What is “Registration” and Why is it so Important in CAOS?

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INTRODUCTION

Registration is a universal problem which must be addressed in almost all computer-assisted or image-guided surgical systems. It is equally important in orthopaedics, neurosurgery, spine surgery, cranio-facial surgery, or any speciality in which computer-assisted surgical techniques are employed. The need for intra-operative registration arises due to the fact that there is an unknown spatial relationship between the pre-operative data (i.e., medical images, surgical plans) and the physical patient on the operating room table. In other words, while it may be possible to visualize a portion of the patient’s anatomy (e.g., a pelvis) within the pre-operative medical images, and also to visualize the same anatomy using intra-operative sensor data (e.g., ultrasound, X-Rays, or direct viewing), the precise spatial correspondence between these two pelvis representations is unknown. The role of registration is to establish this relationship (referred to as the *spatial transformation*), thus allowing 3-dimensional (3-D) locations within the pre-operative data to be unambiguously associated with the corresponding anatomical locations on the actual patient in the operating room, and vice-versa. This abstract provides an overview of several mechanisms for performing intra-operative registration in CAOS applications, and provides additional pointers into the literature for the interested reader.

REGISTRATION SOLUTION METHODS

One of the earliest examples of registration in surgery is the stereotactic head frame used in neurosurgery. These bulky, invasive frames are typically attached to the patient’s cranium with screws prior to a pre-operative CT or MRI scan, and then remain in place for the duration of the surgery. Reference markers which are rigidly attached to the frame (often referred to as *fiducial markers*) can be identified and localized within the pre-operative images. These fiducial markers provide a basis for establishing the spatial transformation which relates 3-D locations in the medical images to the corresponding 3-D locations relative to the stereotactic head frame. Once the transformation is established, any 3-D point which can be identified within a pre-operative image can be precisely localized within the patient’s brain.

In orthopaedics, stereotactic frames such as those used in neurosurgery are not commonly used. However, techniques which employ similar fiducial markers and underlying registration solution methods have been used. A fiducial marker-based registration system similar to the one used in the *Robodoc* system [5] is shown in Figure 1. The figure is divided into two parts; the top part represents actions which are performed pre-operatively, and the bottom part represents actions which are performed intra-operatively. Pre-operatively, the fiducial markers are rigidly affixed to the patient’s anatomy (e.g., femur), and then volumetric CT or MRI images are acquired. Based upon

