Lectures on mechanics

[LESSON #5]

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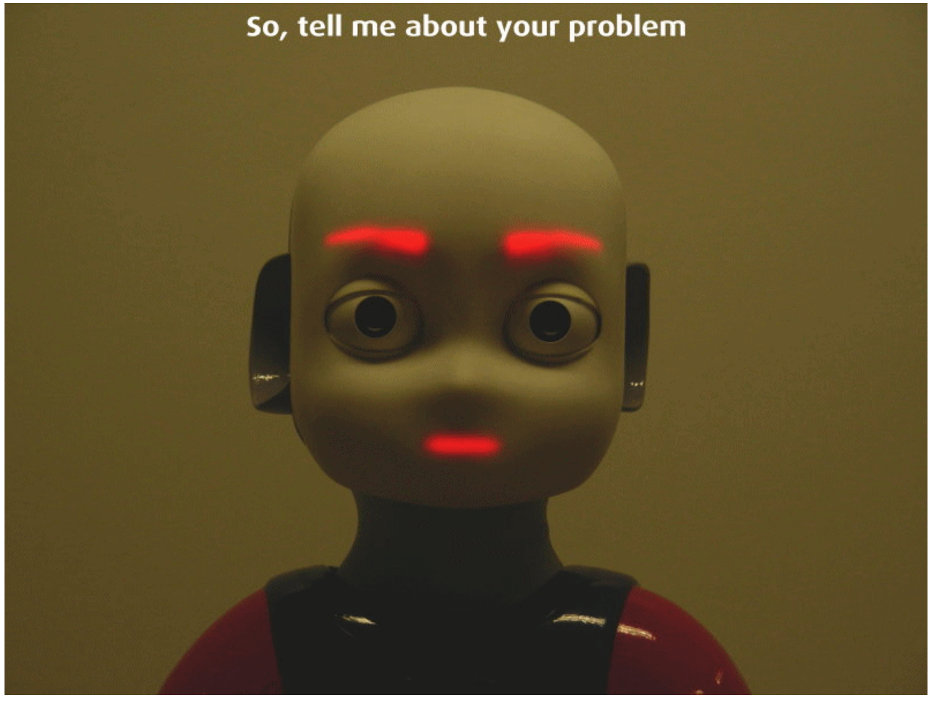
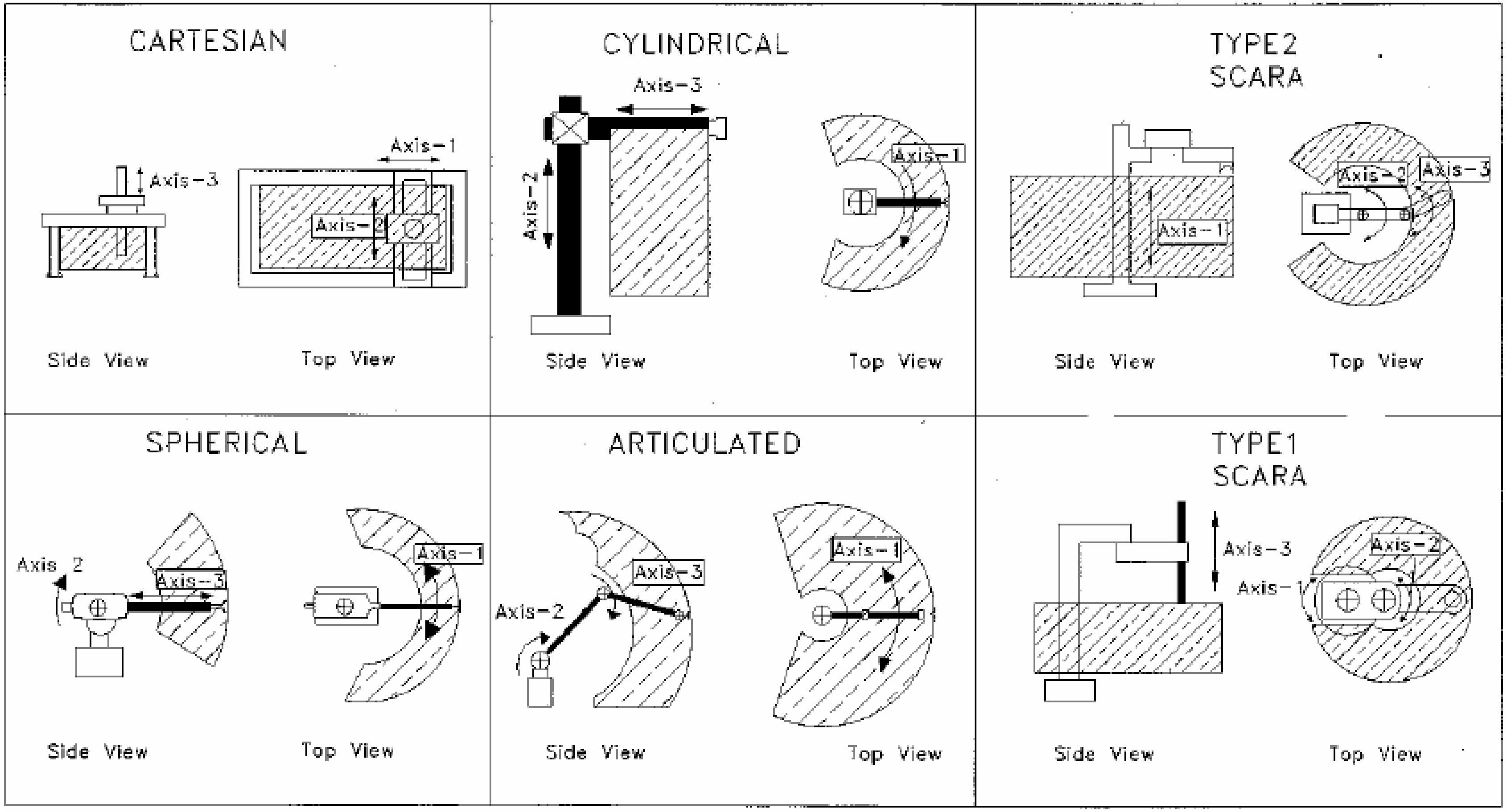


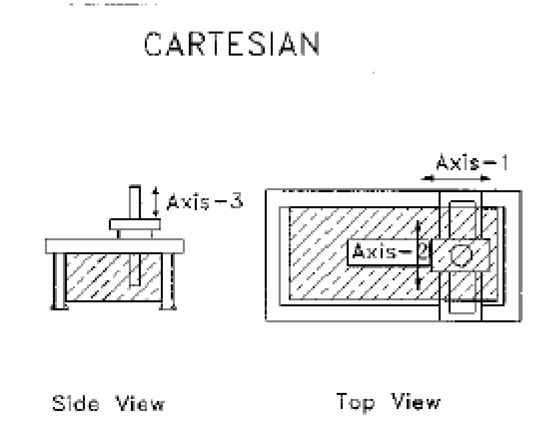
The word “robot” was introduced by the Czech playright Karel ˇ Capek in his 1920 play *Rossum’s Universal Robots.* The word “robota” in Czech means simply “work.”

PART 1 : robot arms topology

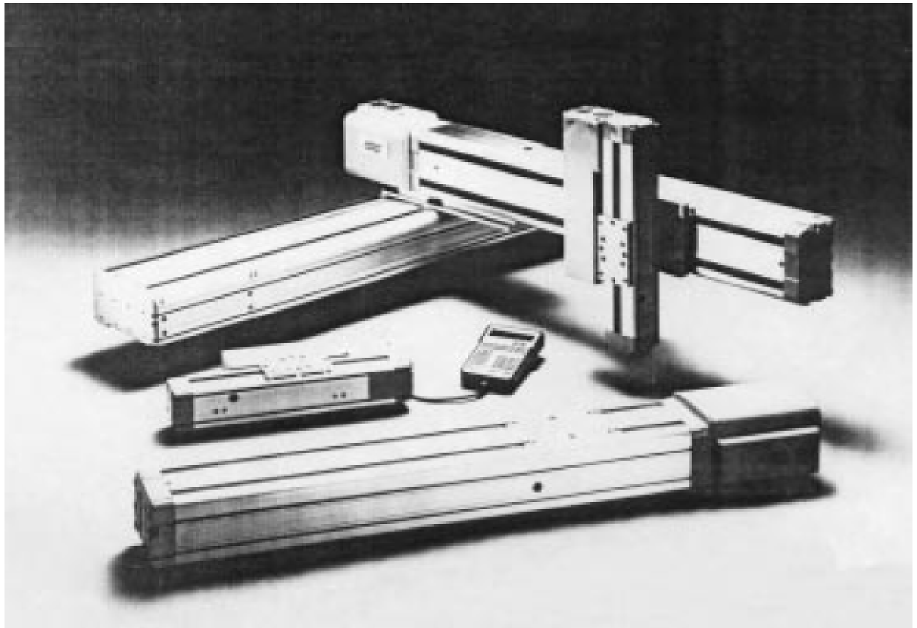


Cartesian Robot:

3 translations + wrist (..)
axis errors non coupled
typical modular design
slower than other robots
from really small to huge!



Cartesian Robot:

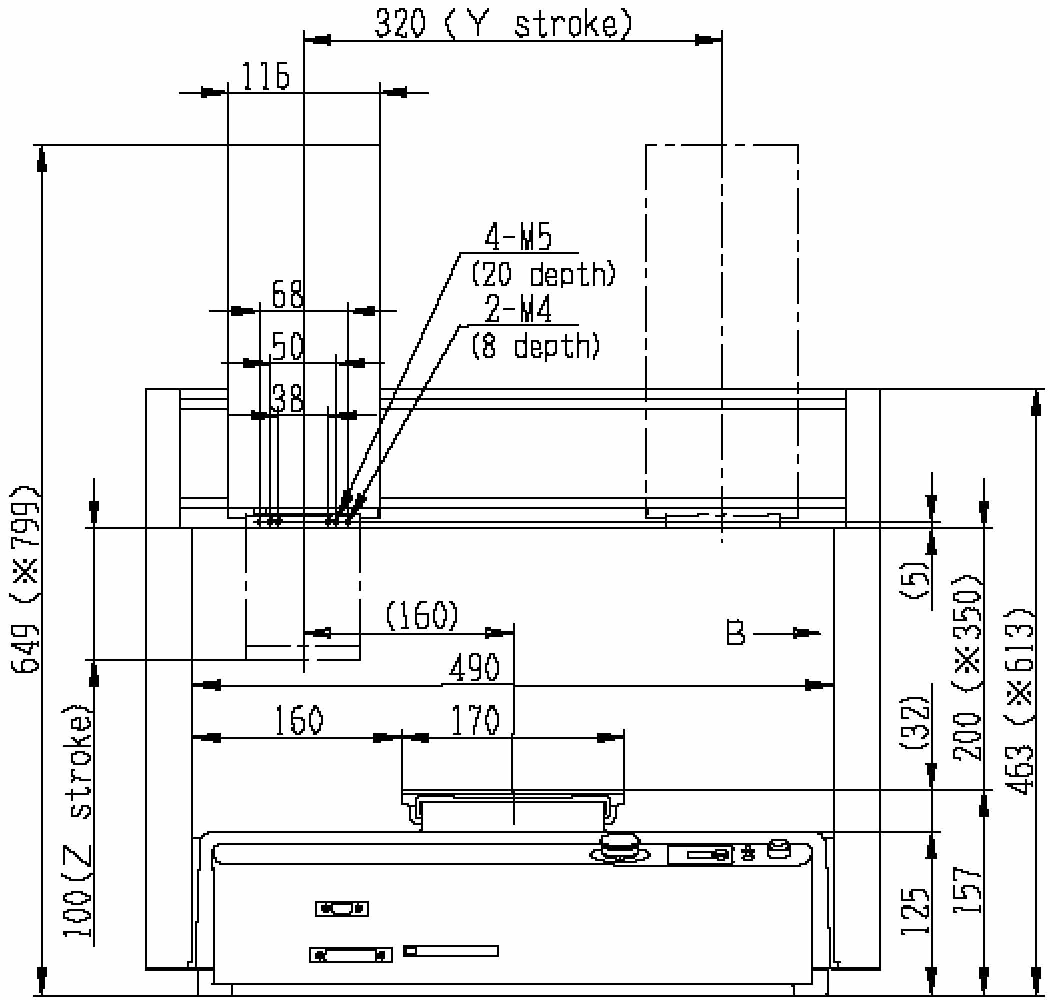


Cable chain

Pneumatic Robot:

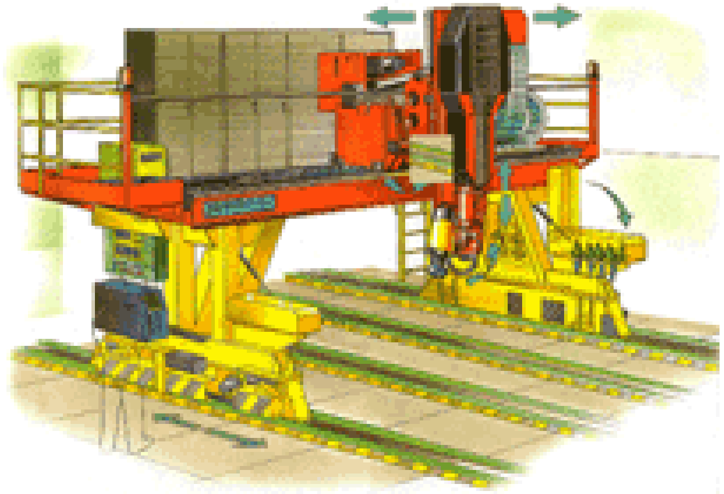
Proportional position closed loop control

Tabletop



Typically stepper motor driven

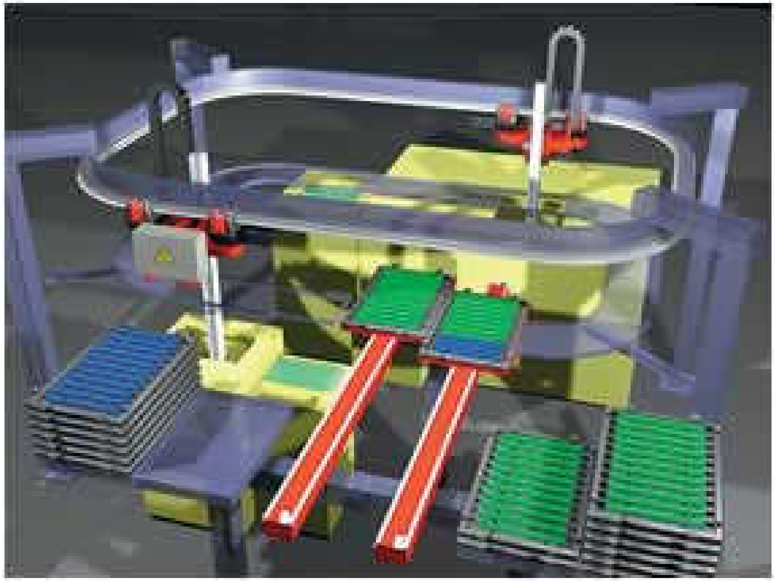
Bisiach Carru

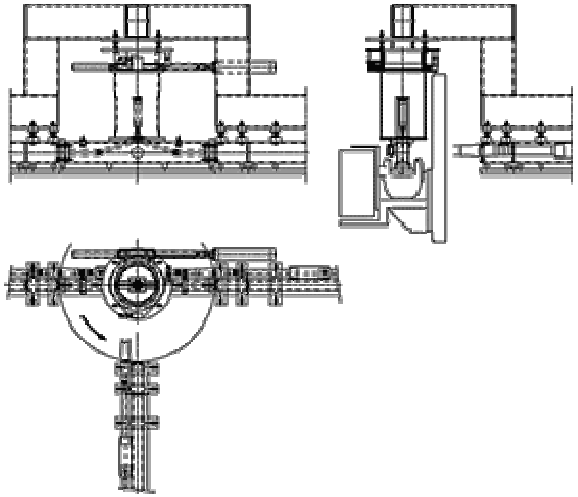


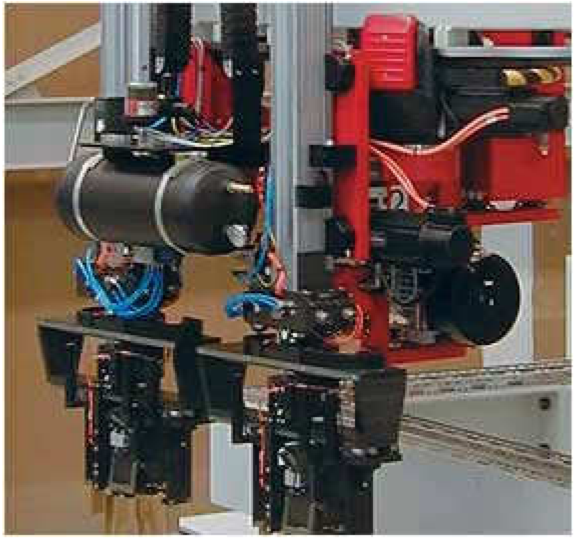
LOOONG gantry robot developed
to weld train frames

Roboloop

Extend an axis to a rail..





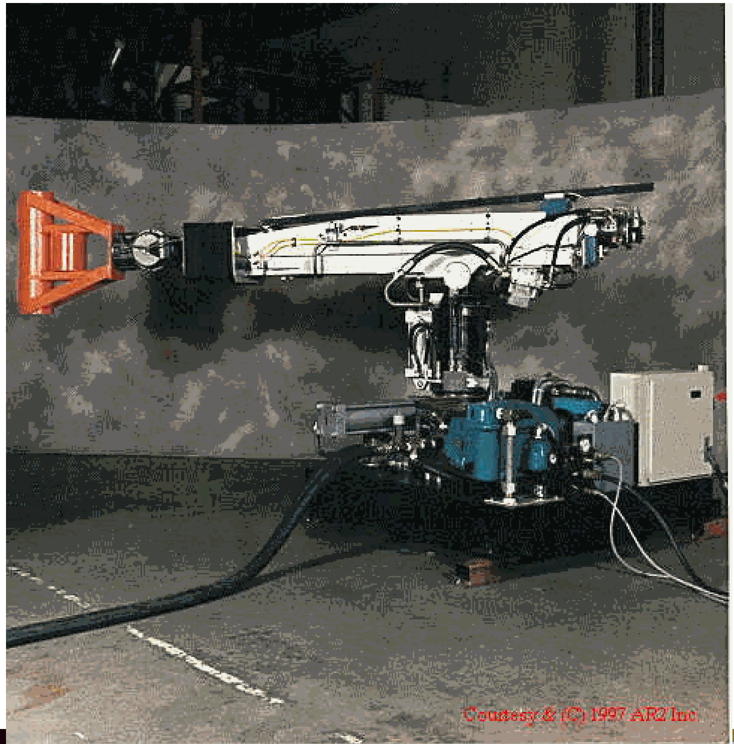


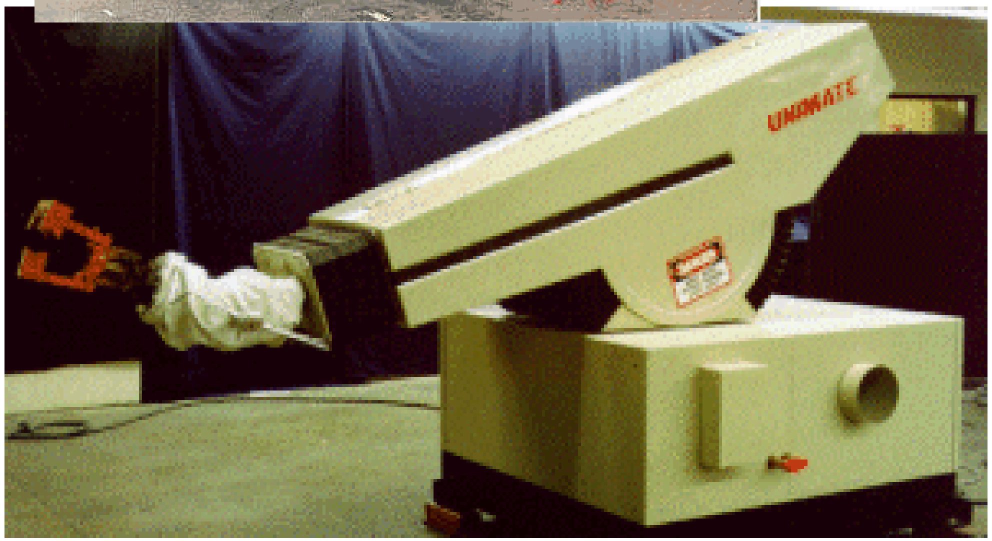
Spherical Robot:

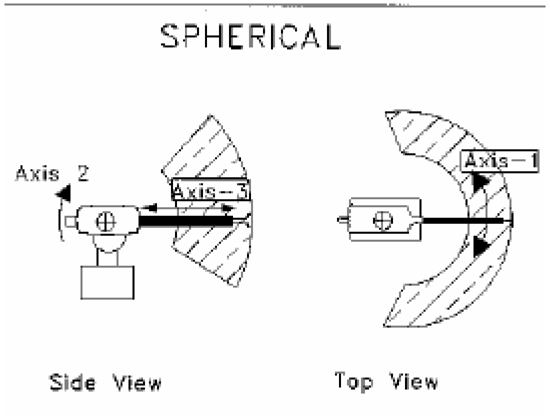
2 rotations + 1 translation + wrist

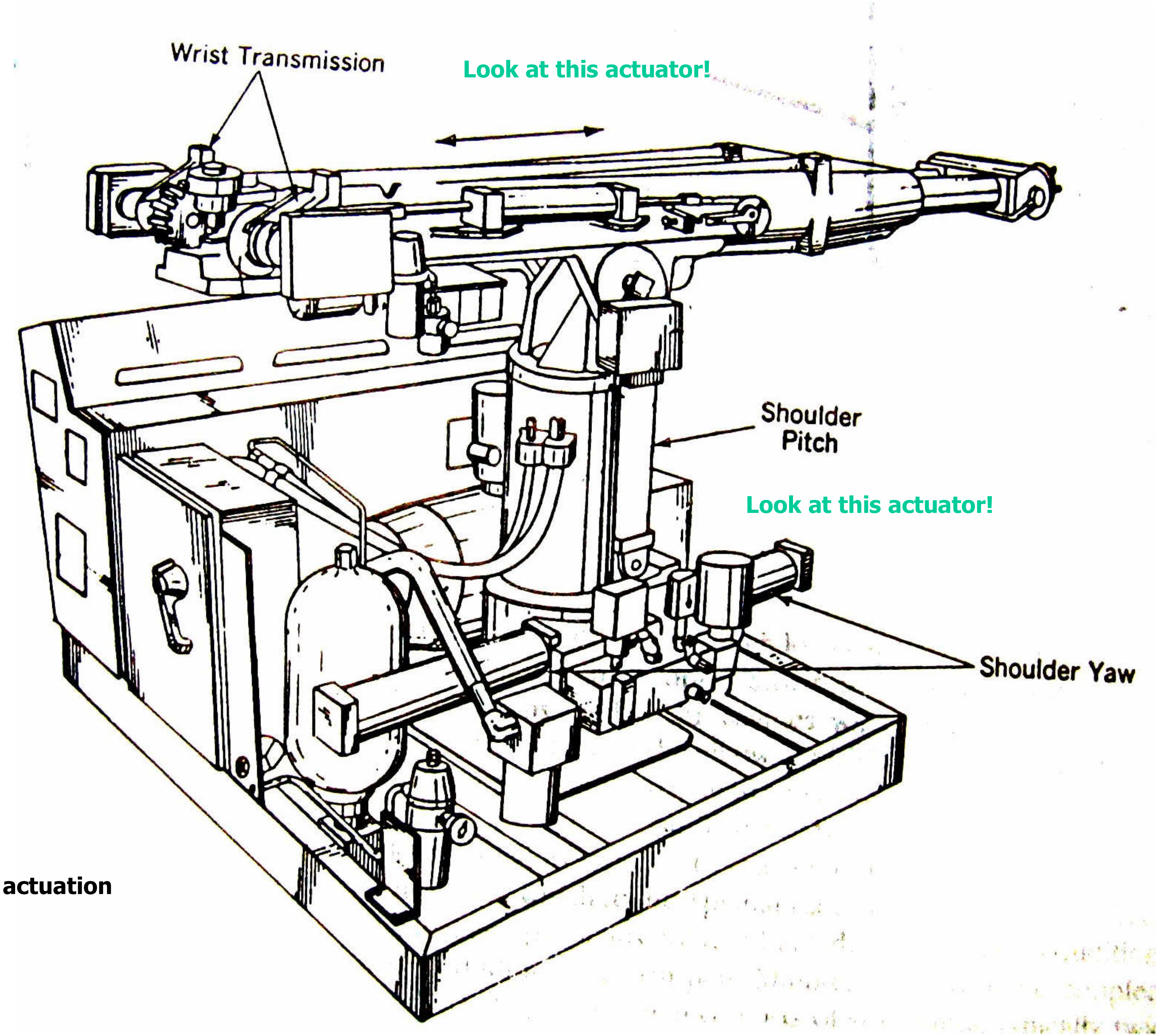
first industrial robot (unimate 2000 – hydraulic)

slower than other robots





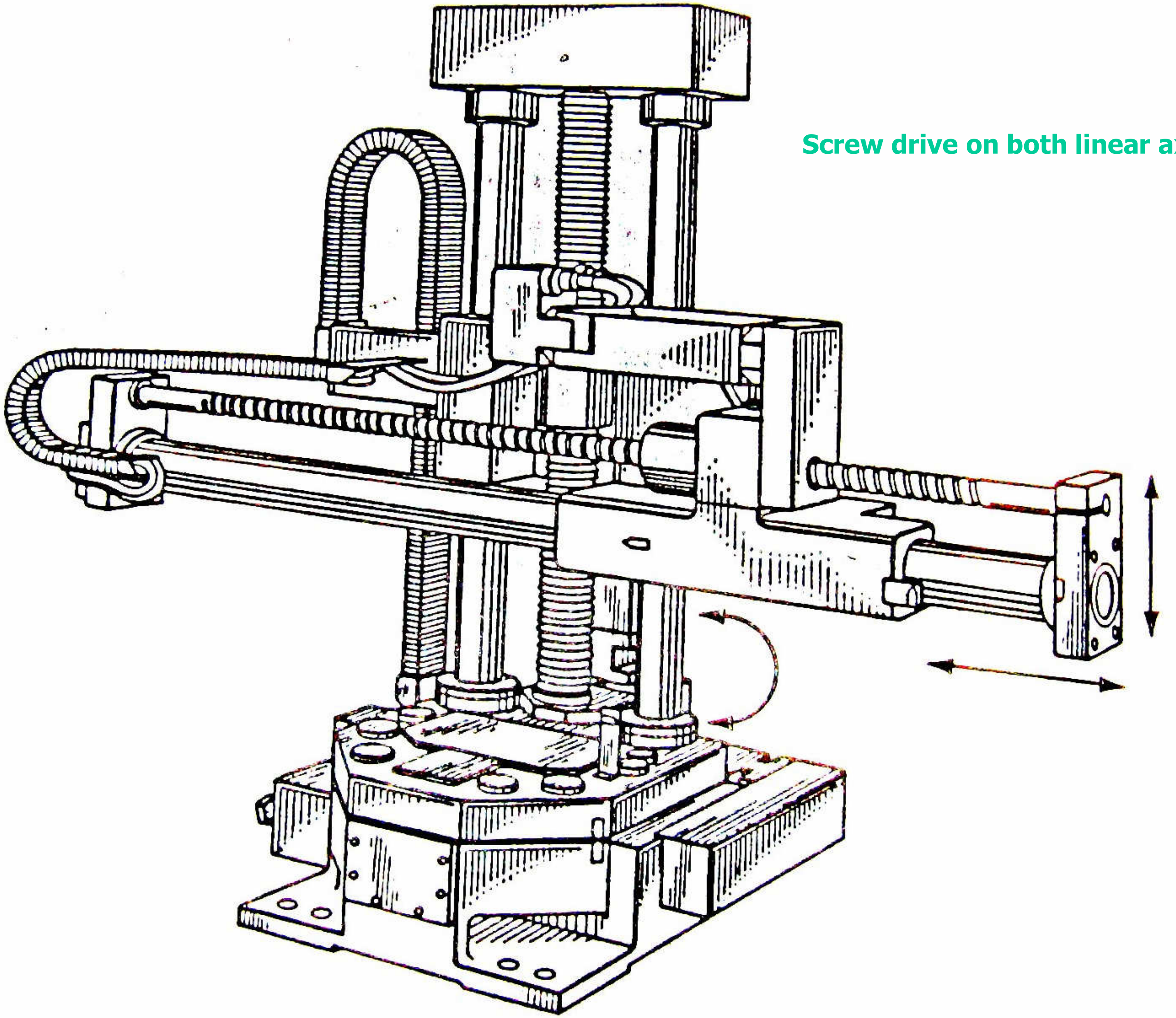




Hydraulic actuation

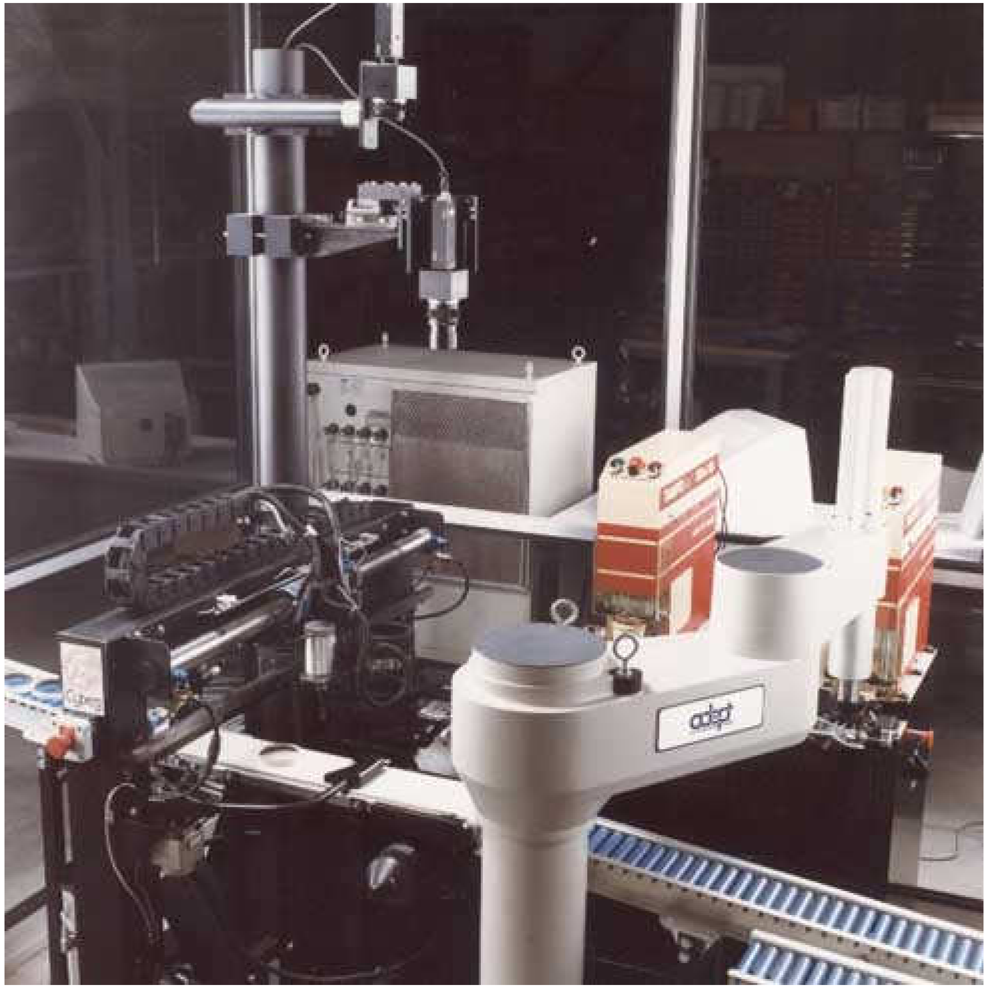
Cylindrical Robot:

1 rotation + 2
translations +
wrist
an easy way to build
an useful robot..



