Augmented Reality for the Rehabilitation Of Walking in children with Cerebral Palsy (ARROW CP) : How to add more fun in walking rehabilitation after surgery ?

Anne-Laure GUINET - Fondation Poidatz, Saint-Fargeau-Ponthierry ; Laboratoire IBISC, Université d'Évry, Guillaume BOUYER, Samir OTMANE, et Eric DESAILLY

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Abstract : The ARROW-CP project is a multidisciplinary approach that combines rehabilitation strategies, motor control and feedback theories and computer science. The global aim is to develop a serious game in augmented reality to improve the gait pattern after surgery in children with cerebral palsy, into evidence-based theories (Moreau, 2016; Macintosh, 2019).
Augmented reality (AR) is a technology that expand the real environment by adding digital holograms into it. AR appears to be a promising field of development for serious games, especially for walking rehabilitation applications. The Microsoft HoloLens device is one of the most popular and advanced AR Head Mounted Display. It includes optical and inertial sensors for position and orientation tracking. Although the algorithm combining the sensors information in the Hololens can estimate the headset's pose in an absolute reference frame, its reliability in walking condition is undocumented. Moreover, as a standard feature, the Hololens is not able to detect the spatio-temporal parameters (step length, cadence, and speed) of the user.
Yet, the two steps required to develop a high realistic application for gait rehabilitation, using position, velocity and acceleration of the headset, is to assess the reliability of the headset tracking, in comparison with a reference motion analysis tracking system. And then, to develop and to test the algorithm for the detection of spatio-temporal parameters from Hololens tracking raw data. We have conducted an experimental procedure in April 2019 to test if the accuracy of the Hololens is sufficient to measure the position and the velocity of the user during 9 walking trials in 3 different conditions. The Hololens signals were synchronized to the MOCAP signals by an automatic time shifting using a local minimum detection. An ICP algorithm (Besl, 1992; Chen, 1992) was used to align the 3D positions given by the two systems minimizing the distance between them, using geometric transformations. The accuracy of the Hololens is sufficiently high to evaluate the position and velocity of the headset, and the user by extension, without time drift. Correlation coefficient was between 0.95 and 1. We have also developped and validated the algorithm that gives in real-time the spatio-temporal parameters for children with cerebral palsy. There is no statistical difference between our algorithm and the reference calculated with 6 heels and 4 pelvis markers (Zeni, 2008).
Today, the first version of ARROW-CP game consists on 5 mini-games, based on 5 differents feedback modalities. Clinical study that test these feedbacks will begin next January.

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How to add more fun in walking rehabilitation after surgery ?

Anne-Laure Guinet, Guillaume Bouyer, Samir Otmane, Eric Desailly

IBISC, Univ Evry-Paris-Saclay, France

Fondation Ellen Poidatz, rehabilitation center, France

MOTIVATIONS AND CONTEXT

- Single-event multi-level surgery (SEMLS) is a popular surgical treatment that is used to realign the musculoskeletal system of children with cerebral palsy (CP).

- **Rehabilitation** after SEMLS is a very hard and long process (mean 6 months) for these children. They improve their kinematics gait parameters and their walking pattern but they failed to augment their **walking speed, cadence and step length**.

- The aim of the ARROW-CP project is to develop and test a **serious game in Augmented Reality on the Microsoft Hololens headset** for children with CP in order to intensify the gait rehabilitation after SEMLS: to minimize the overall time of the rehabilitation protocol and optimize surgical results.

DESIGN AND DEVELOPMENT

- **Engineering part:** develop a real time algorithm to detect the heel strikes in order to calculate cadence and step length of the user, even if he walks with crutches.

- **Augmented reality part:** design human interface computer and holograms.

- **Motor-learning:** develop Knowledge of Result (KR) and Knowledge of Performance (KP) feedbacks modalities.

