Towards Data-Driven Autonomous Robot-Assisted Physical Rehabilitation Therapy

Wei Shi Wang, Rochelle Mendonca, OTR, PhD, Konrad Kording, PhD, Mikael Avery, OTR, Michelle J. Johnson, PhD, Member IEEE

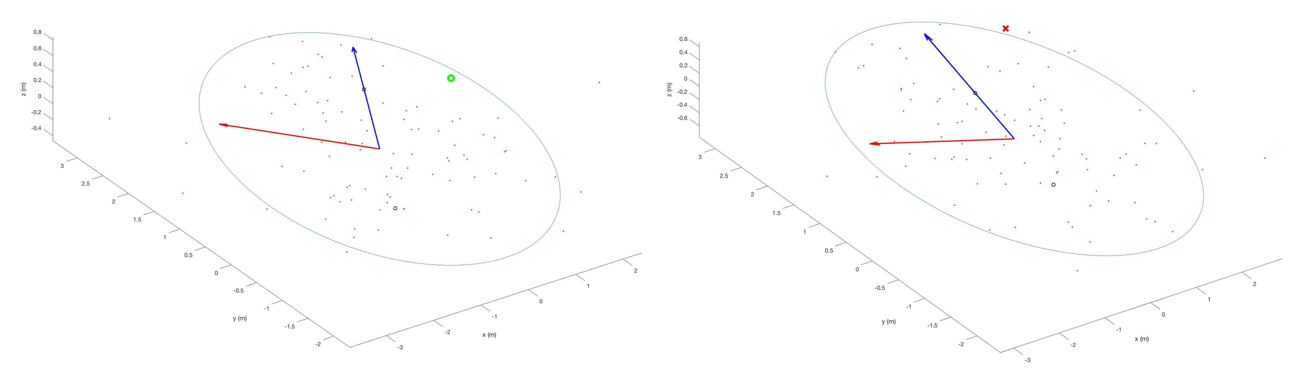
University of Pennsylvania, McGill University

Motivation

- The population of stroke survivors is growing every year, and the projection for 2030 shows that the number of stroke survivors will exceed 70 million.
- It is estimated that there will be a significant shortage of rehabilitation therapists leading to an inability to meet the population's rehabilitation needs.
- Repetitive rehabilitation assistance can be performed by robots to free physical therapists to take more patients.

method

- Demonstrate the acceptable motion for picking up a cup and record the trajectory using IMU (inertia measurement unit). Filter the trajectories with extended Kalman filter. Repeat the motion for 10 times.
- Discretize the recorded trajectories into 100 planes. Perform 2D Gaussian regression on each planes to obtain the error ellipses. Store the ellipses in a HashMap with the longitudinal position as key and ellipses as the value. Input the trained constraint to the BAXTER robot.
- Perform a testing reaching task. Position of the hand is recorded by the IMU. The acceptance of the motion is decided by whether the hand position is within the trained constraint region. The classification relies on simple ellipse property shown as follow:



- BAXTER is programmed to assist the patient by guiding his hand into the constraint region if the motion is characterized as incorrect. Otherwise, it will follow patient's hand.

Robot-human physical therapy algorithm

Algorithm 1 Train from demonstration

Require: A HashMap $M(K,V)$

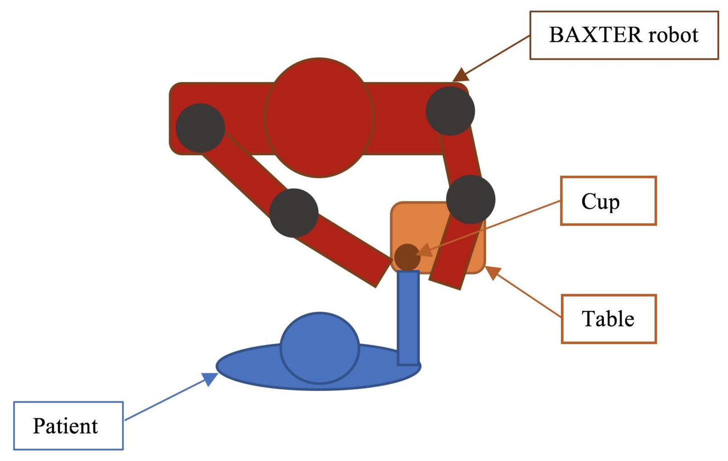
% K and V are keys and values respectively
% Demonstrate the task for n times and store the trajectories t_i to set T
for $i = 1$ to n **do**
    $T \leftarrow T \cup t_i$
end for
Slice T into m planes numbered by x-position x_i
for $i = 1$ to m **do**
    $e_i \leftarrow 2DGaussianRegression(T, m)$
    % $2DGaussianRegression(T, m)$ is a off the shelf algorithm
    $K \leftarrow K \cup x_i$
    $V \leftarrow V \cup e_i$
end for

