Development of a Tracking Dual-plane Fluoroscope for assessing musculoskeletal and orthopaedic kinematics

Background: Video-fluoroscopy allows the accurate reconstruction of human segments in 3D space, and has thus become a well-accepted imaging technique to acquire kinematic information of artificial joints during simple functional movement tasks such as squatting or rising from a chair. However, measurements during functional activities of daily living and high-impact activities such as jump landing have remained extremely limited: the heavy physical structure of the technology has restricted the development of mobile devices, such that only a handful of mobile units exist that enable the tracking of moving joints. The Laboratory for Movement Biomechanics, ETH Zürich, is a world leader in tracking joint kinematics using a single plane moving fluoroscope that enables the 3D reconstruction of e.g. the knee joint throughout complete cycles of activities of daily living (Figure 1). Since the single plane set-up exhibits a relatively large out-of-plane error, a complete understanding of joint kinematics is limited, especially for the assessment of the natural knee in 3D space.

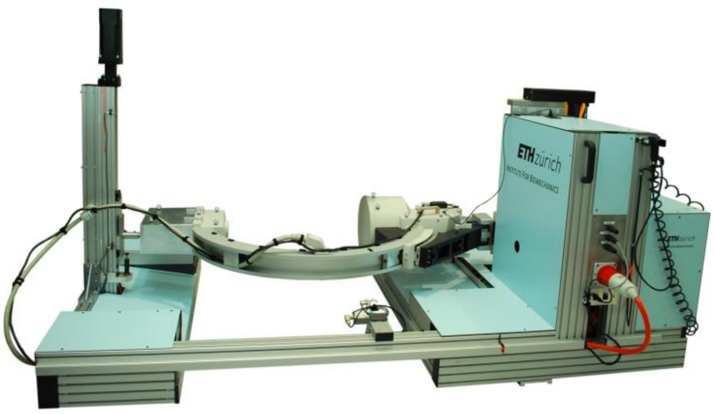

Figure 1: The existing moving fluoroscope at the Laboratory for Movement Biomechanics has allowed an advanced understanding of joint kinematics after implantation of orthopaedic implants – but is limited in its capacity to assess the kinematics of joints with sufficient accuracy in the out-of-plane direction.

Aim: Our goal is to address this deficit and create a state-of-the-art high frequency dual-plane fluoroscopy suite that is capable of tracking human movement in 3D space (Figure 2). By including a second plane of assessment, such a device will overcome the issues of out-of-plane errors and thus allow an accurate registration of implant and natural skeletal kinematics. In addition, a design that separates the image intensifier and source will provide greater freedom of movement, both forwards and backwards but also vertically. The resulting technology will open perspectives not only for the high-speed kinematic and kinetic assessment of implanted and natural joints, but will also provide new opportunities for understanding musculoskeletal interactions during, for example, fracture healing or more challenging sporting activities.

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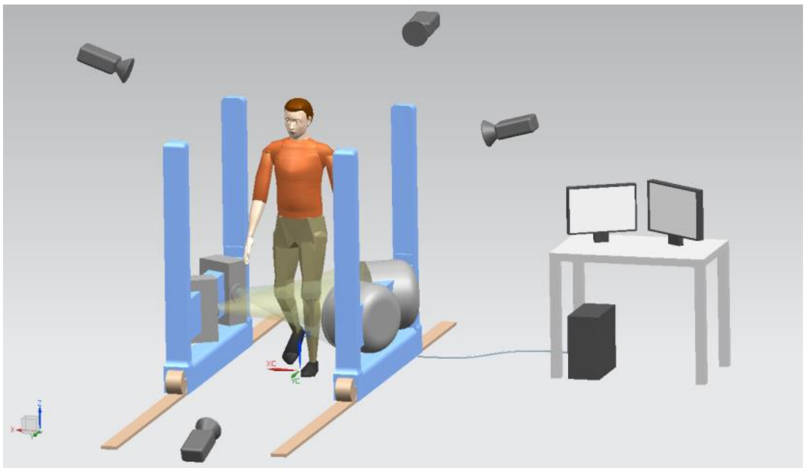

Figure 2: Our vision is to create a state-of-the-art second generation dual-plane fluoroscopy suite for tracking human motion that allows the high-speed, high-accuracy assessment of natural musculoskeletal structures all while allowing the subject freedom of movement.

Methods: The advanced dynamic dual-plane video-fluoroscope will be developed according to five key system requirements: (I) accurate assessment of natural, pathological and implanted joint kinematics, (II) accurate assessment of movements with high segmental accelerations, (III) accurate assessment of unrestricted movements, including stair ascent, (IV) accurate assessment of joint kinematics in patients with variable motion patterns, and (V) simultaneous assessment of ground reaction forces for complete analysis of joint mechanics. The proposed dynamic video-fluoroscope, requiring IT, imaging and robotic technological developments, will be developed at the Institute for Biomechanics (IfB), ETH Zürich. Integration of the system will be achieved in two steps: 1) the system should initially allow the tracking of joints in combination with an existing treadmill that is capable of replicating uphill, downhill and cross-slope walking or running; and 2) the system should enable the capture of free level or ramp walking, stair ascent and decent, and jogging.

Impact: The ability to assess joint kinematics accurately in vivo will have a broad impact on a wide range of clinical and rehabilitation technologies in the fields of orthopaedics and sports medicine. Here, accurate kinematic data during functional activities is crucial for verifying and improving novel surgical implants and techniques, develop novel injury prevention or rehabilitation strategies, analyse the biomechanics of joint degeneration, instabilities or fatigue, as well as provide a gold standard for the validation of biomechanical computational models. Upon successful development and validation, the advanced dynamic dual-plane video-fluoroscope is expected to heavily impact on current scientific and clinical approaches for the assessment and management of joint disease and injury, with tremendous leadership potential in medical innovation world-wide.

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