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The Use of Localizers, Robots and Synergistic Devices in CAS

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Abstract

There are many roles for electromechanical devices in image guided surgery. One is to help a surgeon accurately follow a preoperative plan. Devices for this purpose may be localizers, robots[4], or recently, synergistic systems in which surgeon and mechanism physically share control of the surgical tool. This paper discusses available technologies, and some emerging technologies, for guiding a surgical tool. Characteristics of each technology are discussed, and related to the needs which arise in surgical procedures. Three different approaches to synergistic systems, under study by the authors (PADyC, ACROBOT, and Cobots), are highlighted.

1 Introduction

An electromechanical device of some sort is needed in image-guided surgery, in order to connect the "information world" of images, plans, and computers, to the physical world of surgeons, patients, and tools. That is the situation in which a surgical plan has been created based on diagnostic images, and it is the job of the surgical system to *guide* the surgeon in the accurate execution of his own preoperative plan. The surgeon is again in direct contact with the surgical tool, but an interface device must *also* be connected to that tool, so that the computer may in some way provide guidance. Thought of as human interfaces, the perceptual quality of such a device is often the most prominent factor in the performance of surgical systems. We appreciate a quality that is sometimes called transparency – the quality of being perceptually absent. One purpose of this paper to describe the measures of interface device performance which determine their suitability for use in various surgical situations. We give examples of surgical situations that particularly depend on one or another of these measures. Another purpose is to describe several classes of interface devices, with examples. Previous descriptions of such devices relied on a decomposition in passive, active and semi-active systems [1] in which the degree of passivity was often associated with a type of technology. We prefer to define a new classification

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[4] By *robot* we mean a mechanism with some level of autonomy, programmability and adaptivity

based on function rather than mechanism including localizers, robots, and also a new class which we call *synergistic devices*. Synergistic devices are intended for direct physical guidance of a surgical tool which is also held and controlled directly by a surgeon. Each of the authors is pursuing a different approach to synergistic devices, and these approaches are outlined. The paper concludes with a discussion of the applicability of the technologies to various surgical purposes.

2 Classes of interface devices

2.1 Localizers

Localizers are devices that measure the coordinates of a tool or a pointer, but do not directly control that location. The location is controlled by the surgeon, by physically moving the tool or pointer, and is unconstrained by the localizer. Examples of localizers are passive arms with joint angle sensors, such as the Faro arm [2]. Optical tracking systems perform a similar function, simply collecting coordinates. Localizers have the advantage that achieving transparent behavior is easier than for devices with actuators. In other words they cooperate easily with a surgeon, interfering little with his intended motion. Lacking actuators, however, they cannot offer guidance to the surgeon by providing physical constraint. Instead, the surgeon must explicitly observe and obey some other less immediate mode of guidance, usually a video display of some sort. An interesting variation is the addition of brakes to the joints of an otherwise unpowered localizer arm. In this way, if a surgeon can be guided visually to position the arm in a desired location according to a preoperative plan, the device can "lock" in that position and can subsequently be used as a physical guide. However the intrinsic physical mode of the localizer is passive, allowing the surgeon full mobility.

2.2 Robots

Most robots are fully actuated, having a motor driving each joint. Thus the position of the robot's end-effector is predominantly determined by how it runs its motors, and it intrinsically has little patience for physical "cooperation" with a surgeon. For some applications no cooperation is required; the robot works autonomously. An example is the Adler/Latombe radiosurgery system, in which a heavy payload is moved about a large workspace, both of which exceed human scale. No direct physical input from the surgeon is possible, or needed (see §4.2). In some circumstances, the robot needs some help from the operator, for instance for registration. In this case the "cooperation" problem can be addressed by adding a force sensor to the robot end-effector. The control computer is then aware of forces reflecting a surgeon's intended motion. It may direct the robot motors to comply with that intent. In practice it has so far been very difficult to acheive perceptually smooth cooperative motion in this way, but even primitive "force following" by the robot is useful (see §4.2). Another approach, however, leaves some of the joints of the robot unactuated but still equipped with sensors.

Motion of these joints is naturally free and smooth. Since the decision to leave a joint unactuated is permanent, clever kinematic design of the robot is required so that the resulting "free" motions remain the appropriate ones even as the robot's configuration changes. An example of these mixed acturated/unactuated mechanisms is CMI's Aesop, which holds a laparoscope inserted through a trocar into the body (cf. §4.2). The intrinsic physical mode of actuated robots is active controlling position, and cooperating physically is not their natural mode.

2.3 Synergistic devices

Part of our purpose in this paper is to introduce the notion of synergetic devices, in contrast to localizers and autonomous robots. Synergistic devices are intended for cooperative physical interaction with a surgeon. Both the surgeon and the synergistic device hold the tool, apply forces to it and to each other, and impart motions. Under computer control, the synergistic device may allow the surgeon to have control of motion within a particular plane, while the device dictates motion perpendicular to that plane, for instance. As an example, suppose the surgeon and the synergistic device cooperatively hold a bone saw. The surgeon may maneuver the saw at will within the defined plane, cutting at any desired speed from any angle of approach, and avoiding anatomic structures that must not be damaged. At the same time, the synergistic device confines the blade of the saw to a defined plane based on a preoperative plan, so that the eventual resected surface is flat and corresponds to the plan. Arbitrarily shaped surfaces, with greater or fewer than two dimensions, can be defined based on preoperative plans, and enforced by the synergistic device. The surgeon is free to control the remaining degrees of freedom. Synergistic cooperation has the benefit that the robot can provide accurate, precise geometric motions whilst the surgeon holding the tool can feel the forces applied and modify them appropriately. It also has the psychological benefit that the surgeon is in direct control of the procedure. Several of us have realized the value of a synergistic control of motion. Several distinct approaches to achieving that goal will be described in §4.3.

3 Technical needs

In the following we will use the term *mechanism* to refer to any of these three types of systems. The technical specifications of robotic guiding systems answer a triple requirement: the ability to assist the execution of a given clinical *task* by providing accurate and repeatable precise geometric motions with intricate paths and repetetive motions tirelessly; ease of use for a clinical *operator*; and with maximum *safety* for both the medical staff and the patient. In the following paragraph we will focus on user-oriented characteristics and safety-oriented characteristics only. Task-oriented characteristics are defined in the robotics literature (see [3] for instance).

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