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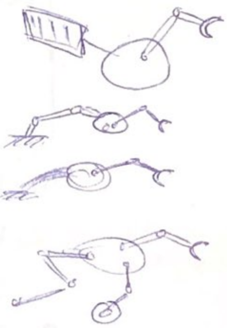
# RSE

Ng Huu Duc

## L2) Introduction to Advanced Robotics

Fields: space, food industry, medical, mobile intelligent vehicles, military

- Space Robotics:
  - Free floating manipulator systems
  - Macro - micro
  - Flexible - based
  - Mobile robots with Articulated limbs



- Names of exp robots in each fields

- Intelligent Vehicles:

3 architectures approache:

- Driver — having human in the loop supervising
- Network — share info - other vehicles
- Vehicle — fully autonomous - no human

(Driver / Network / Vehicle) centric

- Actuators & Joints (Drive)

$$\boxed{F = {}^{3}_{6} \cdot (n - g) + \sum f_i - f_{id}}$$

Rotary drive

Linear drive (directly)

(indirectly)

| F = 1 | F = 2 | F = 3 |
|---|---|---|
| revolute | double prismatic | ball in slot $\boxed{2R\ 1P}$ |
| Prismatic | turn - slide joint | planar joint |
| helical | roller slide | spherical joint (ball) $\boxed{3R}$ |
| | universal joint | |

| F = 4 | F = 5 |
|---|---|
| cylindrical joint $\boxed{2P\ 2R}$ | ball between 2 planes $\boxed{3R\ 2P}$ |
| double turn slide | |
| ball in tube $\boxed{3R\ 1P}$ | |

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L4) DH Convention ..

⊛ Kinematic Structure ( Classification of serial robots )

20 different structures { Translation XYZ
Rotation ABC
intersect / not: 0, 1
Alway $z_0$ first

Forward, inverse kinematics : Geometric, Numerical, Algebraic
solve systems of equas

L6) ☑ Lecture 6. Slide No. 4. CBB 1 1 1 → ? Last digit : REMOVED

Inv Kin

L7) Structural Synthesis

L3) Workspace

?

Reachable    different

orientation

Dexterous    at least one

Kine Redundancy

Intrinsic

Functional

Hyper

No. DOF > No. variables (to describe task)

7

Kine Topology

Serial    workspace, Obstacle avoidance, flexibility, calculation effort

Parallel    accuracy, repeatability, stiffness, load-to-mass ratio

Hybrid

# RSE

## L2) Structural Synthesis

New fields ⇒ ~~new requirements~~ ⇒ changes in requirements
new processes, tasks

| Trade-off solution | Individual Solution (Tailor-made) |
|---|---|
| - No cost of development | - Competitive advantage |
| - Operational reliability / warranty | - High functionality / effieciency / integration |
| - Rapid Initiation | - Low operation cost |
| | - Avoidance of competitors' patents |
| | - Growth in value added |

Task → Conceptual Design → Type Synthesis → Dimensional Synthesis → Design of 2nd Dimension → Design & Implement.. → Robot

Chebychev - Grübler - Kutzbach Criterion

$$F = \begin{matrix}3\\6\end{matrix}(n-g) + \sum^{g} f_i - f_{id}$$

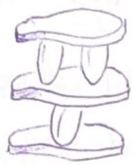
Complex joints
^
planar

# Type Synthesis

(choose what kind of link, joint structure)

1) Chebychev - Grübler - Kutzbach criterion

Step: Definition of motion task $\Rightarrow$ DOF required



Systematic overview of structures

Reduce the field of solutions

Dimension Synthesis

- Evaluation & Selection

Define: $\boxed{\text{Criterion}}$ $\Rightarrow$ $\boxed{\text{Preference Matrix}}$ $\Rightarrow$ Solution scores $\Downarrow$ choose best

(too many links, drives, complex, : ) — (Weight)

accuracy, volume, complexity, stiffness, mass, cost, ..

