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Automatic 3D modeling and simulation of bone-fixator system in a novel graphical user interface

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A B S T R A C T

External ring fixators are widely used in orthopaedics for the purposes of fracture fixation, bone lengthening and deformity correction. In these fixators, the clinician typically brings the bone fragments to an anatomically desired position by changing the lengths of the rods connecting the fixator rings. This task is accomplished by the clinician based on experience and expertise. As an alternative, commercial systems exist where the same task is automatized with the help of an accompanying software that implements a mathematical model of the fixator. In this work, we have developed a graphical user interface (GUI) implementing a mathematical theory introduced previously. The GUI also allows visualization and simulation of the patient specific bone-fixator system, something that lacks in the available software systems. The information gathered from the bone X-ray images is used to convert a canonical bone model to the patient-specific bone model. This conversion algorithm has been tested on eight different bone models and found to be effective. The visualization tool has been used in the simulation of two orthopaedic procedures, one involving a tibia and the other a femur. In both examples, the visualization tool has provided a realistic depiction of the treatment procedure. We believe that the developed GUI equipped with the visualization module could be a useful clinical tool where the clinician can visualize the applied treatment or evaluate different treatment scenarios *a priori* per patient.

1. Introduction

Gough-Stewart platform or simply *Stewart platform* (SP) is a robotic system that consists of two plates or *platforms* (top and bottom) interconnected by six rods with adjustable lengths [1]. Once one platform is fixed as the reference frame, the other one can perform a six degrees-of-freedom motion by changing the rod lengths. The first engineering application of SP has been a flight simulator [2]. Today, it has a wider application area including, equestrian gait studies [3], vibration isolation systems [4], motion simulators [5], cable controlled cranes [6] and robots [7], and tracking of large spherical radio telescopes [8].

External fixators based on SP have been used in orthopaedics for almost two decades. One of the most prominent external fixation systems utilizing SP concept is the *Taylor Spatial Frame* (TSF) [9]. In general, TSF is found to be accurate and practical by users [10–16]. However, there are some physical constraints that the clinician is subject to when setting up the TSF. For example, in TSF, adjacent rods should be connected to neighboring holes on the rings and bone fragments should be fixed perpendicular to the ring planes.

A new mathematical theory has been developed previously that relaxes most constraints associated with TSF [17,18] and provides more flexibility in application. A preliminary graphical user interface (GUI), which implements this mathematical theory and provides a simplified graphical depiction of the bone-fixator system, has been developed as reported elsewhere [19].

Another shortcoming of the existing computer-assisted systems is the lack of a proper visualization tool with which the clinician can visualize different treatment scenarios, confirm the correct treatment and follow the treatment time line. For a realistic depiction of the bone-fixator system, a solid model of the treated bone is necessary which could be created with proper software from radiological slice data (magnetic resonance imaging (MRI) or computed tomography (CT)). However, in certain orthopaedic treatment procedures such as bone lengthening and fracture fixation, it is a common practice to take X-ray images of the treated bone, and MRI or CT scan of the bone in its entirety is rarely performed. Hence, a model creation process based on the available X-ray data seems to be more appropriate in orthopaedic practice.

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To our knowledge, only two early studies exist in the literature that deal with the simulation of bone-ring fixator systems. In the first study, a bone surface model was constructed with two X-ray images taken in perpendicular directions using a back-projection algorithm [20]. The study involved also the combination of the bone model with the model of an Ilizarov apparatus and an interactive GUI, although the mathematical and computing details of the work remained largely unexplained. In the second study, a simulation software called "Simulation Environment of a Robotic Fixator" (SERF) was developed for treatment visualization [21]. Both studies produced relatively primitive models with limited user-interaction capability.

In this work, we report a 3D visualization tool that automatically generates a realistic model of the bone-fixator system at hand. The information obtained by processing the bone X-ray images is used to convert a canonical bone model (obtained *a priori*) to the patient-specific bone model. The visualization tool is a part of the GUI and provides the clinician with an environment to observe the treatment or test different treatment scenarios. The proposed procedure is summarized in Fig. 1 and the steps involved are detailed in the upcoming sections.

2. Method

2.1. Summary of mathematical theory

The new mathematical theory, that relaxes most constraints associated with TSF, has been described elsewhere in detail [17,18]. In this section, we summarize its main features for completeness.

