used for many other surgical procedures where the spatial relation of a surgical object or implant relative to the patient must be precisely determined. It may even be used in combination with the mentioned conventional navigation system so as to provide redundant navigation information and, thus, to make the navigation highly robust and this level of safety may enable autonomous robotic surgery.

SUMMARY OF THE INVENTION

At least the one or the other of the mentioned problems are mitigated or solved by the subject matter according to each of the independent claims. Further embodiments are described in the respective dependent claims.

Systems and methods are proposed, which require neither reference bodies nor trackers, to determine the 3D spatial relation (i.e., relative 3D position and 3D orientation) of a surgical object relative to a part of a patient's anatomy. The proposed systems and methods (implemented as computer program product) are configured to determine the 3D spatial relation based on a single X-ray image depicting at least part of the surgical object and at least a region of interest within the patient's anatomy.

According to a first aspect of the present invention, there is provided a computer program product including instructions which, when executed on a processing unit of a system, cause the system to receive one X-ray image generated at a first point in time, a 3D data set describing at least the region of interest and defining a 3D coordinate system, and a 3D model of the surgical object. The X-ray image is typically a 2D projection image depicting at least part of a surgical object including an anchor point as well as the region of interest within a patient's anatomy. The computer program product is configured to determine a 2D position of the anchor point in the X-ray image and an imaging direction onto the region of interest based on the X-ray image. Based on this information, a 3D position of the anchor point in a 3D coordinate system at the first point in time defined by the 3D data set is determined. Further, a 3D position and 3D orientation of the surgical object relative to the region of interest at the first point in time is determined by means of the computer program product based on the 3D model of the surgical object and the 3D position of the anchor point in the 3D coordinate system at the first point in time. Further, a 3D position and 3D orientation of the surgical object relative to the region of interest at a second point in time is

determined by means of the computer program product based on the 3D position and 3D orientation of the surgical object relative to the region of interest at the first point in time and information about a change of 3D position and 3D orientation of the surgical object between the first point in time and the second point in time.

According to a second aspect of the present invention, there is provided a system comprising a processing unit configured to execute the above-described computer program product.

The surgical object may be a surgical instrument or tool like, e.g., a drill, a needle, or a chisel, or it may be an implant like, e.g., a pedicle screw, a nail, or a plate. The surgical object has a