- Modelling: 1, Kine Dimensions (Joint, link offset, length, angle constrain)

2, ~~Model~~: Tolerances & elasticity

3, Dynamic : Drive power, torque

- Optimization:

| For | Step |
|---|---|
| Workspace | Opt.. parameter? |
| Motion accuracy | Opt... target? — a func of opt. params.. |
| Working speed | Restriction |
| | (Economic) |

# RSE

## L8 ↗ End-Effector Technology

Task ⟹
- Specifications
- Requirements
- Challenges

### TCP Teaching Methods

| 3 points Method | 6-Points Method | Direct List Method |
|---|---|---|
| Tool is straight & in line with faceplate | Ability to twist ref frame ⇒ align with tool tip | Put coordinates & orientations manually |

### Characteristics of Object to be manipulated

- Object to be manipulated
  - Characteristics of object (Geometric & physical, mechanical properties)
    - Shape & size
    - Weight & centre of gravity
    - Properties: materials & fragility
    - Surface & coefficient of friction
  - Loading & Unloading (Operative characteristics)
    - Grip
    - Orientation of object
    - Time between loading & unloading

# (Universal Gripper)
# Human Grasps

Cylindrical

Between ends (tip)

Hook / Snap

Palmary

Spherical

Lateral

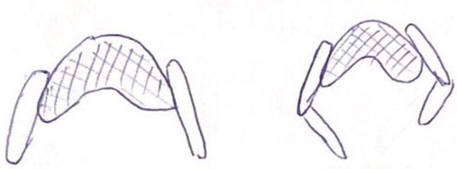
## Grasp Types

Anthropomorphic

Non-anthropomorphic

Contacts

Bilateral

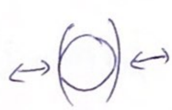


Unilateral

Internal

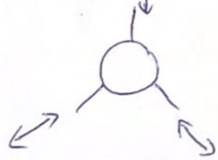
## Shape & Arrangement of Gripper Jaws

2 point centring



3 point centring

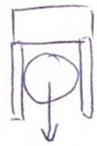
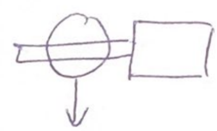
4 ___

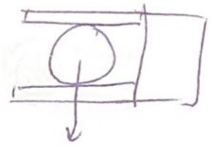


3 ___

# Configuration of Grasping

2 fingers - static case

Planar grasp  Spatial 

Palmary  Grasp with load on 1 finger 

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Dynamic case

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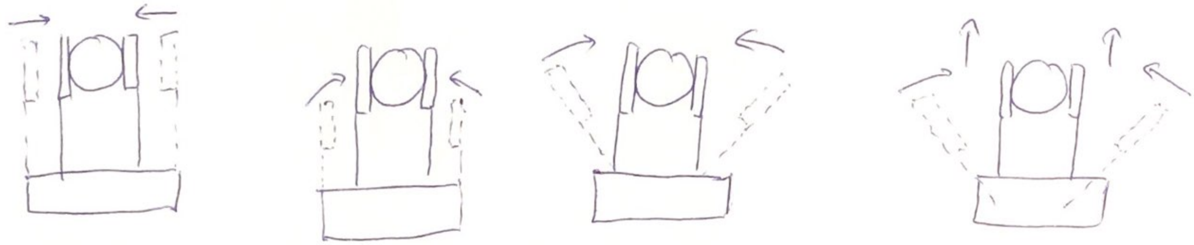
## Characteristics of grasping phases

Initial impact of 1 finger  Static grasp 

—— 2nd ——  Dynamic —— 

—— final grasp  External pertubation 

# Gripper Mechanisms



Linear Displacement | General Translation | Rotation | Rotation & Translation

## Actuator

3 most Common

Hydrolic ↑ force, torque
↓ leak, cost

Pneumatic ↑ safe, performance point to point
↓ efficiency, costly compressed air

Electromagnetic

Brush: ez to operate, wear out

Brushless: ~~ez to operate~~ need controller, stronger

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Electric Servo motor: high $\tau$ and a

Stepper Motor: no feedback control needed ⇒ precise
1 step a time, low cost, variety size, torque
$\pm 1$ $(0 - 180°)$

