ARCS - Skill Design

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1 Introduction

Robot skill in this report is designed for following task requirements of the Bayer Challenge #3:

- Take a sample (minimum 20g)
- Put the sample into the sampling container

These tasks taken out-of-context can be accomplished by simple hard automation on a conveyor line. But we need advanced robot skill in the *context* of other tasks that are to be performed in the whole operation. (*Assumption*: There is separate robot arm to perform this task, OR robot arm used in previous task has changed over end-effector for this task.)

2 Finite State Machine

Attached.

3 Hardware

- Fixed one arm robot. Robot Capabilities: Backdrivable, redundant (7 DOF, serial kinematic chain). *Assumption*: Work-space is reachable.
- **End effector:** Rigid sampling spoon (shape of ice-cream scoop). This is to reduce compliance disturbances on tracking on velocities (TFF). Volume of the spoon is sufficient to collect 20(+5) gm of powder all the time. So, task can finish in one iteration.

  (A motorized sampling tool is avoided *assuming* neck of the bottle is not a "bottleneck"!)

4 Sensing

- **Perception Capabilities**: Force sensors that can detect minimum force 0.1 N. Physical contacts with drum, powder, and bottle are possible during the task. So, distance sensors are eliminated. (Consideration: sensors are to be mounted at safe distance to avoid powder)
- Rotary Encoders for motor position.
- Active sensing: 2D contour tracking on the bottle, (drum if required). Kalman filter is used to recognize features of the bottle, (drum). *Assumption*: tracking errors are small. (Particle filter is used for localization when tracking errors are large.)

5 Control Scheme

- Impedance Control scheme for guarded motions (i) to touch powder, (ii) to touch bottle, (iii) to touch drum.
- Hybrid Force Control scheme for 2D-contour tracking.
- Free space motion controllers for sampling routine motion, and powder dropping motion.

6 Guarded Motion

(In the context of motion towards powder bed as well as motion towards bottle.)

6.1 TFF

move compliantly {
with task frame
defined relative to the end-effector,
at the center of the end-effector,
with task frame directions:
axt = velocity 0 rad/s
ayt = velocity 0 rad/s
azt = velocity 0 rad/s
xt = velocity v mm/s
yt = velocity 0 mm/s
zt = velocity 0 mm/s
} until -f N < xw or yw or zw force < f N

6.2 COP

Objective funtion: Minimize thermal energy generated by actuator.
min $\int_0^T \tau_i^2 dt$
s.t.
$\tau = M\ddot{q} + C\dot{q} + G$
$q_{i,min} \leq q_i \leq q_{i,max}$
$v_- \leq \dot{x}_N \leq v_+$
$0_- \leq \dot{y}_N \leq 0_+$
..
$0_- \leq \dot{a}x_N \leq 0_+$
$0_- \leq ax_N \leq 0_+$
..
More constraints on the arm segments to avoid obstacle, avoid crossing the trajectory to be followed by end effector.

End-effector is N-th segment of the kinematic chain. From given velocity and acceleration constraints on this segment, constraints on each joint are calculated by dynamics algorithms.

6.3 Monitoring

- Orientation of the end-effector to the world frame. (Using encoder position information and kinematic chain calculations.)

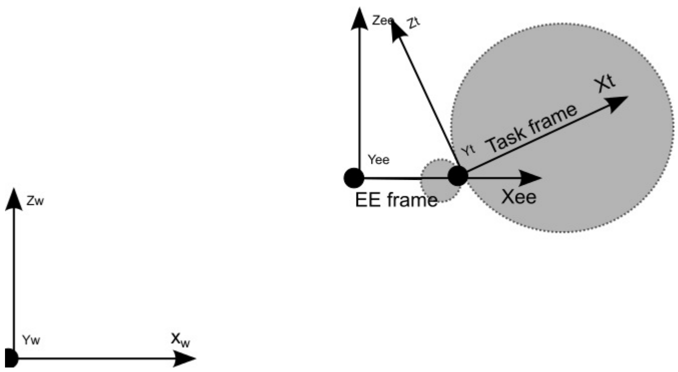
- Contact forces by monitoring force sensor data.

