Optimal control of a mobile manipulator for spraying and suckering tasks in viticulture

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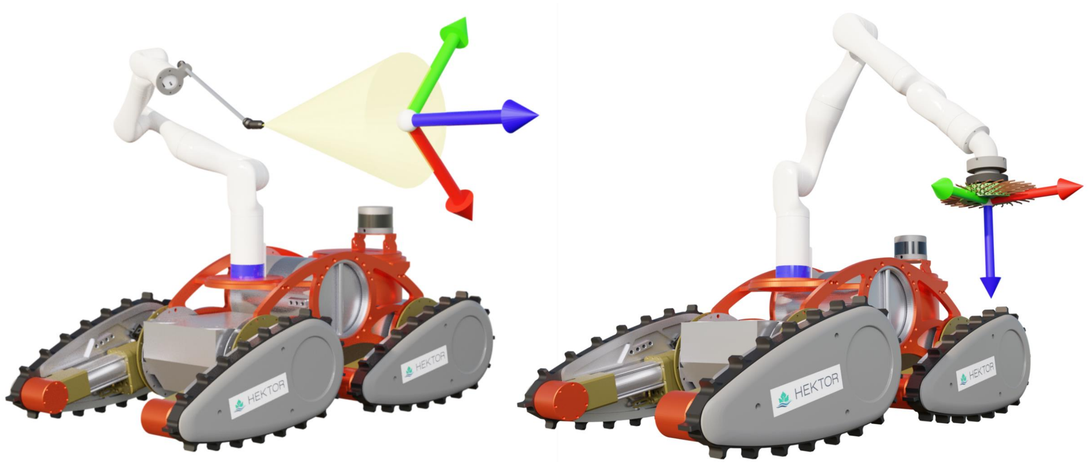
1. Introduction

The main objective of this work is to develop optimal control algorithms for viticultural tasks of spraying and suckering. Prioritized task-space control is used to resolve functional redundancies posed by the tasks, which are both performed with axis-symmetric tools.



Mobile manipulator with axis-symmetric tools used for vineyard spraying and suckering.

2. Problem Description

Tasks performed with axis-symmetric tools are called 3T2R tasks [1], since three translational components and only two rotational components are controlled. Orientation around the approach axis of such tools does not affect task execution. A robot arm with more than five degrees of freedom can generally achieve the desired 3T2R task in multiple ways, and optimization is used to resolve the redundancy in an optimal way.

3. Methodology

Prioritized task-space control [2] replaces the weighted quadratic criterion functions, used in standard task-space control, with priorities, that are guaranteed to be satisfied. The solution to a criterion function of a certain priority is found in the null-space of the solutions to all previous priorities.

For the task of continuous vineyard spraying, to achieve even coverage of the plant canopy, position of the spraying frame is prioritized over its orientation. Tasks used for continuous spraying are:

- Spraying frame position
- Spraying frame approach axis orientation
- Desired joint positions

For the task of selective vineyard spraying (spraying a specific part of the plant), prioritized positional inverse kinematics algorithm is used. Tasks used for selective spraying are:

- Spraying frame position
- Spraying frame approach axis orientation
- Elbow position

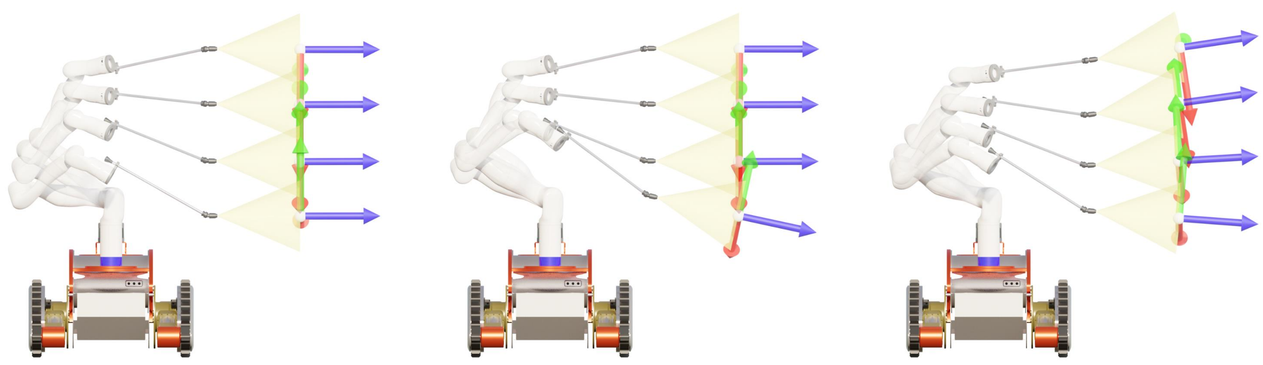
The prioritized positional inverse kinematics algorithm is based on sequential prioritized task-space control.

