Designing Minimum Discomfort Medical Fixtures using Submodular Coverage Algorithms

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***Abstract*— to be finalized!**

Keywords – submodular grapsing, patient positioning, external beam radiation therapy

I. INTRODUCTION

Every year, [todo:X] cases of cancer are treated with Radiation therapy in United States. External Radiation Therapy, along with its variations, is a common form of radiotherapy treatment. With external radiation therapy, radiation is usually administered as a complex combination radiation beams directed at the tumor. Advanced techniques of dose calculation and treatment delivery are employed to permit design of treatment fields to maximize the differential in dose delivered to tumors and healthy tissue.

Accuracy and precision in patient positioning is essential for success of external radiation delivery systems. Since radiation therapy is delivered over multiple sessions, repeatability of a patient positioning system is important to maintain registration between the patient and radiation delivery equipment.

Presently, a variety of patient positioning systems are employed in clinical procedures. However, most if not all of these systems are one-size-fits-all. This leads to problems in maintaining conformance between simulated and physically delivered radiation dose distributions over multiple sessions. Furthermore, these patient positioning systems are inconvenient for the patients often requiring local anesthesia to relieve pain.

For instance, stereotactic radiotherapy (SRT) is used primarily for treating tumors in the brain. The procedure has sub-millimeter accuracy, but assumes exact patient to machine registration. Commercially available head positioning solutions for SRT usually require the patient's head to be placed in a cubical frame with multiple pegs securing the head in its place. One example of such a system is illustrated in figure 1. These pegs are uncomfortable and the the frame only allows the head to be placed in a small set of orientations.

Additionally, the ability to easily position the head in any orientation simplifies planning for radiation dose in external radiation therapy. For e.g., if a patient is immobilized in a non-supine position, reaching tumor might become easier due to decreased hindrance from healthy tissue.

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Fig. 1. The figure shows a Leskell Coordinate Frame G used for Stereotactic Radiosurgery. As illustrated in the picture, the patient head is placed in a frame and secured in place with use of multiple pins

The key insight in building a principled solution for immobilization is customization to patient anatomy. We propose a solution which leverages redundant point contacts and uses surface contacts. This higher degree of customization is also facilitated by recent advances in additive manufacturing and 3D printing.

After a 3D reconstruction of the patient anatomy using a CT (or MRI) scan, we use redundant contact points and surface contacts to the set of minimal grasp points required for immobilization. This reduces maximum force at any contact point. The benefit of inclusion of additional contact points is a submodular function, which allows us to find the optimal set in reasonable time.

This study builds upon the previous work from Schulman et al [1]. In this paper,

- We describe an algorithm which minimizes maximum contact force and immobilizes the subject.
- We evaluate the performance of algorithm on multiple instances of [todo:X] body parts.
- We create a patient specific head positioning system using 3D printing.

II. RELATED WORK

Grasping and manipulation of real world objects has been studied for over a century. The problem of fixturing objects, whether by use of mechanical jigs and fixtures, or by actuated robots, has garnered research interest across disciplines.

A review of Grasping and closure for robotics is provided by Bicchi and Kumar [2]. A detailed explanatory material on grasping has been provided in [3].

As covered in both [3**?**], a fundamental requirement of grasping and manipulation is to constraint an object in equilibrium and control position and orientation of the object

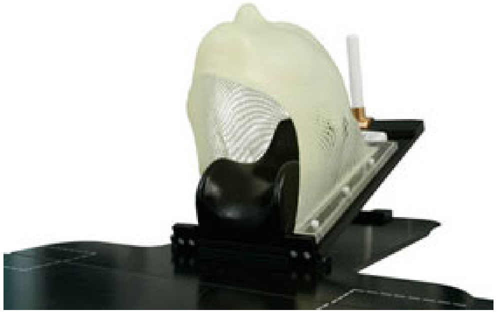

Fig. 2. The figure shows a Elekta HeadStep used for Stereotactic Radiosurgery. As illustrated in the picture, the patient head is placed in a frame and secured in place with elstic mask

as needed. Grasp closure has been characterized in two useful manners: Form Closure and Force Closure.

The joint vector of forces and moments at a contact point in $\mathbb{R}^3$ is called as wrench. An rigid object grasped by a set of rigid contact points (may be fixed or actuated), is said to be form closed if it is impossible to move the object. Similarly, a rigid object is said to be force closed if an arbitrary wrench can be counteracted by a change in contact wrench intensity. Force closure is similar to form closure but relaxed to allow for friction forces to balance object wrenches.