Screw drive on both linear axis!

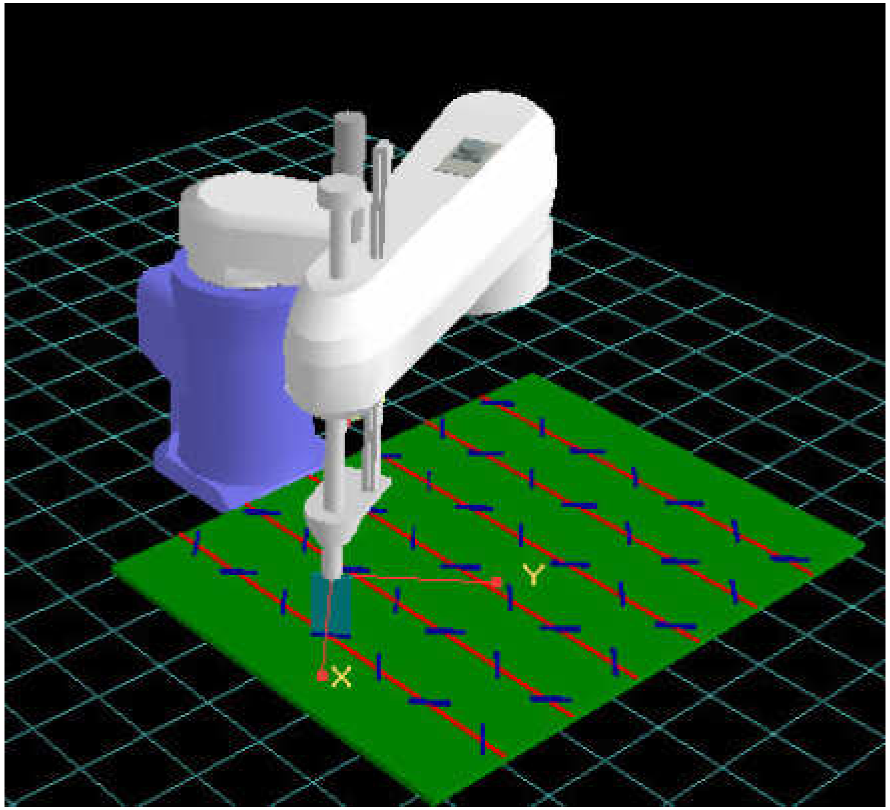
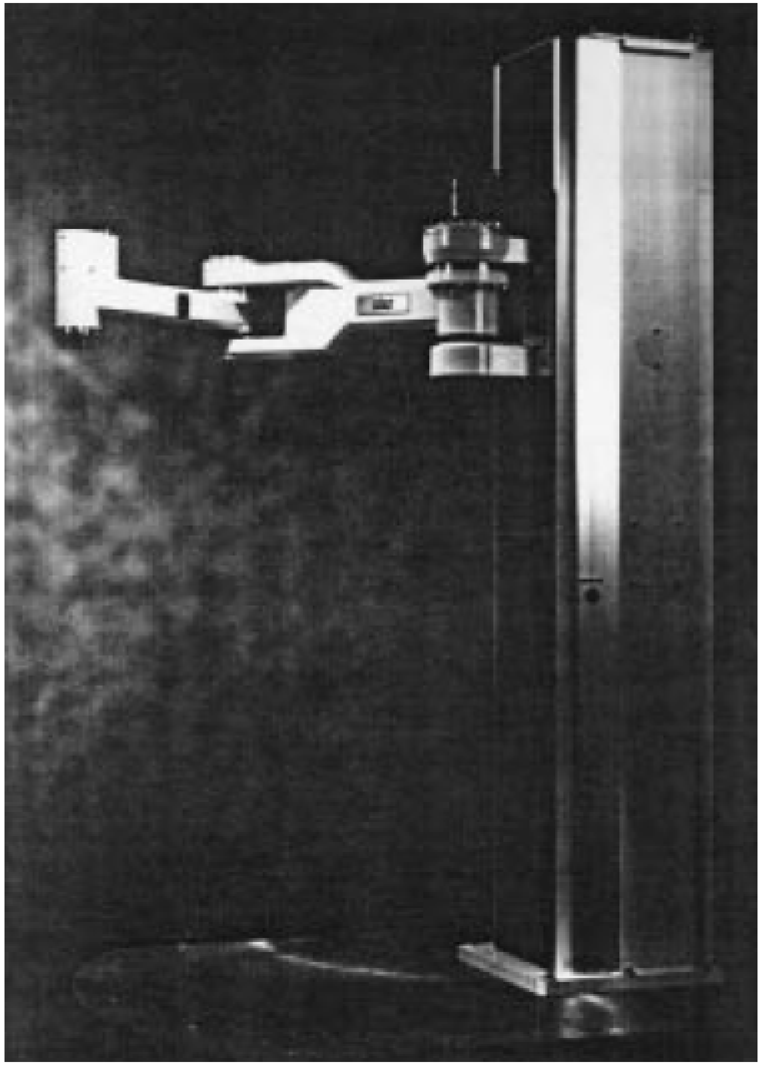
SCARA Robot:



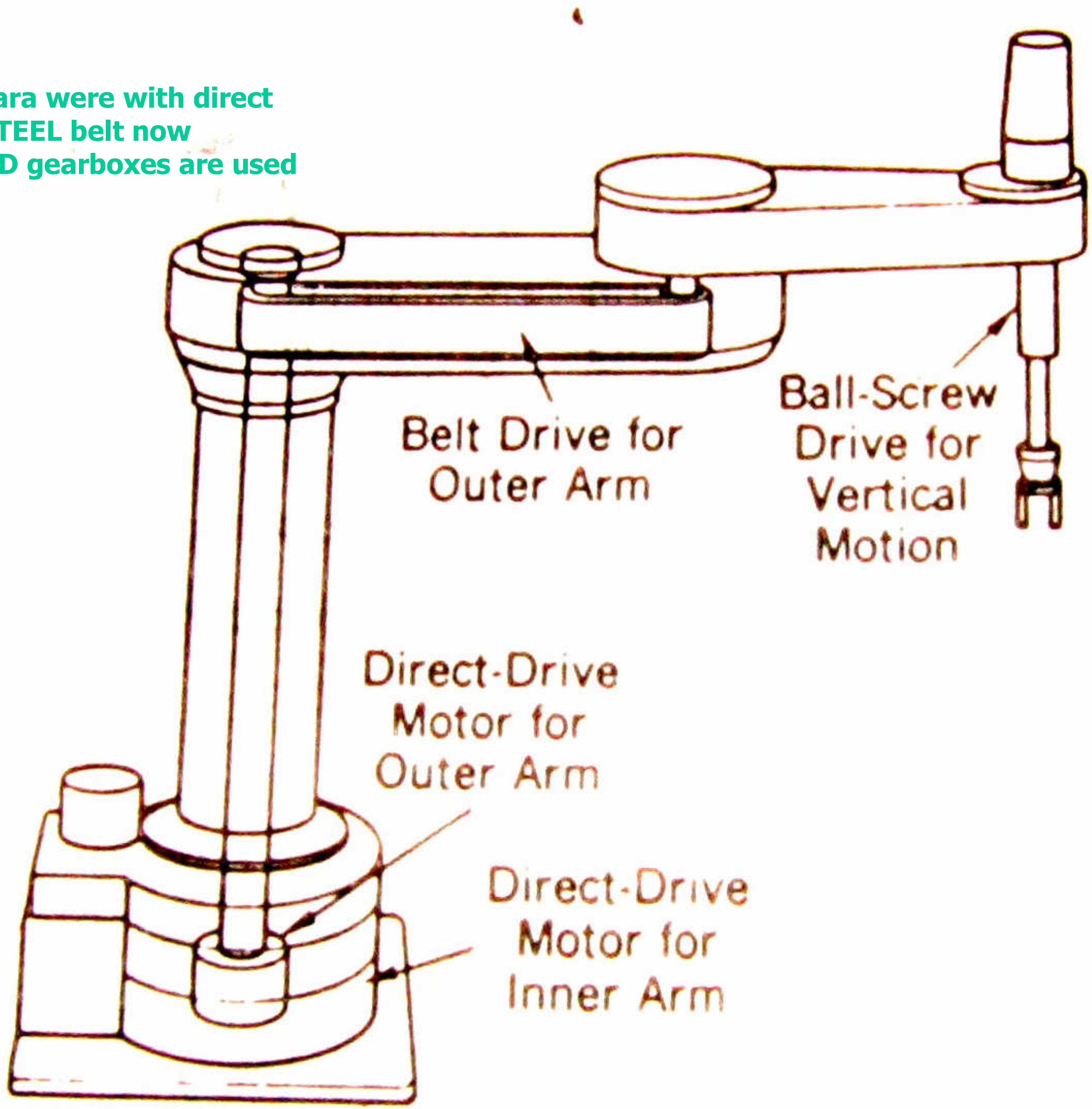
2 rotations + 1 translation + wrist (1 rotation) selectively compliant assembly robot arm)

traditionally used for high precision high speed assembly robot:

0.02 repeatability
10 m/s max speed
0.5:1 m range

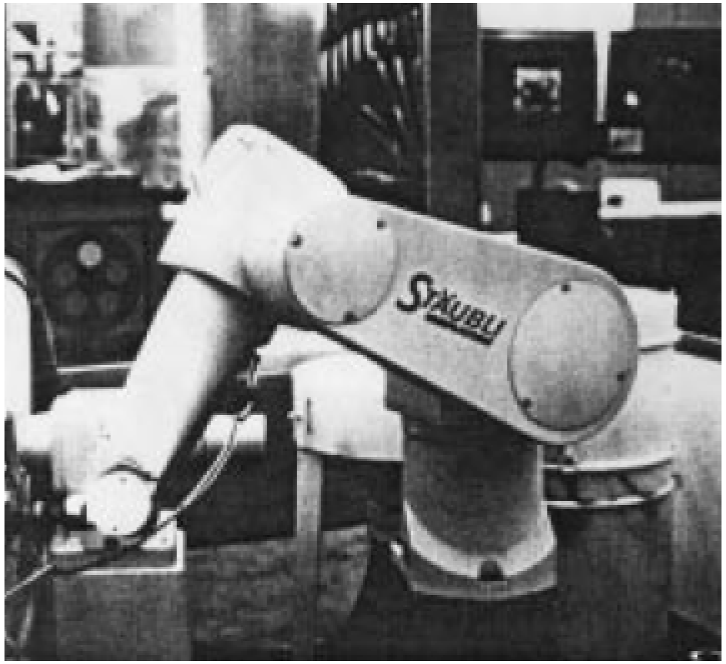

Y
X


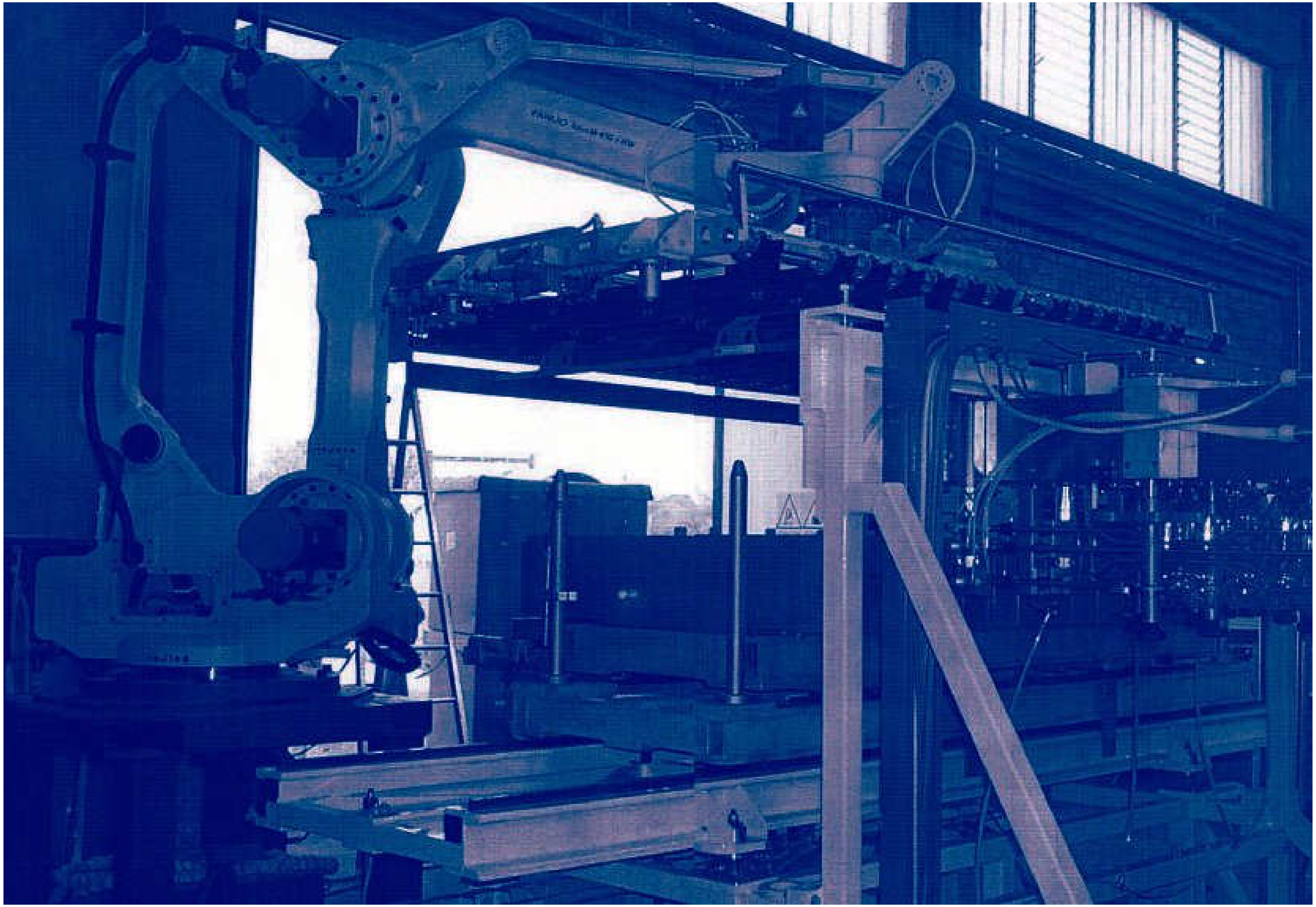
The first scara were with direct drive and STEEL belt now generally HD gearboxes are used



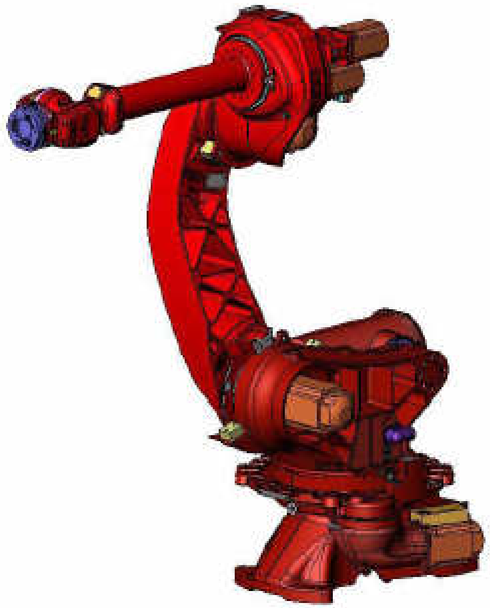
Articulated Robot:

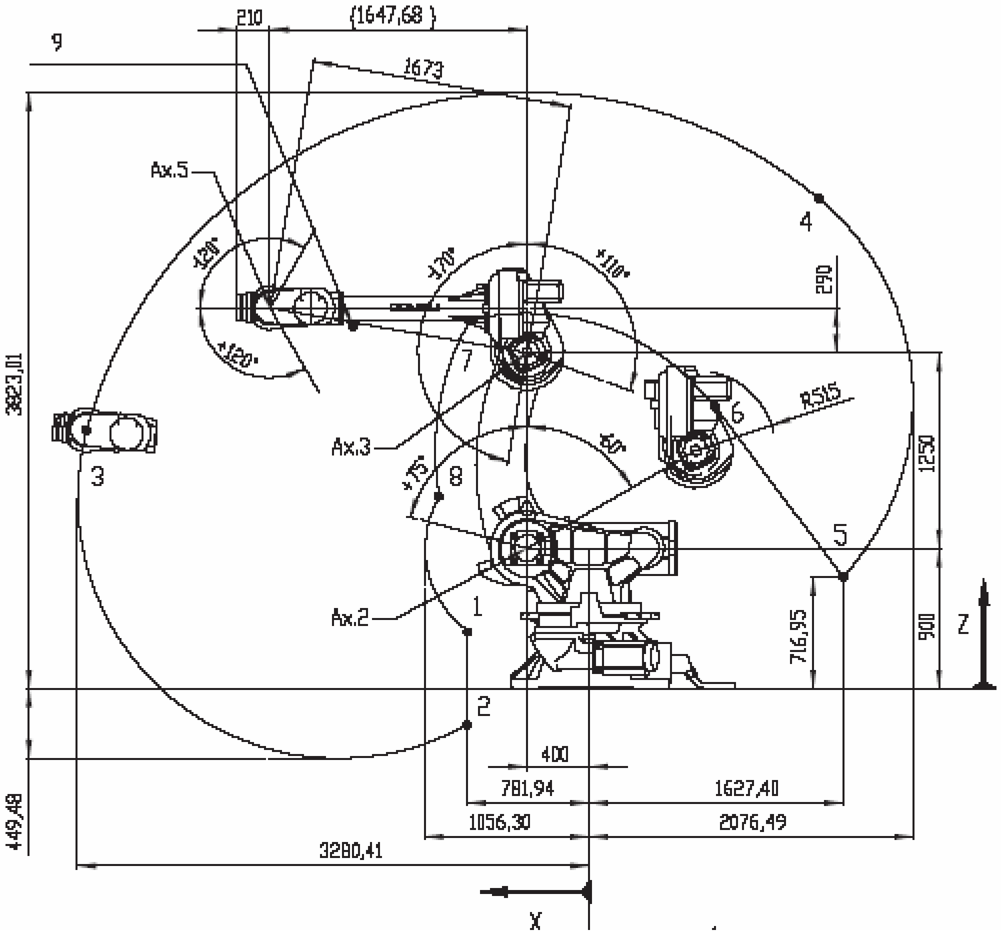
X rotations
NO translation
wrist (..)





COMAU

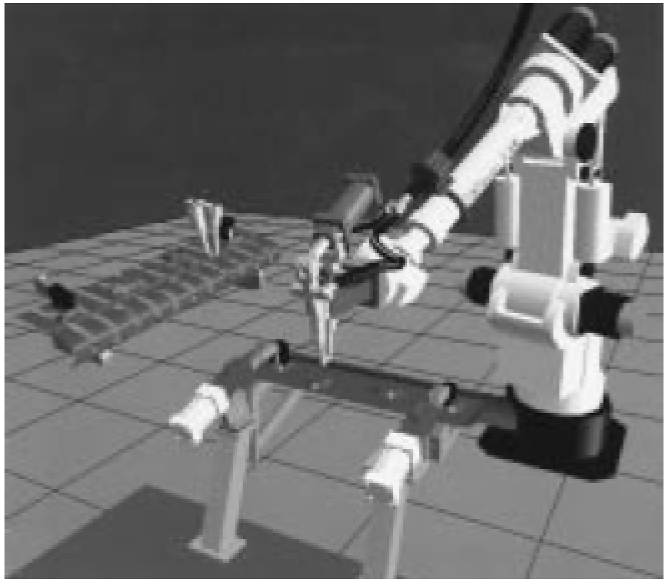




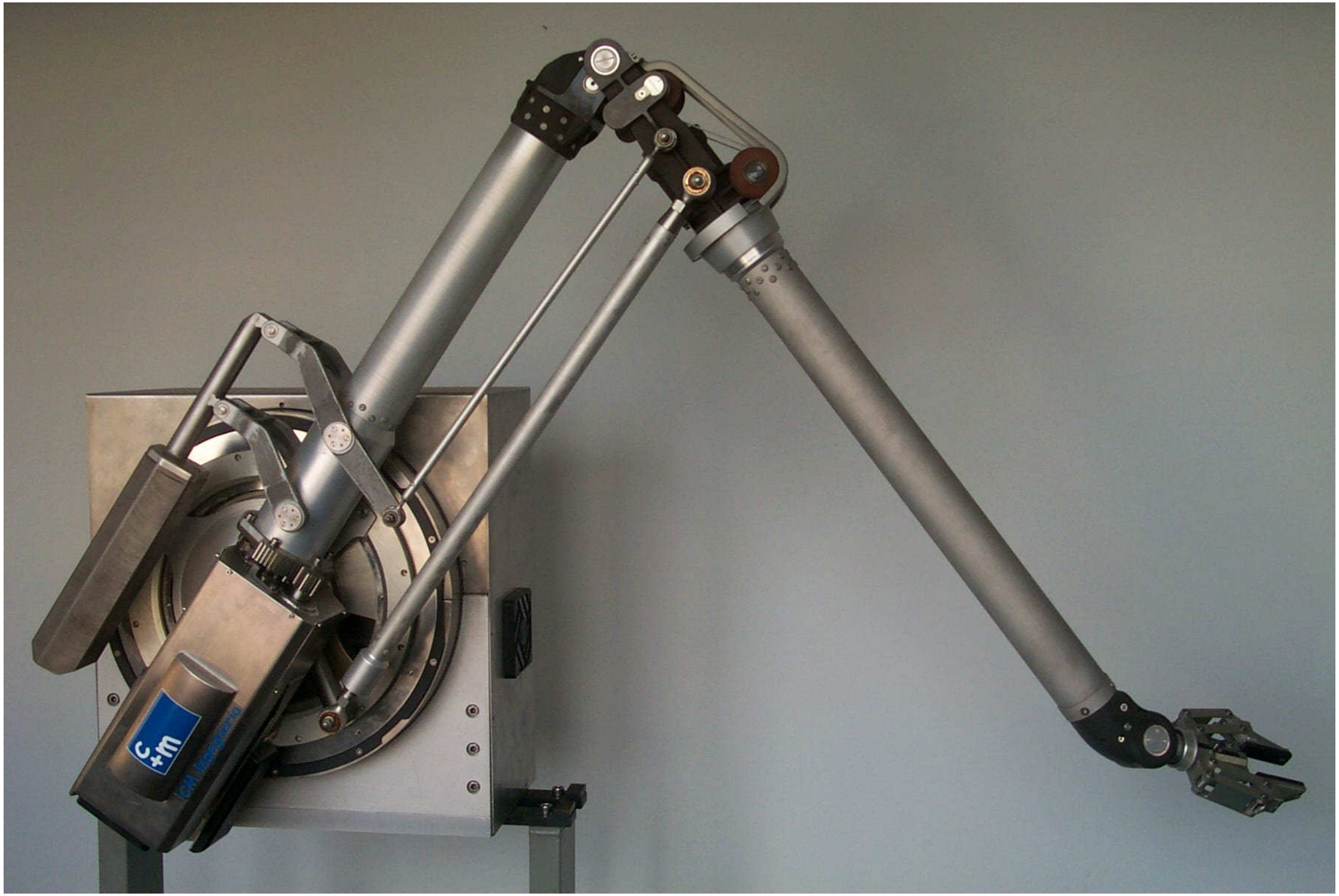
210
(1647,68)
9
1673
Ax.5
4
-120°
-170°
+110°
290
+120°
7
3823,01
R515
6
Ax.3
-60°
1250
3
+75°
8
5
Ax.2
1
716,95
900
Z
2
400
781,94
1627,40
1056,30
2076,49
449,48
3280,41
X

