Autonomous and mobile robot for hydroponic greenhouse picking tasks

Department of Computer, Control, and Management Engineering Antonio Ruberti

Sapienza Università di Roma

Candidate

Federico Rollo

ID number 1851121

Thesis Advisor

Prof. Giuseppe Oriolo

Introduction

- Agriculture 4.0:
  - new technologies
  - the necessity of more products in a minor time.
- Different solutions presented during these years to overcome population growth.
- Use of robots to perform hard labor in less time with more productivity



Case of study

- Development of a zucchini flower picking robot for the SolarFields hydroponic greenhouses.
- SolarFields company is a clean energy productor which is investing in hydroponic greenhouse start-ups like Idroluppolo
- These companies are working together to find healthy solution to provide fresh and biological fruits on the market
- Robotics and automation aims to make the production processes fully autonomous

Existing robots

Root AI

Rubion

Iron Ox

Sweeper Robot

Project specifications

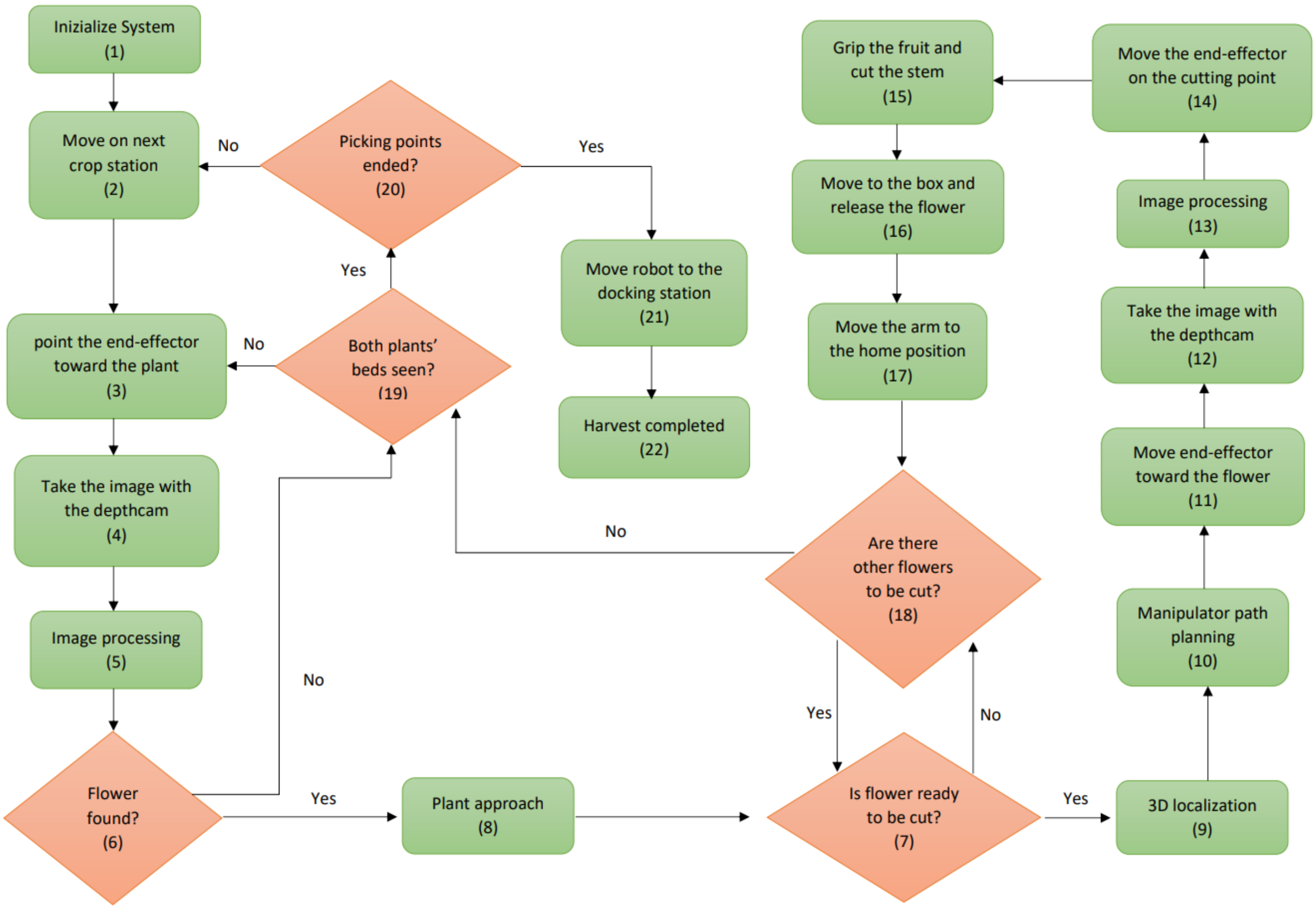
- The robot is composed of three main parts:
  - Mobile platform
  - Robotic arm
  - Vision system
- The aim of the robot is to move inside the greenhouse and pick the zucchini flowers on the plants