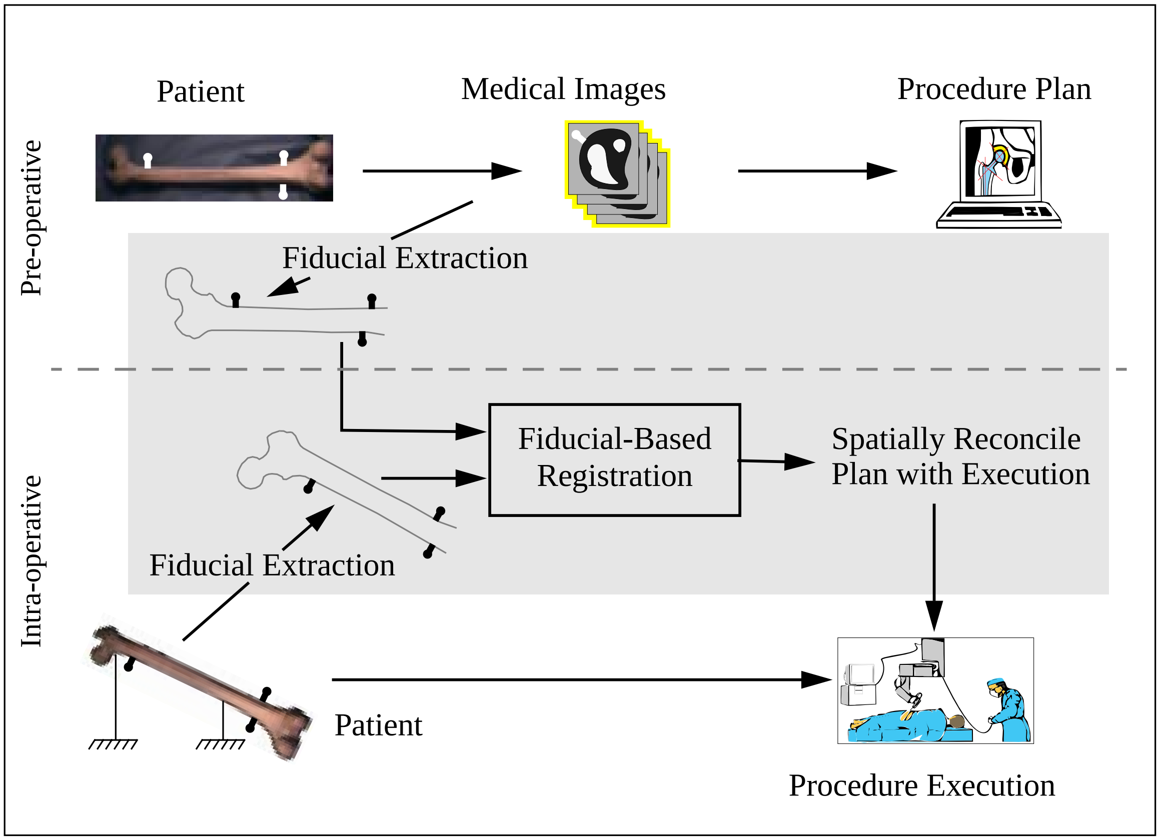

Figure 1: An overview of fiducial marker registration.

these images, the surgeon constructs a plan of the procedure to be performed during surgery using a computer workstation. The 3-D locations of the fiducial markers within the images are then automatically determined by the computer. At this time, the 3-D locations of the fiducial markers are only known relative to the pre-operative images. Intra-operatively, the fiducial markers are physically exposed, and the locations of these markers are measured using an intra-operative sensing device (see the abstract in this proceedings entitled “Intra-operative Position Sensing and Tracking Devices” for more information on these devices). Given the two sets of corresponding fiducial marker locations (i.e., from the pre- and intra-operative measurements), a computational procedure referred to as *fiducial-based registration* is then used to determine the spatial transformation required. Using this transformation, any 3-D point which can be identified within the medical images can be precisely located on the patient in the operating room using the intra-operative sensing device to provide navigational guidance. This capability provides the basis for accurately executing the pre-operatively specified procedure plan. Conversely, given the location of a particular 3-D point on the patient (i.e., based on an intra-operative sensor measurement), its corresponding 3-D location within the pre-operative images can be precisely identified and visually displayed to the surgeon in real-time.

Unfortunately, there are disadvantages of the fiducial marker-based registration approach. First, it is necessary to affix the fiducial markers to the patient before the pre-operative images are acquired. This is an invasive and costly process which may require an additional surgical procedure. Second, depending upon the type of intra-operative sensor used, the fiducial markers may need to be physically exposed during surgery, even if the markers are located far from the primary surgical site. This may result in additional blood loss and additional time required to suture the soft tissues in the vicinity of the markers. Several groups have attempted to eliminate the need for *artificial* fiducial markers by using anatomical landmark points (e.g., the anterior superior iliac spine of the pelvis) as a basis for registration. However, this approach is prone to relatively large errors due to the difficulty of manually identifying sets of anatomical landmarks from the pre-operative images, and then identifying the precisely corresponding landmarks on the patient during surgery.

An alternative to fiducial-based registration is a class of methods collectively referred to as *shape-based registration*. The basic concept of these methods is illustrated in Figure 2. Shape-based registration does not require the attachment of artificial fiducial markers prior to the scanning process. Rather, a computer is used pre-operatively to extract a geometric description of the shape of an anatomical structure (e.g., the proximal femur). At this time, the location of this geometric description is only known relative to the pre-operative images. During surgery, an intra-operative sensor is used to acquire a similar representation of the shape of the same anatomical structure. The location of this second geometric description is only known relative to the intra-operative sensor. These two shape descriptions provide the input to the shape-based registration process, and the output is the required spatial transformation. In practice, the intra-operative sensing device may measure discrete 3-D points on the object's surface (e.g., using a digitizing probe), 3-D curves on the surface