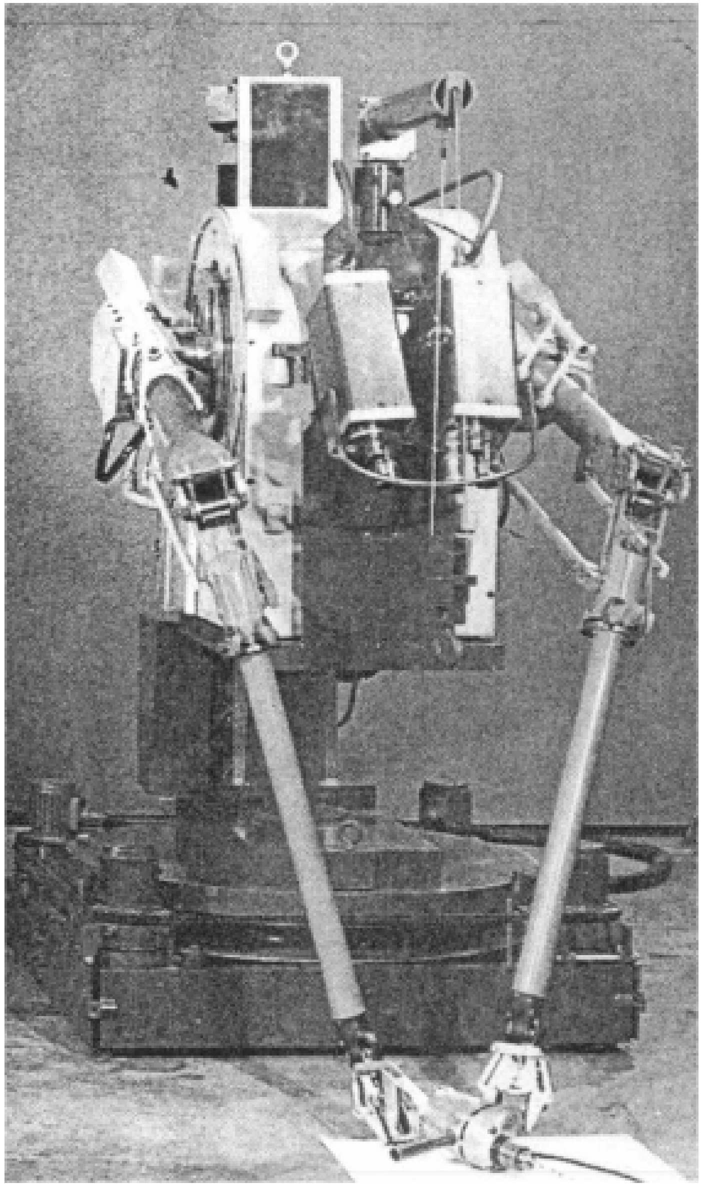
PANASONIC (TIG WELD)

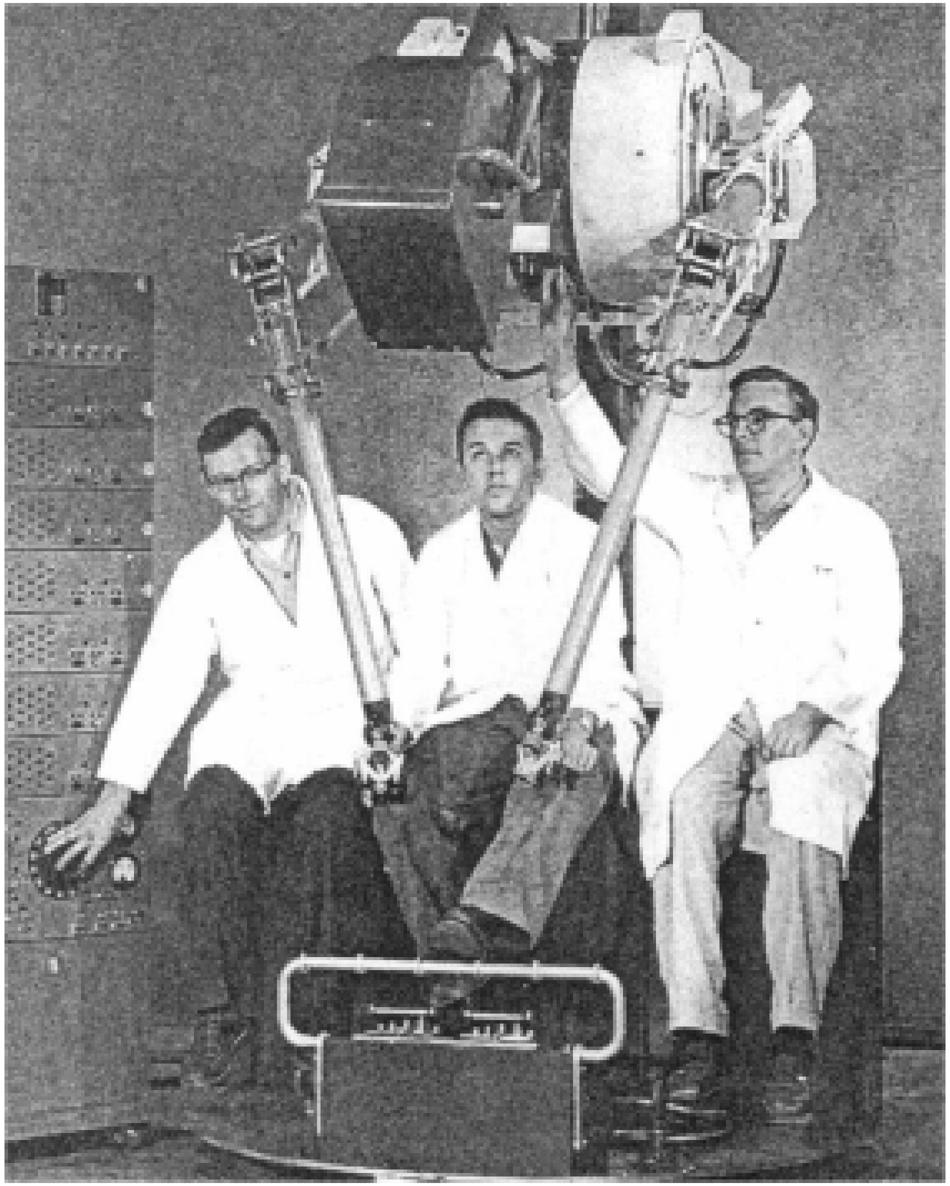
Spot weld



Teleoperation (MASCOT)







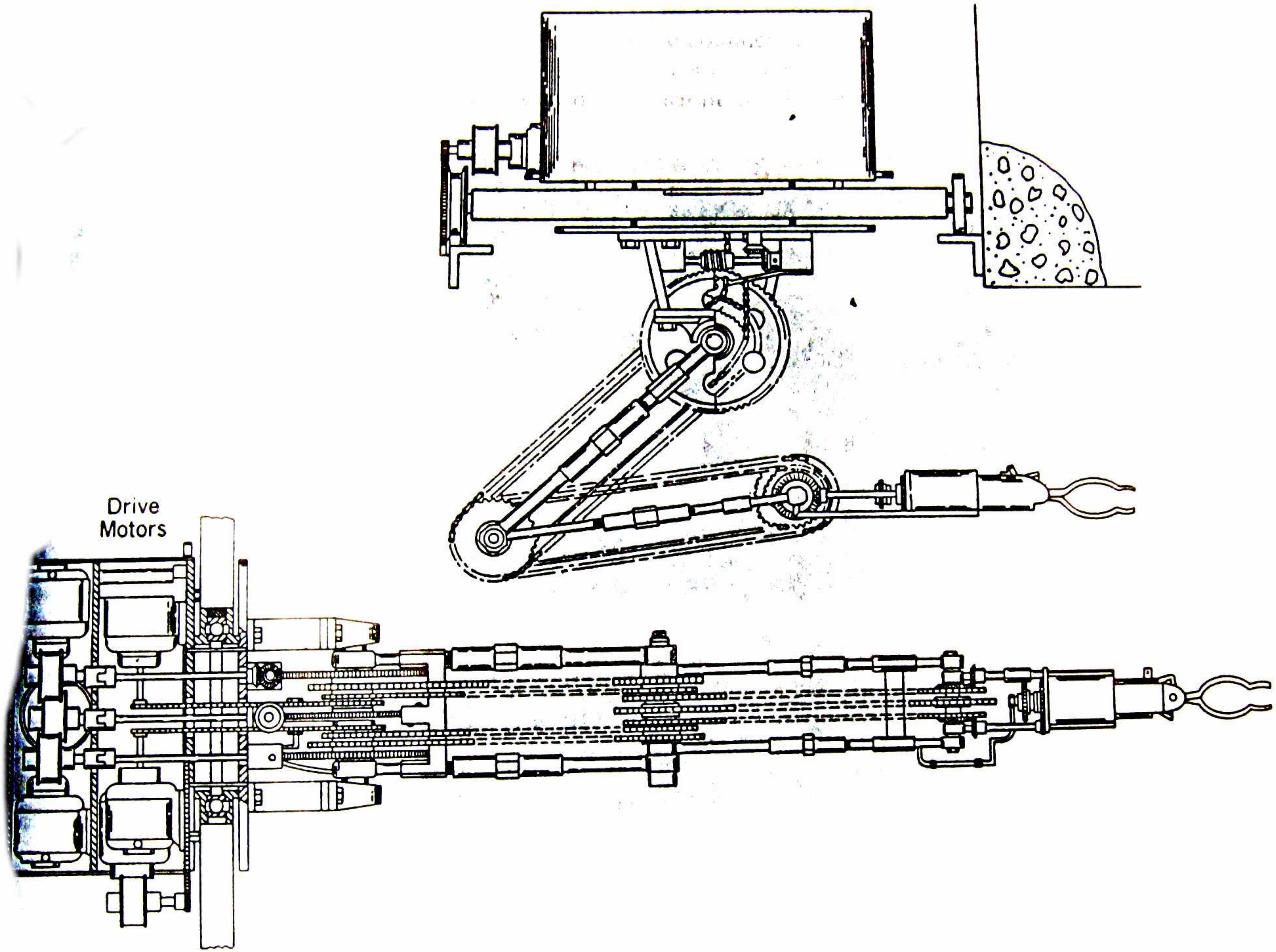
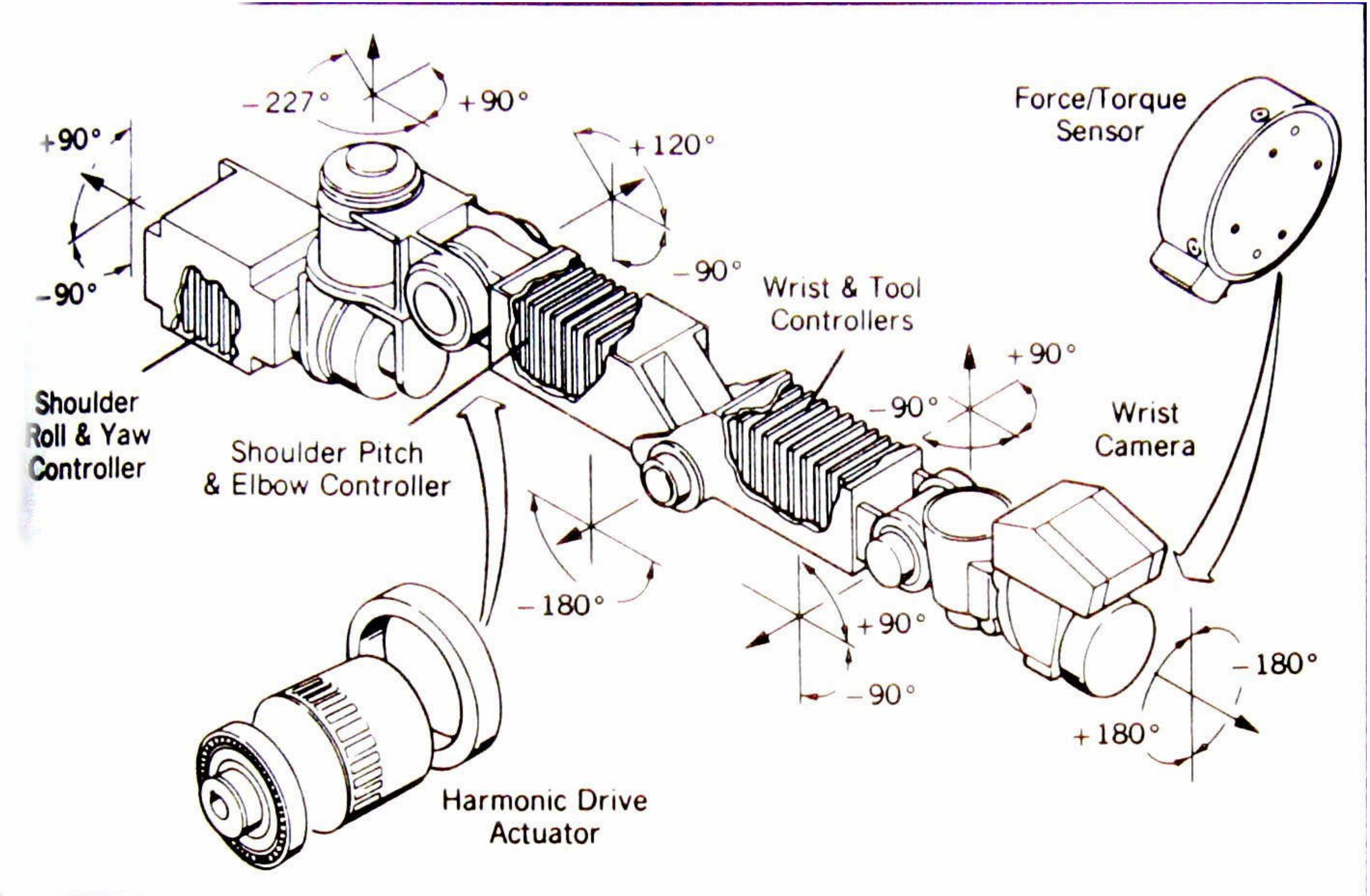


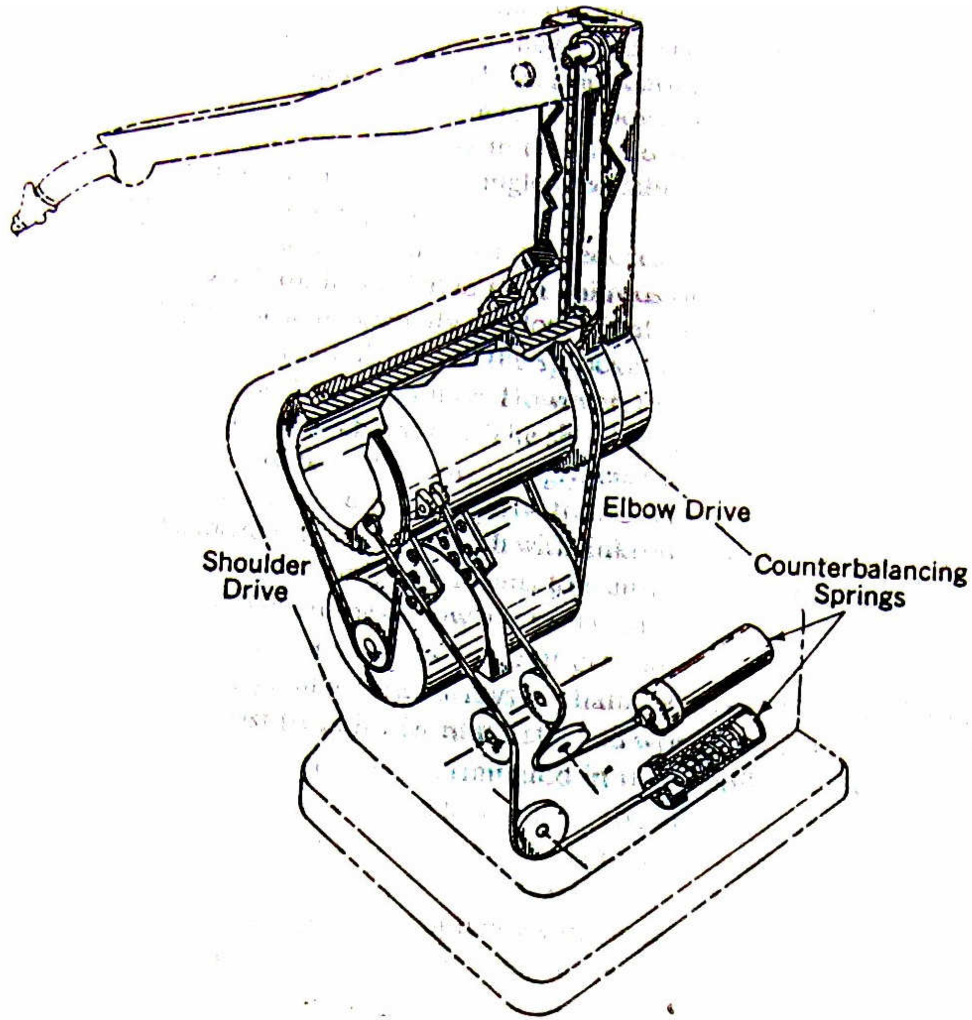
Figure 2.43 Case Institute Arm Design

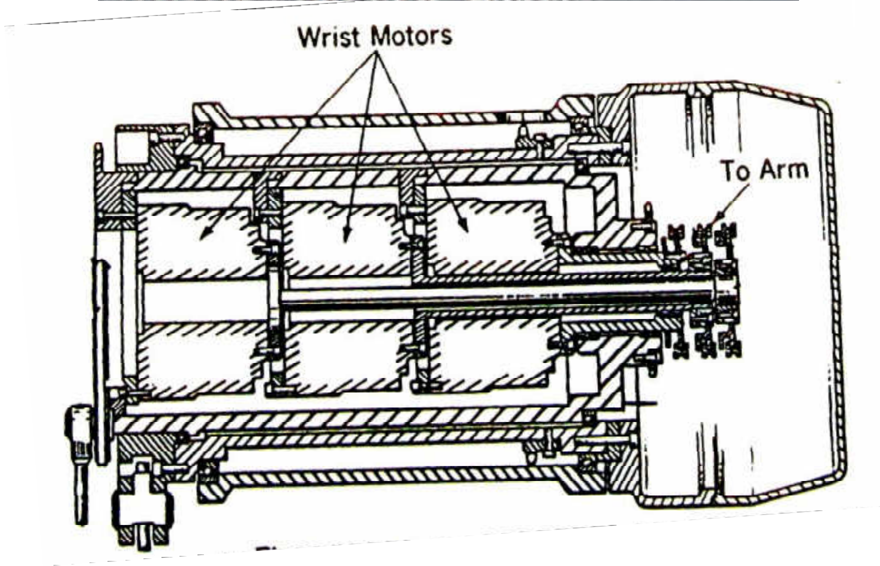
Modular design (SPIDER ARM)



Compare the HD length with the CSD used in ICUB

Motor relocation





Direct Drive

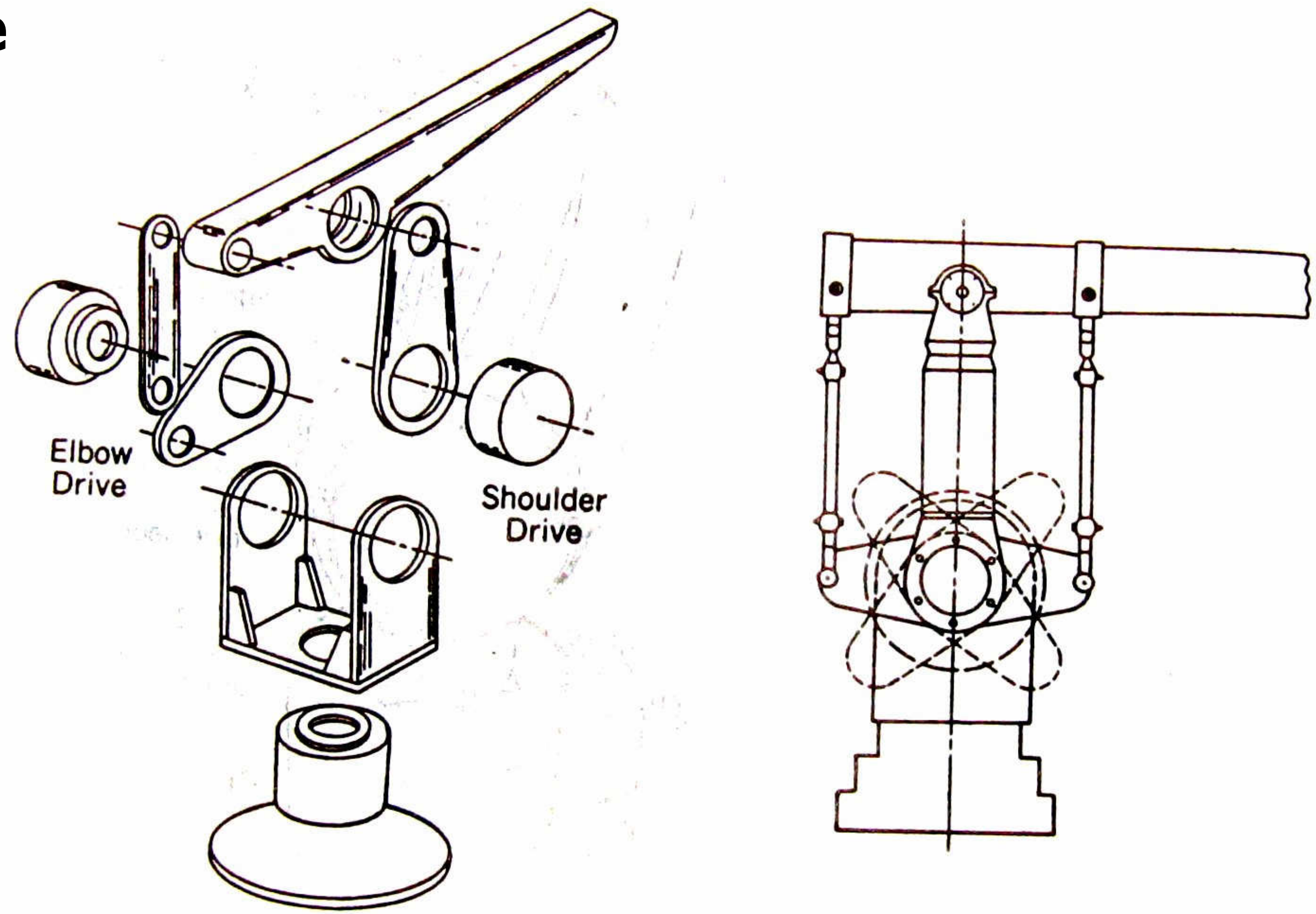
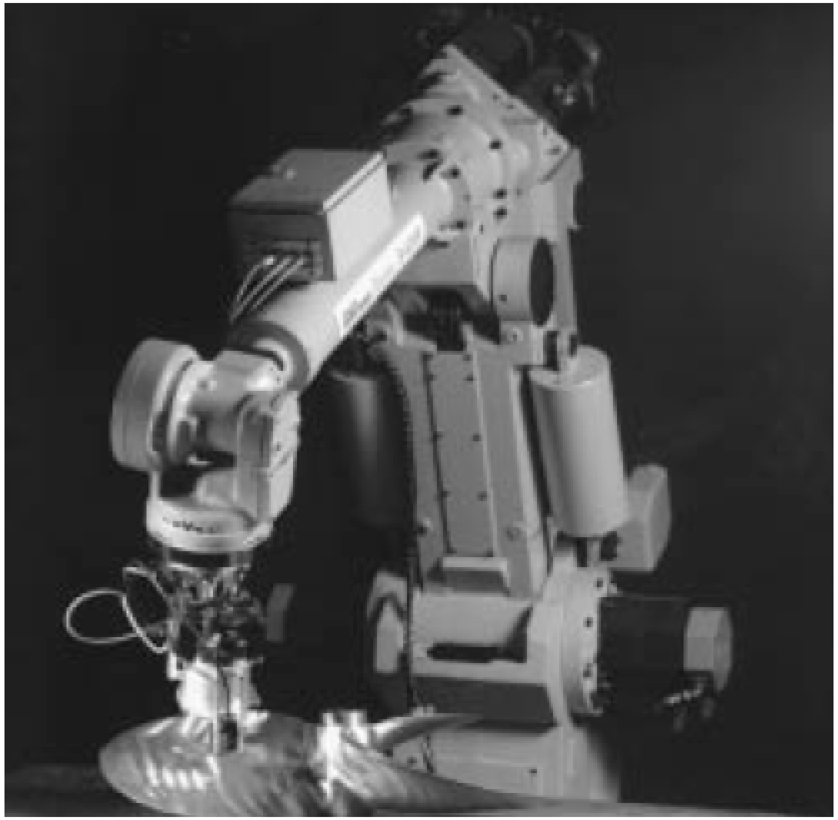
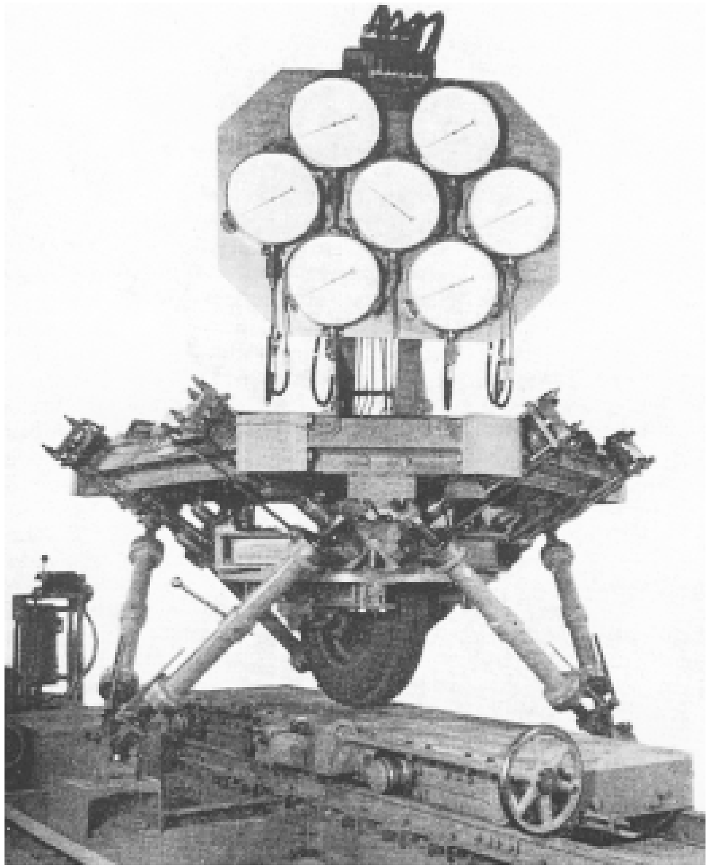