# Sensors

| Proprioceptive (Internal) | | Exteroceptive (External) |
|---|---|---|
| Joint positions<br>Velocities<br>accelerations<br>Torque | Measure | Force, Tactile<br>Prexinity Range<br>Vision |
| Encoder<br>Tachometer | | Strain gauge<br>Sonars, Laser, radar<br>CCD CMOS |

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# RSF

## L9, Components of Robotics System

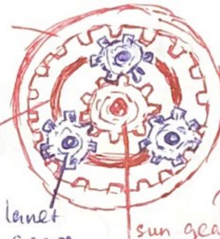
Base frame - Carousel - Swinging link - Arm - Hand

## Gear units

Speed reduction & Torque Transmission

Transmission rotary motion motor → joint (spatial distance)

### Planetary Gear (Epicyclic)

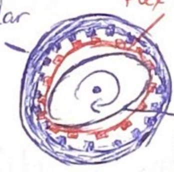



$\frac{\omega_s}{\omega_c} = \frac{r_s + r_R}{r_s} > 1$

↑ efficiency
gear ratio
torque trans...

↓ complex construction
bearing

### Harmonic Drive

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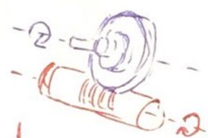
$r = \frac{n_f - n_c}{n_f} \in [-1, 0]$

### Cycle - Drive


$r = \frac{P - L}{L}$

less friction, oil leak
compact design
high efficiency
low maintainance
quiet

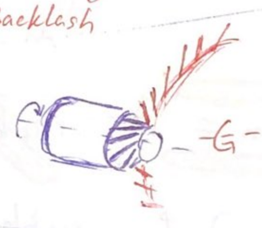
### Worm Gear



Low speed
High ratio
Stiff, load capacity

Poor efficiency
Friction
Elasticity
Backlash ↓

### Bevel Gear




Smooth
noiseless

efficiency ↓
gear ratio

### Tooth Belt Drive



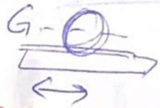
Ratio

Elasticity
⇒ Instability

### Ball Screw

Efficient
Smooth
Stiffness for short travel medium

### Rack & Pinion Drive




Backlash, low force

L12) Mobile Manipulators

| Legged | vs | Wheeled |
|---|---|---|
| over come many obstacles | | |
| floating base | $><$ | fixed base |
| Complicated dynamic | | |
| Terrain Interaction | | |

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Omnidirectional

Non - holonomic

Subject to Pfaffian velocity contraint
$A(\xi)\dot{\xi} = 0$

Depends: type of wheels

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DoF: Steering, Mobility, Maneuverability

$\delta_M = \delta_m + \delta_s$ — $(\delta_m, \delta_s)$

$\delta_m = 3 - \text{rank}\left[C_1^*(\beta_s)\right]$

$\delta_s = \text{rank}\left[C_{1s}(\beta_s)\right]$

Differentiable degree of freedom DDOF $= \delta_m$

## Wheels

Omniwheel

Free sliding $\perp$ driving direction

$\gamma = 0$

Mecanum

Free sliding $\angle 45°$ Driving direction

$\gamma = \frac{\pi}{4}$

Caster

# RSE

## L12 Mobile Robotics

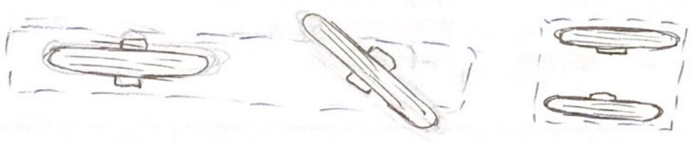
### DoF ⇒ 5 Structures - of practical interest

| (3, 0) | (2, 0) | (2, 1) | (1, 1) | (1, 2) |
|---|---|---|---|---|
| No fixed, No steering | No steering | No fixed wheel | 1↑ fixed wheels | 0 fixed wheels |
| Only mecanum & caster | 1 or more fixed wheels | At least 1 steering wheel | 1↑ steering wheels | 2↑ steering wheels |
| Omnimobile | Ex: Wheelchair | | Ex: car-like | |

No. wheels

① ↑: high manoeuvaibility, low rolling resistance
↓: unstable without dynamic control

② ↑ : reduced sized
↓ : balancing prob



③ ↑ Statically stable
Simple Structure
zero turning radius
low fabrication cost
Systematic errors are easy to calibrate

?