- The following work is divided in two main parts:

Feasibility study and design of algorithm and robot structure

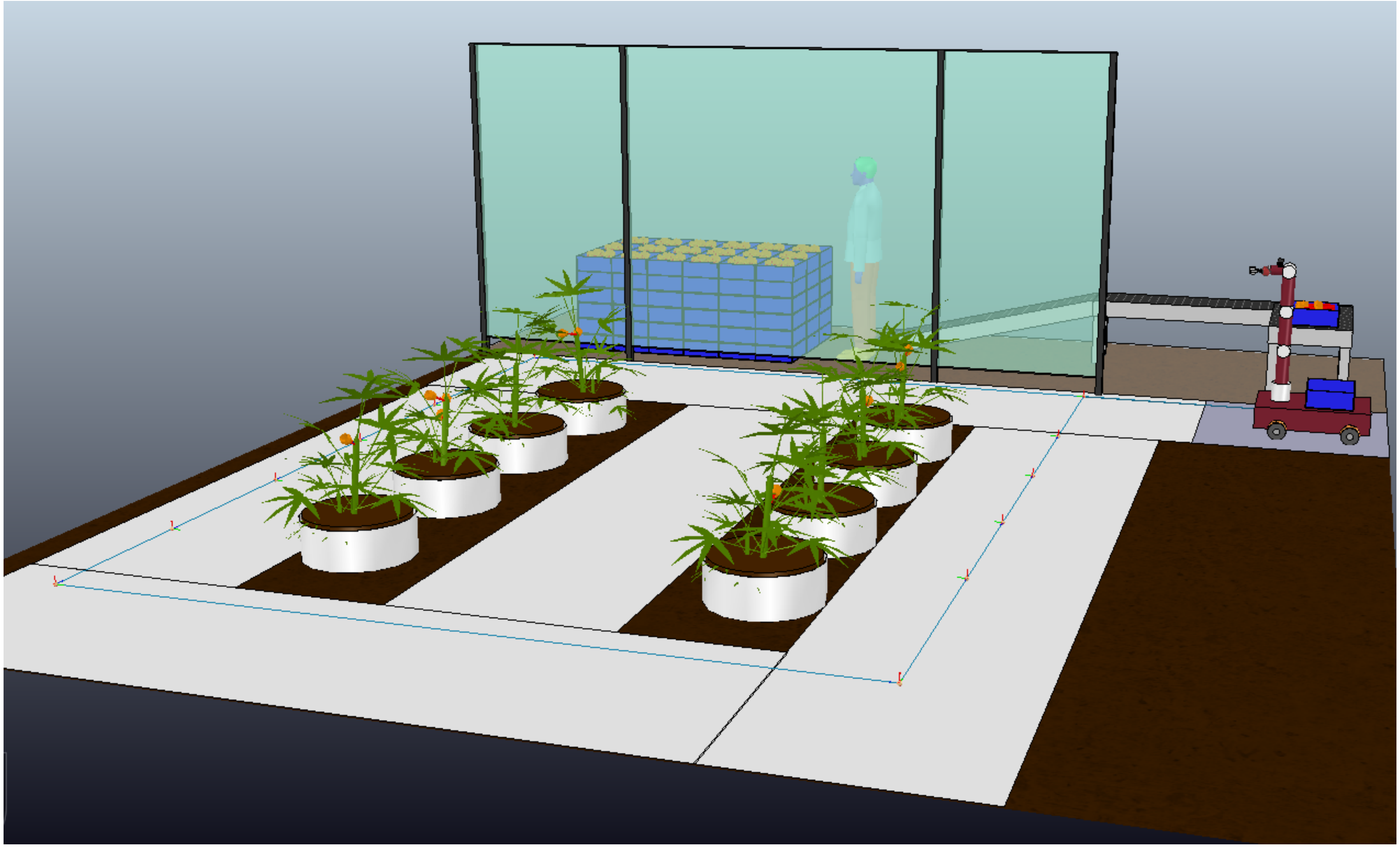
Simulation and control of the robot to prove the project feasibility

Algorithm



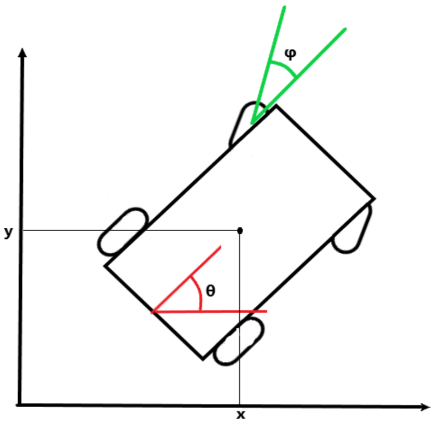
Inizialize System (1)
Move on next crop station (2)
No
Picking points ended? (20)
Yes
Move robot to the docking station (21)
Harvest completed (22)
Yes
point the end-effector toward the plant (3)
No
Both plants' beds seen? (19)
Take the image with the depthcam (4)
Image processing (5)
Flower found? (6)
No
Yes
Plant approach (8)
Is flower ready to be cut? (7)
Yes
No
Are there other flowers to be cut? (18)
No
Yes
3D localization (9)
Manipulator path planning (10)
Move end-effector toward the flower (11)
Take the image with the depthcam (12)
Image processing (13)
Move the end-effector on the cutting point (14)
Grip the fruit and cut the stem (15)
Move to the box and release the flower (16)
Move the arm to the home position (17)

