Workspace Analysis for Planning Human-Robot Interaction Tasks

Nikolaus Vahrenkamp, Harry Arnst, Mirko Wa¨chter, David Schiebener, Panagiotis Sotiropoulos, Michal Kowalik, and Tamim Asfour

Student Talk by Tonye Brown

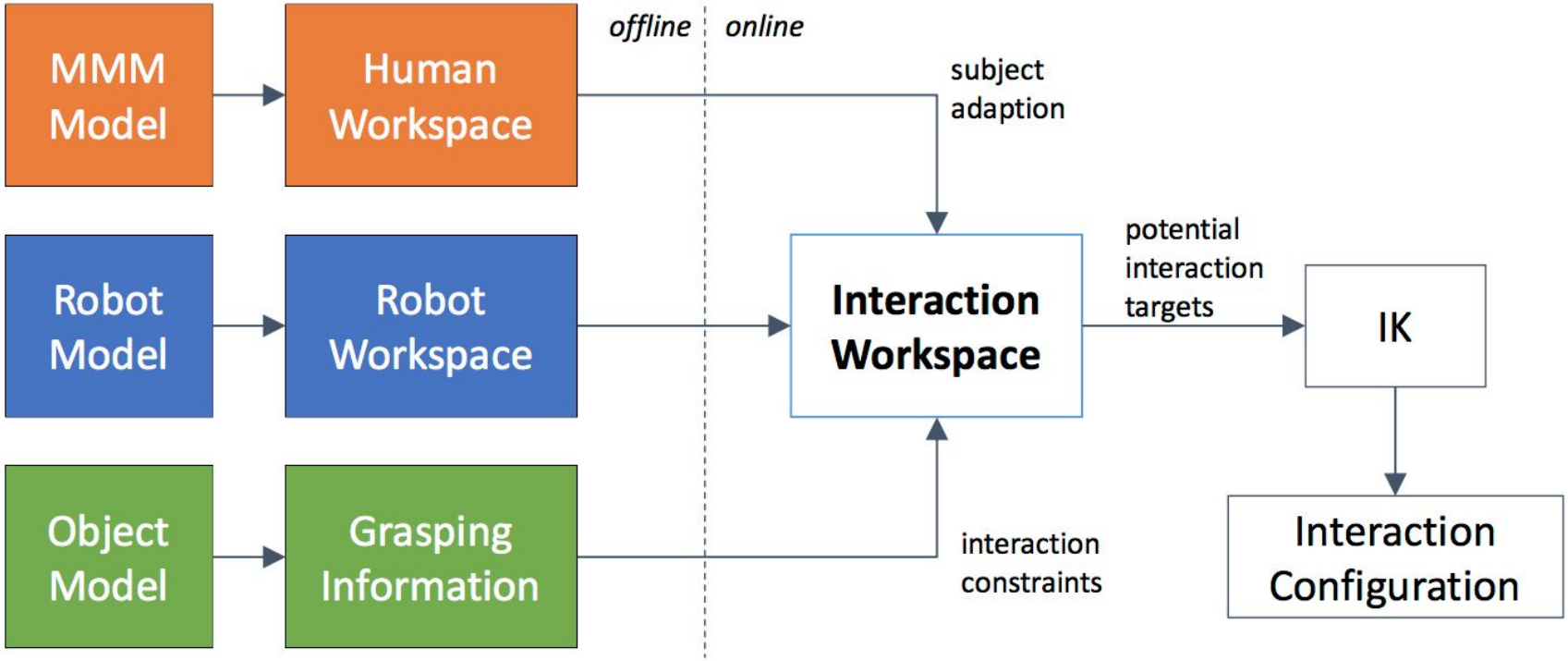
User Modeling for Hand-Over Tasks

- Useful for tasks such as grasping and motion planning.
- Important for robots that have to act in human-centered environments.
- Therefore, use human-centered constraints for planning interactions such as comfort and safety.