↓ Difficult of moving irregular surfaces
Only bidirectional movement available

④

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## L12) Wheeled Mobile Robotics – Kinematics & Constraint

$N = \mathrm{sum}(N_f, N_s, N_c, N_{sw})$ fixed, steering, caster, swedish

Posture coordinates $\xi(t) = [x(t) \;\; y(t) \;\; \theta(t)]^T$

Orientation angles $\beta(t) = [\; \ldots \;]^T$

Rotation coordinates $\varphi(t) = [\varphi_f(t) \;\; \varphi_s(t) \;\; \varphi_c(t) \;\; \varphi_{sw}(t)]^T$

Position of wheels $l = [\; \ldots \;]^T$ $\quad l_i > 0$

$\alpha = [\; \ldots \;]^T$ $\quad \alpha_i$ from ${}^R e_{x_0}$

$\gamma = [\; \ldots \;]^T$ $\quad \neq 0$ for Swedish wheel

Radii of wheels: $r = \ldots, \; r_{sw} = \ldots$

$\boxed{\text{Standard wheels: } \left[\begin{array}{l}\text{fixed}\\ \text{steering}\end{array}\right. \text{wheels}}$

Rolling constraint / Pure Rolling Condition | Nonslip Condition

Standard wheels: $d = 0, \; \beta = \text{const}$

steering: $\beta_s = \beta(t)$

$[s(\alpha+\beta) \;\; -c(\alpha+\beta) \;\; -l_i c\beta] \cdot {}^R\dot{\xi} - r\dot{\varphi} = 0$ | $[c(\alpha+\beta) \;\; s(\alpha+\beta) \;\; l_i s\beta] \cdot {}^R\dot{\xi} = 0$

Caster wheels: $d \neq 0, \; \beta_c \neq \text{const}$

$[\; \ldots \;\; (d+l)s\beta] \_\_ + d\dot{\beta} = 0$

Swedish Wheel | Omni wheel $\gamma = \pi/2$; Mecanum $\gamma = \pi/4$ $\quad \beta = 0$

$[-(\alpha+\beta+\gamma) \;\; \_\_ \;\; (\beta+\gamma)] \_\_ - r c\gamma \cdot \dot{\varphi} = 0$ | $[-(\alpha+\beta+\gamma) \;\ldots\; (\beta+\gamma)] \_\_ - r s\gamma \dot{\varphi} - r_{sw}\dot{\varphi}_{sw} = 0$

for Standard wheels:

$C_1^*(\beta_s) \cdot {}^R\dot{\xi} = 0$

$C_1^*(\beta_s) = \begin{bmatrix} C_{1f} \\ C_{1s}(\beta_s) \end{bmatrix}$

$\boxed{J_1(\beta_s, \beta_c)\, R(\theta)\dot{\xi} - J_2\dot{\varphi} = 0}$

$\varphi_{sw}, r_{sw}$

$\varphi, r$

$r_{sw} < r$

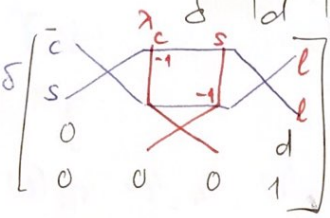
$J_1(\beta_s, \beta_c) = [J_{1f}, J_{1s}(\beta_s), J_{1c}(\beta_c), J_{1sw}]^T; \; J_2 = \begin{bmatrix} r & & \\ & \ddots & \\ & & r_{sw}c\gamma \end{bmatrix}$

# Formulary

DH- Convention:

| $\theta$ | $d$ | $\alpha$ | $a$ |
|---|---|---|---|
| $\delta$ | $d$ | $\alpha$ | $l$ |

$$\vec{e}_{x_i} = \vec{e}_{z_{i-1}} \times \vec{e}_{z_i}$$

$^{i-1}T_i =$ 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Mobile robot

1) $^{G}\xi = {}^{G}R_R(\theta) \cdot {}^{R}\xi = \begin{bmatrix} c\theta & s\theta & 0 \\ -s\theta & c\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ \theta \end{bmatrix}$