Algorithm 2 Real-time robot-human therapy

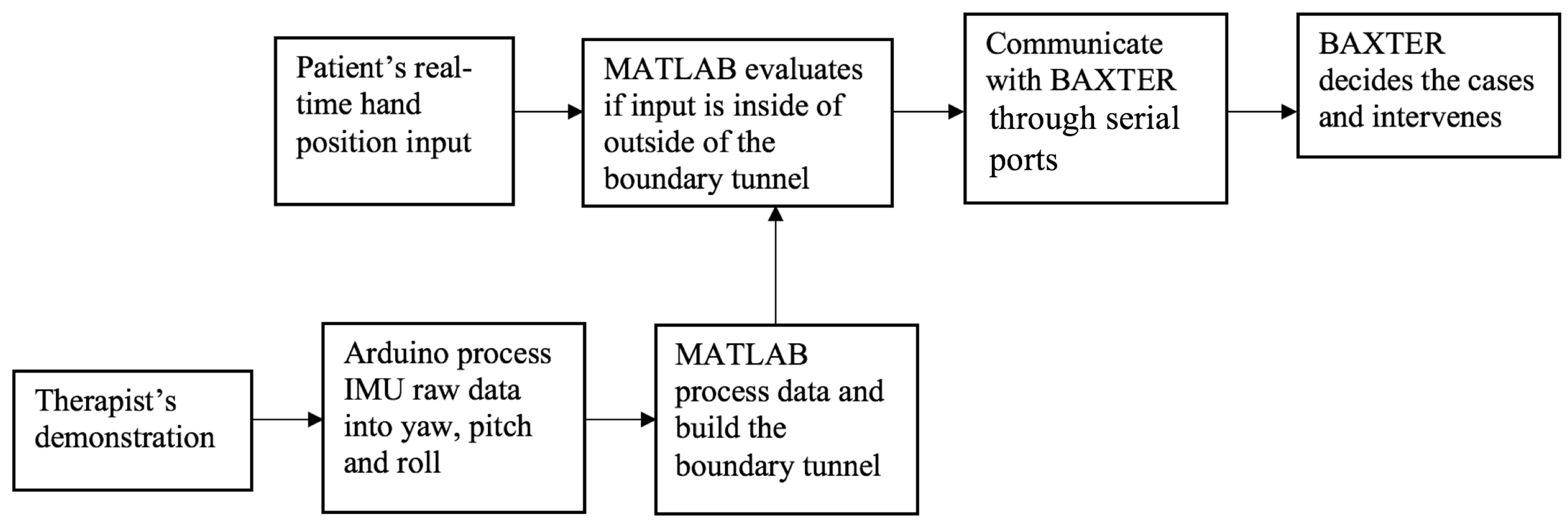
Require: The HashMap $M(K,V)$ from algorithm 1

Initialize consecutive count $j \leftarrow 0$
Divide the tunnel into q sections, $S_q \in S$
while Therapy contiues **do**
    Collect real-time IMU data u
    $P_{closest} \leftarrow BinarySearch(u, M)$, find the closest plane
    % $BinarySearch(u, M)$ is a off the shelf algorithm
    $C \leftarrow Classification(u, P_{closest})$
    if $C = 1$ **then**
        $j \leftarrow j + 1$
    else
        $j \leftarrow 0$
    end if
    if $j \geq 3$ or $x_u \geq Max(K)$ or $u \in$ same S_q for more than 3 seconds **then**
        $RobotAssist(u)$
        % $RobotAssist(u)$ implements $Moveit$ package in
        % Robotics Operating System (ROS) to move the robot
        % hand to u
    end if
end while