Greenhouse environment

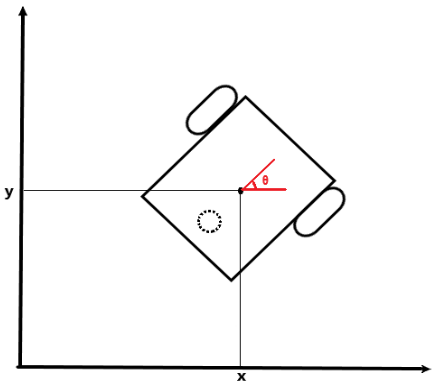


Mobile Platform

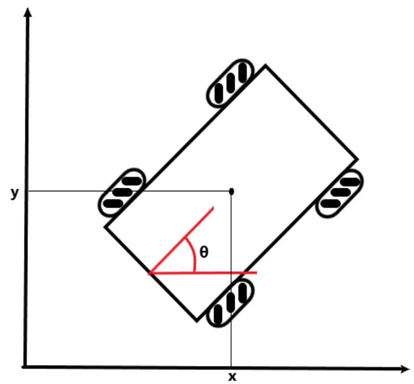
- Three different mobile platforms have been considered:



Car-like robot

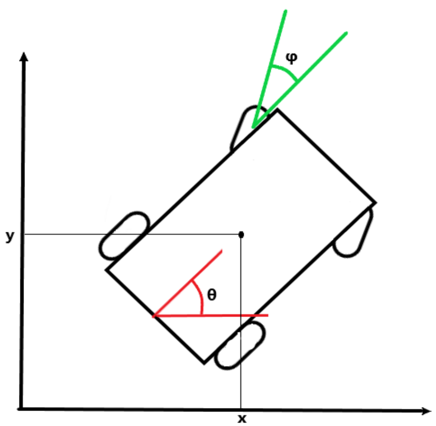


Differential drive robot



Mecanum wheels robot

Car-like robot



Car-like robot

- Pro
  - Good stability
  - Good traction force
- Cons
  - Difficult to control in narrow passages
  - Necessity of maneuvers

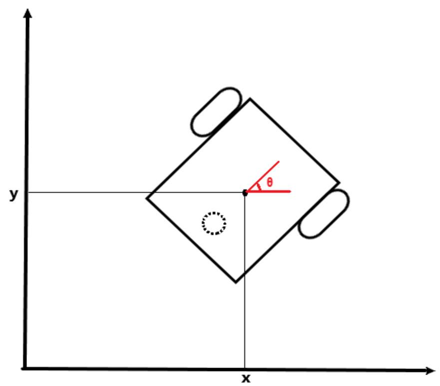
$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ \tan\frac{\phi}{l} & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix}$$

Front wheel drive kinematic model

Differential drive robot

- First configuration → two actuated wheels and an omnidirectional wheel

- Pro
  - Simple model
  - Good controllability
- Cons
  - Bad stability due to manipulator arm attached on



Differential drive robot

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix}$$

Unicycle model

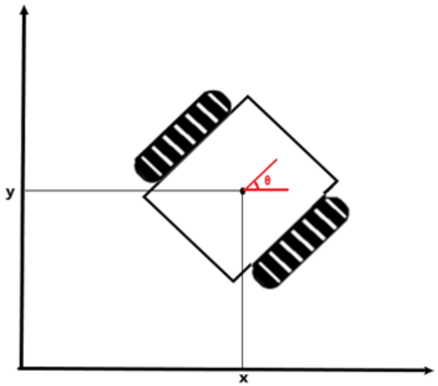
$$\begin{bmatrix} v \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{r}{2}(\omega_r + \omega_l) \\ \frac{r}{d}(\omega_r - \omega_l) \end{bmatrix}$$

Differential drive input transformation

Differential drive robot

- Second configuration → two actuated crawler

- Pro
  - Simple model
  - Good controllability
  - Good stability
  - Good traction
- Cons
  - Expensive



Differential drive robot

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix}$$

Unicycle model

$$\begin{bmatrix} v \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{r}{2}(\omega_r + \omega_l) \\ \frac{r}{d}(\omega_r - \omega_l) \end{bmatrix}$$