$\boldsymbol{q} \leftarrow \boldsymbol{q}_{initial}$
tasks $\leftarrow[\,]$
while $\sum \|\boldsymbol{err_i}\| \geq \varepsilon_e$ ***and*** $\sum \|\nabla \boldsymbol{err_i}\| \geq \varepsilon_\nabla$ **do**
  for $i \leftarrow 0$ **to** N **do**
    $\boldsymbol{J}_i \leftarrow$getTaskJacobian($\boldsymbol{q}$, tasktype$_i$)
    $\boldsymbol{err}_i \leftarrow$getTaskError($\boldsymbol{q}$, tasktype$_i$)
    $\nabla \boldsymbol{err}_i \leftarrow$updateGradient($\boldsymbol{err}_i$)
    $\boldsymbol{err}_i \leftarrow$clampTaskError($\boldsymbol{err}_i$,tasktype$_i$)
    tasks.insert($\boldsymbol{J}_i, \boldsymbol{err}_i$)
  end
  $\boldsymbol{q} \leftarrow$solvePTSC(tasks, constraints)
  tasks.clear()
end

Prioritized positional inverse kinematics pseudoalgorithm.

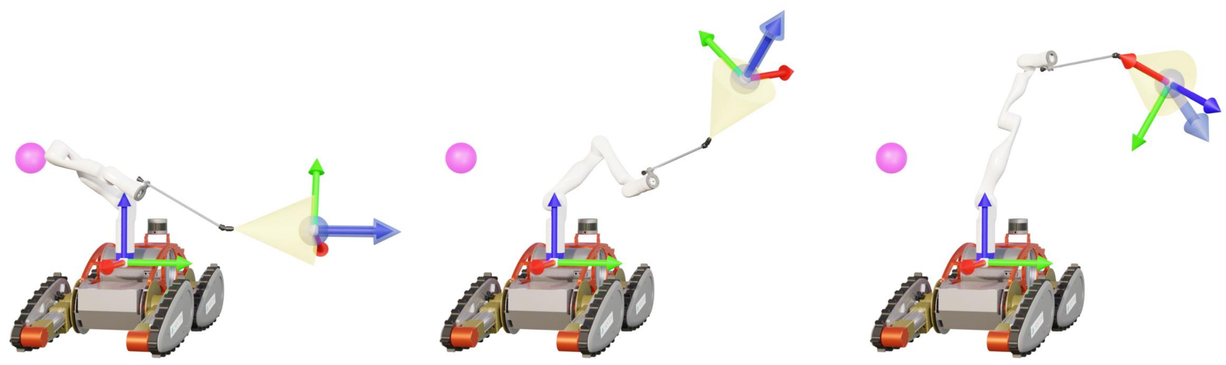
4. Results

The method was tested on three continuous spraying examples. Low spraying velocity results in the entire 3T2R task being feasible. In an example with low spraying velocity and a positional constraint on nozzle height, prioritization becomes noticeable when the constraint is active. In the high spraying velocity example, joint constraints cause the prioritization to be in effect during the entire trajectory.



Continuous spraying using constrained prioritized 3T2R task control.

Similarly, the prioritization of the translational component over the rotational one is present in selective spraying examples using prioritized positional inverse kinematics.



Selective spraying using prioritized positional inverse kinematics.

5. Conclusion

The results demonstrate the utility of prioritized optimization for the control of mobile manipulators in agricultural spraying. The vineyard spraying task has a clear prioritization between its translational and rotational components, allowing prioritized optimization to select the optimal control inputs for the manipulator. For the vine suckering task, a similar method is proposed, with a more complex prioritization of the 3T2R task components.

Acknowledgments

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References

[1] M. Schappler et. al, "Resolution of functional redundancy for 3t2r robot tasks using two sets of reciprocal euler angles," in Advances in Mechanism and Machine Science, pp. 1701–1710, Springer, 2019
[2] M. de Lasa, et. al, "Feature-based locomotion controllers," ACM Transactions on Graphics, vol. 29, pp. 1–10, July 2010.

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