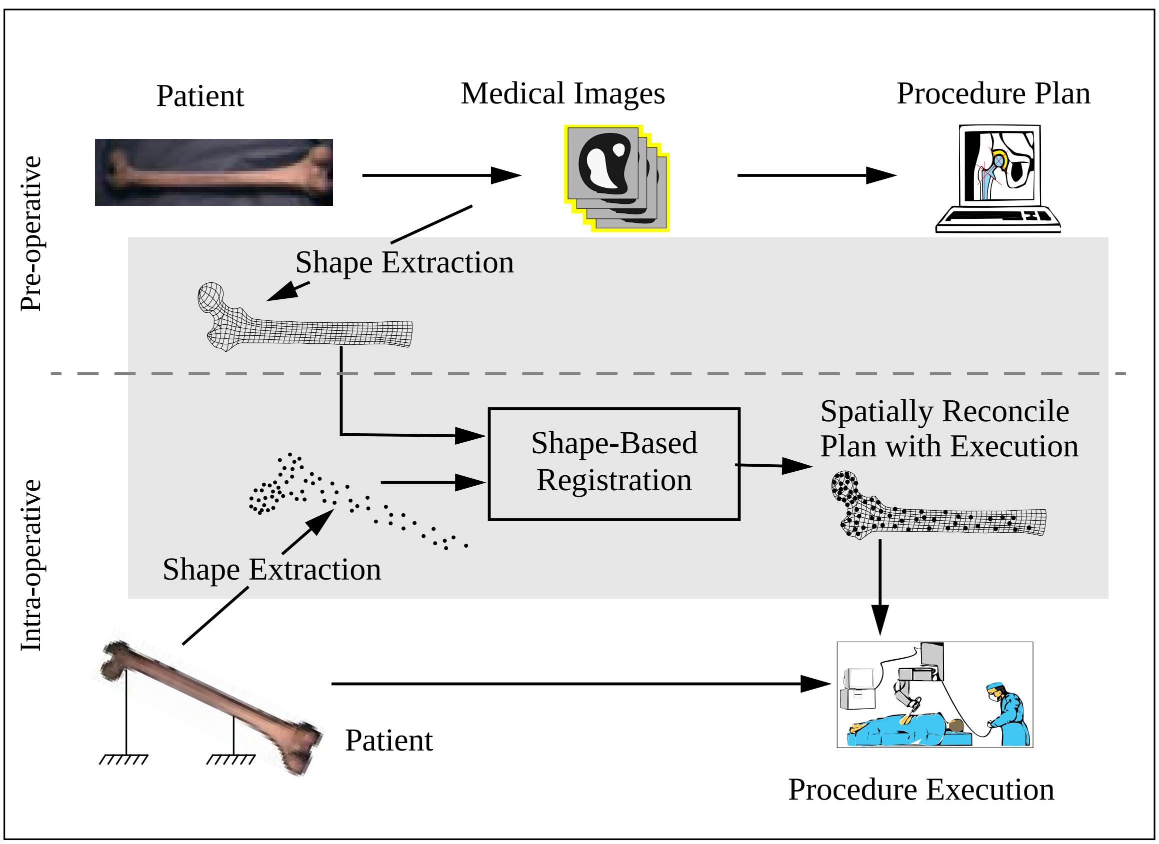

Figure 2: An overview of shape-based registration.

of the object (e.g., using an X-Ray imager), or a complete description of the object's surface (e.g., using a ultrasound imager or an optical range sensor). Shape-based registration methods are gaining popularity in CAOS systems, and may soon completely eliminate the need for artificial fiducial markers to perform accurate registration.

CONCLUSION

The importance of registration in CAOS and other surgical specialities cannot be understated. Any time it is necessary to relate spatial information from medical imagery to the patient on the operating room table, registration is required. In general, the accuracy with which a surgeon can achieve a pre-operatively constructed procedure plan is directly related to the accuracy with which registration can be performed; errors in the registration process will introduce inaccuracies into the surgical procedure.

This abstract has focussed on the registration of pre- and intra-operative data. In general, many other types of registration exist. For example, it may be desirable to register complementary images of the same anatomical region acquired using two or more medical imaging modalities (e.g., CT, MRI, PET, SPECT, etc.) Related registration methods can be used to perform such tasks. The references below provide an initial set of pointers into the registration literature for the interested reader.

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