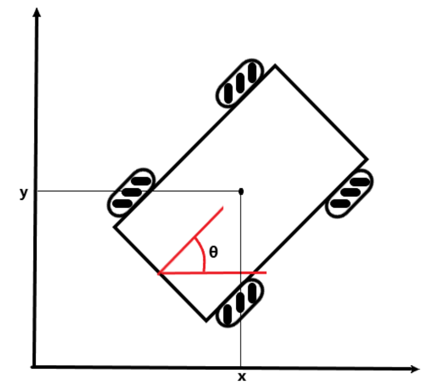
Differential drive input transformation

Mecanum wheel robot

- Pro
  - Omni-directionality
  - Good controllability
  - Good stability
- Cons
  - Bad traction on rough terrain

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \frac{r}{4} \begin{bmatrix} 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & -1 \\ -\frac{1}{(d_x+d_y)} & \frac{1}{(d_x+d_y)} & -\frac{1}{(d_x+d_y)} & \frac{1}{(d_x+d_y)} \end{bmatrix} \begin{bmatrix} \omega_{FL} \\ \omega_{FR} \\ \omega_{RL} \\ \omega_{RR} \end{bmatrix}$$

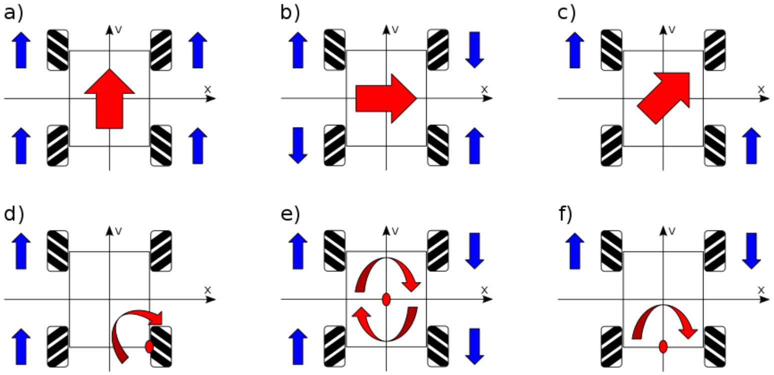
Mecanum wheel robot kinematic model



Mecanum wheels robot

Mecanum wheel robot

Mecanum wheel



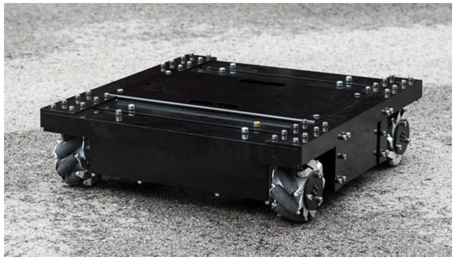
Omni-directionality

$$\begin{bmatrix} \omega_{FL} \\ \omega_{FR} \\ \omega_{RL} \\ \omega_{RR} \end{bmatrix} = \frac{1}{r} \begin{bmatrix} 1 & -1 & -(d_x + d_y) \\ 1 & 1 & (d_x + d_y) \\ 1 & 1 & -(d_x + d_y) \\ 1 & -1 & (d_x + d_y) \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix}$$

Inverse kinematic model

Mobile platform prototypes

OMR10



- Dimensions(mm): 480 x 450 x 134
- Load capacity: 20kg
- Max speed: 0.6m/s
- Battery life: 8h
- Charging time: 4h