Once the fixator is attached to the patient, two X-ray images are taken in perpendicular directions (conventionally, anterior-posterior (AP) and medial-lateral (L) views). Then, certain

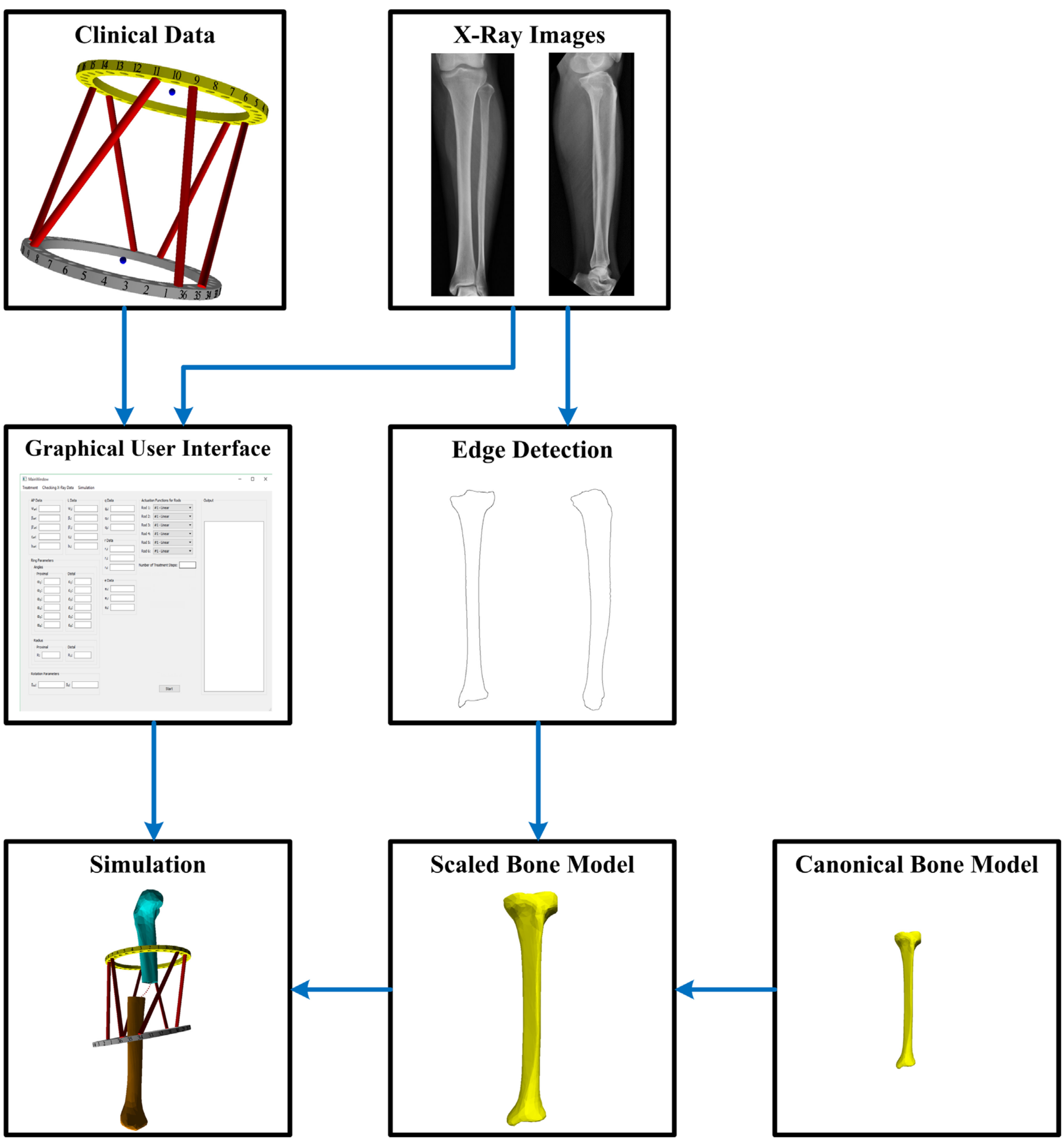

Fig. 1. Steps involved in the simulation procedure. (Each step is described in detail in the text).