$^{G}\dot{\xi} = {}^{G}R_R(\theta) \cdot {}^{R}\dot{\xi} + {}^{G}\dot{R}_R(\theta) \cdot {}^{R}\xi$    if: origin of Robot $\Rightarrow {}^{R}\xi = 0$

2) $N = N_f + N_s + N_c + N_{sw}$

$\beta(t) = \dots$
$\varphi(t)$

$l$    $l_i > 0$
$\alpha$    $\alpha_i$ from $^{R}e_{x,R_0}$
$\gamma$    $\gamma_i \neq 0$ for Swedish wheels

2.1) $C_1^*(\beta_s) \cdot {}^{R}\dot{\xi} = 0$ , $C_1^*(\beta_s) = \begin{bmatrix} C_{1f} \\ C_{1s}(\beta_s) \end{bmatrix} \Rightarrow \begin{matrix} \delta_m \\ \delta_s \end{matrix}$

2.2) $J_1 \cdot {}^{R}\dot{\xi} - J_2 \dot{\varphi} = 0$    $\boxed{J_2 \text{ is diagonal matrix}}$

$\Rightarrow J_2^{-1} J_1 \cdot {}^{R}\dot{\xi} = \dot{\varphi}$

# RSE

## L11, Control Architectures

### Deliberative

Sense → Plan → Act

Sensors → Perception → Modelling → Planning → Task execution → Motor control → Actuators

↓ fragile: uncertainty, slow react to changes, unexpected occurences

### Reactive

Sense → Act

Behaviors arranged in a strict priority order

Example: Sense →
- 3 Create map
- 2 Exploration
- 1 Go arround objects
- 0 Avoid objects

→ Act

↑ react fast to changes
does not rely on accurate model
no need replanning

↓ Task oriented
No flexibility
No memory, reason ability for optimization
Complex task ⇒ large set of behaviors