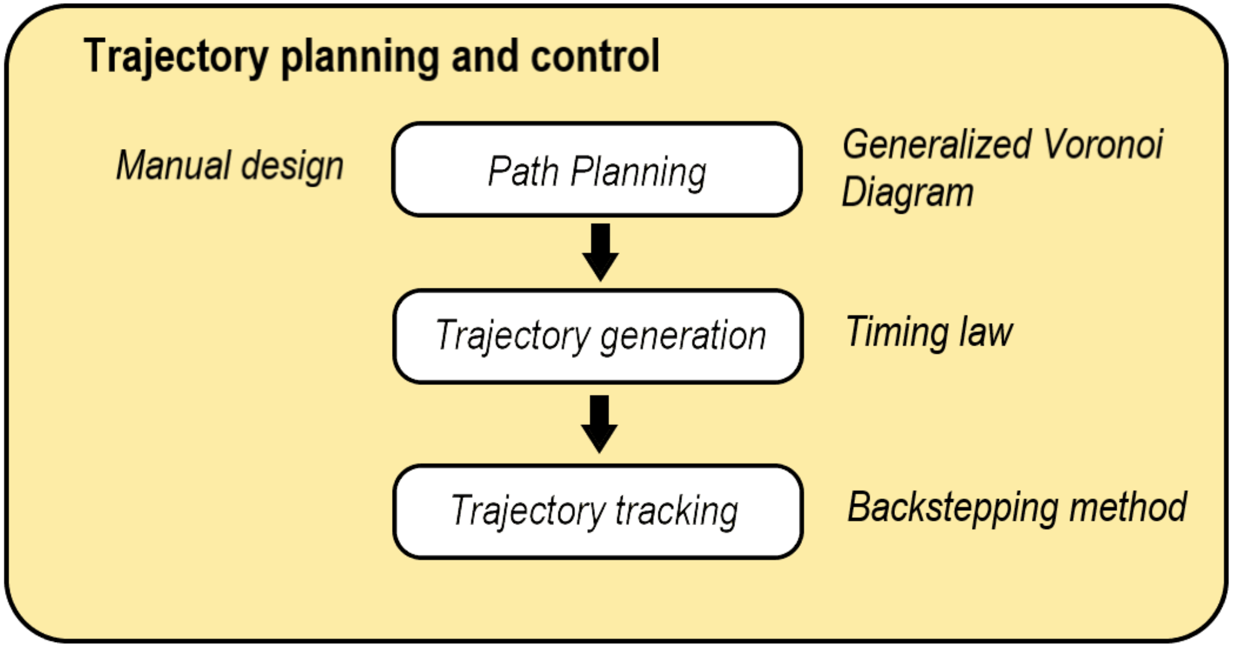
4WD mecanum

- Dimensions(mm): 400 x 307 x 123
- Load capacity: 10kg
- Max speed: 0.6m/s
- Battery life: 6h
- Charging time: 4h
- Sensors: 4 ultrasonic

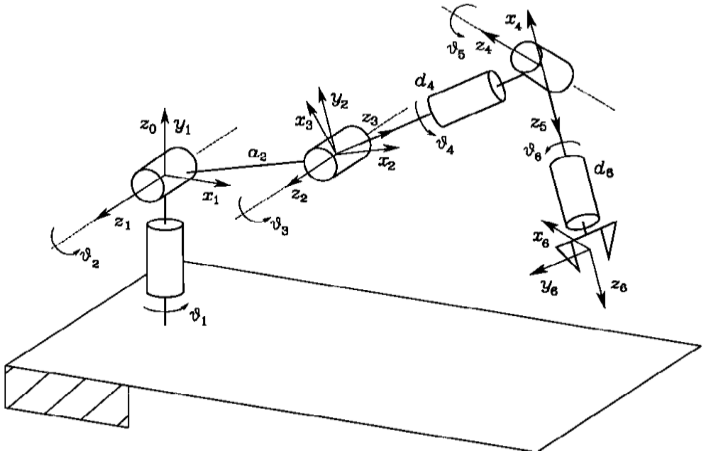
MP-500

- Dimensions(mm): 986 x 662 x 409
- Load capacity: 80kg
- Max speed: 0.8m/s
- Battery life: 7h
- Charging time: 5h
- Sensors: 2 lidar - 4 ultrasonic

Trajectory planning and control



6 DOF robotic arm



6 DOF robotic arm

- 6 DOF robotic arm has been proven to be enough for the picking task
- The forward and inverse kinematics have been computed for simulation purposes using Denavit-Hartemberg convention
- The differential kinematics has been derived by the forward kinematics and it has been used for the robot control

6 DOF Manipulator arm prototypes

Gen3

- Payload: 0.5kg
- Max e-e speed: 50 cm/s
- Max reach: 706mm
- Weight: 5.4kg

Gen3 Light

- Payload: 2kg
- Max e-e speed: 50 cm/s
- Max reach: 891mm
- Weight: 7.2kg

Kinova RGB-D

- RGB sensor:
  - Resolution: 1980x1080 at 30fps
- Depth sensor
  - Resolution: 480x270 at 30fps
  - Min distance: 18cm

Vision System

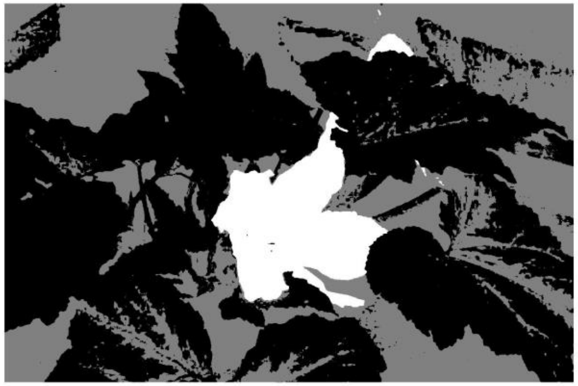
- One of the fundamental modules for the picking task.
- RGB-D camera chosen based on the ToF technology
- Recognition, identification and localization of the flowers inside the environment.
- Two objectives:
  - Flower recognition
  - Flower separation and localization
- Two algorithm have been developed to accomplish these tasks:
  - K-mean algorithm for color clustering
  - Moore-Neighbor tracing algorithm modified by Jacob's stopping criteria for flower separation

