Towards Accurate Drilling Guidance for Orthopaedic Surgery

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INTRODUCTION

In orthopaedic surgery, drilling accuracy is very important. Depending on the procedure, the exact placement of a screw or wire can affect the quality of the surgical outcome. This in turn affects patient health and costs of further treatment. Currently surgeons have only 2D imaging from peri-operative radiographs (X-rays). This can work adequately, but not infallibly, for bones with simple shapes but not for complex bones such as the scaphoid (wrist), distal humerus (elbow) and talus/calcaneus (ankle). In such cases, surgeons, even experienced ones, often have to re-drill multiple times before they are satisfied with the placement of their hole or wire. This increases the duration of surgery, the risks for the patient and the costs for the health system. Inaccurate drilling can also damage delicate tissue around the bone, leading to complications for the patient. Sometimes imperfect screw positioning may be (or must be) accepted. This comes in contrast to general guidelines of surgical practice, for example in the UK the Getting It Right First Time (GIRFT) initiative [1].

One potential solution to this issue is the use of computer-assisted techniques. Computer-assisted surgery utilizes computer technology for preoperative planning and intraoperative guidance of surgical interventions either manually or semi-automatically. Initially developed for use in neurosurgery, this technology has become prominent in several orthopaedic applications. The main concept is the use of segmented radiographs (CT and/or X-rays), for planning and registration of bones, and some form of external navigation system [2]. In [3] this is achieved for the scaphoid, a small, complex bone in the wrist area. Liverneaux et al. used only intra-operative fluoroscopy and continuous update of the registration model to ensure correct navigation registration with the navigation system. Although the system operated well it was limited by the use of intra-operative fluoroscopy, complex registration, limited access, and a global image navigation system that can be subject to occlusions.

A potential solution can be the use of a localised vision-based navigation system. The use of a camera system on-board the acting device addresses the issue of occlusions since in small distances such an event is less likely to occur. Moreover, it has been demonstrated that in other demanding and rapidly changing application this approach can be implemented in real-time control cases ensuring accurate and precise results [4].

With this work, the authors are proposing a new system that can be used in small, complex bones where precise drilling is required. The system will enable the surgeon to accurately guide a wire or make a hole in a single pass. The system will be using a local imaging system and a special probe, to address the occlusion concerns and remove the need for any registration of radiographs.

MATERIALS AND METHODS

Hardware

The system will be composed by two elements. The first is the *tracking unit,* Figure 1a, that is active and composed of a) a set of cameras, b) a control unit, c) an indicator system, and d) a battery. The tracking unit will be mounted on existing drilling systems; facilitating a universal mounting approach. The second element is the *guidance probe,* Figure 1b, which will have a) a metal tip and b) a number of optically detectable features.

All computational operations take place in the tracking unit. Namely, tracking of the probe, calculation of relevant posture, and updating the surgeon. The tracking unit is using the camera to detect the features on the probe; these can be a number of reflective spheres, or 2D QR-like images to allow 3D tracking. Based on the relative position and orientation of the features the necessary transformation is computed and an indication is provided to the surgeon to adjust drilling

Workflow

The workflow, Figure 2, will consist of two distinctive phases, the setup, and the operation phase. In the setup phase, the tracking unit is placed on the drill. Since the unit will be in the surgical field a suitable sterilisation
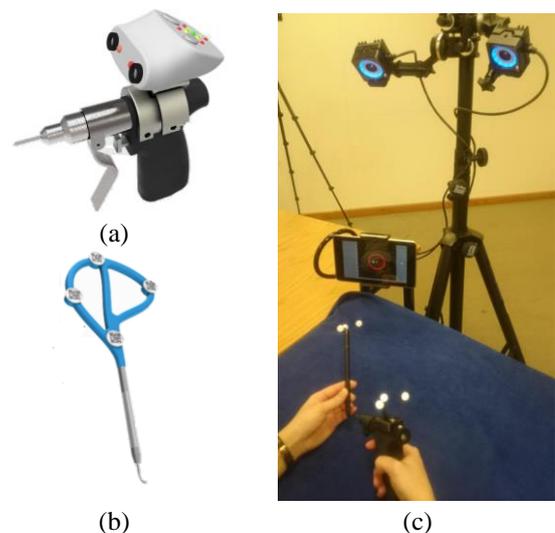