6.4 Control

- From the output of dynamics algorithms and COP τ_d is computed. A computed torque control is used for joint space tracking.
- Impedance controller is used for the end-effector tracking.
  $F_{ext} = M\Delta\dot{v} + C\Delta v + K\int vdt$
- (MPC: Can it predict contact and slow down before collision?)

7 Miscellaneous

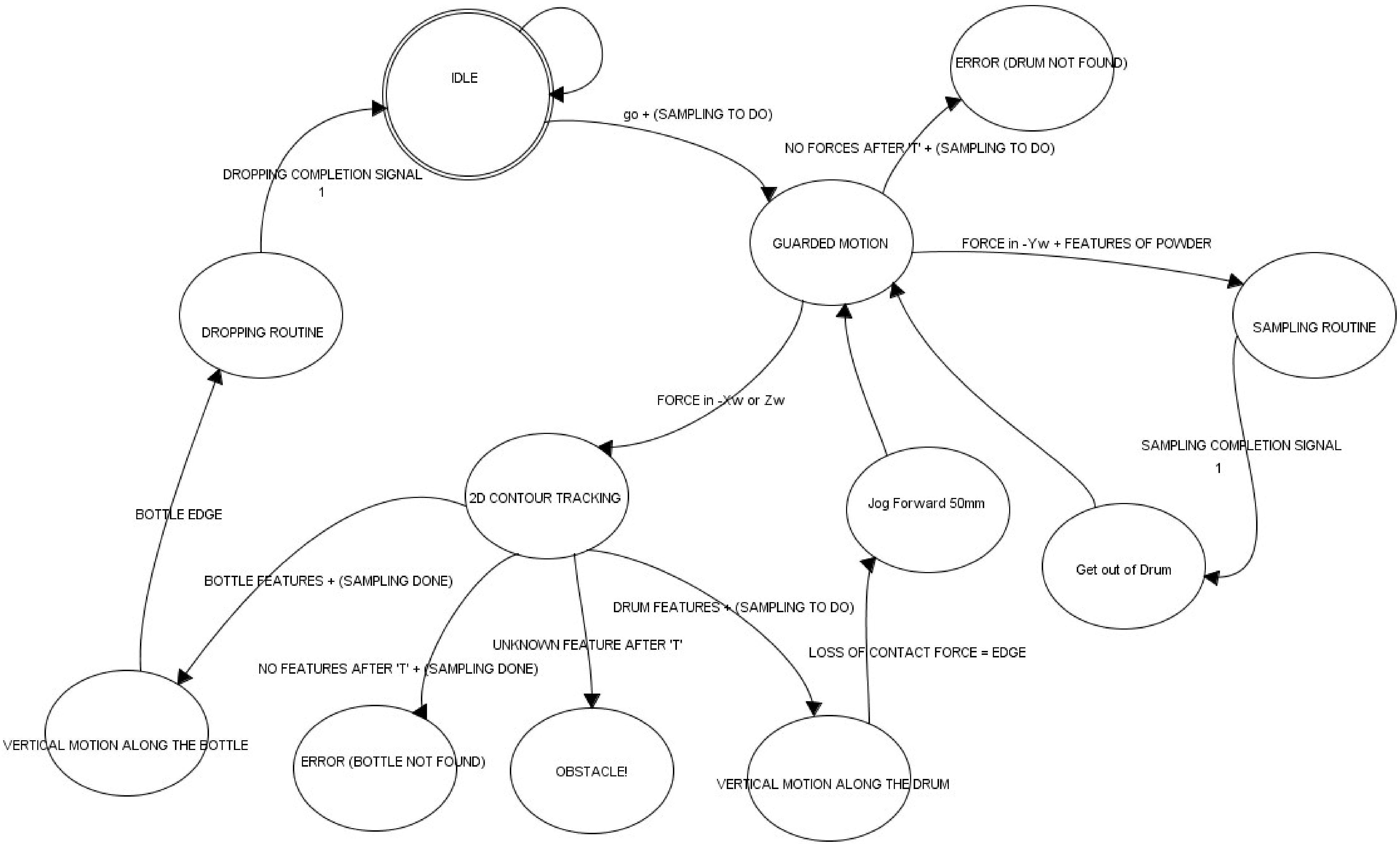
7.1 2-D Contour Tracking

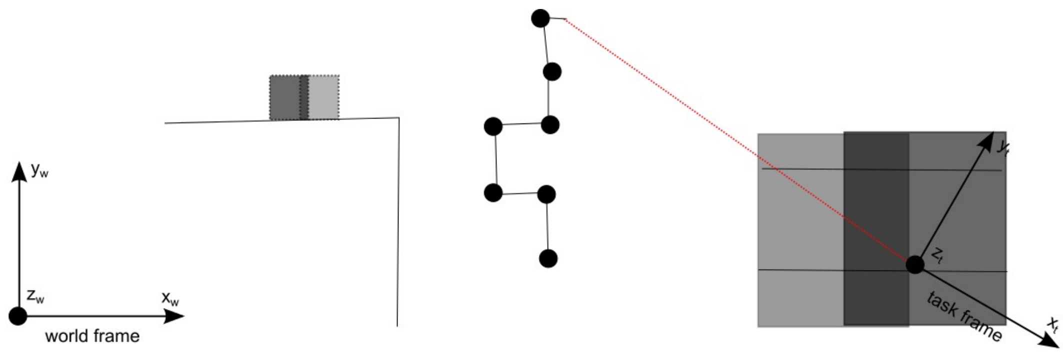