Flower identification

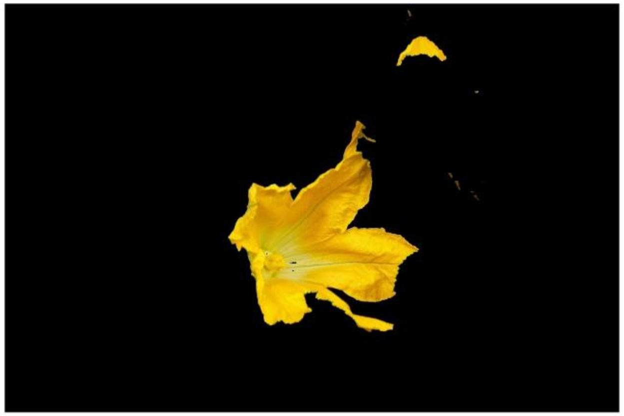
Original image

First cluster

Second cluster



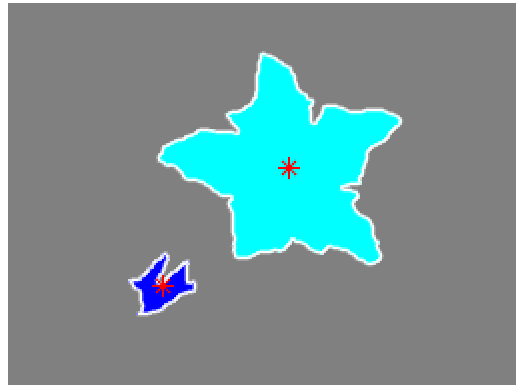
Labeled image



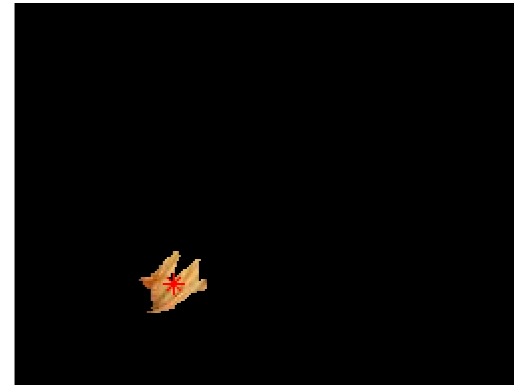
Third cluster

Flower separation and localization

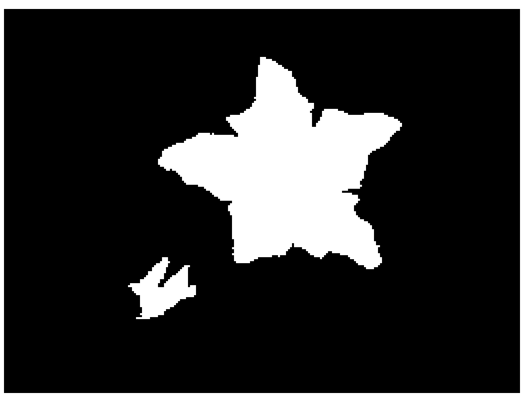
Flower cluster



Labeled image



First flower



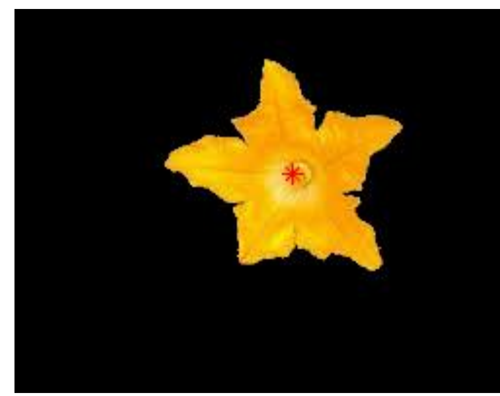
Binarization, noise attenuation and hole filling

$$z_\epsilon = D(X_I, Y_I)$$

$$x_\epsilon = \frac{z_\epsilon(X_I - C_x)}{f_x}$$

$$y_\epsilon = \frac{z_\epsilon(Y_I - C_y)}{f_y}$$

Flower 3D localization



Second flower

Trajectory generation

Path planning

- Position path

$$p(s) = p_i + s\frac{p_\varepsilon}{\|p_\varepsilon\|}$$

$$\dot{p}(s) = \dot{s}\frac{p_\varepsilon}{\|p_\varepsilon\|}$$

- Orientation path

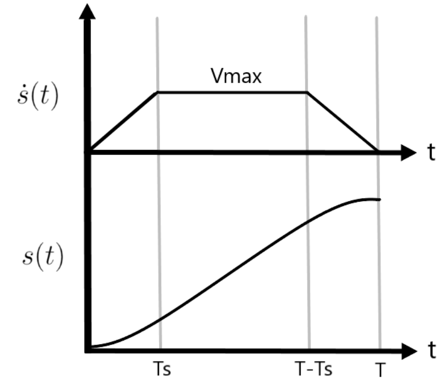
$$\phi(s) = \phi_i + s\frac{\phi_\varepsilon}{\|\phi_\varepsilon\|}$$

