Design of Surgical Robots

Blake Hannaford

Biorobotics Lab, Department of Electrical Engineering
http://brl.ee.washington.edu

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Outline

• Telemanipulation history and Concepts
• Surgical Robotics Overview / History
• RAVEN
• HapSMRT
• NEEMO

History

• Nuclear Teleoperators (waldos) 1940’s
• Computer controlled telerobots 1980’s
• Haptic Interfaces and commercialization 1990’s
• Emergence of Medical Telerobots 00’s
Ray Goertz

September 15, 2000

Blake Hannaford, U. of Washington
Telerobot (JPL ~1987)

Remote Surgery (2001)

Marescaux

New York

France
Clinical Experience

- ~2003
- Dr. Mehran Anvari
- Southern Ontario to Hudson’s Bay
- Zeuss robot
- Canadian Health Ministry Approval
- 25 patients

“RAVEN” Surgical Robot

- Goal: surgical care for combat casualties in “golden hour” after trauma.
- Concept: Robot arms remotely controlled by surgeon
- Compact Spherical Mechanism
Instrumented Endoscopic Grasper

Forces - Raw Data

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Blue DRAGON
Analysis and Uses of surgical recordings

- Design Specs: e.g. Histograms / PDFs
- Skill Assessment:
  - Hidden Markov Models
  - Markov Models
  - Train HMMs of each skill cohort
- Procedure tracking
  - Identify completion of sub-procedures
  - Catch errors?
Surgical Robot Project – Design Goals

- Develop a smaller, more dexterous surgical robot.
- Aim to provide force feedback to surgeon.
- Increase its mobility and ability to operate on its own.
- Evaluate in experimental surgery (porcine model)

Spherical Mechanism

- Axes intersect at port
- Compact
Design Optimization Goals

- Design Freedoms: 2 link angles
- Must reach measured Extended Dexterous Workspace (90deg)
- Must have good isotropy in Dexterous workspace (60deg).

Serial vs. Parallel Smackdown!
Serial Mechanism Isotropy

- Isotropic – good motion properties in all directions
- Inverse of Jacobian Matrix condition number
- $0 < \text{Isotropy Score} < 1$
  - Each point in workspace has an Isotropy Score
  - Score = 0: can move in one direction but not another
  - Score = 1: can move equally well in all directions

Mechanism Isotropy

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Optimization for Laparoscopy

- From Blue Dragon Experiments – 95% of surgeon motion falls within 60° cone
- Optimize mechanism over surgeon’s workspace instead of entire hemisphere

Serial - 60° link angles

Isotropy versus azimuth and elevation

Points with Isotropy > 0.3
Results
Serial

DWS (60° cone) – Best Design: \( \alpha_{th} = 52° \) and \( \alpha_{th} = 40° \)
Current Prototype
Remote Operation Architecture

- Phantom Omni
- Touch Screen
- Foot Pedal

RTAI-Linux
Software Architecture

- Modular architecture based on standard data structures.
- 1000Hz real-time control based on RT-Al Linux
- Internet Protocol between master/slave
- PLC based safety/E-stop processor with 4 states.
Safety Goals

- Reliable robust use for animal experiments.
- Reduce false alarms
- Prevent damage to equipment and tools
- NOT human rated

Safety System Principles

- Use simple, robust logic and hardware.
- Support a hardware E-Stop
- Keep surgeon in control for any software action.
- Reduce risk due to software complexity
Control Architecture

Control and actuation
- Motors, Encoders, Amplifiers
- RTAI Linux Host
- Foot Pedal
- I/O Board

Safety System
- Brakes
- PLC
- E-Stop

Safety States

E-STOP or Watchdog Timer

- E-STOP
- Init
- Pedal Up
- Pedal Down
- Ready
- Start

Pedal
- Pedal
Safety System Implementation

- Programmable Logic Controller (PLC) implements all state transitions
- Linux sends heartbeat signal
- PLC implements watchdog timer
- Linux s/w follows PLC state transitions.
- E-stop state cuts motor power and applies brakes.
Portable Surgeon Side Console

• Hardware
  - PC laptop
  - Two Omni haptic device
  - USB foot pedal
  - Video display (NTSC and PC Video)
• Software
  - SSS (surgeon site software)
    - SGUI (surgeon’s graphical user interface)
    - HDC (haptic device client)

Master Station Setup

![Image of Master Station Setup]
SGUI

- Allows execution of high-level commands
- Written using Qt 4.1.2 from Trolltech, Inc.
- Surgeon tab
  - Allows setting
    - Scale factor
  - Status display (System status)
  - Tool selection (For future)
- Engineer tab
  - Remote IP address of surgical robot

HDC

- Haptic device client
  - Sends commands to surgical robot
    - Position increments – micron units
    - Orientation increment – micro-radians units
    - Use UDP for data communication
      - Low overhead
      - Fast
  - Haptic device mapping
    - Mapping of Haptic Interface Device (HID) to the motion of surgical robot
      - Pitch is mapped to tool wrist
      - Roll is mapped to tool shaft roll
  - Indexing
    - Allows surgeon to operate within the comfortable workspace of Omni
    - Foot pedal is used to engage indexing
Communication Protocol

- UDP packets
- 100-1000 packets per second
- Incremental motion commands

Data Packet Structure

typedef struct {
    unsigned int sequence;
    int c_timestamp;
    int s_timestamp;
    int delx[2];    // microns
    int dely[2];
    int delz[2];
    int delyaw[2];   // micro-rad
    int delpitch[2];
    int delroll[2];
    int buttonstate[2];
    int footpedal;
    int checksum;
} masterToRobot_data;
Video Feedback

• Desirable Features
  - Video picture quality
  - Low encoding/decoding latency
  - Robustness to network jitter, loss
  - Low cost
• Current Alternatives:
  - HaiVision Hai 500 hardware codec
  - VLC, Skype and iChat
    * Free video chat software