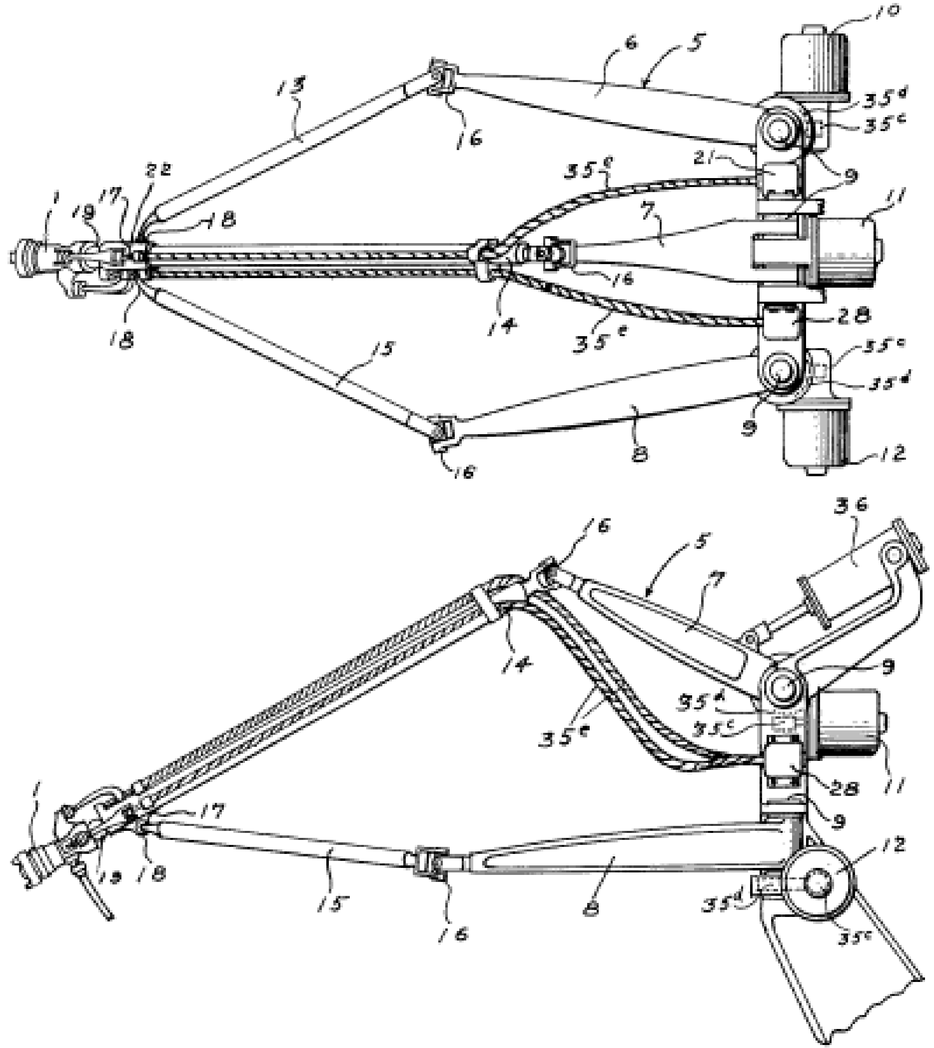
Figure 2.65 MIT Arm Drivetrain

Propeller finishing

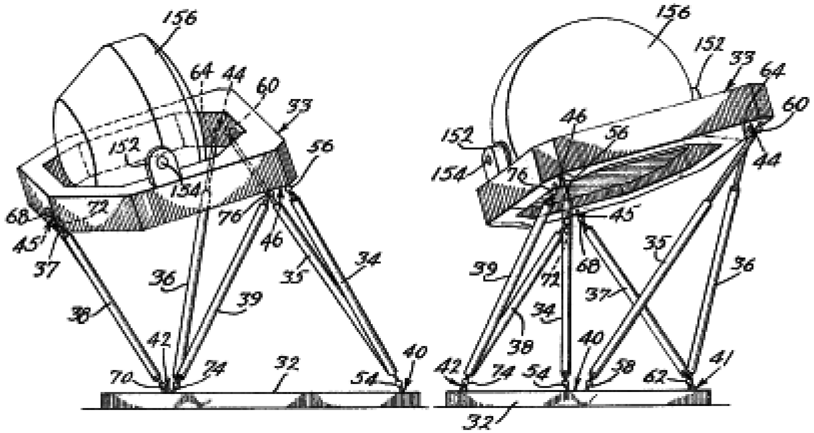


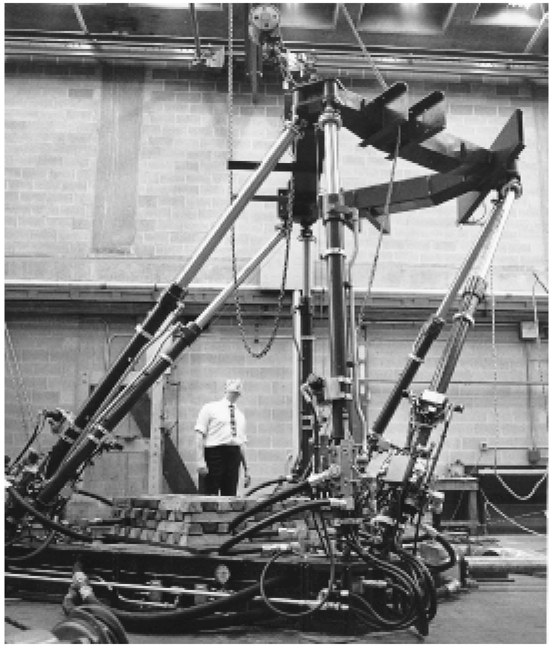
PMK Robot:

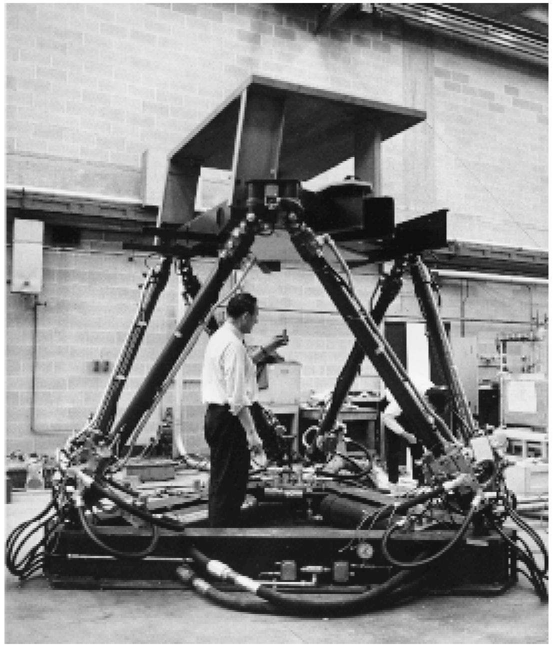




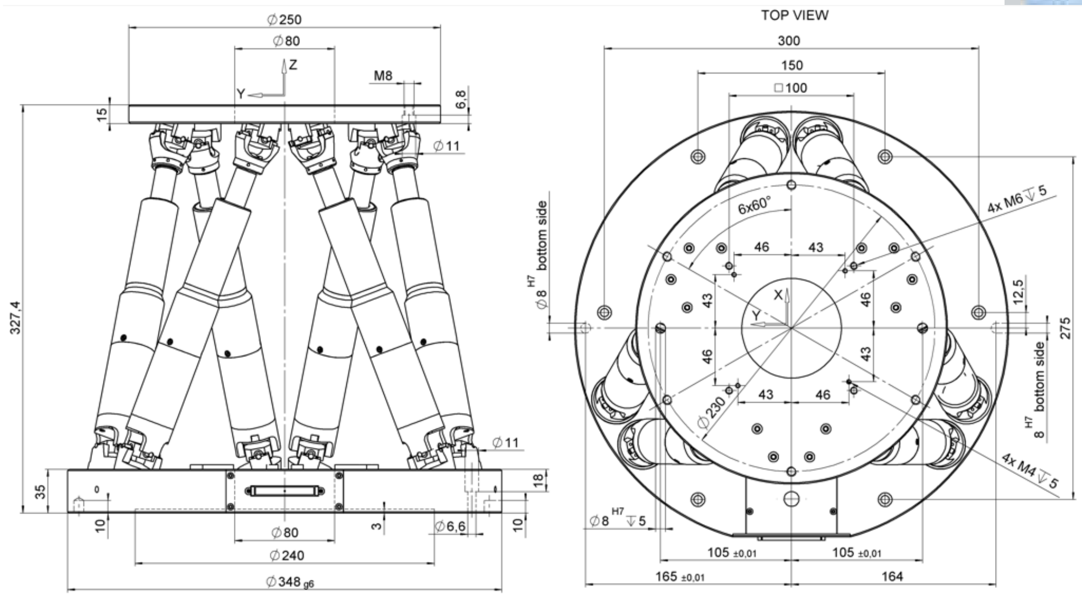
PMK Robot:





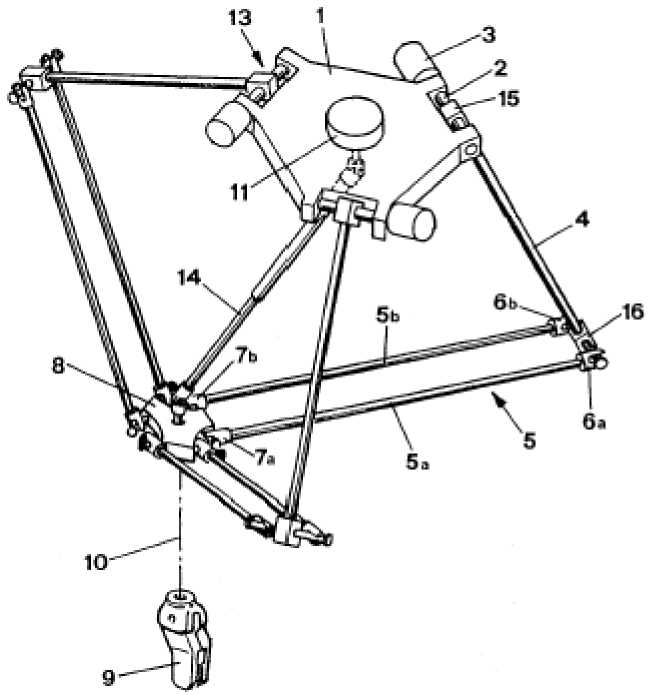


HexaLight™ 6-Axis-Parallel Kinematics Microrobot



- •Six Degrees of Freedom
- •Rapid Response
- •No Moving Cables for Improved Reliability and Precision
- •10 kg Load Capacity
- •Repeatability to ±2 μm
- •Actuator Resolution to 0.016 μm
- •Significantly Smaller and Stiffer than Serial-Kinematics

PMK Robot:



PMK Robot:

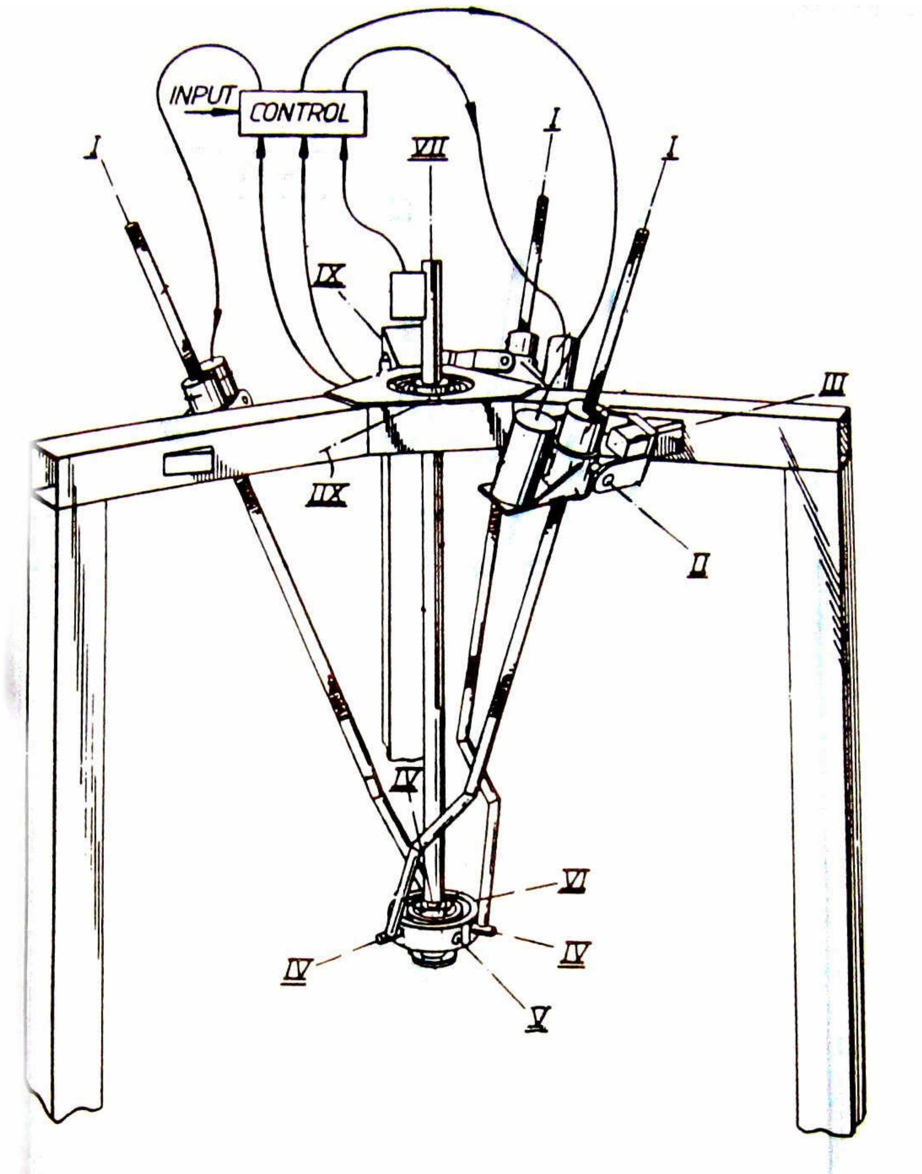
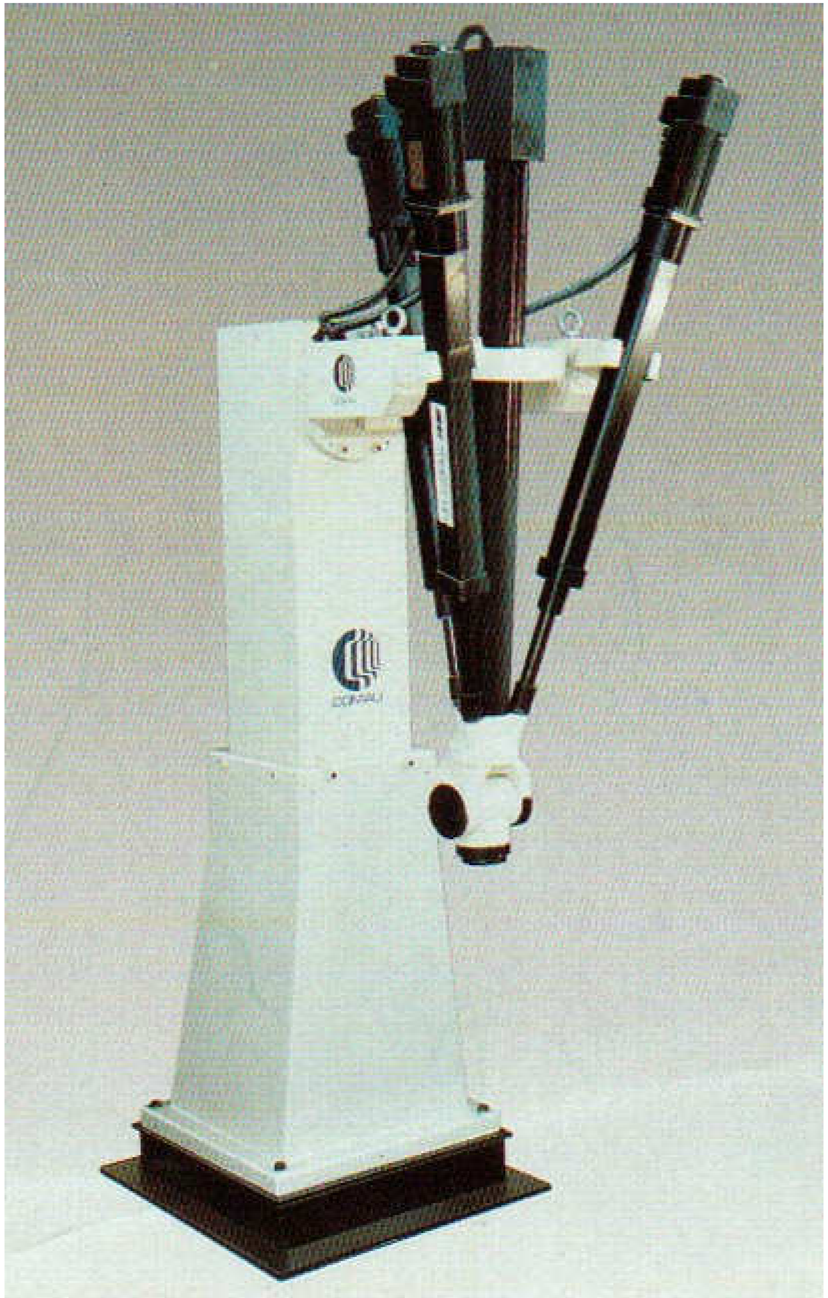


Figure 2.92 Design of Tetrabot



Spine Robot:

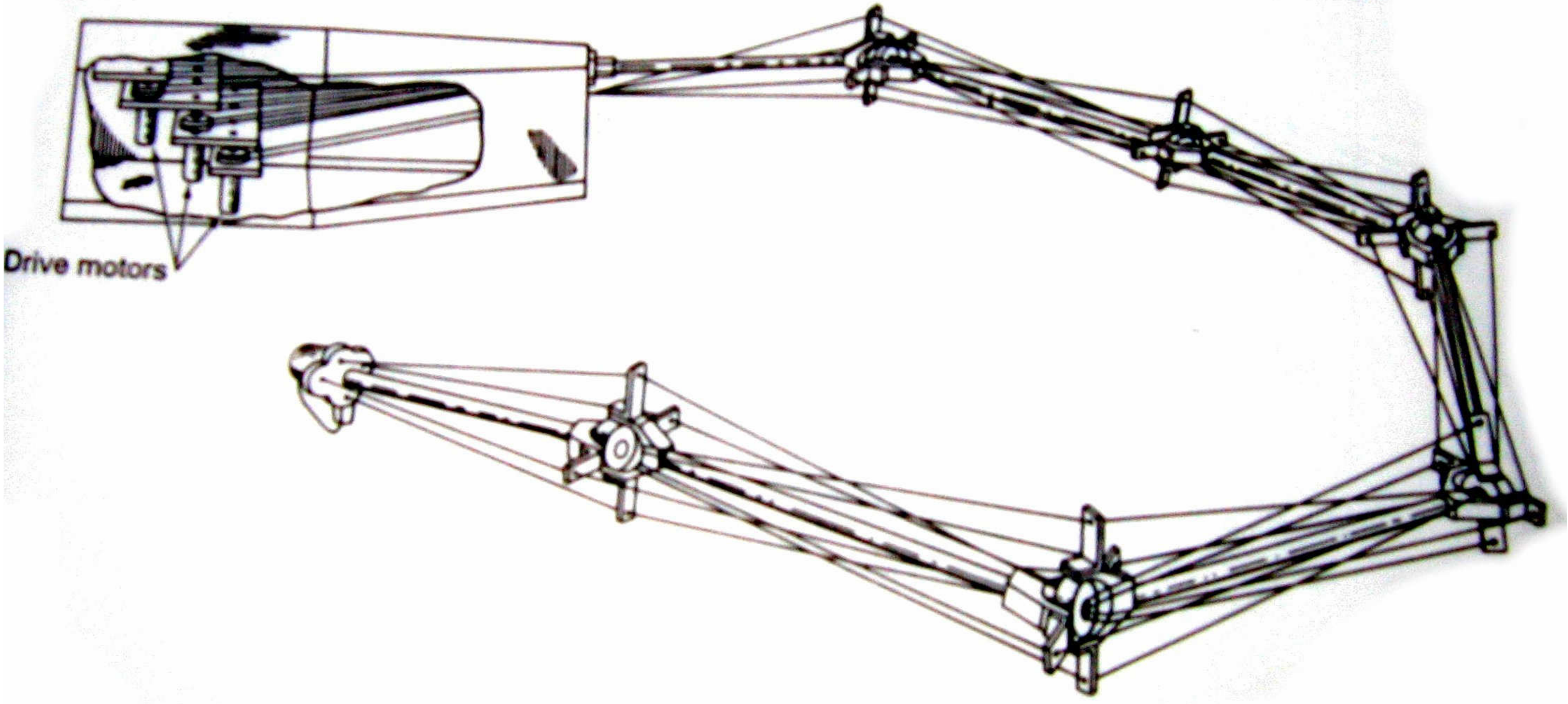
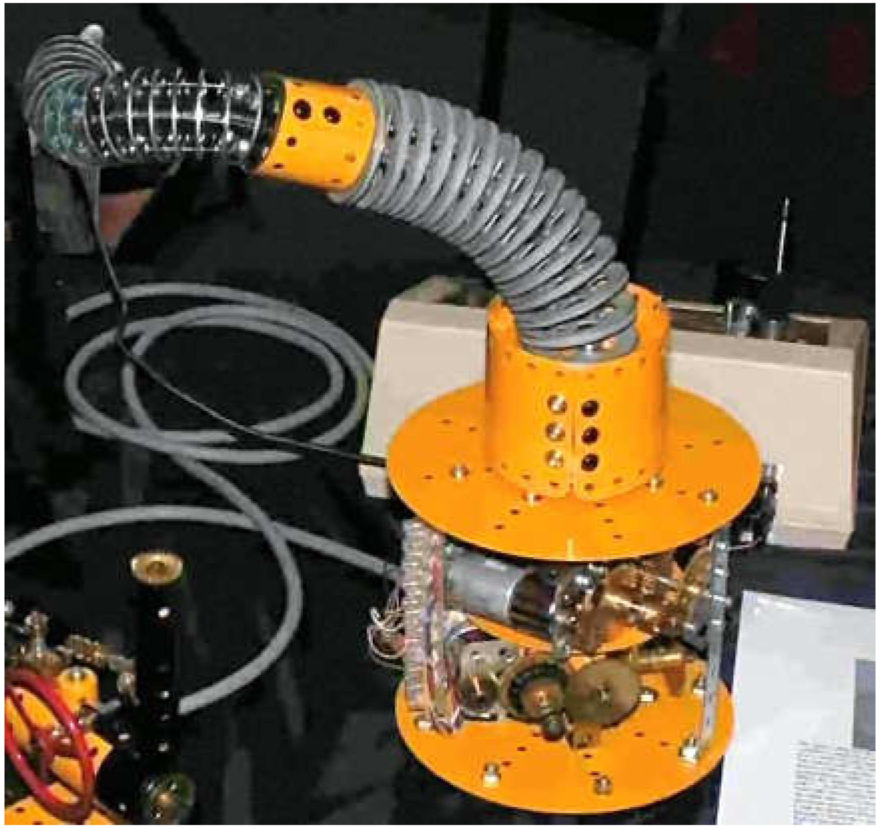


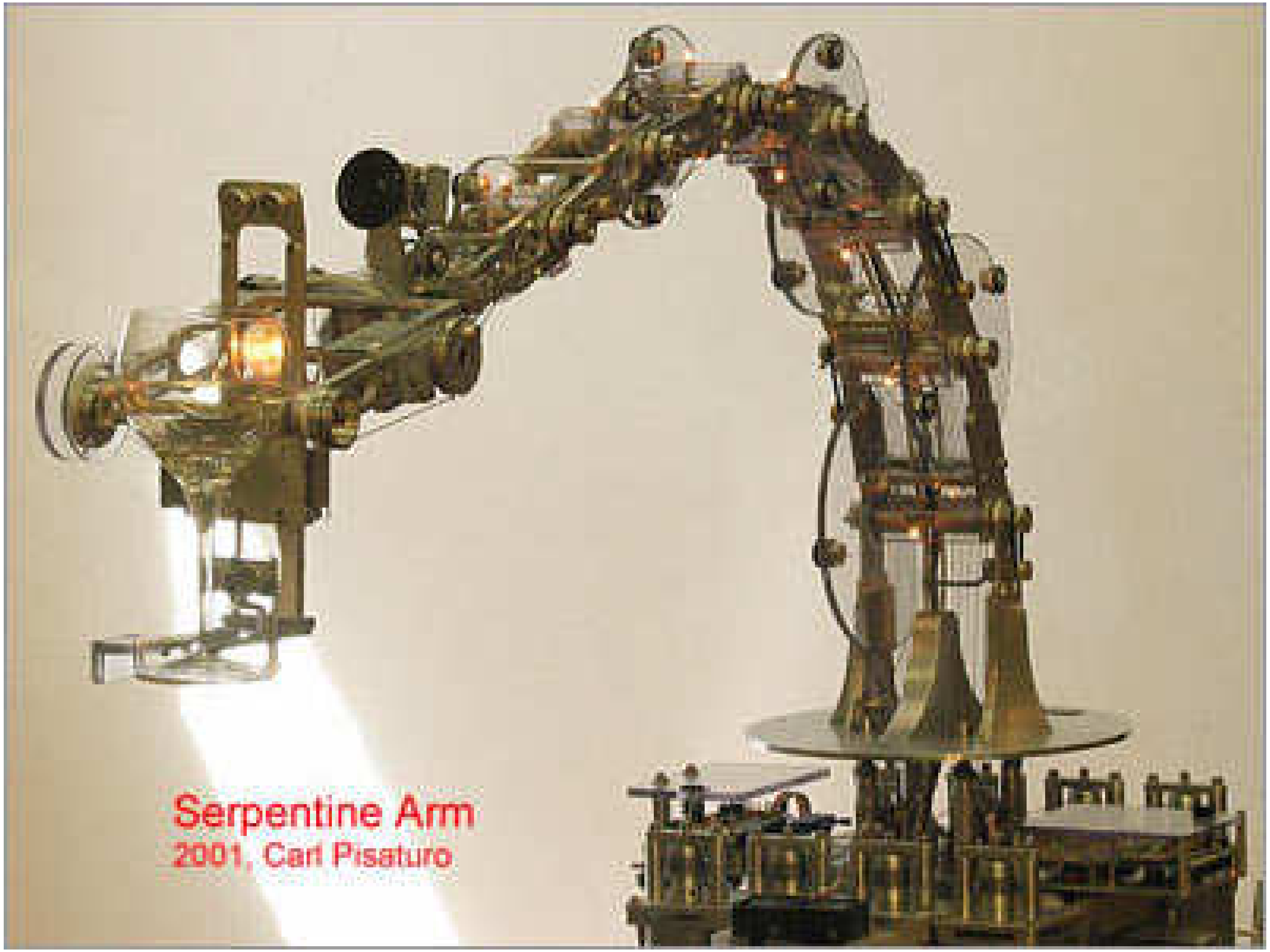
Figure 2.76 NASA Space Crane

...?

