm). The cycle begins with the knee under study flexed and the foot resting on the step. Then the subject proceeds to full knee extension lifting in the air the other foot. The movement must be natural and the participant is asked to return to the first position as soon as full extension is reached. When the contralateral foot returns to the floor, one cycle is completed. This task is functional and includes all movements of the knee, therefore it is possible to estimate the flexion and extension, as well as the rotation of tibia with respect to femur.

2. Inertial Sensors and system

MetamotionR sensors (MBIENTLAB, San Francisco, USA). Python 3.8.12

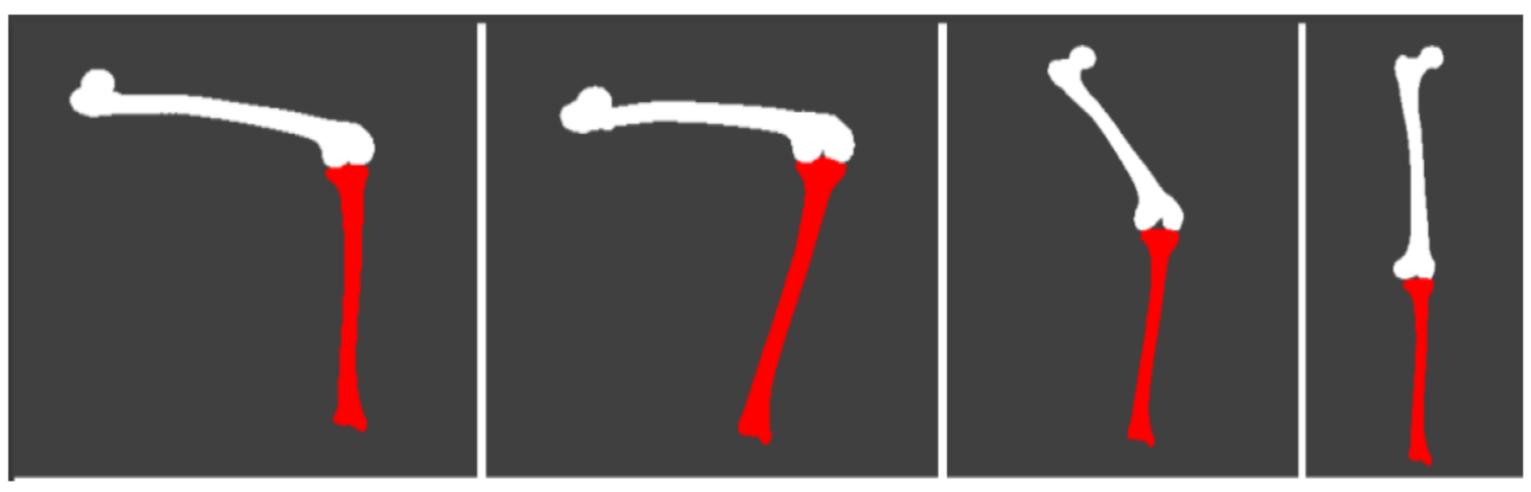


Figure 3. 3D representation of the movement of the knee at 0%, 25%, 35% and 50% of stepping up. Represented by URSINA engine.

3. Sensor to segment calibration

Static calibration with two positions. First, the subject stands up with her/his arms at the sides of the body and foot to foot distance equivalent to the shoulder of the subject, for 10 seconds. Then the subject lays down (supine) in her/his back with feet pointing up for 10 seconds [1].

4. Sensor fusion algorithm

After performing a performance analysis between 2 sensor fusion algorithms based on complementary filters [2][3] and 2 Kalman filters [4][5], Valenti's algorithm based on complementary filters is selected [2].

RESULTS AND DISCUSSION

Preliminary data during 10 cycles of the motor task show that flexion and extension is consistent at chair height. This movement varies between -8° and 94°. It is also observed that at the end of each cycle there is a preparation movement of about 6 to 12° of flexion. This preparation movement is performed to take the necessary impulse for the extension of the motor task (Fig 2). Normal tibial rotation is about 25° during step-up. The measurements in Fig 2 show measurements of 14° which are compatible and of the same order of magnitude. After total knee replacement this range is reduced to less than 10°. In Fig. 3 the representation of the knee movement during half a cycle is represented in a custom made software using Ursina Engine. This is to support the visualization of the motor task for clinical use. CHAKAMO has the potential to measure 3D knee movements. Considering the anatomy of the knee, rotation is possible. The clinical relevance of CHAKAMO is to allow an easy and real-time assessment of axial rotation during open chain or closed chain movements.

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