ayt can be tracked on velocities. It's important to maintain close to zero rotations about axy and azt to avoid powder spillage in context of tracking bottle contour.

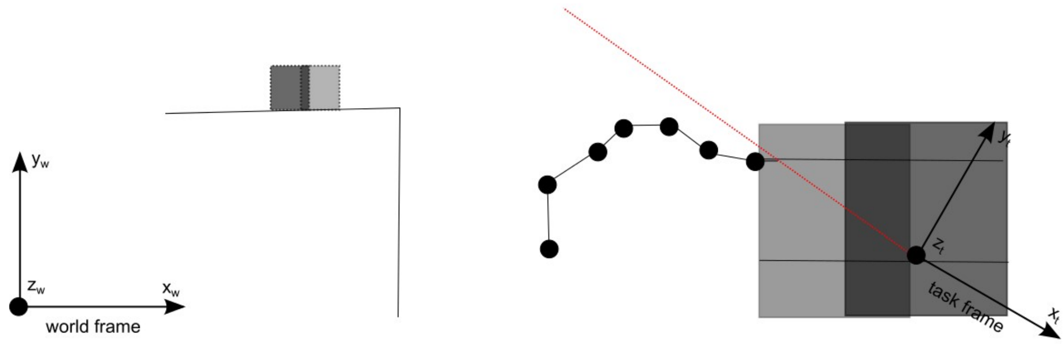
7.2 Sampling Routine

A nominal trajectory is fed to program, that executes the motion required to dip into the powder, turn, pull back and shake excess powder. Then COP is formulated to minimize deviations from the nominal trajectory, and this is monitored.