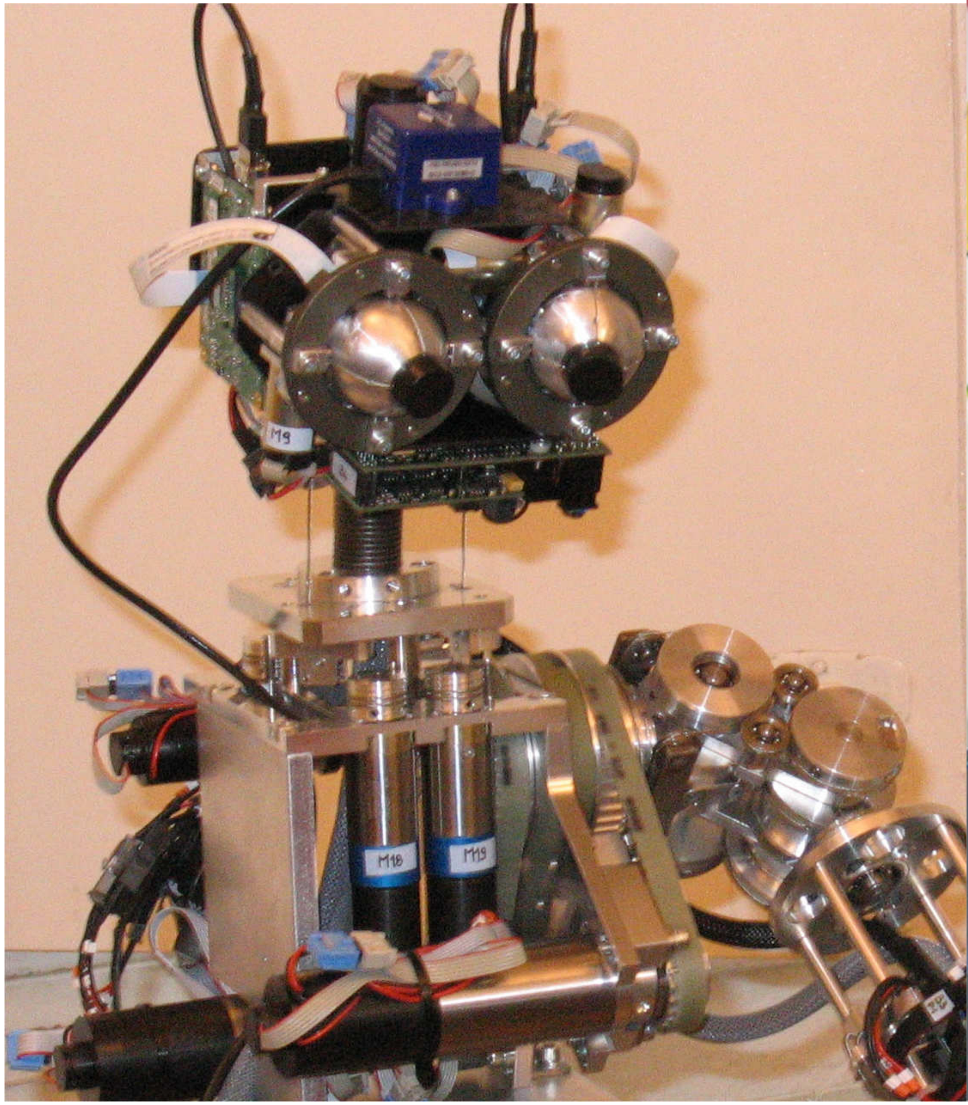
Spine Robot:

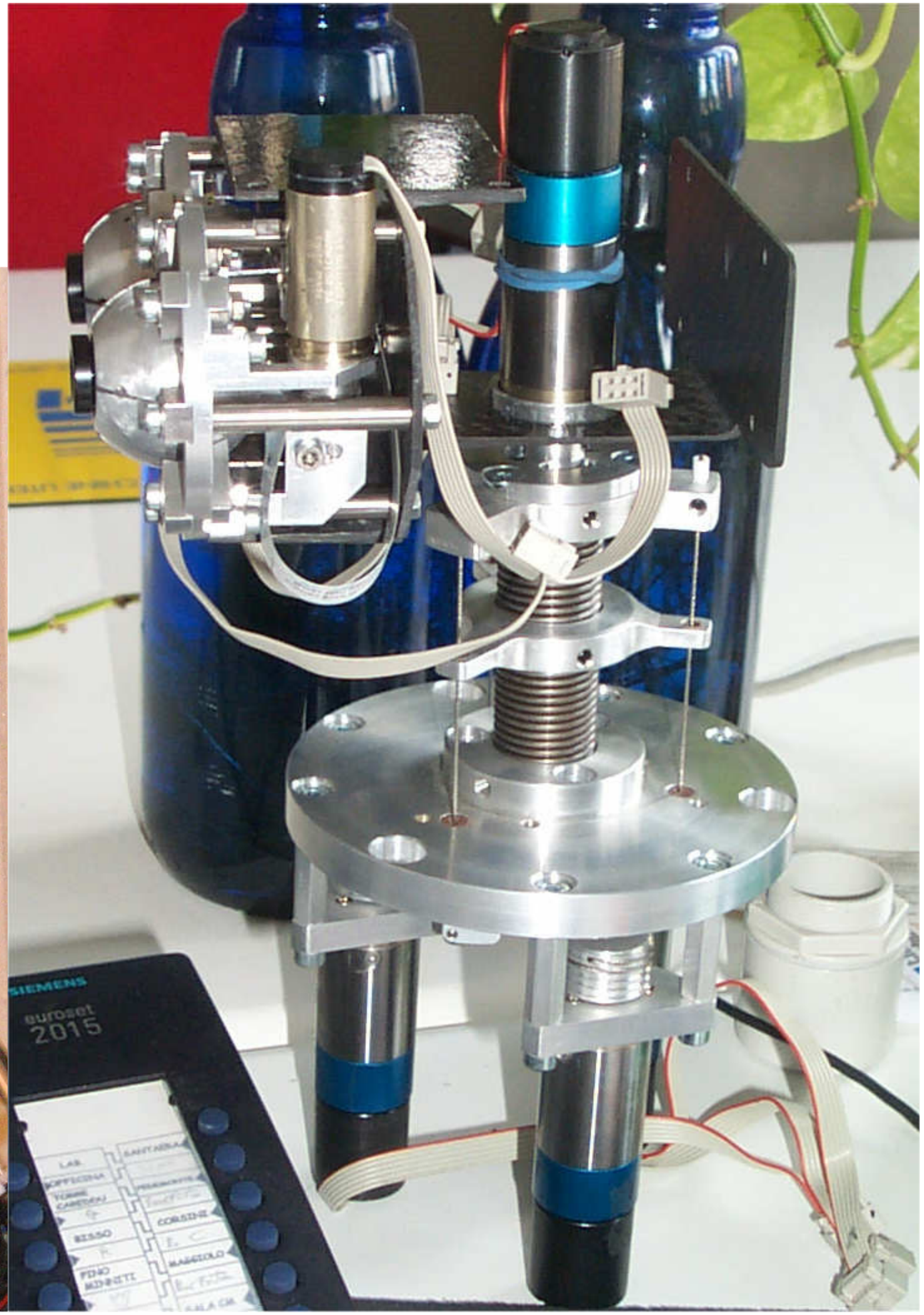


Spine Robot:



Spine Robot:





PART 2 : robot wrist

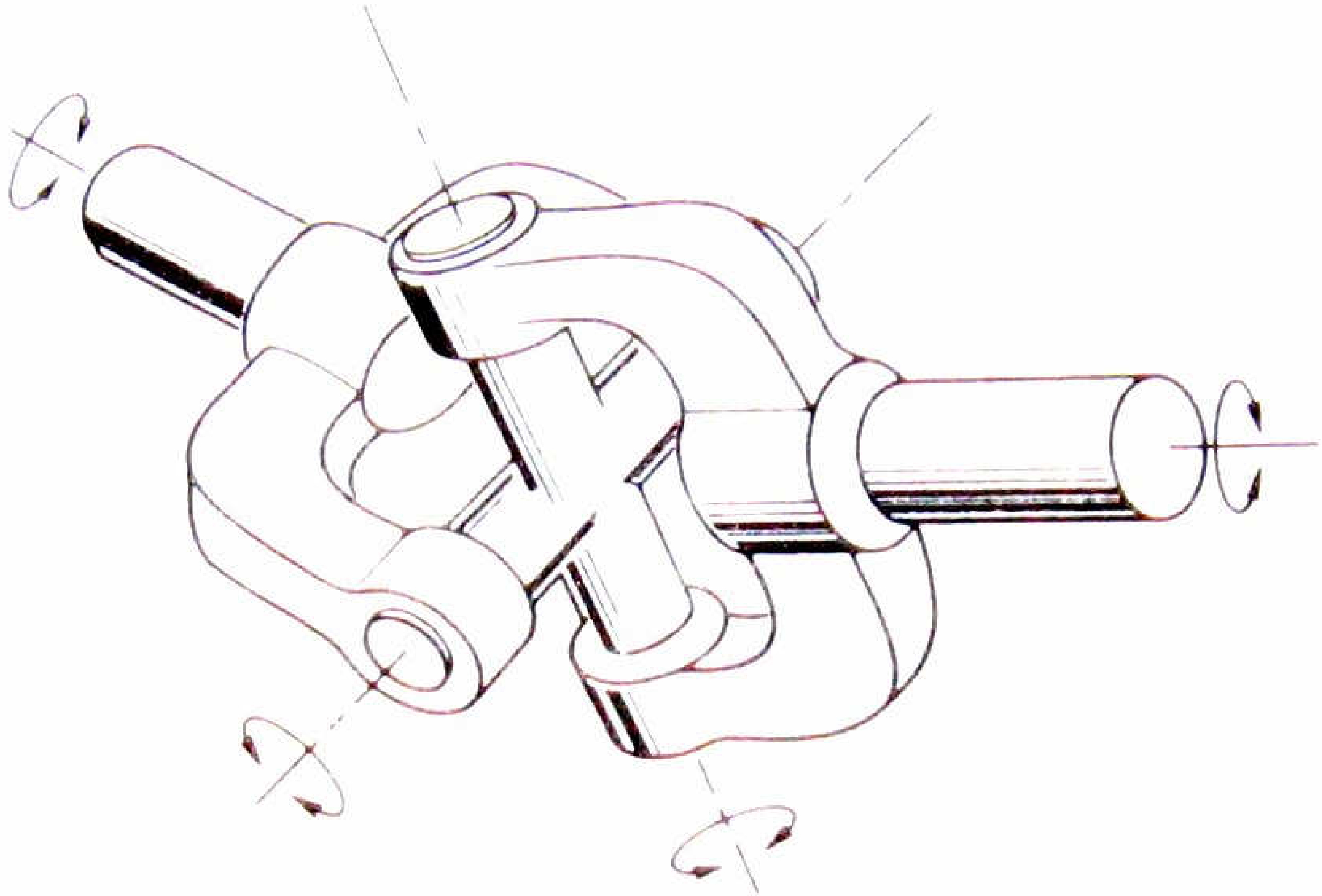


Figure 3.3 Kinematics of the Human Wrist

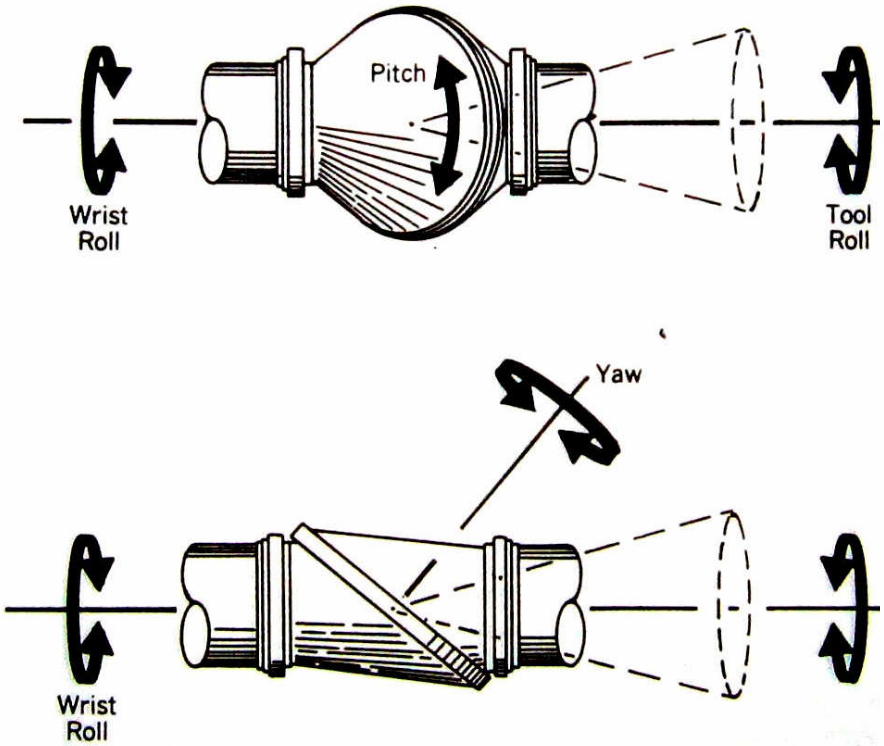


Figure 3.5 Roll-Pitch-Roll Wrists

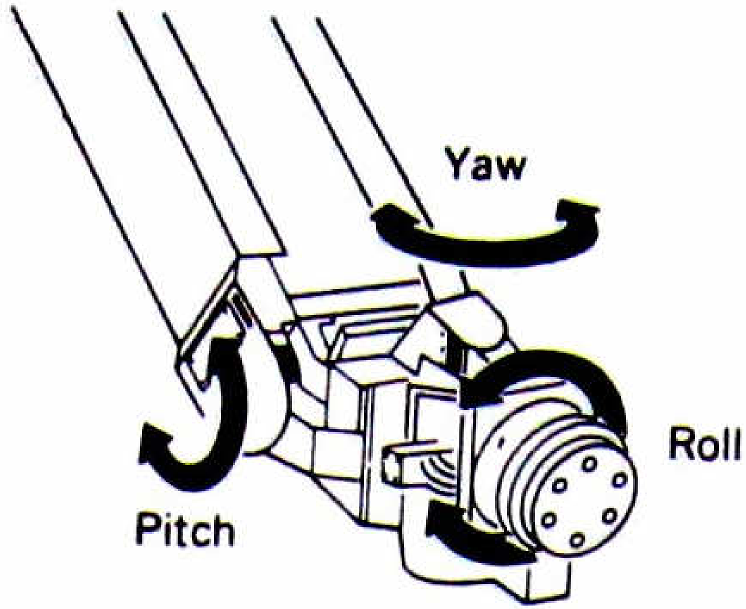


Figure 3.4 The Three Degrees of Freedom

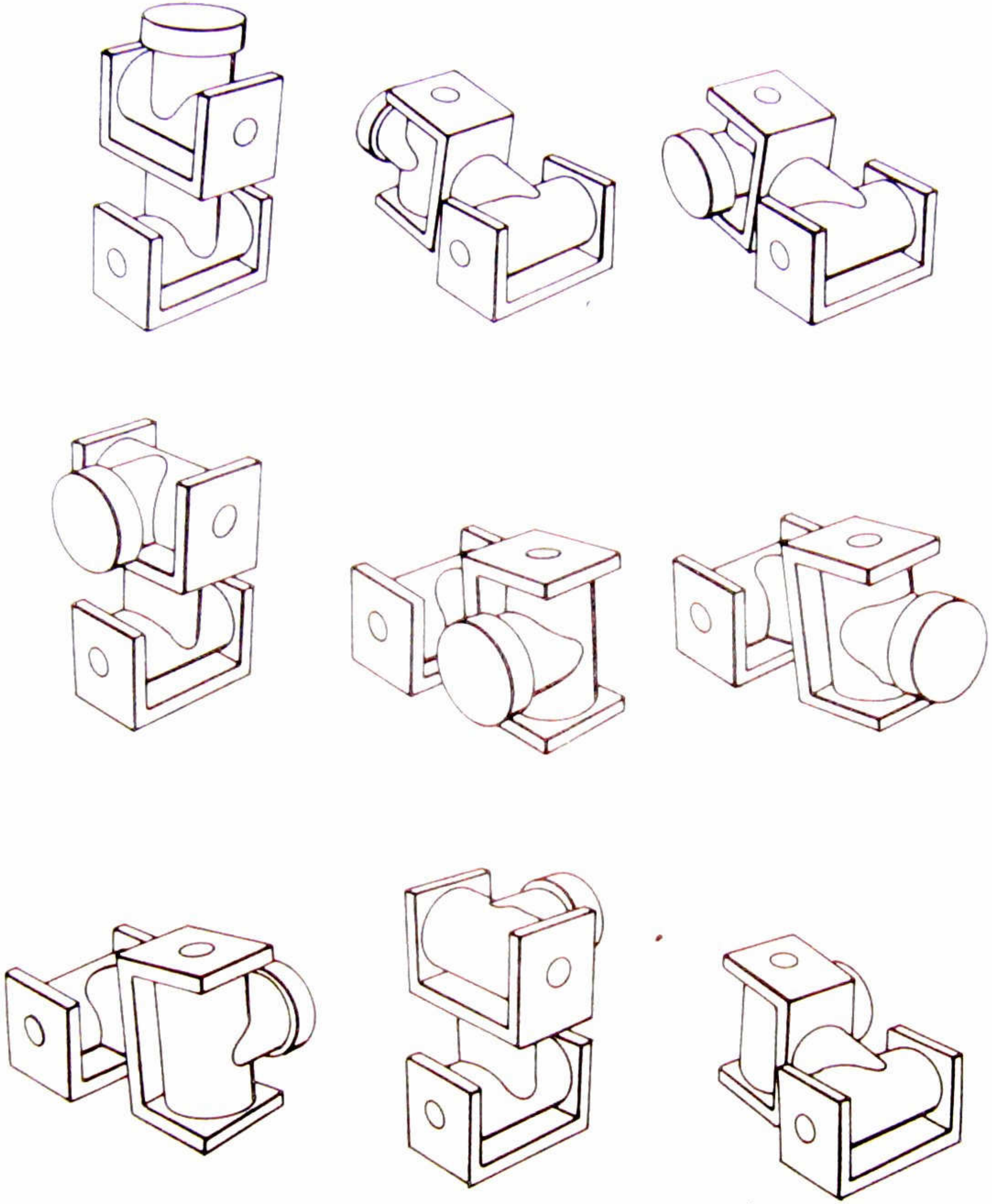


Figure 3.8 Pitch-Yaw-Roll Wrist Moving in Circumduction

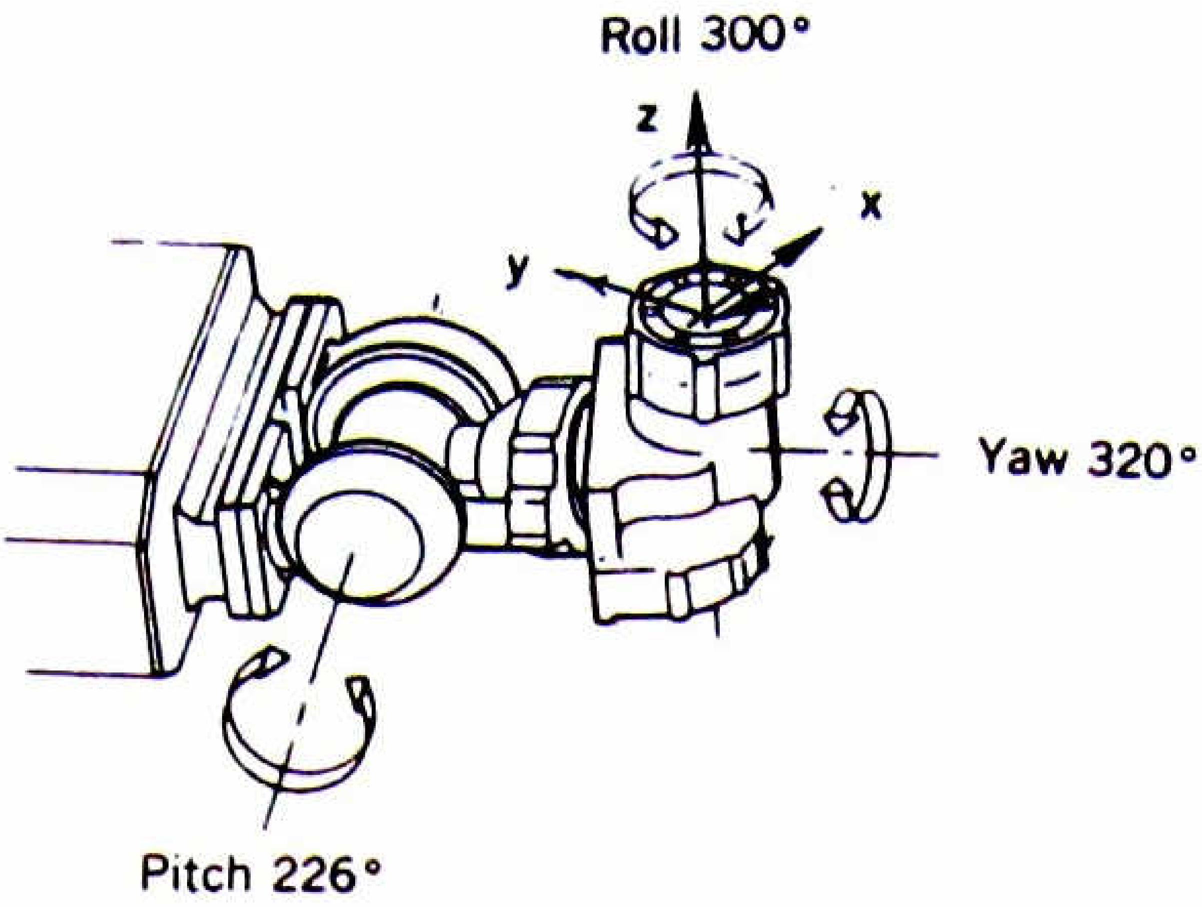
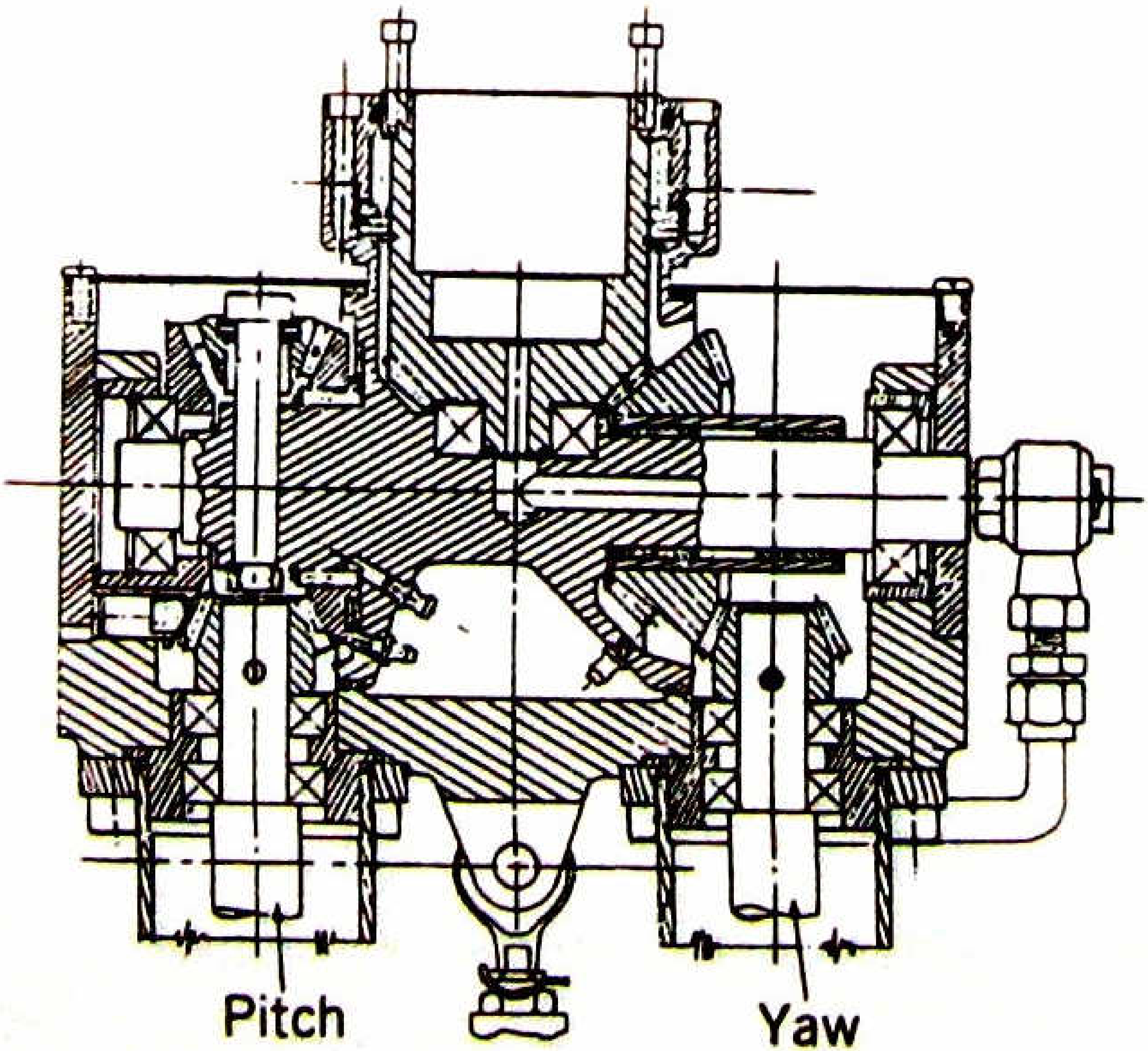
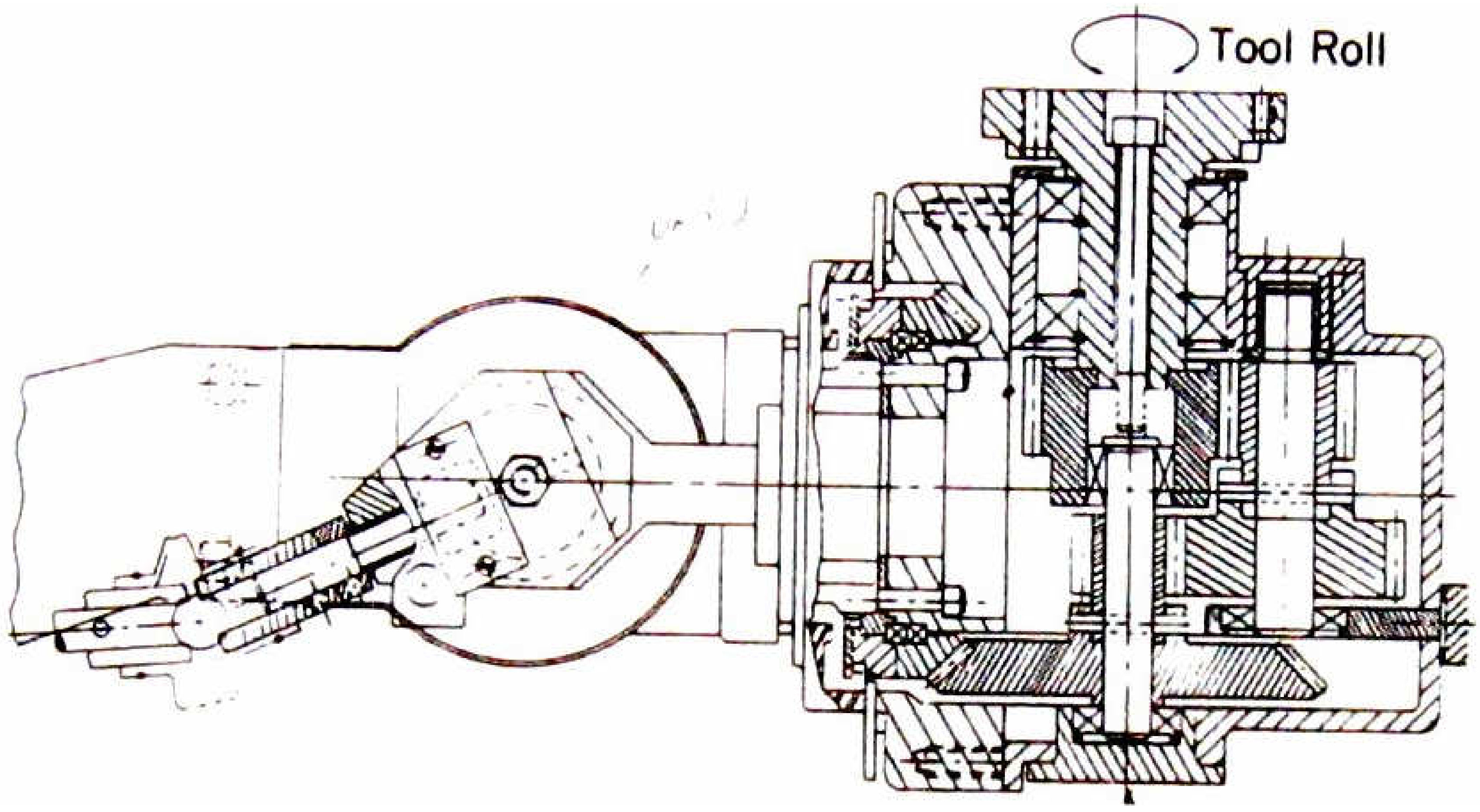