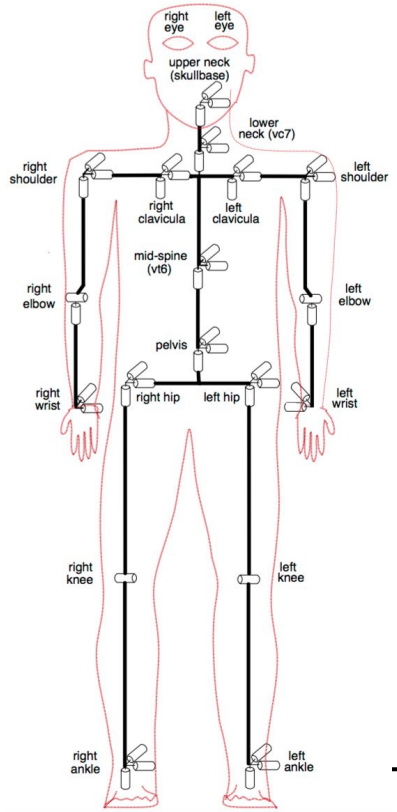
The Interaction Workspace

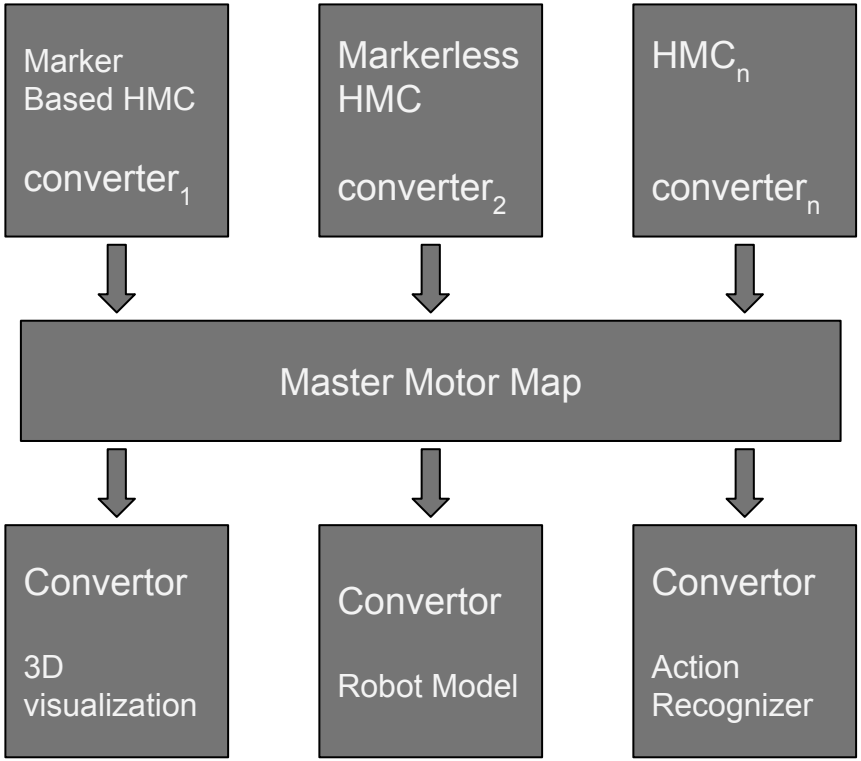
An approach that provides task specific information about dexterity and comfort of the human user and efficiently builds and queries data for potential interaction targets.

Task-specific constraints can be taken into consideration online as different quality measures can be incorporated.

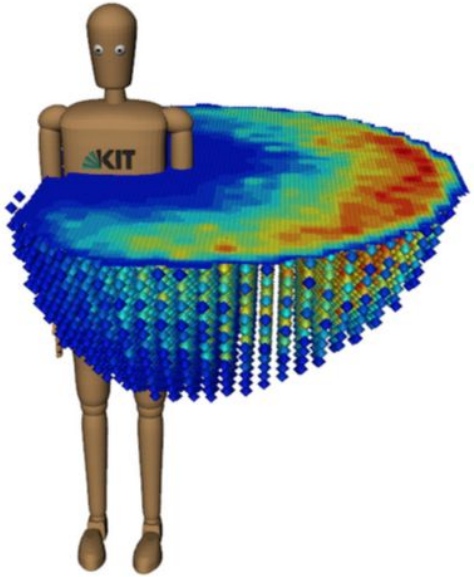

MMM Model
Human Workspace
offline
online
subject adaption
Robot Model
Robot Workspace
Interaction Workspace
potential interaction targets
IK
Object Model
Grasping Information
interaction constraints
Interaction Configuration

Master Motor Map





Human Workspace



- 6D pose space (t,R) where $t \in \mathbb{R}^3$, $R \in SO(3)$
- Voxel describing the human's arm local dexterity denoted by $q \in [0,1]$
- Local dexterity, computed offline using a sampling-based method, is a measure of manipulability.
- Other factors are taken into consideration online such as travel cost and spatial error, visibility, collision/safety and effort.