In applications of fixturing and grasping in healthcare, often form closure is preferred over force closure due to use of passive positioning systems. For instance in SRT, patient's head is immobilized using a passive device ensuring no disturbance while treatment is being delivered.

Markenscoff et al [4] showed that 3D objects with piecewise smooth boundary (including polyhedra) can be form closed in atmost seven frictionless contacts. We note that choosing this minimal set of contact points can result in a high normal contact force at a subset of contacts. In medical fixturing, such characteristics of a fixture are undesirable because they may lead to localized pain, skin rupture and even injury. Hence we propose the use of redundant contacts for form closure.

Modular grasping fixtures have been described by Brost and Goldberg al [5]. Grasping deformable objects has been a challenge in manipulation research. Gopalakrishnan and Goldberg [6] describe new techniques using D-Space for holding deformable parts. Borst et al [7] proposed a fast and robust grasp planner. Fast grasp planning and fixturing has since been explored by a number of research efforts [todo:find papers].

Teichmann and Mishra [8] provided an algorithm for grasp quality optimization by a reduction of grasping problem given a set of contact points to a convex set cover problem. Ferrari and Canny [9] published a seminal work on geometric grasp quality metrics. They quantified the concepts of total force and maximum force as convex hull and minkowsky sum of contact wrenches, respectively.

Wang [10] proposed an optimal 3D part fixture design methodology given a point set of contact points.

Bale et al [11] propose a new vaccum based device for extremity immobilization. [todo:published works in medical/body part fixturing]

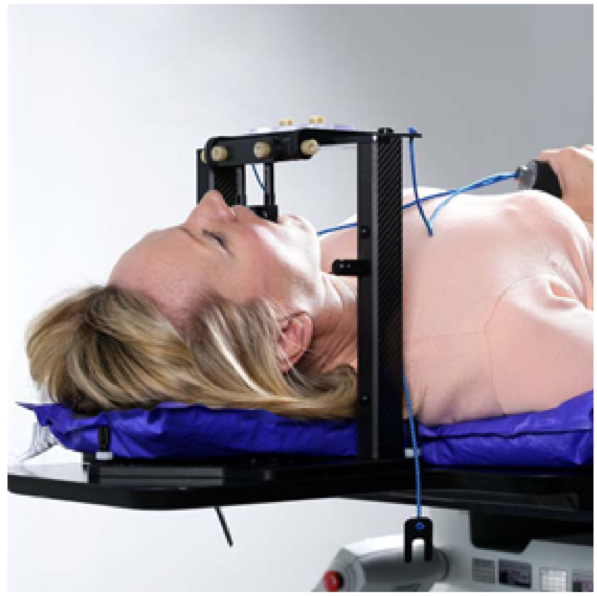

Fig. 3. The figure shows a Elekta HeadFix used for Stereotactic Radiosurgery. As illustrated in the picture, the patient head is placed in a frame and secured in place with vacuum activated mouthpiece holding the patients upper jaw.

There are a number of commercial medical patient positioning systems currently used in clinic. As shown in figure 1, the Leskell coordinate frame G four tapping screws keep the frame attached to the patient's head. This frame requires local anesthesia to minimize patient discomfort during the procedure.

Figure 2 shows a Elekta HeadStep which is used for immobilization in cranial as well as head, neck and shoulder procedures. It uses an elastic mask to cover the face and the head with incisions for breathing.

Figure 3 shows a Elekta HeadFix which is used for head immobilization. It uses a vacuum activated head frame system which uses a mouthpiece to clamp down the patients upper jaw. The impression of the upper jaw is patient specific.

[todo: Look up if there are other companies doing similar stuff Keywords patient positioning in SBRT]

Our work extends the findings of Schulman et al[1] to applications in medical fixturing. Furthermore we also propose a method of initial generation of feasible contact points using geometric intuitions from local curvature and also no-go zones as specified by a phycisian (viz. mouth, eyes, ears, nose etc.) Similar methods can also be used for generating form/force closure grasps for physical objects using multi-fingered hands or multiple hands.

III. PROBLEM STATEMENT

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IV. OUR APPROACH

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V. EXPERIMENTS

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VI. Results

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VII. Discussion and Future Work

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