Figure 3.13 Unimate 2000B Wrist



Pitch
Yaw


Tool Roll

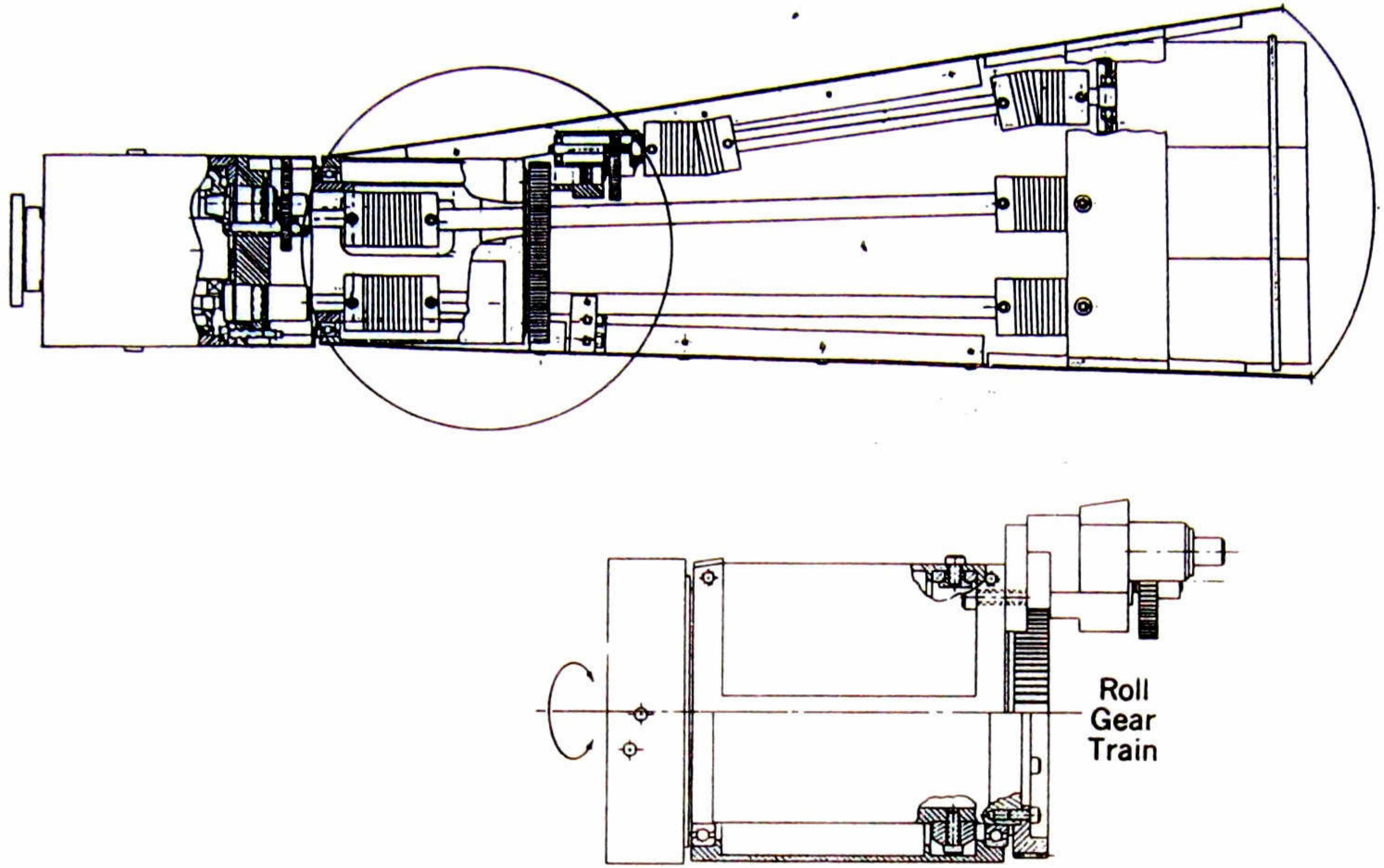


Figure 3.17 Drivetrain of Puma Wrist

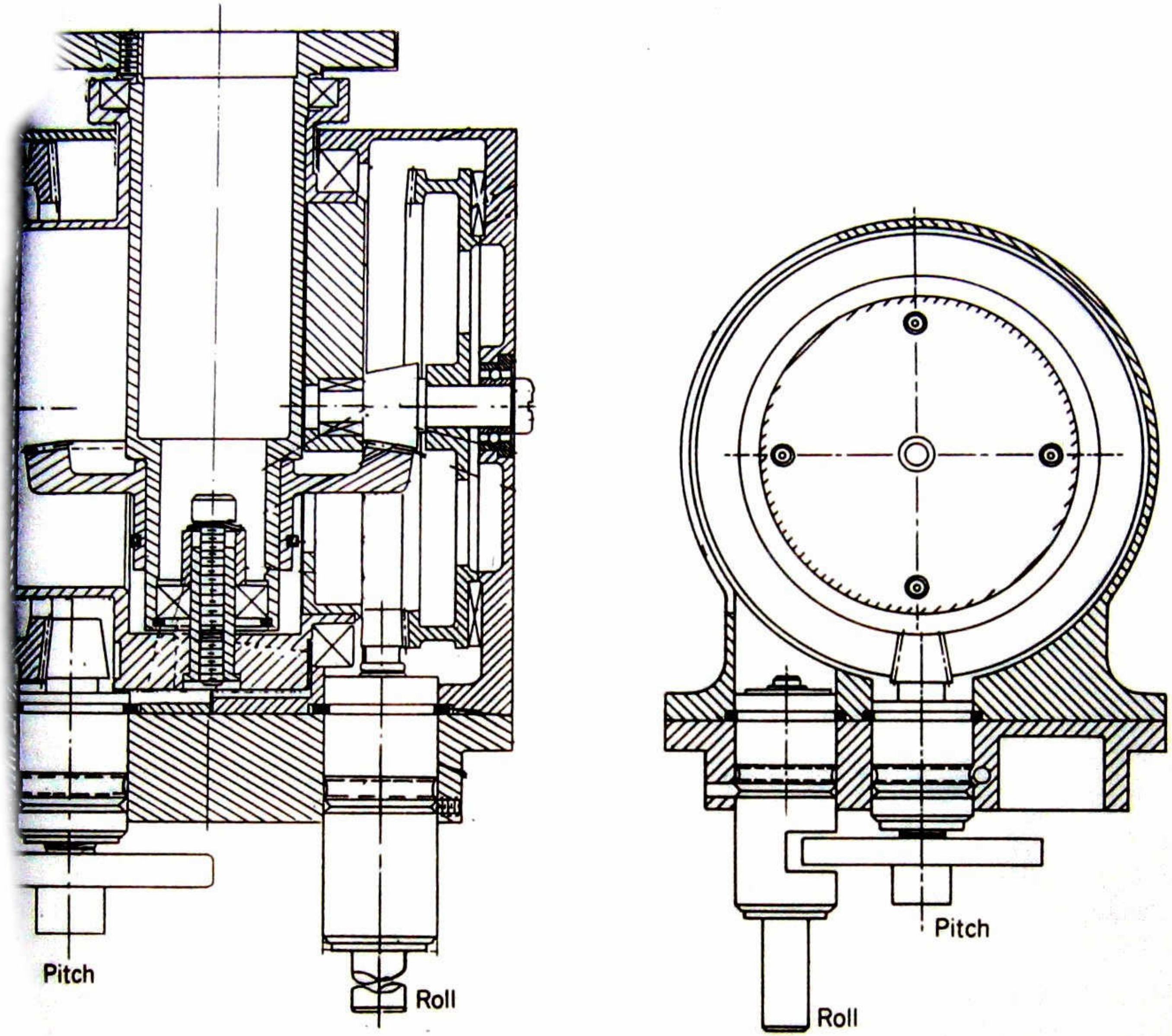


Figure 3.16 PUMA Wrist: Front and Side Sections

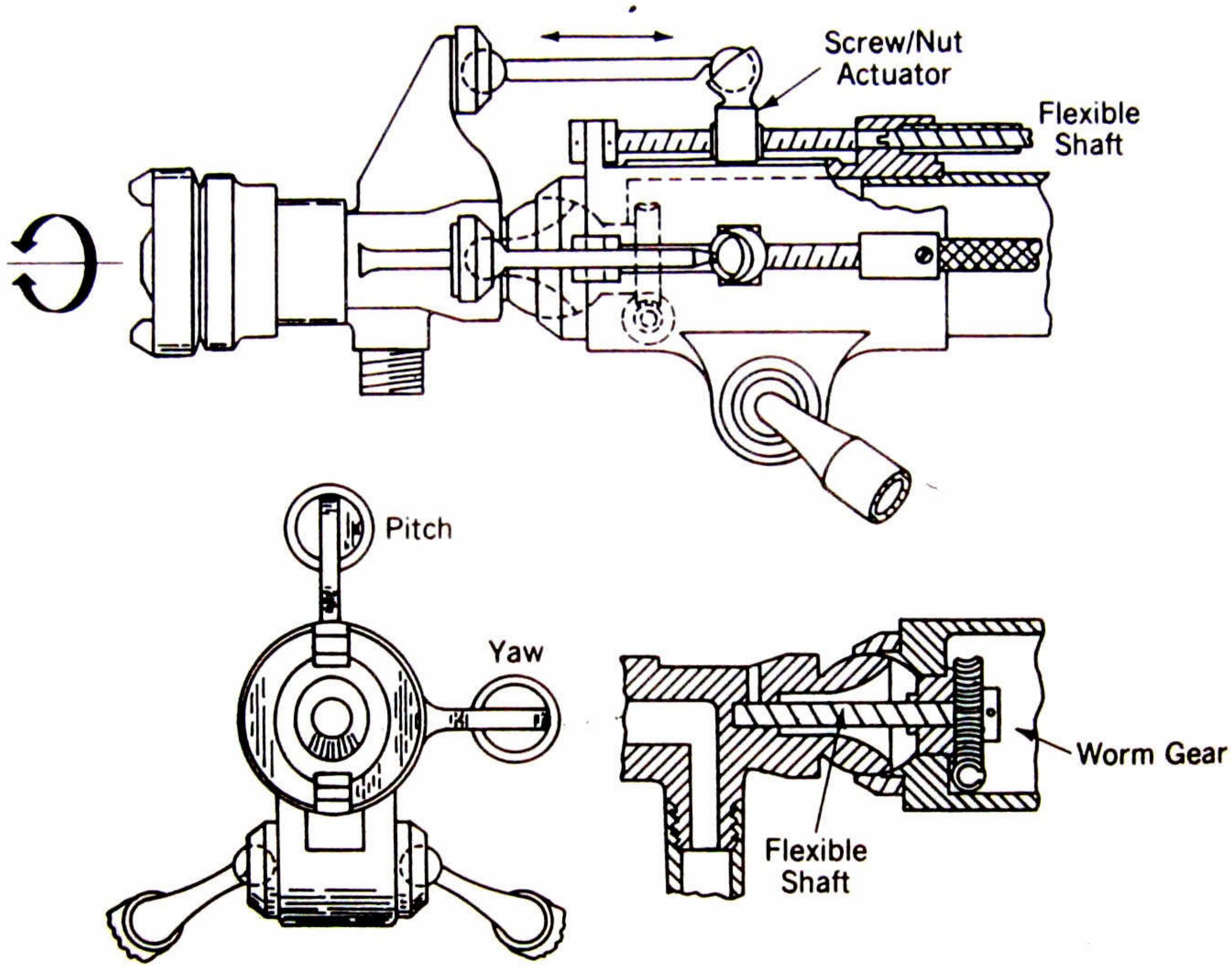
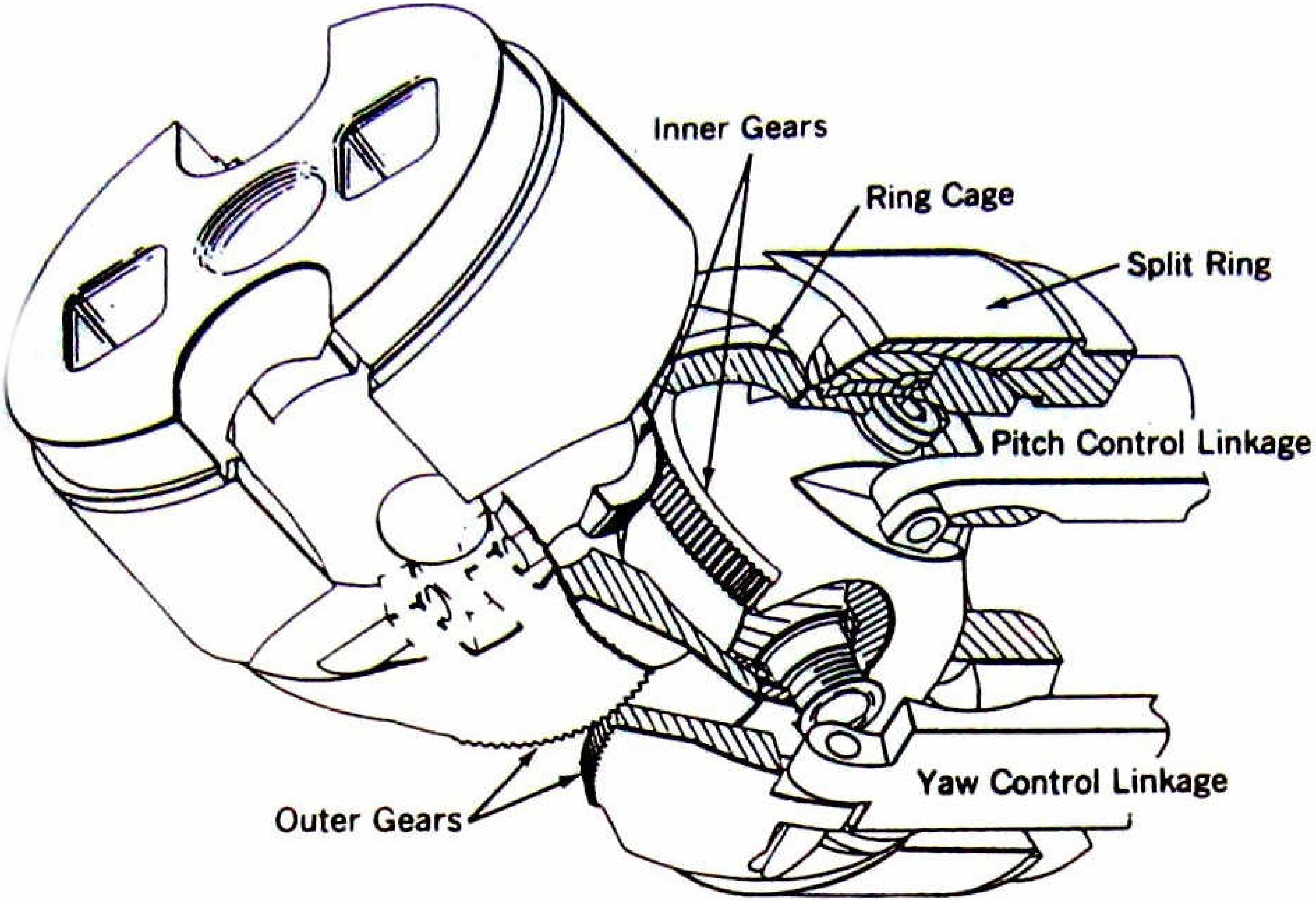
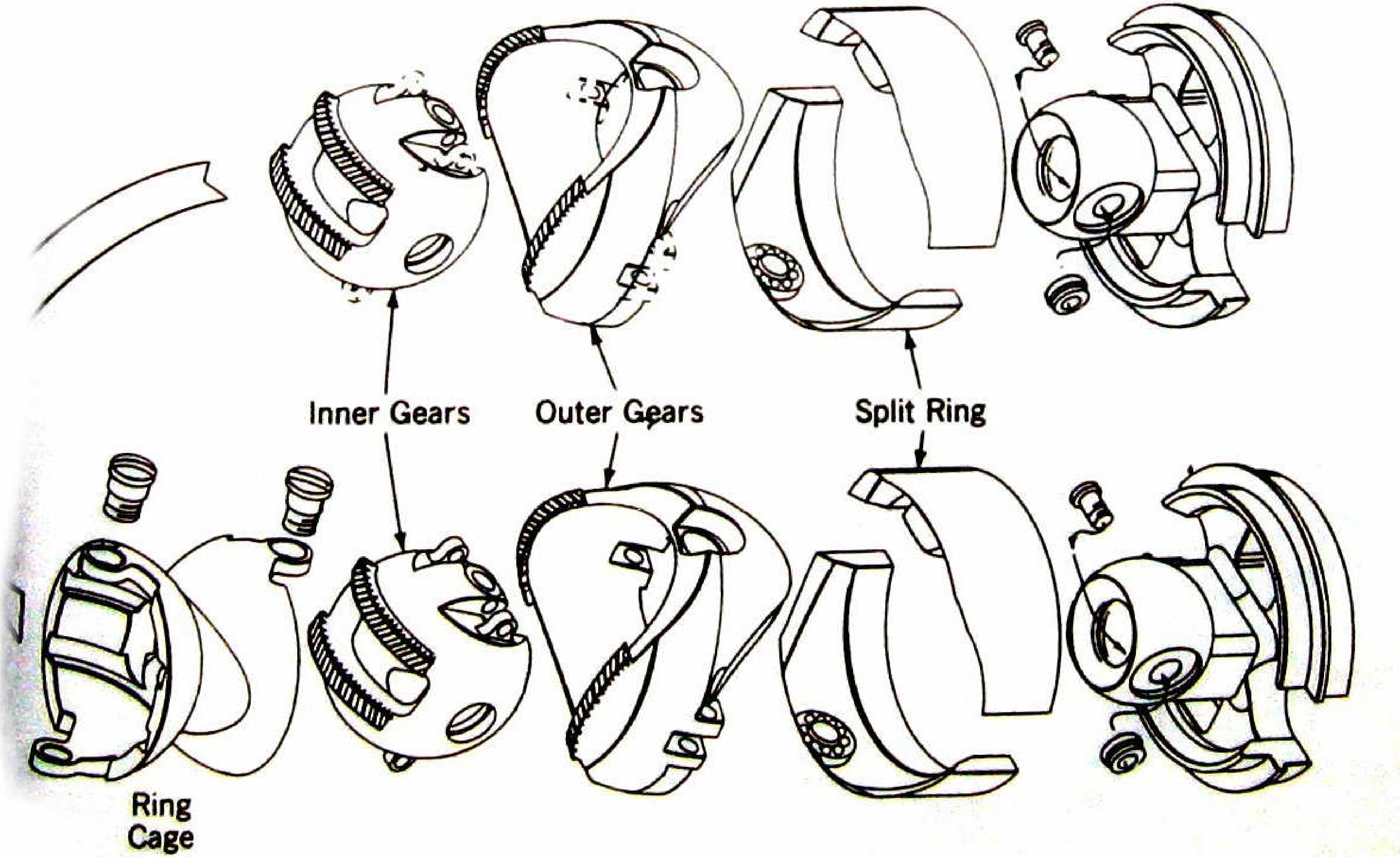
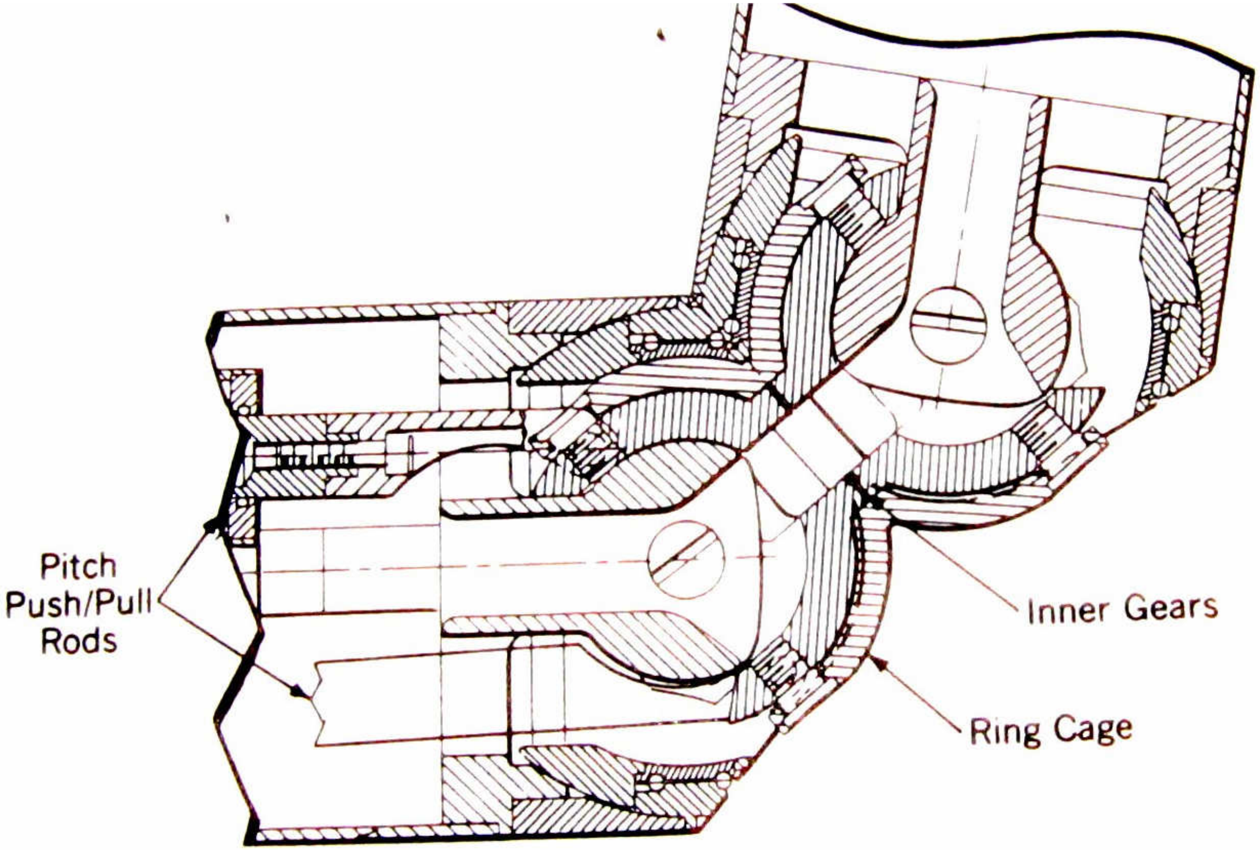


Figure 3.12 Wrist from "Position Controlling Apparatus"

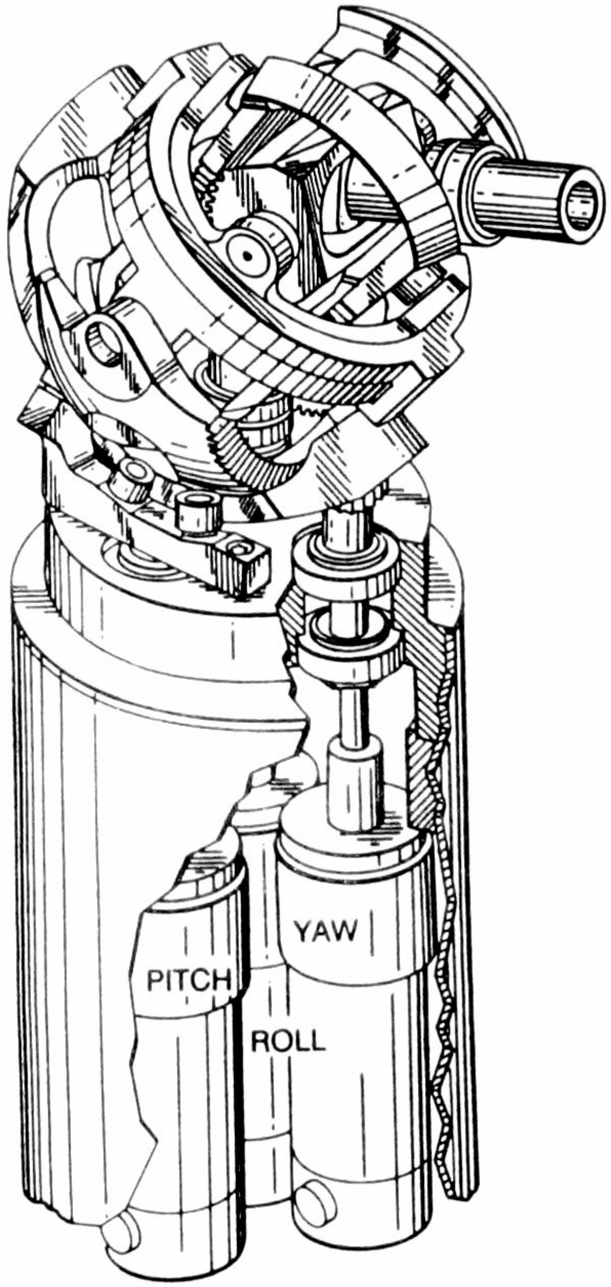

Inner Gears
Ring Cage
Split Ring
Pitch Control Linkage
Yaw Control Linkage
Outer Gears


Inner Gears
Outer Gears
Split Ring
Ring Cage

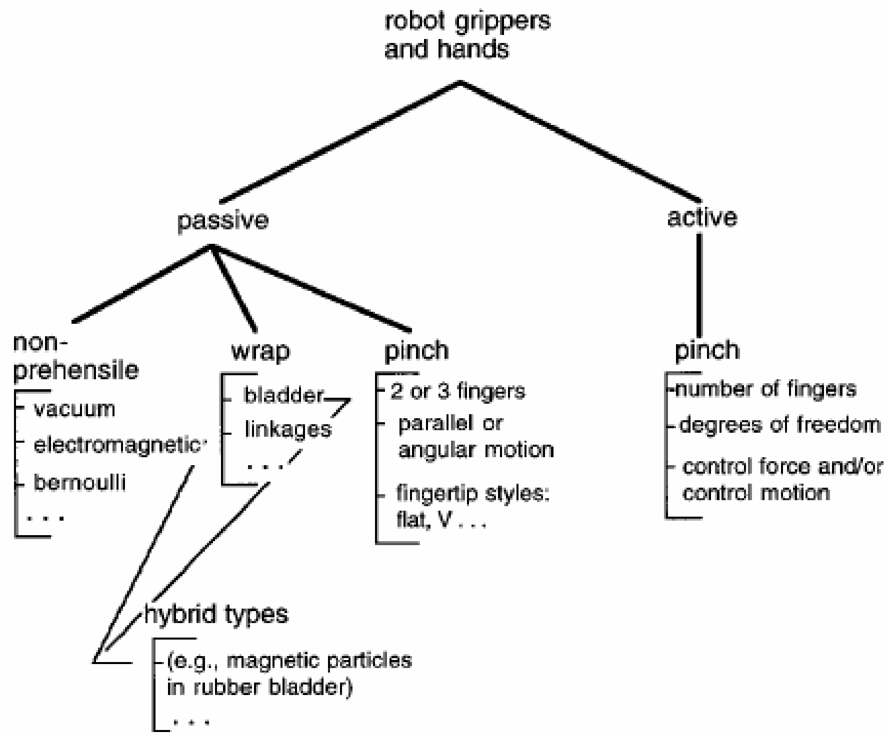

Pitch
Push/Pull
Rods
Inner Gears
Ring Cage


Y

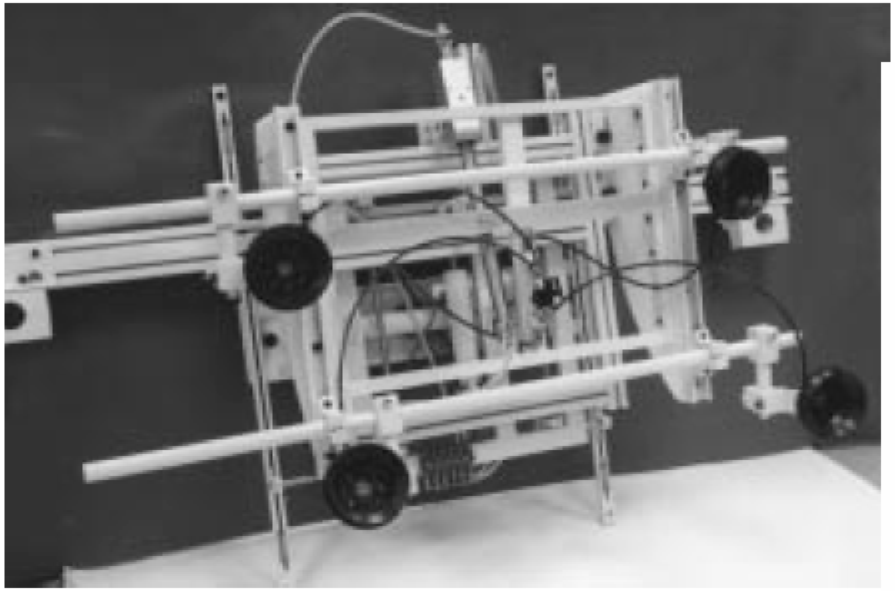

www.anthrobot.com

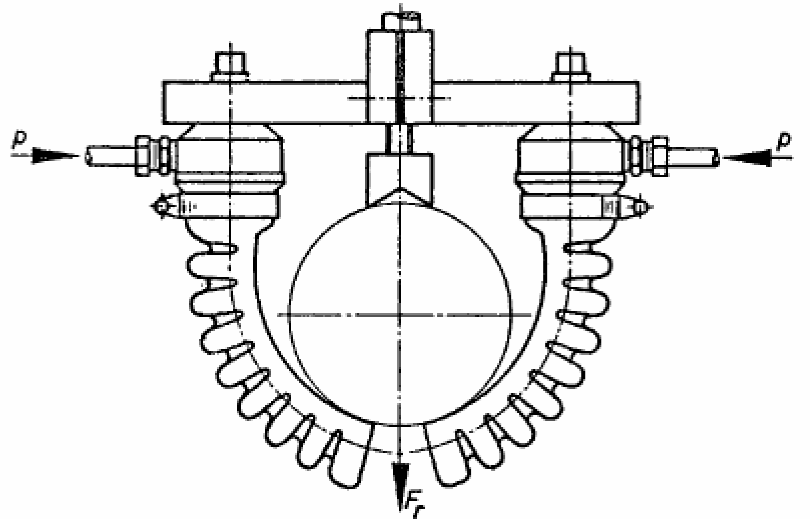

YAW
PITCH
ROLL

PART 3 : grippers



A taxonomy of the basic end effector types.