(a)

(b)   (c)

Figure. 1. System versions. Proposed final prototype, (a) tracking unit and (b) guidance probe. (c) Evaluation setup with optical tracker (OptiTrack®) and feedback screen.
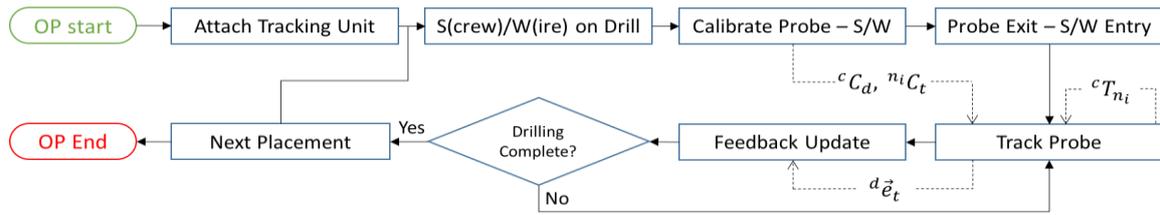
Figure. 2. Proposed system workflow. Continuous lines are the sequence of the steps and dotted lines the exchange of data between steps, either transformation matrices for calibration and tracking or error data for feedback.

regime will be followed, i.e. either the entire unit be sterilisable or the use of a sterile drape. Moreover, the guidance probe, which will be sterile, is placed close to the surgeon for fast access.

For the tracking phase, the surgeon will place the wire or screw on the drill and manual calibration will take place. The calibration approach is for the surgeon to touch the wire/screw to the tip of the probe and the unit will register their relative position and orientation and generate two calibration transformation matrixes ^cC_d and $^{n_i}C_t$, for the drill to the camera reference frame and of the tip to the probe's markers, respectively. Following this, the surgeon will select an exit point on the operated bone and place the tip of the probe on this while placing the wire/screw tip on the entrance point. The final step will be to pivot the drill so they can align the tip with the exit point, using the indication on the tracking unit. The unit will be calculating the desired motion to achieve the alignment (e.g. pivot left/right/up/down). The unit will perform the calculations by generating the transformation matrices between the camera and the markers, n, $^cT_{n_i}$ and then the error vector from the tip to the drill $^d\vec{e}_t$ taking into account the calibration matrixes. The indication will be given based on the error vector information.

Prototype testing

Evaluation of the principle of operation was done by using an external tracking device (OptiTrack®) and a feedback screen, Figure 1c. Users of varying experience (surgeons and engineering students) were asked to drill a wire into material mimicking bone. The test aimed to evaluate the accuracy of the system in terms of distance from target, but not orientation error. The users were given a drill and a probe with optical markers, and asked to drill from one point, through the material to an exit point using the probe and feedback screen. The average distance from the desired exit point, standard deviation and confidence interval at 50% are reported.

RESULTS

The users completed 25 attempts of the evaluation experiment, which involved drilling a route of average length of 8mm. The average distance from the desired exit point was 2.10mm, SD 0.87mm, $CI_{50\%}$ 0.12mm.

The errors can be attributed to the following sources, accuracy of the optical tracker, precision of the marker holder geometry, and bending of the wire during drilling.

CONCLUSION AND DISCUSSION

This work proposed a new way to assist orthopaedic surgeons when performing high precision drilling operations in small or complex geometry bones. The first prototype showed promising results and demonstrated the potential of the approach. The benefits can be significant and further work is required to enable this method to reach the operating theatre. Although other commercial options are available, the authors believe that this solution can prove more cost effective.

A faster operation can be a significant cost saving where by improved efficiency certain procedures will take less time, allowing additional procedures to be performed in a given period. The improvement of accuracy will have a direct positive effect to patient outcomes. Moreover, the system can be used as a training aid for surgeons, to help improve their accuracy, reducing risk, meaning that surgeons in training can get experience with complex cases in a controlled and safe environment.

The next steps are to develop the stand-alone version with the on-board camera and feedback and investigate an appropriate geometry for the probe. Improve the accuracy of the system to sub-millimetre levels and compensate for the other error sources identified, as well as evaluate orientation accuracy. The more compact version will be tested for sterilisation in order to get closer to market allowing clinical testing to be conducted, demonstrating the efficacy of the method in a real setting.

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