$$\dot{\phi}(s) = \dot{s}\frac{\phi_\varepsilon}{\|\phi_\varepsilon\|}$$

- Final path

$$\dot{x}_d(s) = \begin{bmatrix}\dot{p}(s)\\ \dot{\phi}(s)\end{bmatrix}$$

Timing law

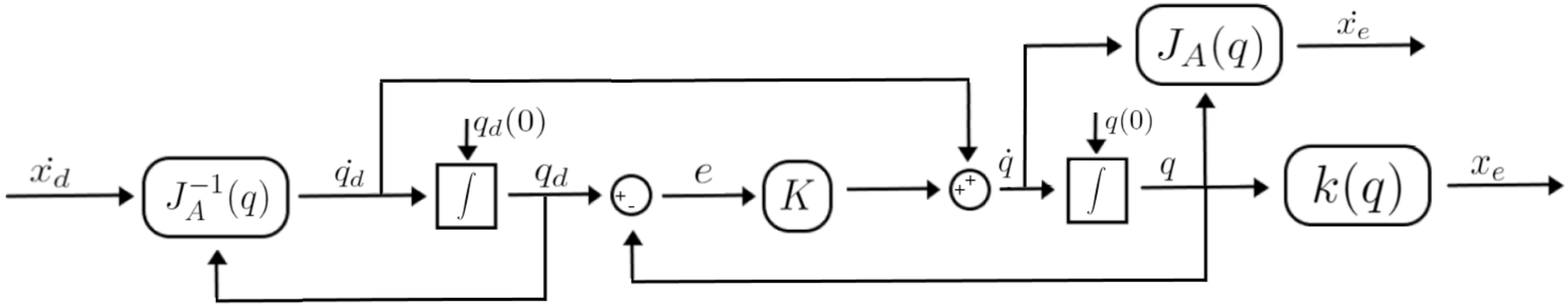


$$T_S = \frac{V_{max}}{A_{max}}$$

$$T = \frac{lA_{max} + V_{max}^2}{A_{max}V_{max}}$$

$$\dot{s}(t) = \begin{cases} A_{max}t, & t \in [0, T_s] \\ V_{max}, & t \in [T_s, T - T_s] \\ -A_{max}(t - T), & t \in [T - T_s, T] \end{cases}$$

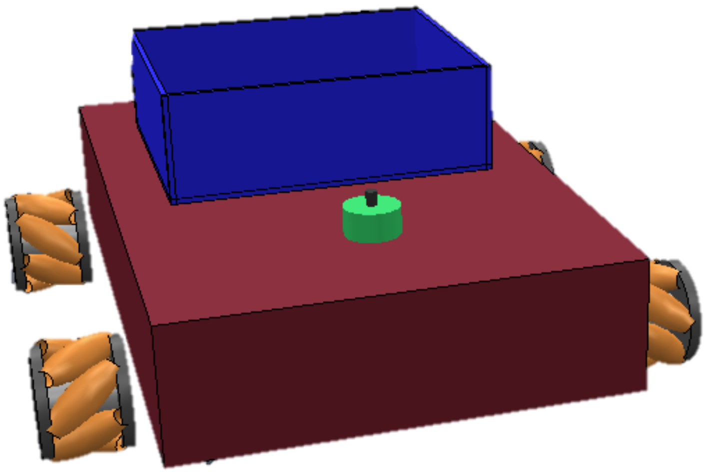
Robotic arm kinematic control

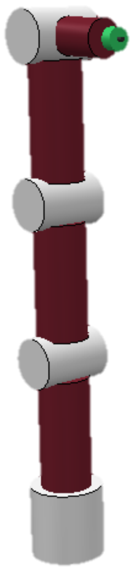


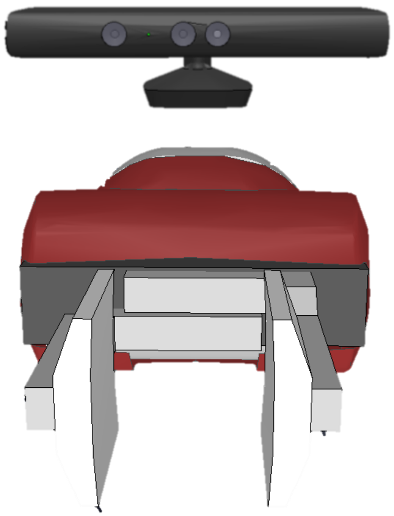
- A kinematic controller has been used to control the robot
- The input of the control loop is the cartesian speed trajectory of the robot's end-effector
- The trajectory is converted from the speed cartesian space to the speed joint space using the robot inverse analytic Jacobian
- Two contribution for the robot input:
  - Feedforward → $\dot{q}_d$
  - Feedback → $K(q_d - q)$