### Hybrid

Plan ↓

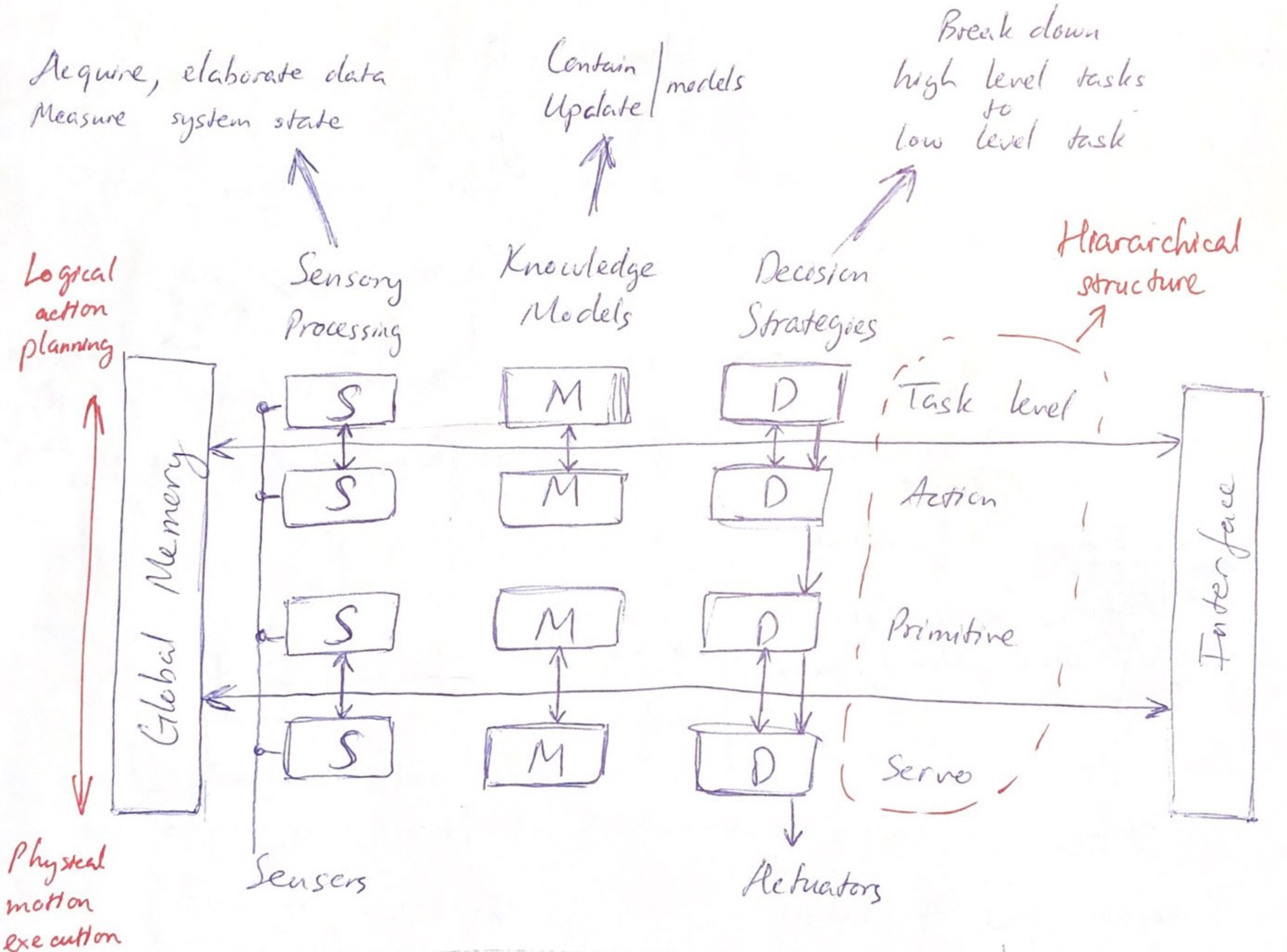
Sense → Act

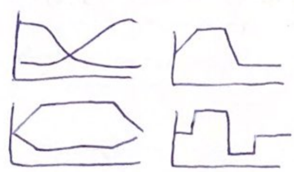
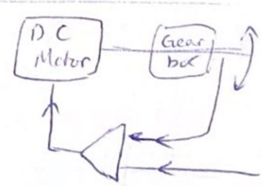
Sensors → Behavior Set → Pre-processed sensor data → Task planning → Behavior activations → Behavior Set → Actuators

↑ Permits goal based strategy
Reduce planning complexity

↓ Behavior choice limits range of possible tasks

# Functional Architecture




| Task | Action | Primitive | Servo |
|---|---|---|---|
| User specifies task | Sequences of intermediate config (motion path) | Compute admissible trajectories<br>Decide control strategy | Provide driving signals |
| Handling |  |  |  |

# Programming Environment

| | | |
|---|---|---|
| Teaching by showing | Robot oriented proggramming | Object oriented programming |

Need robot

No logical conditioning

## Hardware Architectures

Boards

| | | | | | |
|---|---|---|---|---|---|
| System board (CPU) | Kinematic board 10-100Hz | Dynamic board 10-100Hz | Servo board 100-1kHz | Force board 100-1kHz | Vision board 1-10Hz |

## Safety Requirements & Standardisation

ISO 12100

IEC 62061

13849-1

61508-3

62061

ISO 10218-1
-2

ISO /TS 15066: Safety related stop, Hand guidance
Speed & Distance monitoring
Performance & force limitation

$$F = \frac{3}{6}(n-1) - \frac{3}{6}g + \sum_{i=1}^{g} f_i - f_{id}$$

n : link

g : joint

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joint

| | | Speed | Accuracy |
|---|---|---|---|
| J | P( ... ) | 100% | CNT 50 |
| L | PR( ... ) | 10mm/s | FINE |

Linear

uframe

OFFSET PR(11)

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1: RO [4: Close Gripper] = ON

2: RO [5: Open ___ ] = off

} Close Gripper

Ng Huu Duc