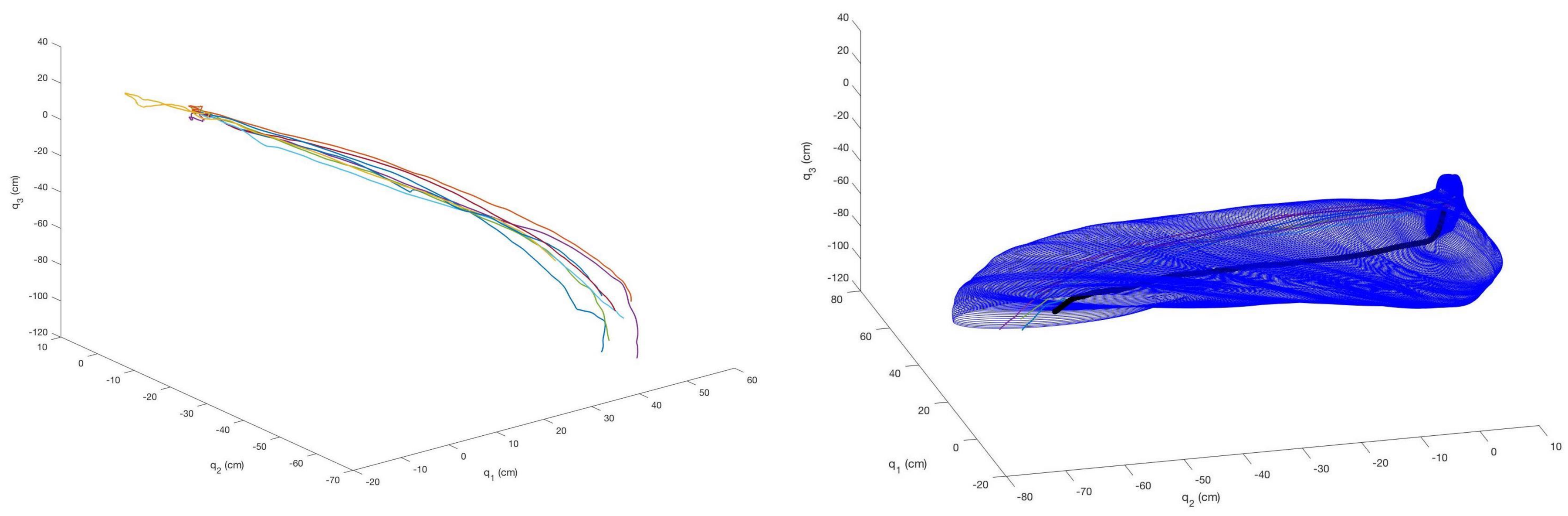
Robot-human task oriented physical therapy setup



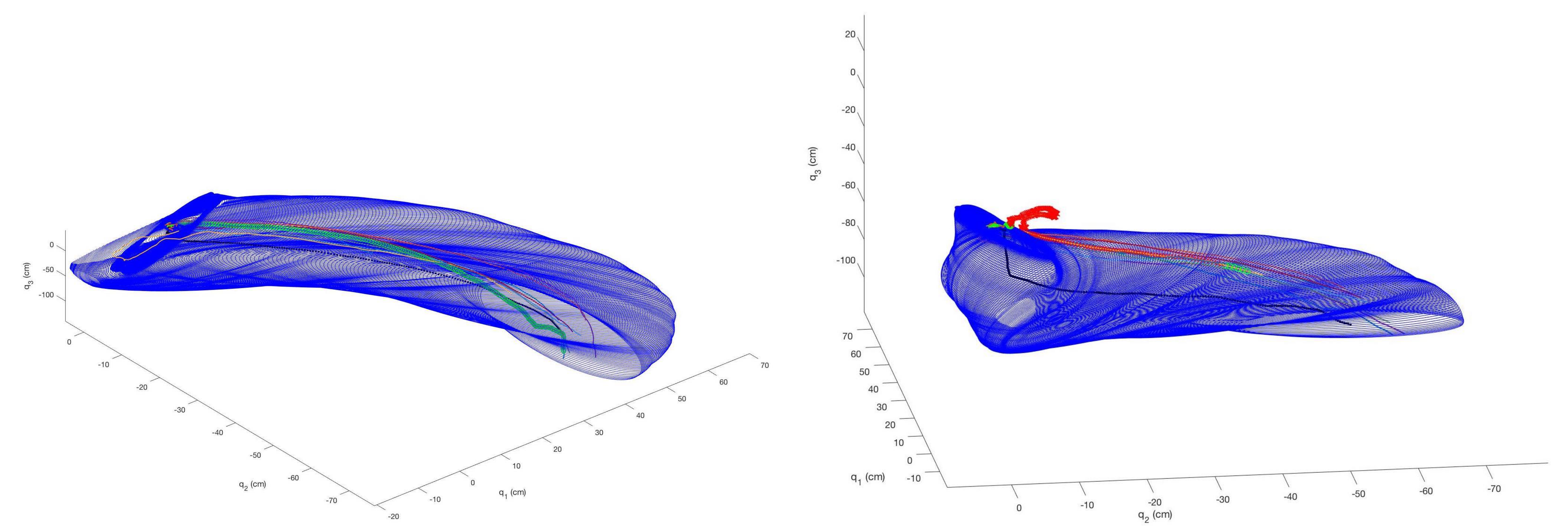
Work flow chart



Demonstrated trajectories and boundary region



Demonstrated trajectories and boundary region



Conclusion

The preliminary results prove the feasibility of this method, however, many limitations exist. The performance can be improved by implementing more complex machine learning models such as Gaussian and increasing the number of IMUs.

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General Robotics, Automation, Sensing & Perception Lab

Rehabilitation Robotics Laboratory

Perelman School of Medicine
University of Pennsylvania