p
p
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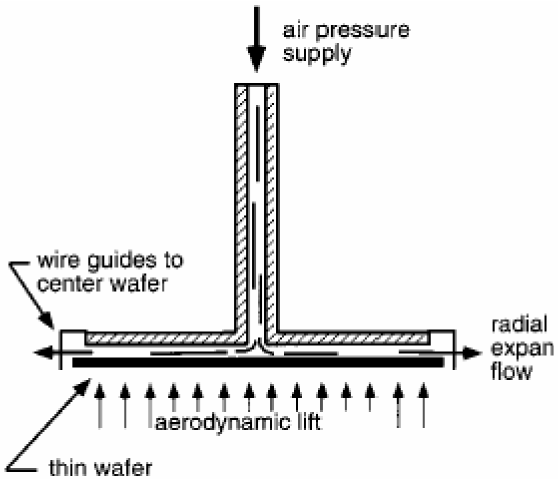
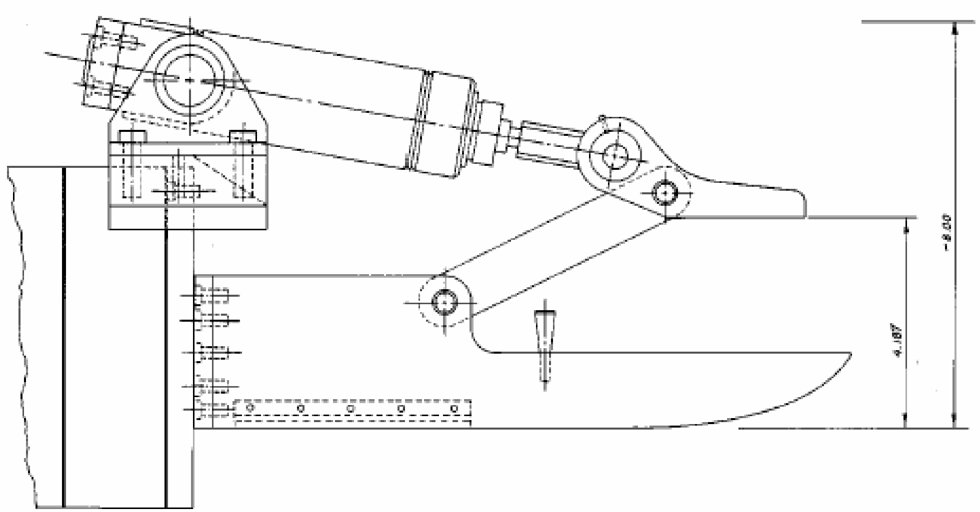
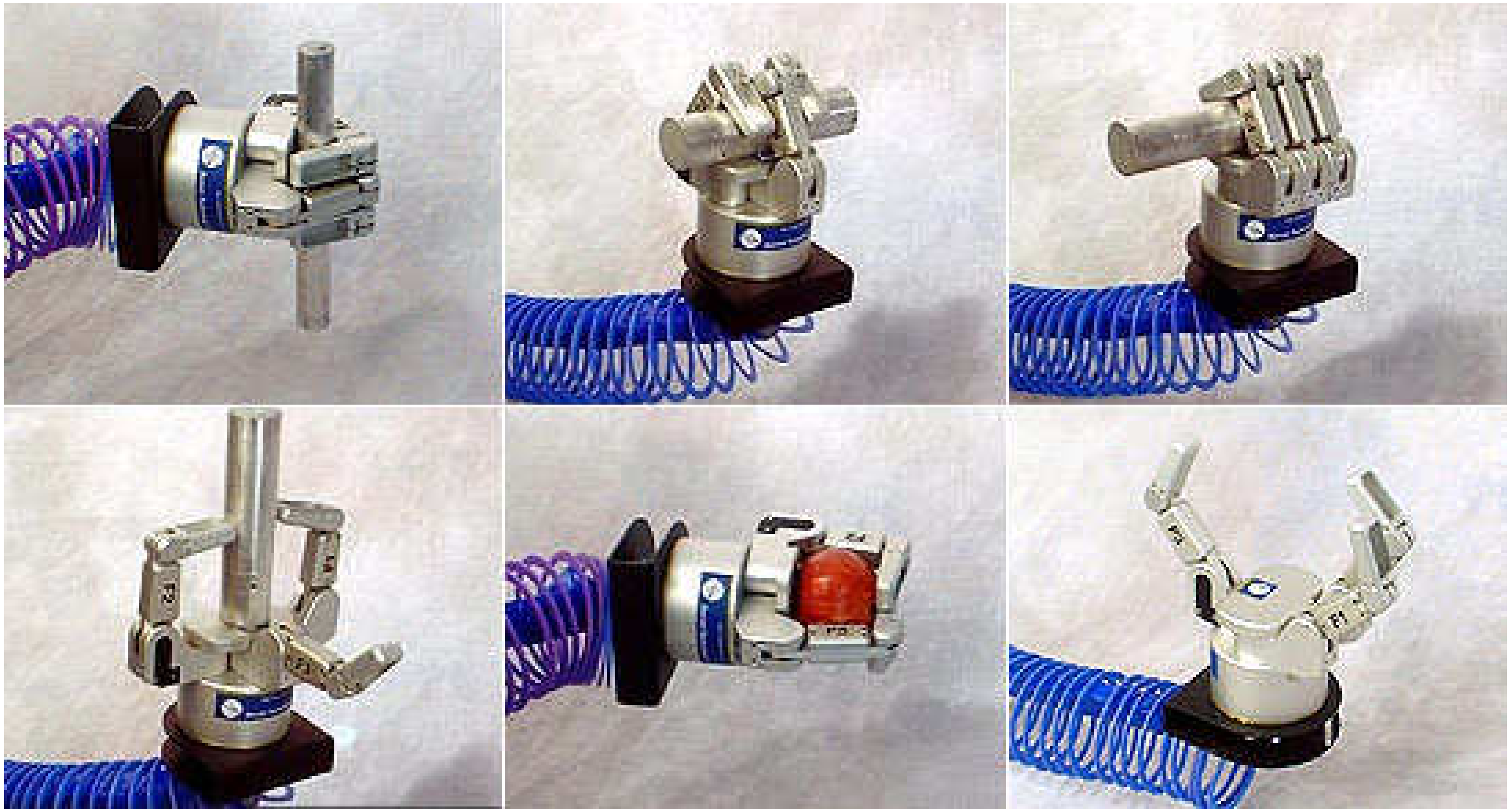
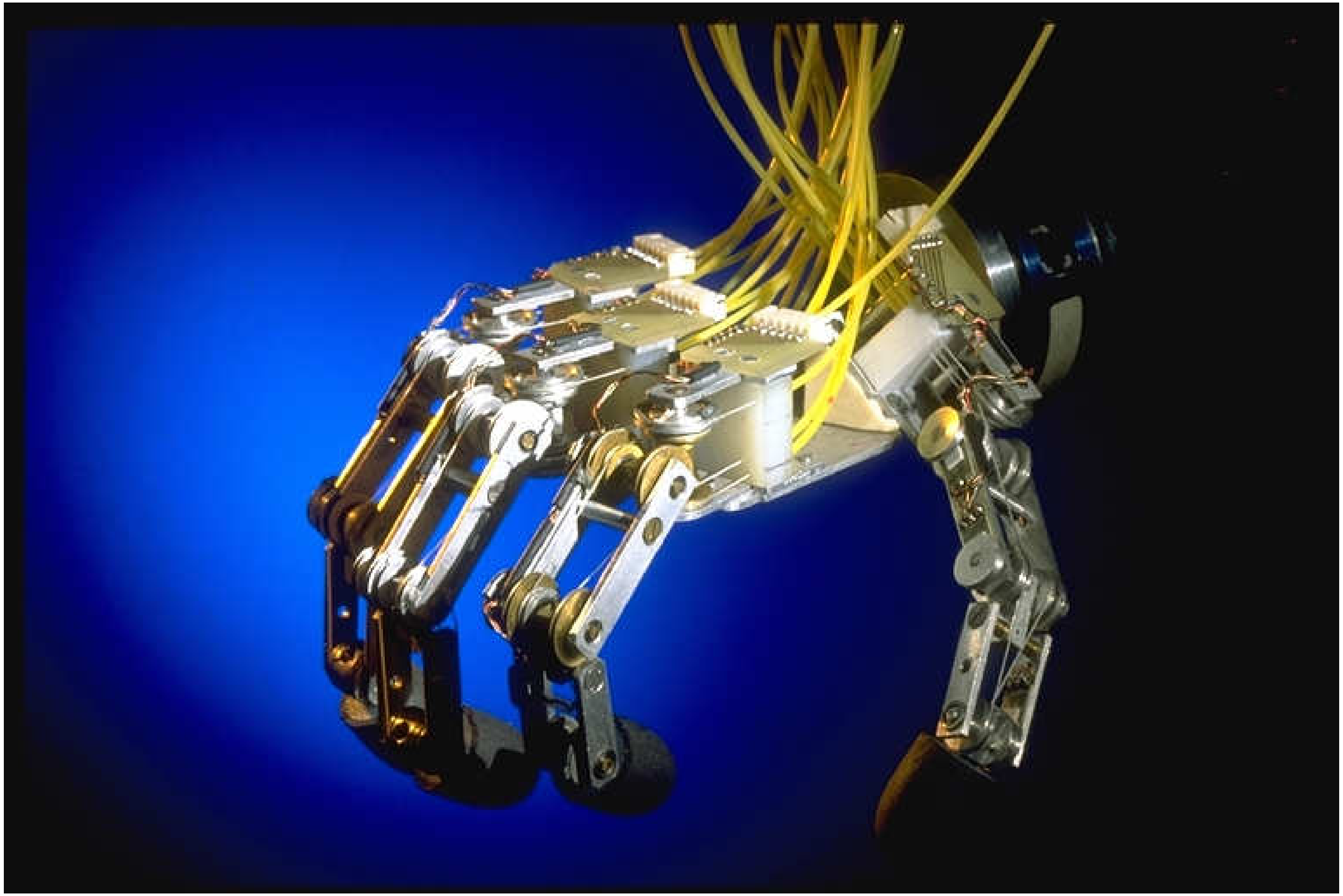
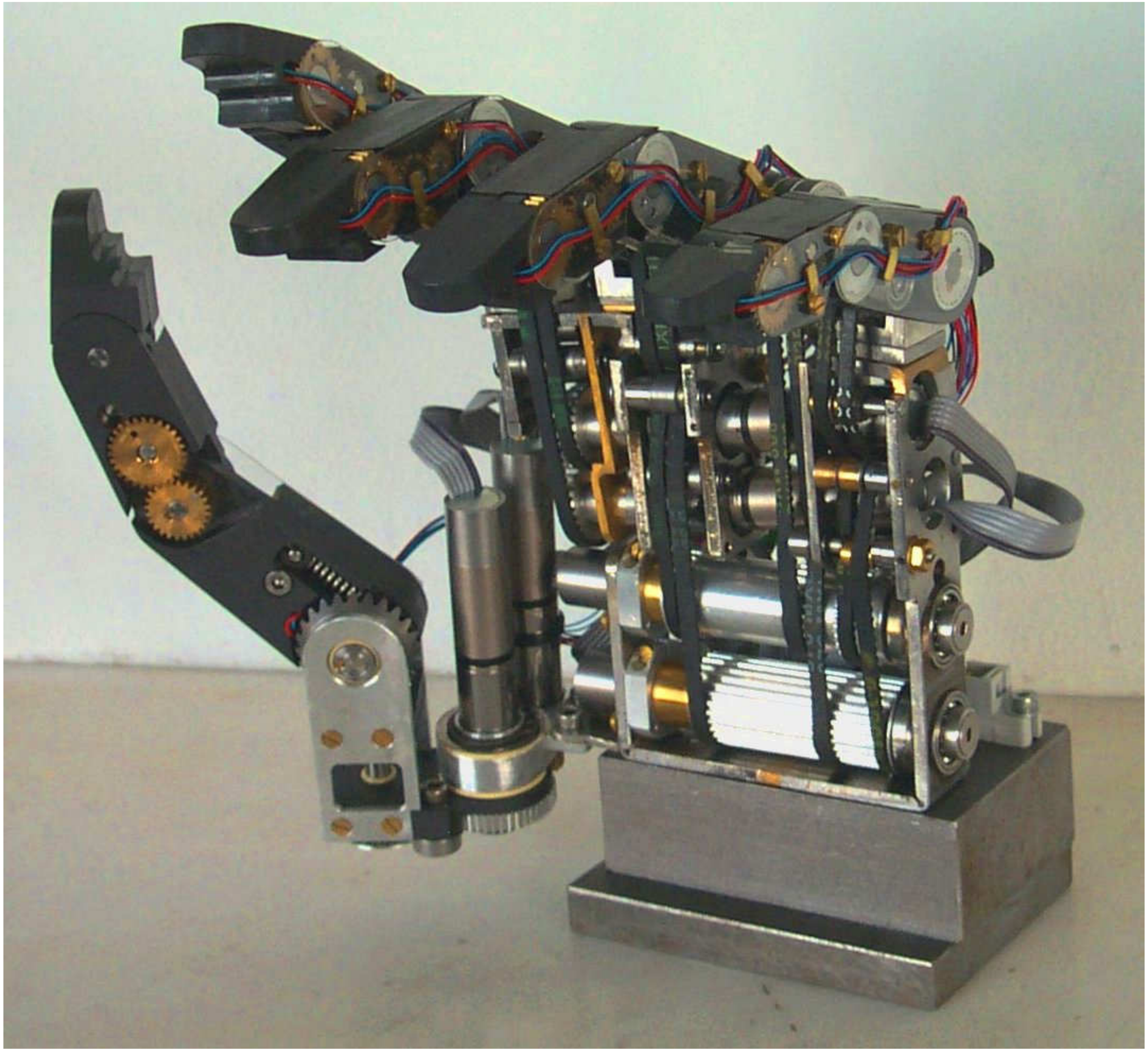

air pressure
supply
wire guides to
center wafer
radial
expan
flow
aerodynamic lift
thin wafer

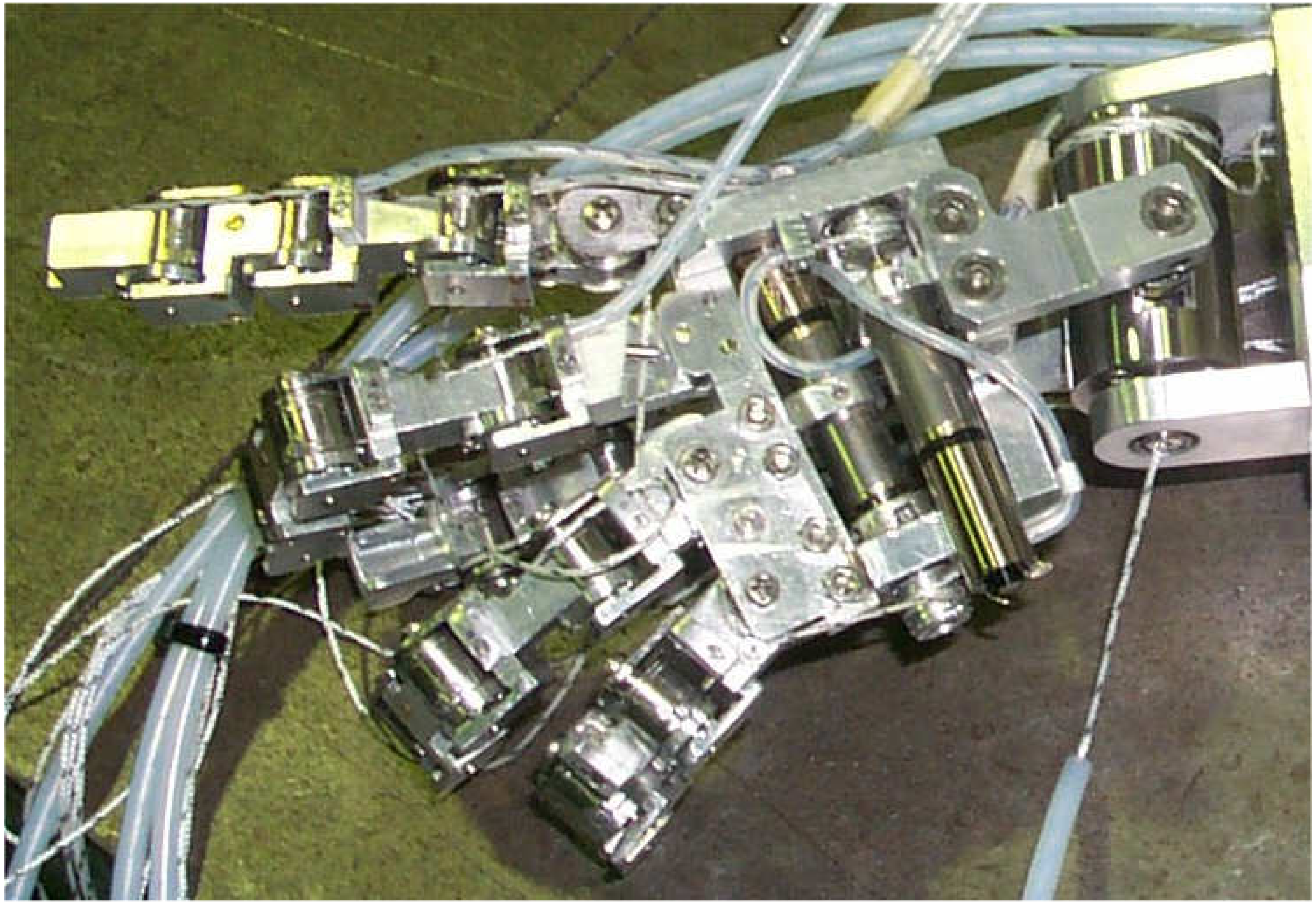


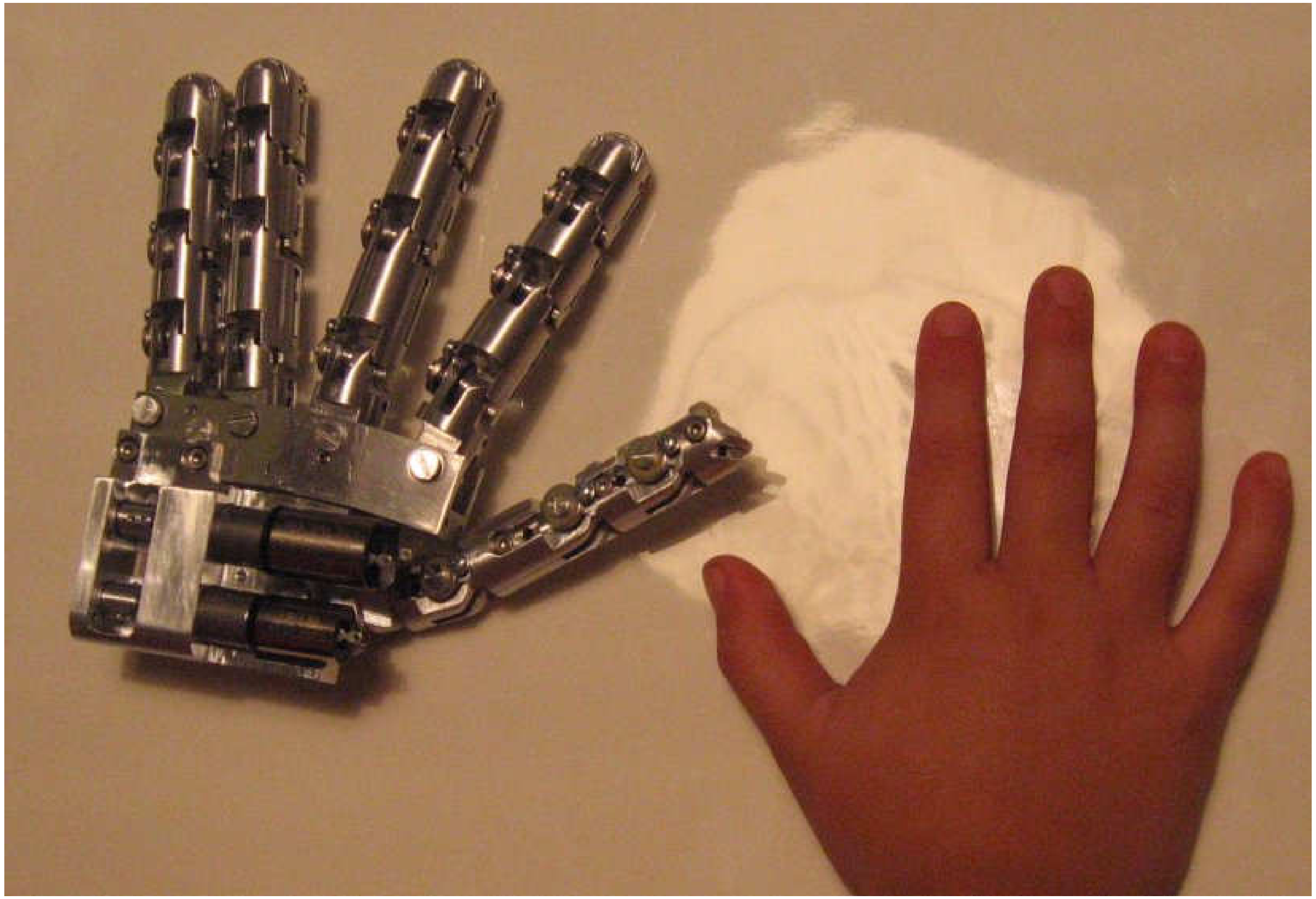

naiss
Typ NK







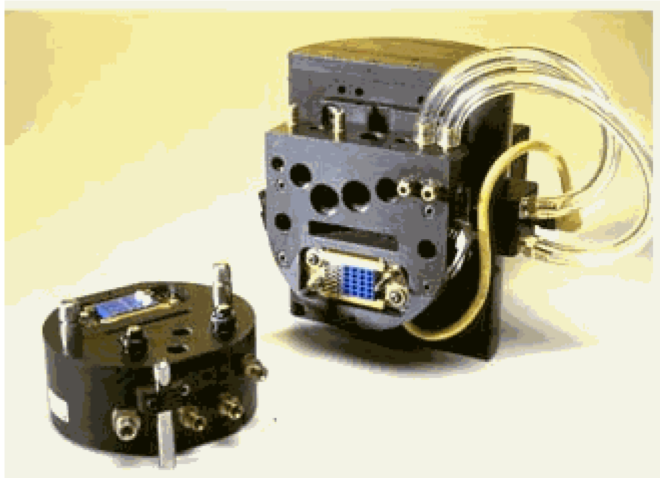



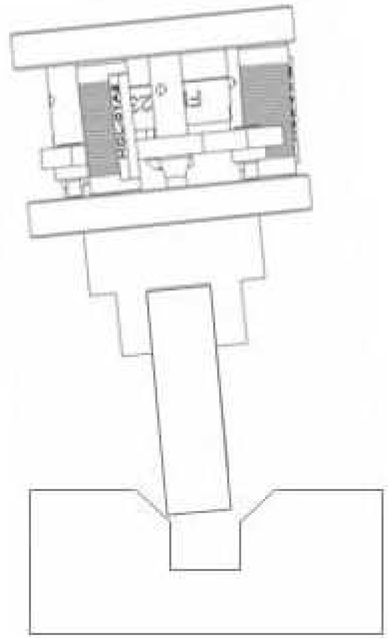


Example Program

This program demonstrates a simple pick and place operation.

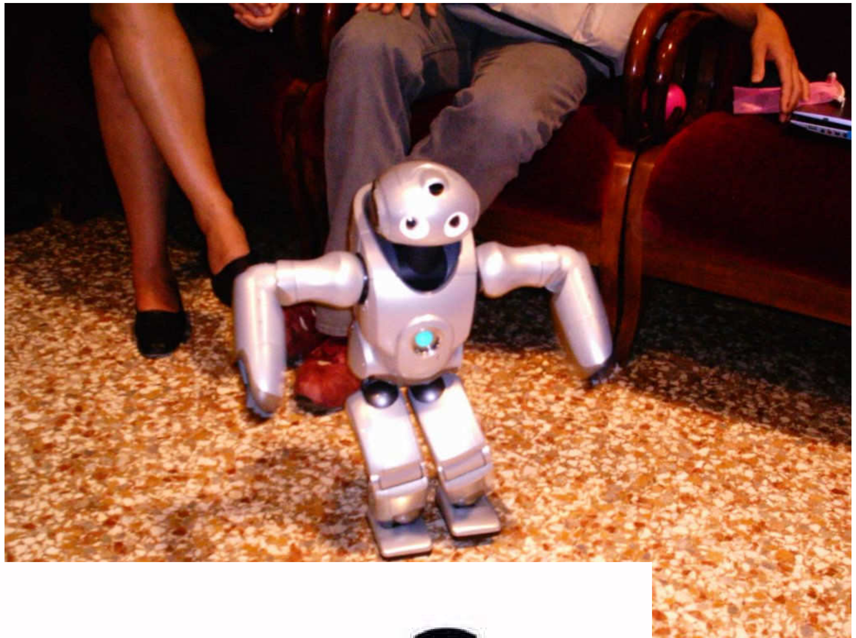
```
.PROGRAM move.parts()
; Pick up parts at location “pick” and put them down at “place”
parts = 100                               ; Number of parts to be processed
height1 = 25                              ; Approach/depart height at “pick”
height2=50;
Approach/depart height at “place”
PARAMETER.HAND.TIME = 16                  ; Setup for slow hand
OPEN                                      ; Make sure hand is open
MOVE start                                ; Move to safe starting location
For i = 1 TO parts                        ; Process the parts
APPRO pick, height1                       ; Go toward the pick-up
MOVES pick                                ; Move to the part
CLOSEI                                    ; Close the hand
DEPARTS height1                           ; Back away
APPRO place, height2                      ; Go toward the put-down
MOVES place                               ; Move to the destination
OPENI                                     ; Release the part
DEPARTS height2                           ; Back away
END                                       ; Loop for the next part
TYPE “ALL done.”, /I3, parts, “parts processed”
STOP                                      ; End of the program
.END
```

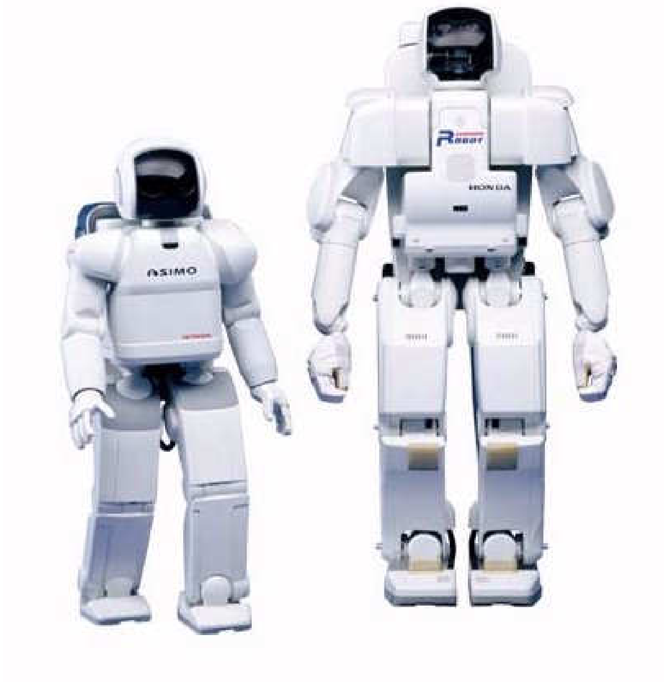




RCC and wrist flanges

PART 4 : more advanced robots

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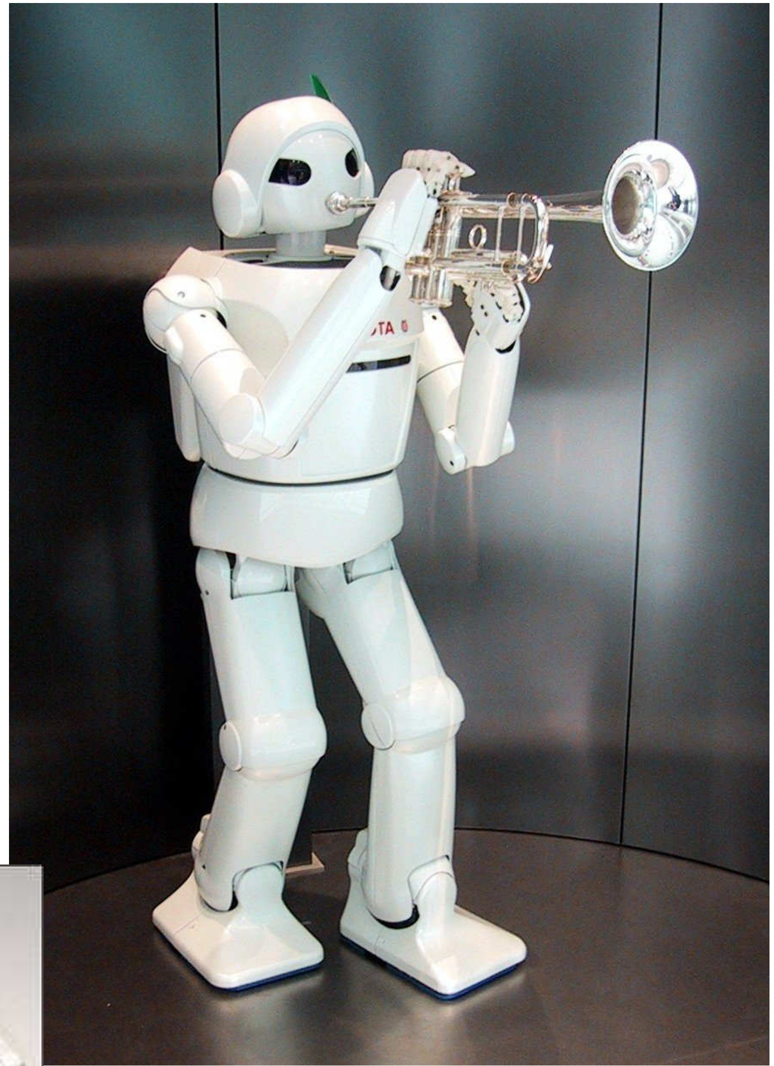