Travel Cost and Spatial Error

$$c_{spatial} = \|p_{current} - p_{target}\|_2$$

Cost based on the spatial displacement of the arm.

$$c_{joint} = \sum_{i=1}^{n} \alpha_i \cdot (\theta_{current,i} - \theta_{target,i})^2$$

Cost based on the displacement of joints from current configuration to target configuration.

Visibility, Collision and Effort

The cost function for visibility is proportional to the angle between the direction of the current gaze and the given potential target interaction

The safety parameter deals with collisions and is inversely proportional to the distance between the tool center point and any possible obstacles.

Effort measures the overall torque of all joints in the arm. Minimal joint torque are good candidates for least effort.

Total Quality Value

$$q_i = 1 - tanh(\beta_i c_i),$$

$$q_{online} = \sum_i \omega_i q_i, \quad + \quad q_{dexterity} \quad \Rightarrow \quad q_{total}$$

i ∈ {joint,spatial,visibility,safety,effort}

Algorithm for Interaction Workspace

For hand-over tasks, the following conditions are necessary:

- Reachable for Robot’s tool center point.
- Object when held by robot becomes reachable and graspable by human.
- Satisfy task-dependent constraints.

Create Interaction Workspace

Interaction Workspace is completely covered by Robot Workspace.

It can be built using intersection of the Robot Workspace and Human Workspace which have been computed offline.

Algorithm 1 Buildup of the Interaction Workspace

```
function INTERACTIONWORKSPACE(G_human, g_robot)
    W_robot ← workspace of the robot
    W_human ← workspace of the human
    W_I ← empty Interaction Workspace
    for all Pose p_voxel ∈ W_I do
        if W_robot.isReachable(p_voxel) then
            for all Grasp g_human ∈ G_human do
                Pose p_object ← g_robot · p_voxel
                Pose p_human ← p_object · g_human
                Configuration c_human ← IK(p_human)
                Quality q ←quality(c_human)
                W_I.updateEntry(p_voxel,q)
    return W_I
```

Identify Suitable Interaction Targets

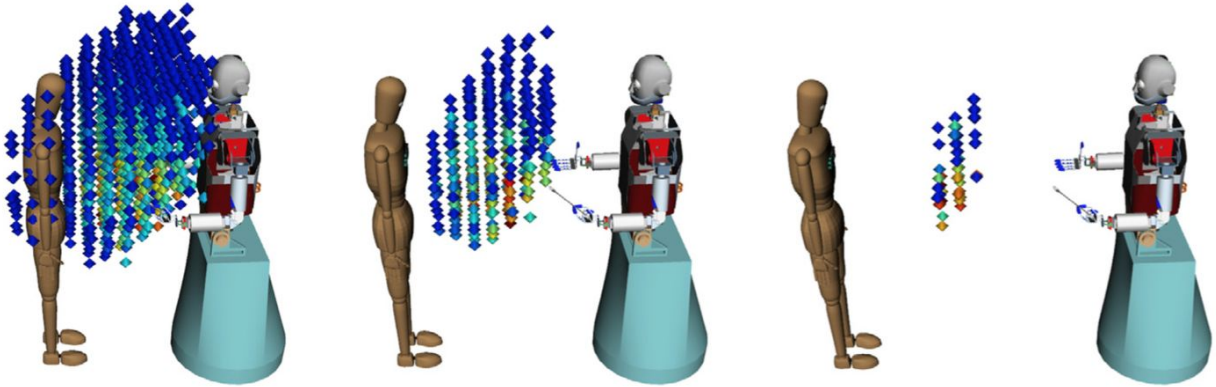
Algorithm 2 Compute a Hand-over Target

```
function SEARCH-HAND-OVER-CONFIGURATION
    W_I ← Interaction Workspace
    while !Timeout() do
        Pose p ← pose with highest quality in W_I
        Configuration c ← IK(p)
        if isValid(c) then
            return c
        else
            W_I.remove(p)
    return failure
```