EVALUATION

Experimental protocol:

Study 1: During 9 walking trials in 3 different conditions for 5 healthy subjects, including walking exits outside off the GaitLab, the 3D raw coordinates of the headset were measured simultaneously by the HoloLens and a VICON system both at 100Hz.

Study 2: The Step Detection algorithm has been tested on the gait analysis data from children walking with crutches (n=34) or without aids (n=34). The results were compared with Gold Standard value from Zeni algorithm which calculate spatio-temporal parameters with more reflective markers.

Study 3: *(work in progress)* After a training session, the 5 feedback modalities and control (no feedback) are randomized. All the patients walk during 3 min for each feedback with different gait speed objectives.

The performance will be evaluate in terms of the accuracy in percentage.

Experimental protocol summary for 3rd study:

OBJECTIVES

- To assess the reliability of the Hololens headset tracking, in comparison with a reference motion analysis tracking system (VICON motion capture).

- To test the new algorithm for the detection of spatio-temporal parameters from Hololens tracking raw data.

- To develop different feedback modalities to regulate gait parameters in children with CP based on motor-learning theories.
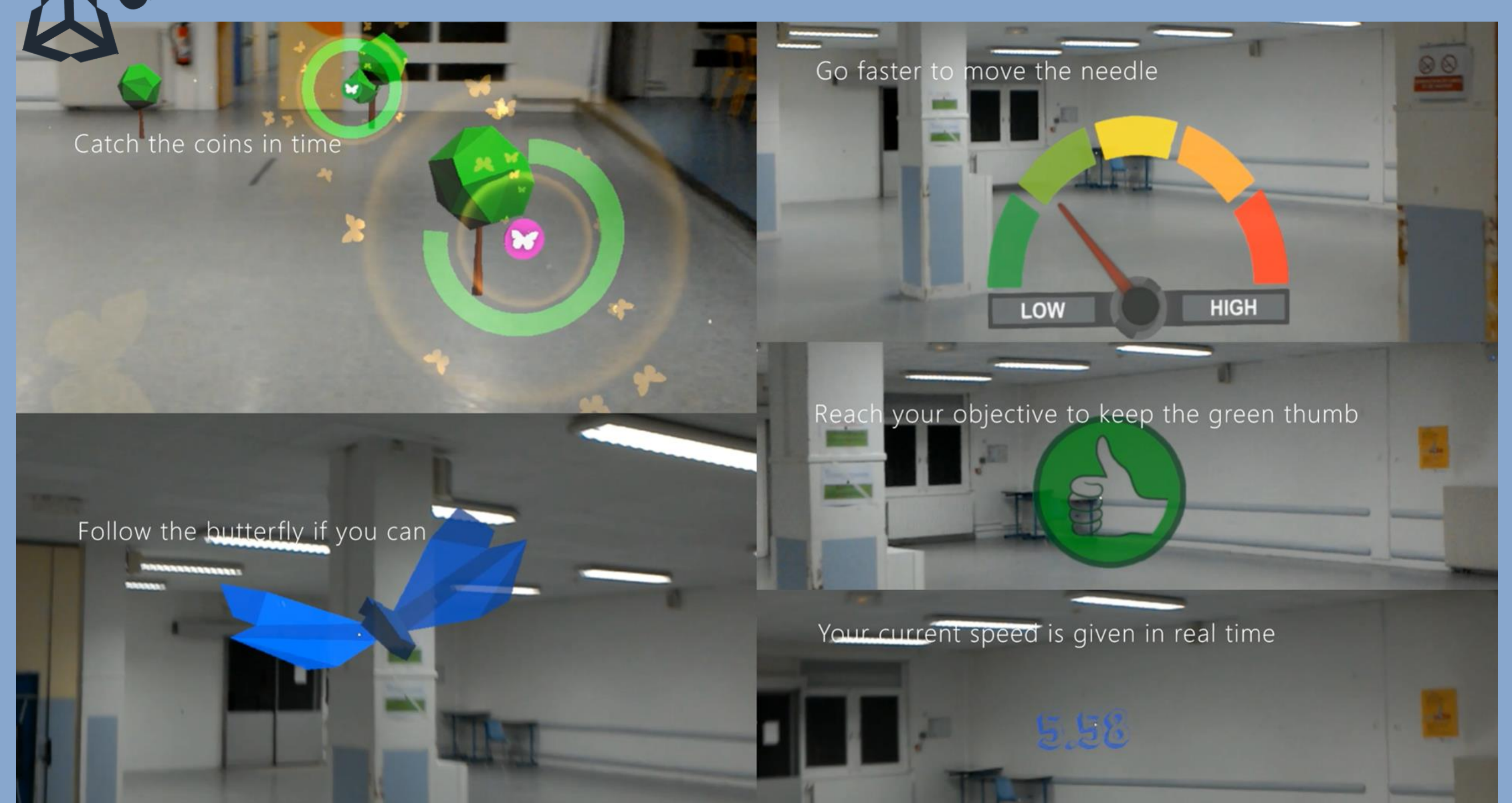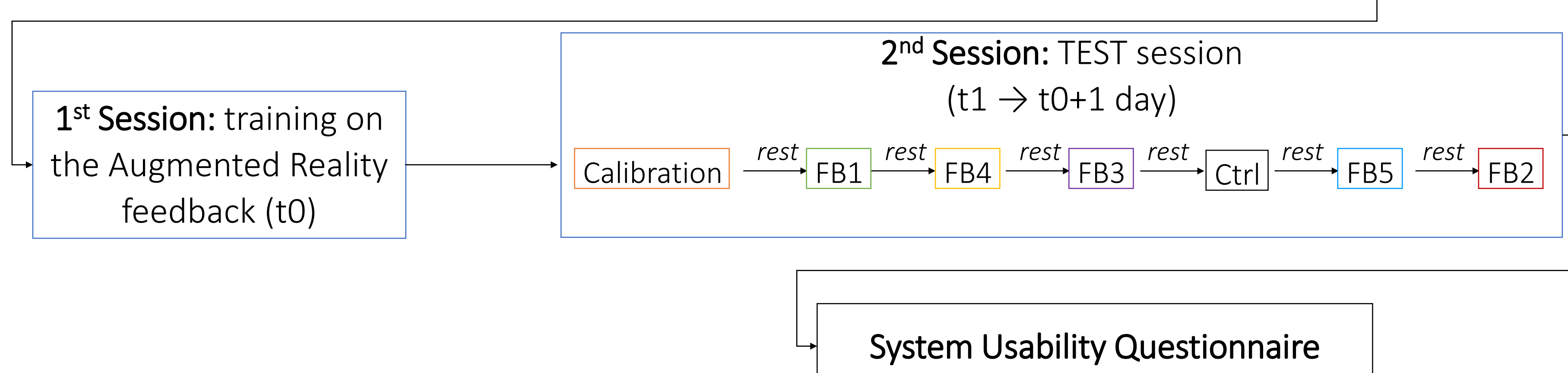
Microsoft Hololens   VICON motion capture

Feedback modalities

Catch the coins in time

Go faster to move the needle

LOW   HIGH

Follow the butterfly if you can

Reach your objective to keep the green thumb

Your current speed is given in real time

Consent form and subject information sheet

1st Session: training on the Augmented Reality feedback (t0)

2nd Session: TEST session (t1 → t0+1 day)

Calibration — *rest* → FB1 — *rest* → FB4 — *rest* → FB3 — *rest* → Ctrl — *rest* → FB5 — *rest* → FB2

System Usability Questionnaire

FUTURE WORK

- **Sensorial Feedback** have been shown to be essential to improve motor learning, however… *what are the best feedback modalities to regulate gait parameters in children with CP?*

- **Serious game** appears as a good way to motivate children for rehabilitation but… *what are the ingredients to keep them involved for a long time?*