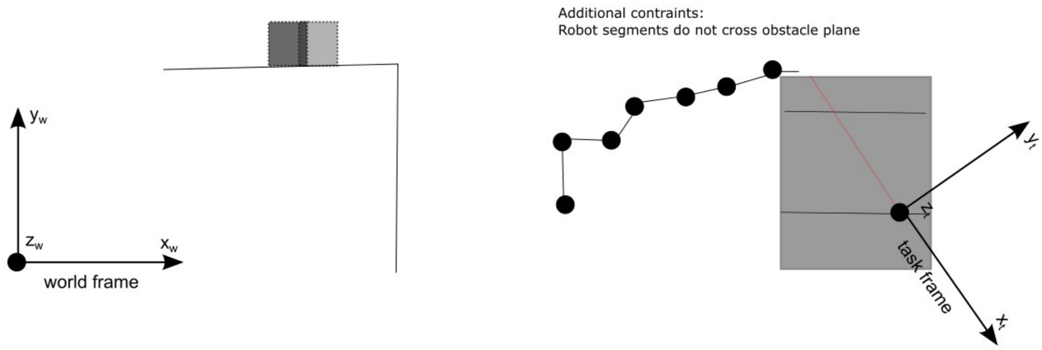

IDLE
go + (SAMPLING TO DO)
DROPPING COMPLETION SIGNAL
1
ERROR (DRUM NOT FOUND)
NO FORCES AFTER 'T' + (SAMPLING TO DO)
GUARDED MOTION
FORCE in -Yw + FEATURES OF POWDER
SAMPLING ROUTINE
DROPPING ROUTINE
FORCE in -Xw or Zw
SAMPLING COMPLETION SIGNAL
1
2D CONTOUR TRACKING
Jog Forward 50mm
BOTTLE EDGE
Get out of Drum
BOTTLE FEATURES + (SAMPLING DONE)
DRUM FEATURES + (SAMPLING TO DO)
UNKNOWN FEATURE AFTER 'T'
LOSS OF CONTACT FORCE = EDGE
NO FEATURES AFTER 'T' + (SAMPLING DONE)
VERTICAL MOTION ALONG THE BOTTLE
ERROR (BOTTLE NOT FOUND)
OBSTACLE!
VERTICAL MOTION ALONG THE DRUM



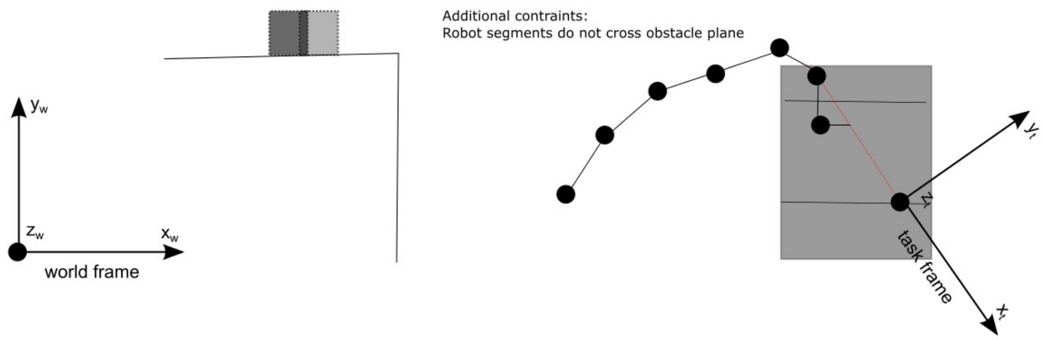
y_w
z_w
x_w
world frame
y_t
z_t
task frame
x_t



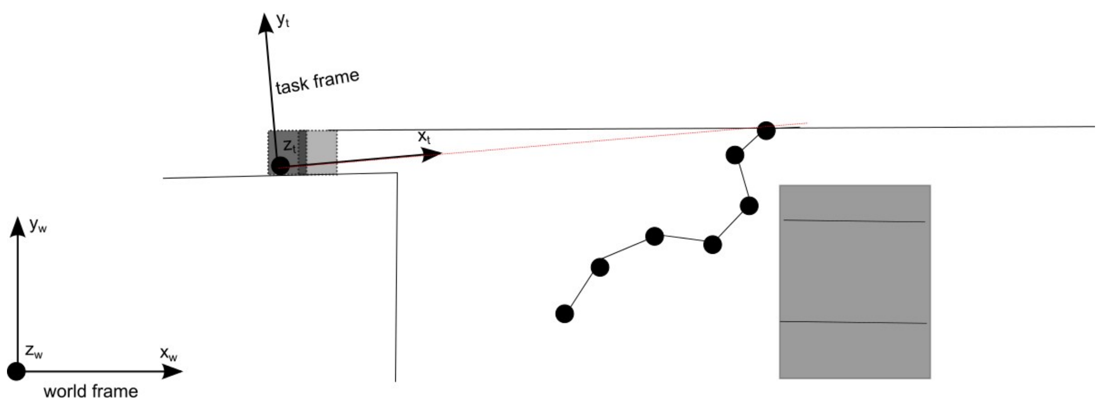
y_w
z_w
x_w
world frame
y_t
z_t
task frame
x_t



Additional contraints:
Robot segments do not cross obstacle plane
y_w
z_w
x_w
world frame
y_t
z_t
task frame
x_t



Additional contraints:
Robot segments do not cross obstacle plane
y_w
z_w
x_w
world frame
y_t
z_t
task frame
x_t



y_t
task frame
z_t
x_t
y_w
z_w
x_w
world frame