SAMPLING OF 3DOF ROBOT MANIPULATOR JOINT-LIMITS FOR HAPTIC FEEDBACK

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OUTLINE

• Introduction
• System Components
• Methods
  • Algorithms
  • Results
• Conclusion and future work
TELEOPERATION

• Remote control of robot by a human operator

• Teleoperated robots have numerous applications – assisting in medical procedure, rover control in space, micro-assembly etc.
INTRODUCTION

• Teleoperation - robot proxies can extend human-control to uncertain and dangerous task environments.

• Key is to build seamless and intuitive interfaces for remote control of sophisticated proxies.

• Controlling complex teleoperated robots can be confusing
  • Slave vs. Master kinematics
INTRODUCTION

• The kinematic complexity may result in situations that are frustrating and confusing for the human master.

• **Joint limits might be inconsistent**

• The master/input device may freely command configurations that violate joint limit constraints of the slave/remotely operated proxy
  
  • Perceived failure mode is not clear; joint limit reached, communication failure, software e-stop etc.
INTRODUCTION

• Potential Solutions
  • Kinematically identical/scaled master and slave
    • Non-modular
    • Requires slave specific masters
  
• Constrain master kinematics to that of slave via haptic feedback
  • Human sensomotoric pathway uses proprioception to indicate joint limits
  • Haptic feedback is an intuitive and efficient feedback channel
MOTIVATION

• Kinematic dissimilarities were addressed using haptic feedback – an ideal solution because the human body itself leverages proprioceptive haptic feedback at its own joint limits.

• Haptic feedback has proven to benefit telerobotic tasks – robot-assisted minimally invasive surgery (RMIS), micro assembly and remote welding etc.
  • Task or environmental cues
  • We introduce feedback about the slave device state to enhance operator awareness and reduce confusion
• KUKA youBot constrained to 3DOF motion
• Visual feedback provided via standard LCD monitor
• Bilateral teleop: Sensable PHANToM Omni
  • 3DOF haptic feedback
  • 3DOF motion commands
• Communication facilitated via AC router.
• National Instruments Compact RIO controller.
METHOD OVERVIEW

• Surface sampling i.e. forward kinematics at joint limits systematically sample end effector location - at least one joint limit reached
• Cartesian points stored in simple tree like structure.
• The tree structure facilitated indexing and retrieval of local joint-limit point clouds.
• Efficient point-cloud based haptic rendering techniques employed using local point-clouds fetched at joint limits
  • Provides indication of translational motion to remove device from joint limit
POINT CLOUD HAPTIC FEEDBACK

• Joint limits easily visualized in joint space, but ideal cartesian translational haptic feedback not clear
  • If boundaries represented in cartesian space, haptic feedback is clearly defined via point-cloud rendering methods
• Unfortunately, joint limit surface may overlap in cartesian space – non overlapping point cloud local to the current joint configuration must be used
Joint space limits were systematically sampled as a Cartesian point cloud.

Algorithm used to generate point clouds:

→ for minimum joint limit of each joint $A_i$, servo through all possible joint configurations for the remaining joints (forward kinematics determine servo step size to maintain minimum resolution)
→ repeat the above step for the maximum joint limit of $A_i$
→ repeat above steps for all joints of interest

The joint limit surfaces now represented as a point clouds is sampled in a tree structure which is traversed via current configuration
LOCAL POINT CLOUD RETRIEVAL

• Because of the tree-structure, locating the local non-overlapping point cloud is direct and trivial.

• Algorithm for point cloud retrieval:
  → If current joint configuration is at a limit, for each joint $A_i$, calculate indices of neighboring points from table (enabled by systematic sampling of points)
  → If not at joint limit, proceed with inverse kinematics based on user commanded input

LPC when all three joints are at limits
LOCAL JOINT LIMIT SEARCH

• Workspace limits feedback can also be rendered in tandem.

Union of Point Clouds for rotary joints A1-A4
LOCAL JOINT LIMIT SEARCH

Local point cloud at A1 and A2 limits

Local point cloud at A4 limits
CONCLUSION AND FUTURE WORK

• Results indicate that using this naïve tree structure approach for point cloud storage and retrieval, the joint limits for a 3DOF robot manipulator can be well represented and maneuvered in cartesian space – as the commanded position moves along a joint limit, the correct local point cloud is retrieved.

• Techniques used in this paper raise the potential for using similar point-cloud based methods in higher DOFs (both input and slave device).

• Immediate next steps include algorithmic improvements - replacing the tree structure with a more efficient, constant look-up time mapping table.

• Extend research to user studies that include teleoperated robots in more sophisticated task environments.
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