Simulation

- Tools
  - Matlab
  - Vrep
- The robot mobile platform and its 6 DOF manipulator arm have been developed on Vrep using joints and primitive shapes

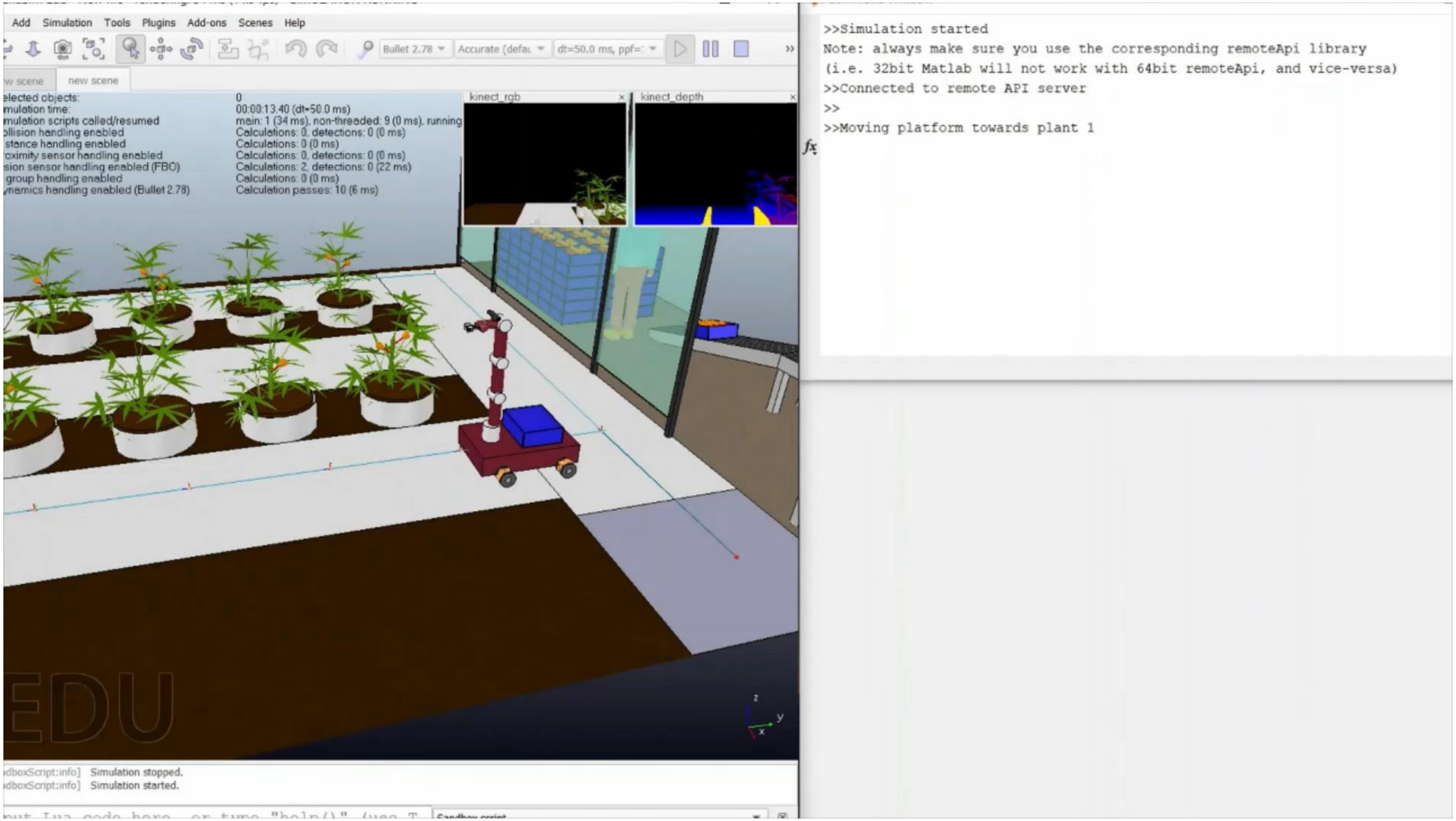






Simulation

Simulation


Add Simulation Tools Plugins Add-ons Scenes Help
kinect_rgb
kinect_depth
>>Simulation started
Note: always make sure you use the corresponding remoteApi library
(i.e. 32bit Matlab will not work with 64bit remoteApi, and vice-versa)
>>Connected to remote API server
>>
>>Moving platform towards plant 1
Simulation stopped.
Simulation started.

Conclusion

- Although the project has been simplified, the simulation had proven that the algorithms and the structure used works. This project could be applied to a real application scenario in an agriculture 4.0 hydroponic greenhouse.

- Future improvements:
  - Implement a localization systems
  - Improve the machine learning algorithms
  - Use multiple robots - distributed systems
  - Use a more sophisticated robot controller
  - Others