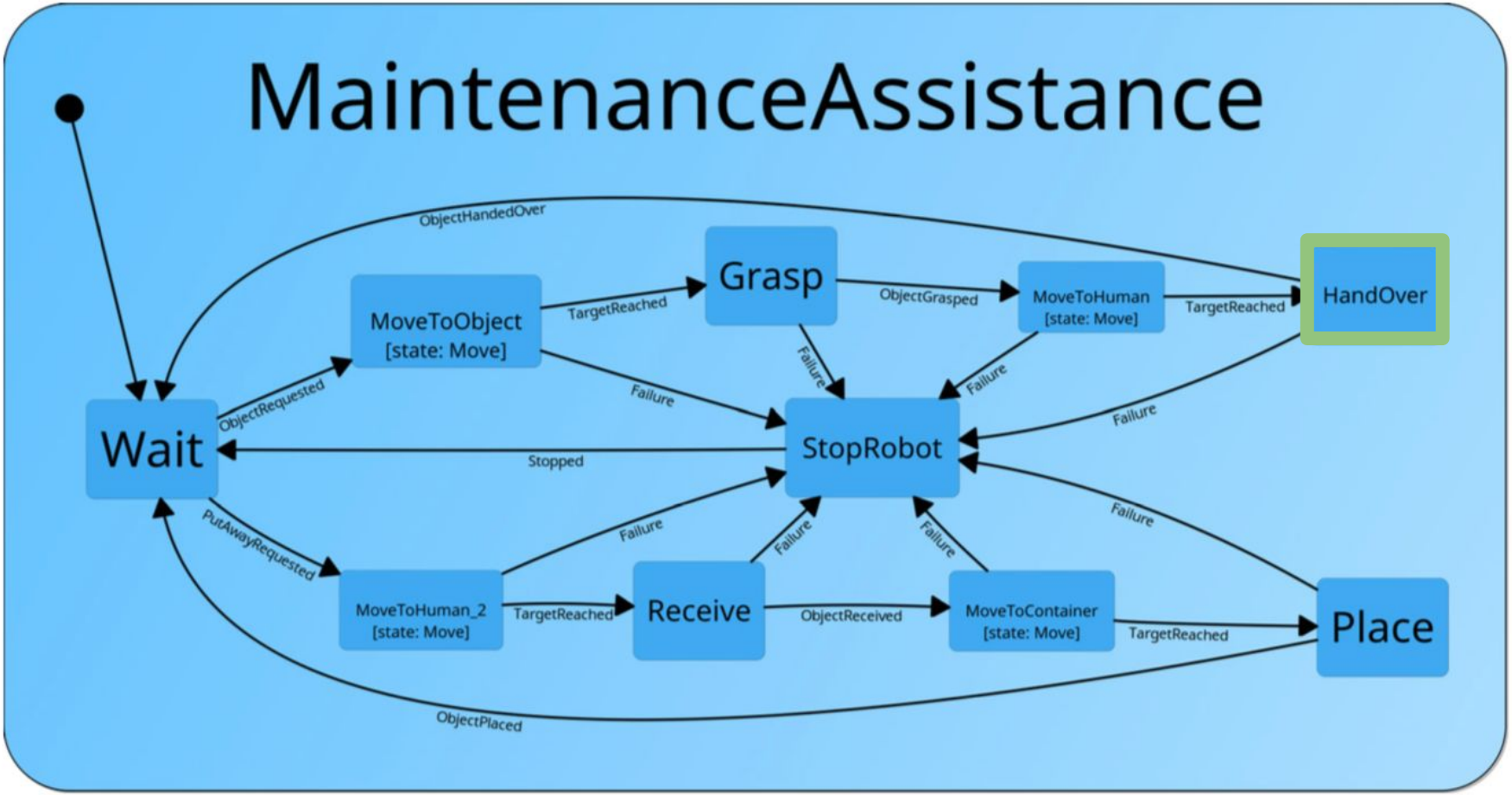
The potential interaction targets need to be verified by IK solver since representations are approximated and to ensure there are no self-collisions.

If IK solver fails, then remove potential target.

Evaluation and Application in Hand-Over Tasks



- Greater distance between robot and human decreased the size of interaction workspace and time needed to compute it.
- Due to less potential targets.


