# Compact and Flexible Tracking System for Total Knee Replacement Surgery

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*In the context of total knee replacement surgery, a wireless and battery powered tracking system using shadow imaging technology has been developed for measuring the 6D position of a surgical tool relatively to the patient's bones.*

The overall goal of the project is to develop a smart, patient customizable instrumentation to assist surgeons during a total knee replacement. To this end, CSEM developed a miniatureized tracking system based on shadow imaging technology [1, 2] that can be directly integrated with patient-specific templates and surgical instruments.

Before the surgery, the patient undergoes a scanning procedure (CT-scan), from which a 3D model of the patient's anatomy and landmarks are computed to form a preliminary plan for the implantation. During surgery, the patient's anatomy is registered using a specific template (negative form) that fits the bone, to match the 3D models and initial plan with the surgical situation. With the tracking system integrated into the surgical templates, the application can directly compute and render the exact position of a surgical tool relatively to the patient's bone. The system also allows to intra-operatively plan and adapt the implant position.

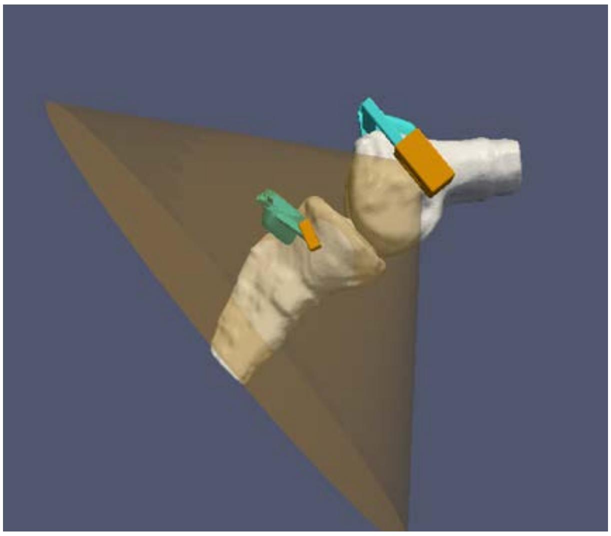

*Figure 1: Simulation of the target and tracker devices (yellow) mounted with CAD-designed patient-specific tools (Medivation AG).*

The tracking system is made of two separate devices. The tracker device includes an image sensor, a microcontroller running a micro kernel operating system and a Bluetooth low-energy communication system-on-chip. The target device includes an IR receiver and five LEDs that are fired sequentially under the control of a small microcontroller.

Shadow imaging is a technology that uses an image sensor with an optical mask placed on top of it. By synchronizing the LEDs and the image sensor, each LED casts a shadow on the image sensor, from which one can compute the direction of the light source and then reconstruct the 6D position of the target. The use of an optical mask instead of traditional optics results in a very compact system in particular given the wide-angle constraint. Moreover, shadow imaging offers better precision and better depth of focus.

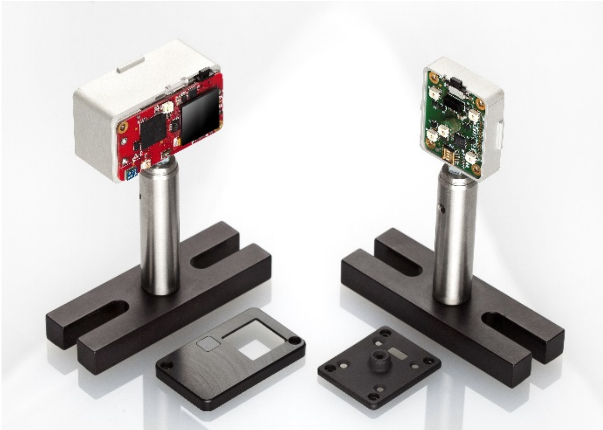

*Figure 2: Sensor (left) and tracker (right) prototypes mounted on optical posts (front covers removed).*

In the context of such a knee surgery application, the target device must be able to move up to a distance of a dozen of centimeters in front of the tracker device and to rotate with an angle of more than ±45 degrees in all direction. The typical positioning accuracy is much less than ±1.0 mm and the typical angular accuracy is less than ±1.0 degrees. The operating temperature ranges from 10 to 30°C.

The target and tracker devices are both designed to be single use, battery powered and fully wireless. The size of the tracker prototype is 26 × 44 × 24 mm including the space required by a CR123 battery. The overall size of the target prototype is 26 × 32 × 14 mm. The tracking system can operate at more than ten 6D measurements per second with an autonomy of several hours. The addressing and synchronization of the LEDs is done by the tracker device using a dedicated IR link. The control and data communication between the tracking system and the surgical navigation system relies on Bluetooth Low-Energy services.

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[1] E. Grenet, *et al.*, "spaceCoder: a nanometric 3D position sensing device", CSEM Scientific and Technical Report (2011) 89.

[2] E. Grenet, *et al.*, "Embedded sun tracker with extreme precision", CSEM Scientific and Technical Report (2013) 100.