MaintenanceAssistance
ObjectHandedOver
Grasp
MoveToObject
[state: Move]
TargetReached
ObjectGrasped
MoveToHuman
[state: Move]
TargetReached
HandOver
Failure
Failure
Failure
ObjectRequested
Failure
Wait
StopRobot
Stopped
PutAwayRequested
Failure
Failure
Failure
Failure
MoveToHuman_2
[state: Move]
TargetReached
Receive
ObjectReceived
MoveToContainer
[state: Move]
TargetReached
Place
ObjectPlaced

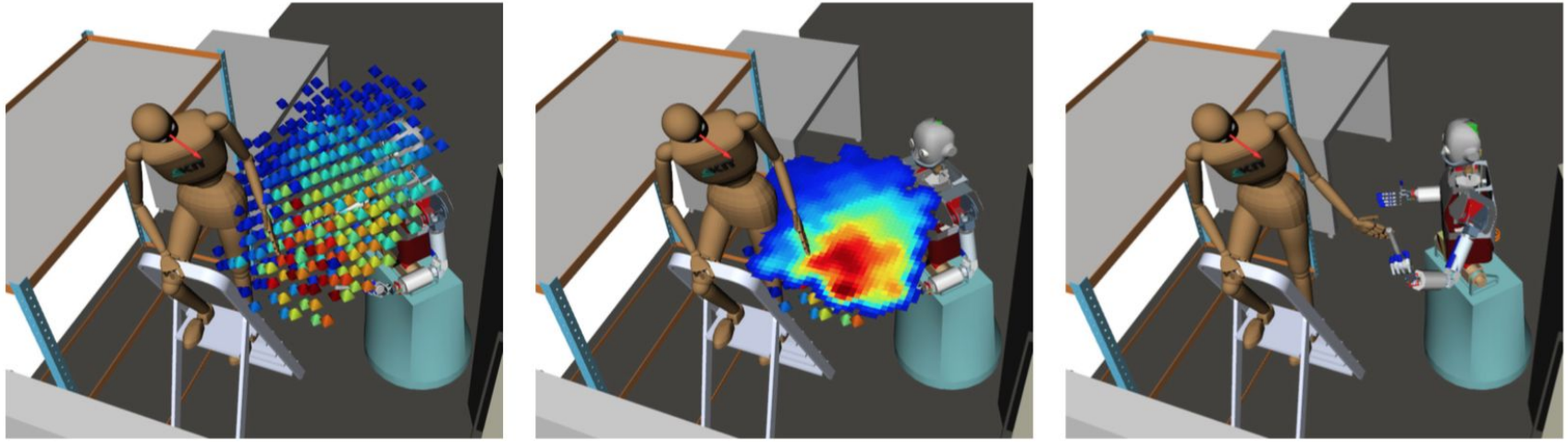
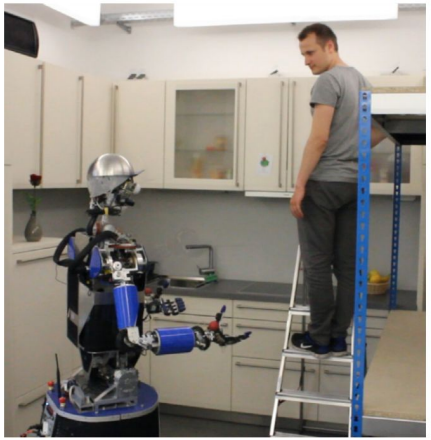
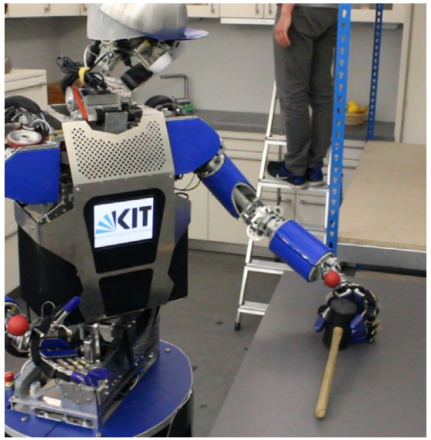


Fig. 6. Scenario of a task to hand over a mallet that is held in the robot's left hand. (a) Interaction Workspace. (b) Cut through the Interaction Workspace. (c) Interaction Target.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Conclusions

- Provides a method for considering human-centered constraints in robot manipulation and path planning.

- Adaptable to different tasks and human subjects and can be constructed in an efficient manner using precomputed models.

Future Work

- Application of Interaction Workspace to different tasks.

- Investigate other quality measures to maximize comfort and ease for human user.