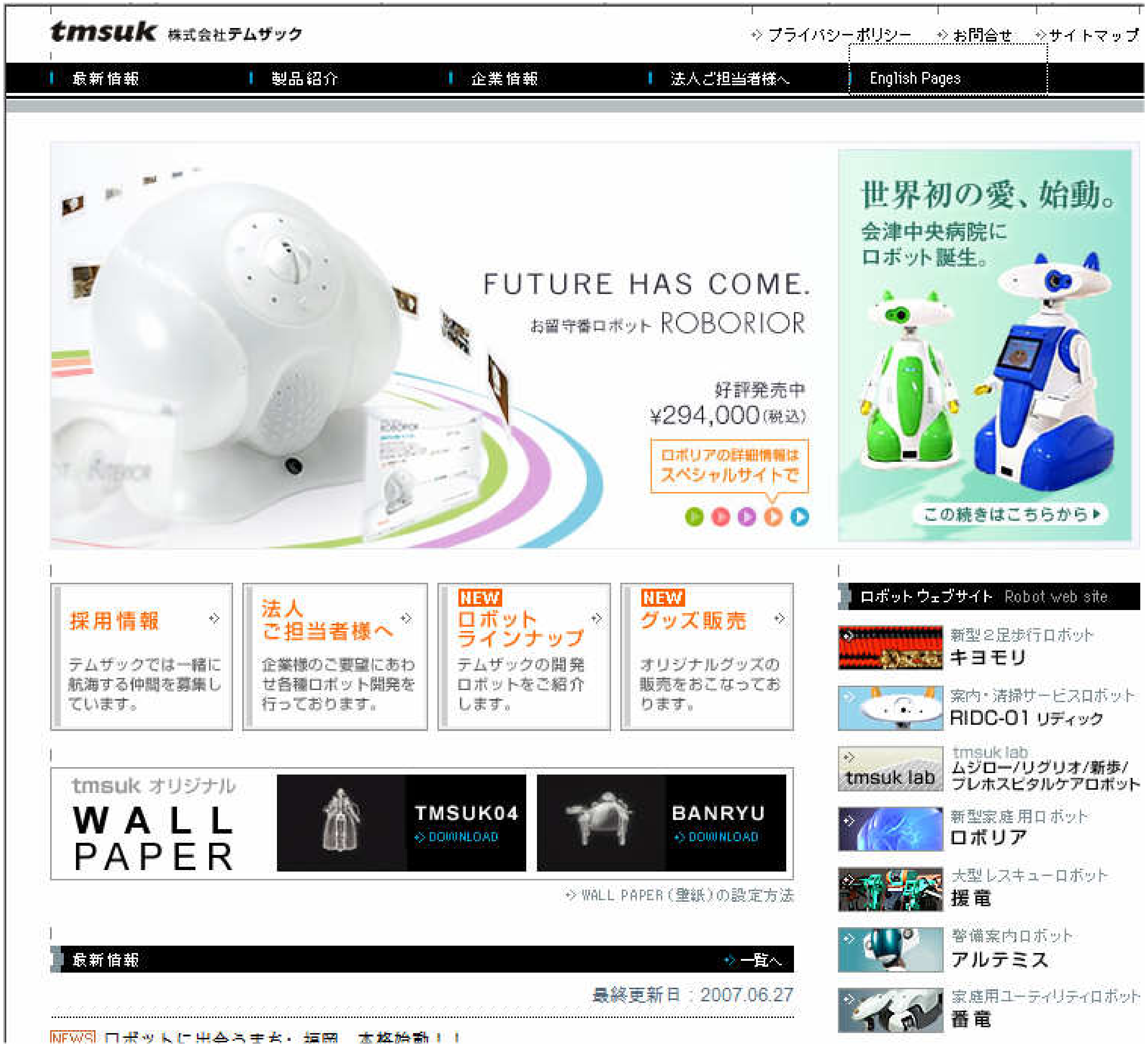
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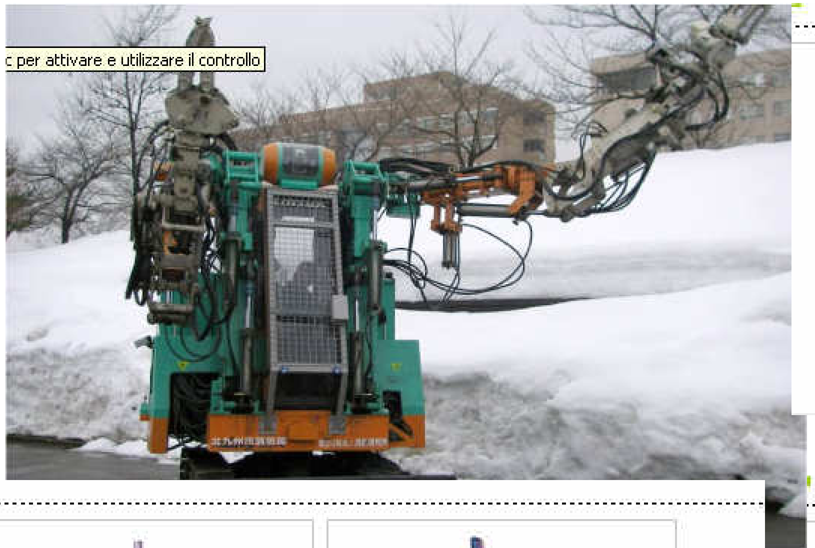
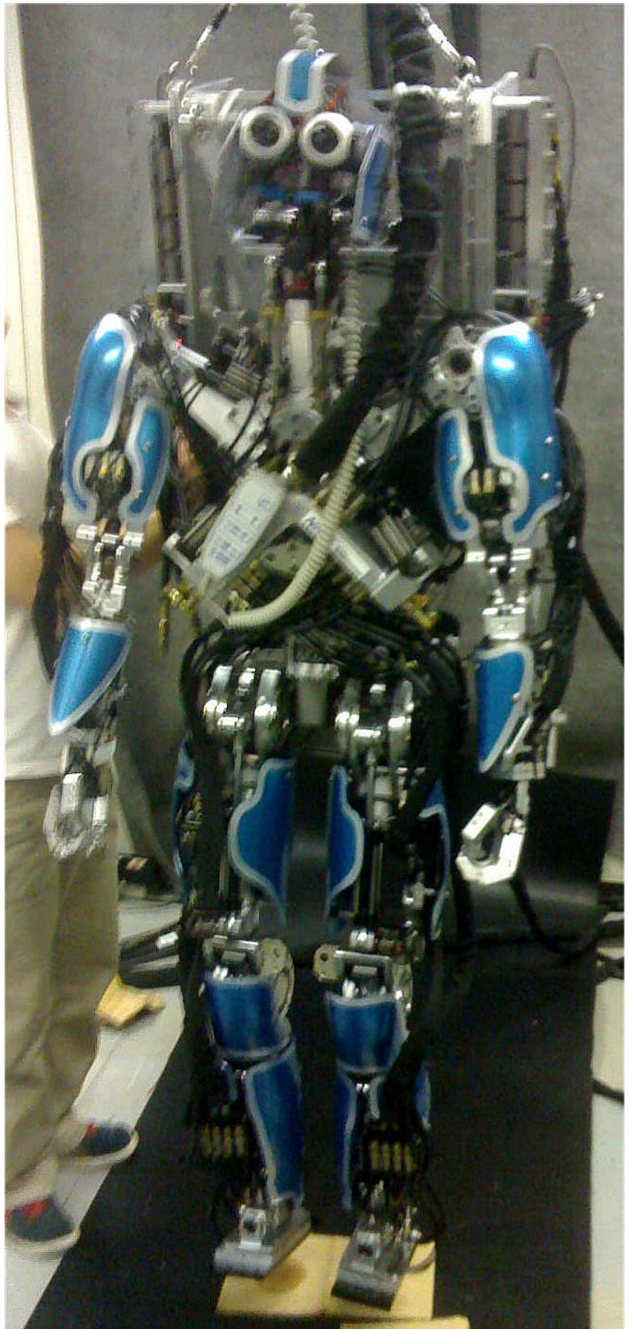
プレホスピタルケアロボット
新型家庭用ロボット
ロボリア
大型レスキューロボット
援竜
警備案内ロボット
アルテミス
家庭用ユーティリティロボット
番竜

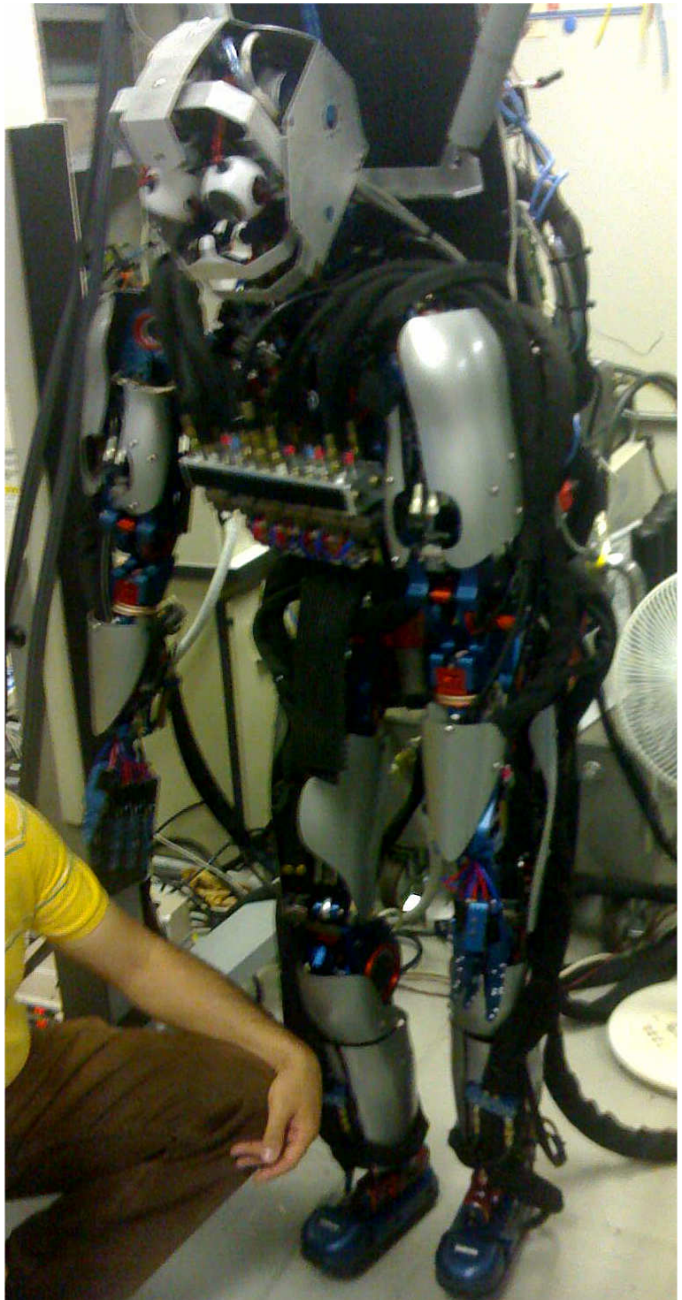

正面
側面
背面
RIDC-01

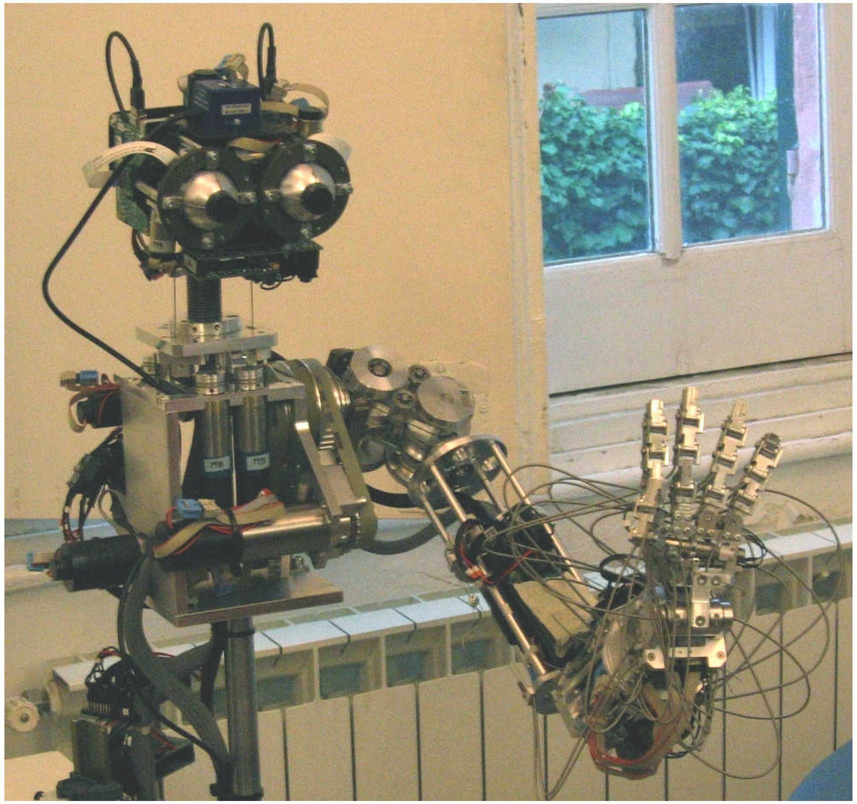
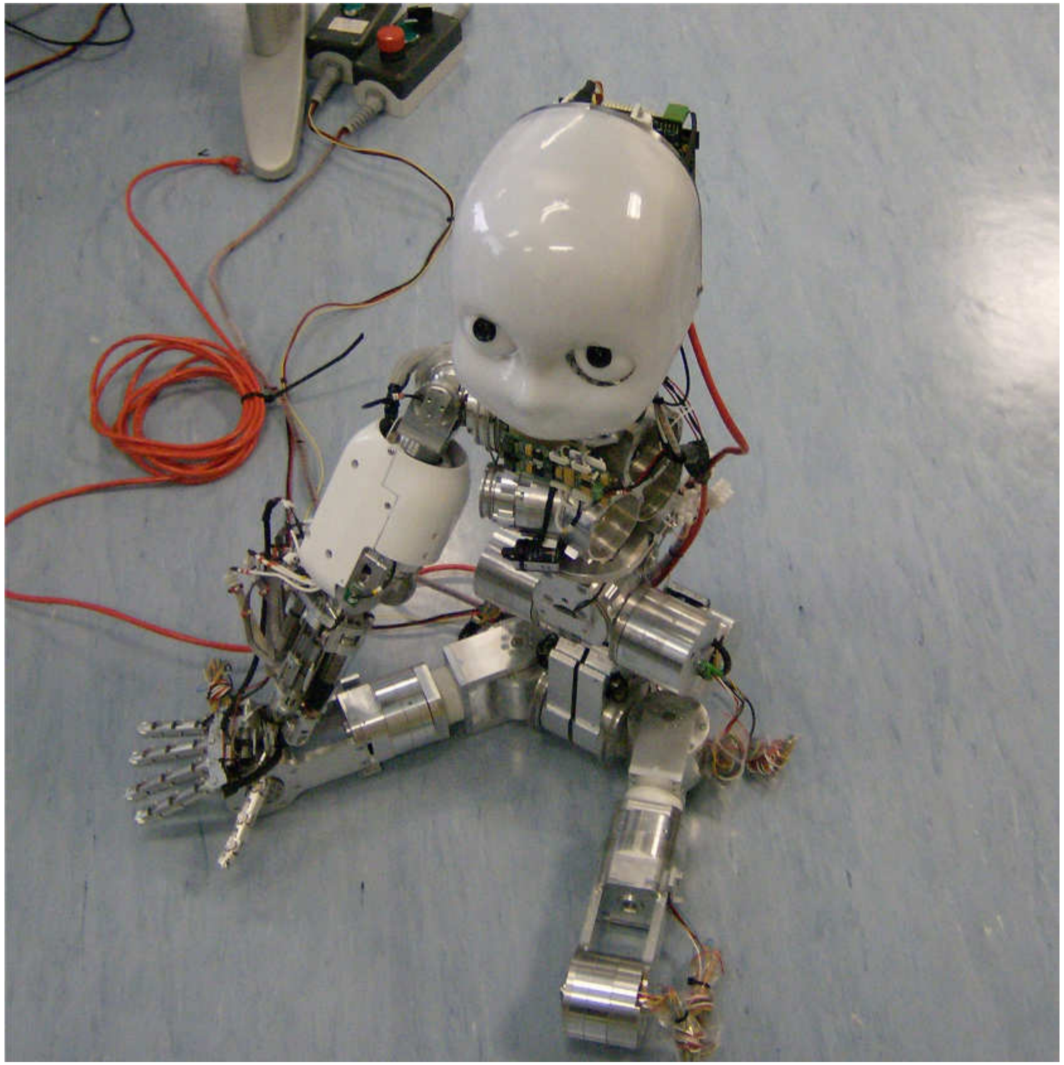

c per attivare e utilizzare il controllo


photo


(a)

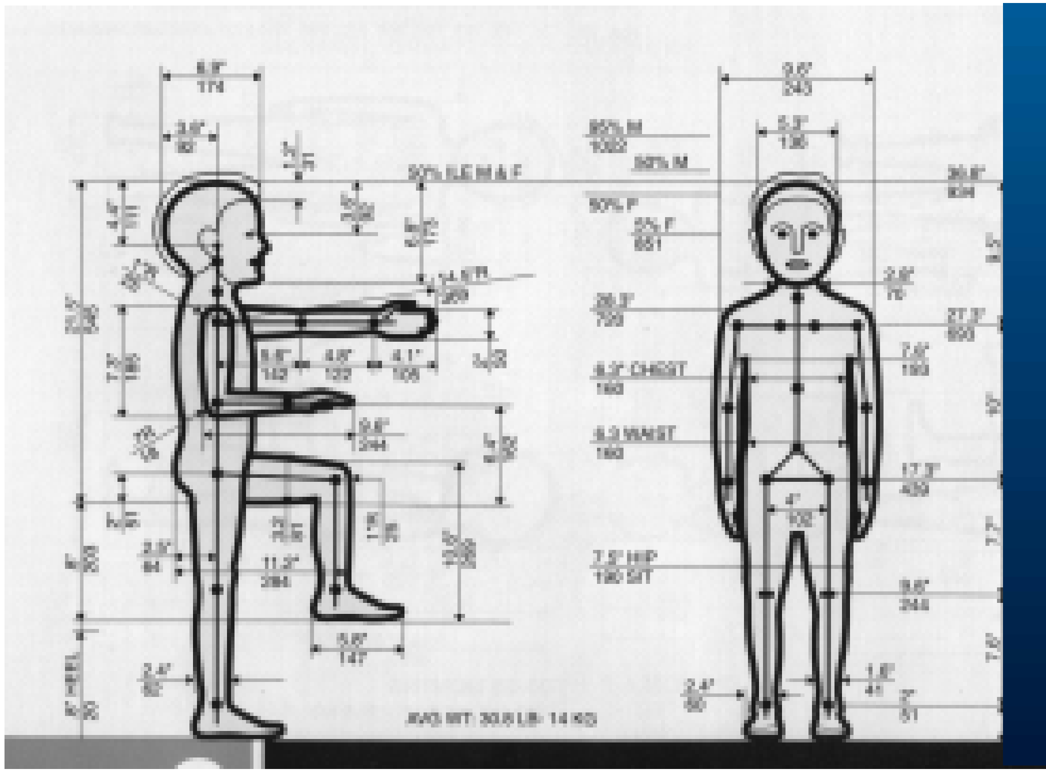


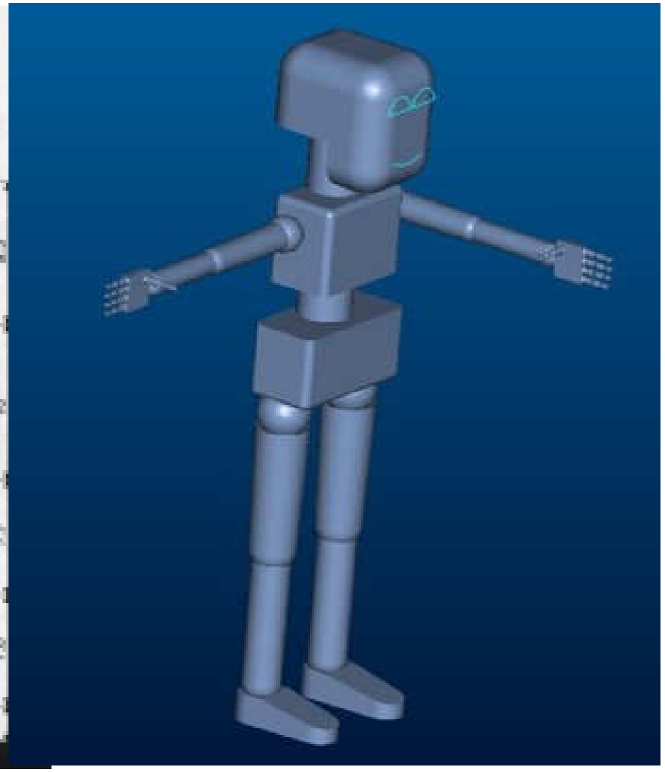


iCUB approach in humanoid design

From normotype to a 3D common reference model





All must fit in the model !

Platfom weight definition

From different experiences on robotics and common “a priori” evaluation a total weight goal with sub group weight distribution is defined

CUB weight preliminary table list	
	AVRG
HEAD	1.5
LOWER ARM+HAND left	1.25
LOWER ARM+HAND right	1.25
UPPER ARM left	1.15
UPPER ARM right	1.15
UPPER TORSO	3.75
LOWER TORSO	6.5
LEG left	3.5
LEG right	3.5
upper body	10.05
lower body	13.5
TOTAL WEIGHT	23.55

Number of degrees of freedom (task oriented selection)

Arm: 7 dofs;

Waist: 3 dofs;

Leg: 6 dofs;

Hand: 9 dofs;

Head: 6 dofs.

TOTAL: 7x2+3+6x2+9x2+6=53 DOFS

First simulations and first results

1 Hz Crawling	
DOF	Maximum Torque (N.m)
left_arm_1	48.4
left_arm_2	45.6
left_arm_3	10.9
left_elbow	29.4
torso_1	45.8
torso_2	27.2
torso_3	30.1
left_leg_1	46.3
left_leg_2	37.1
left_leg_3	36.8
left_knee	27.4
left_ankle	12.4

0.5 Hz Crawling	
DOF	Maximum Torque (N.m)
left_arm_1	40.4
left_arm_2	18.1
left_arm_3	7.9
left_elbow	18.6
torso_1	34.3
torso_2	26.5
torso_3	13.7
left_leg_1	38.5
left_leg_2	15.1
left_leg_3	23.2
left_knee	28.0
left_ankle	11.3

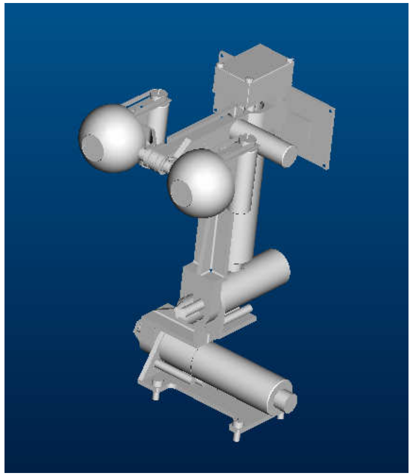
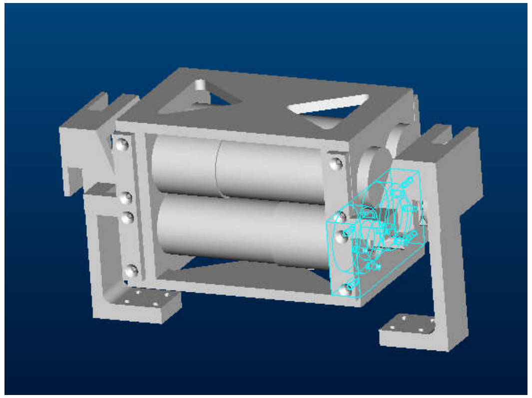
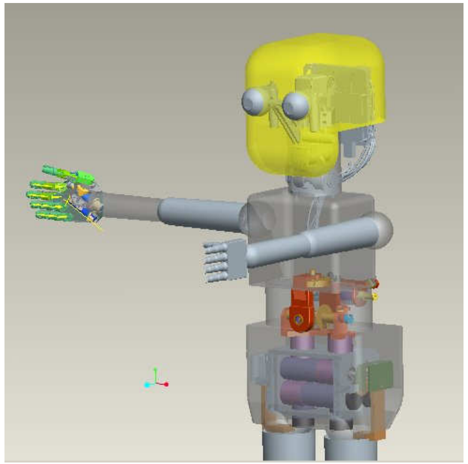
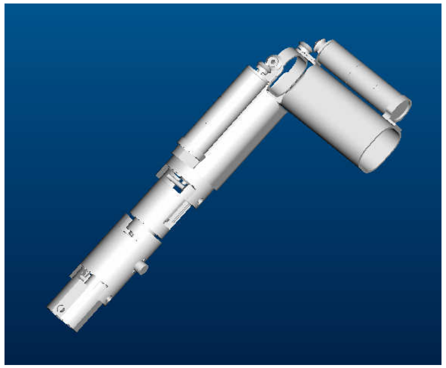
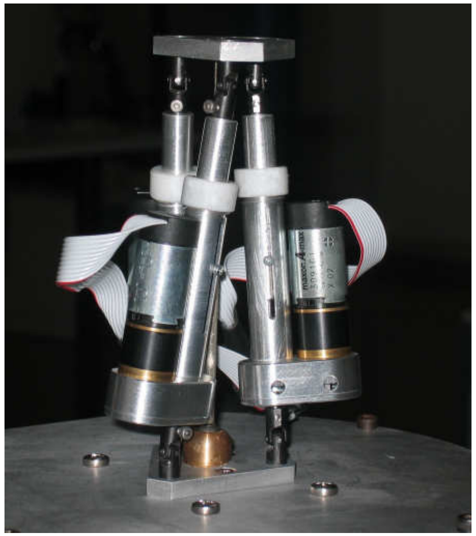
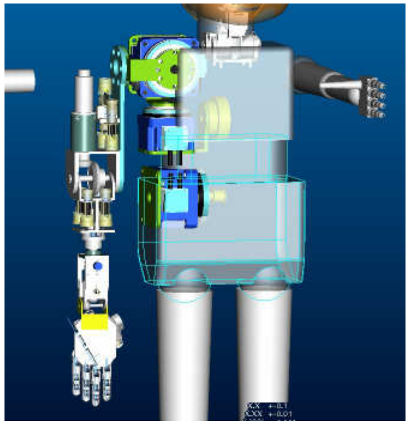
- Work done at EPFL gives to mechanical engineers reference performances for the actuator selection and the design task

- First limitation in the design is the POWER DENSITY for motors
- Second limitation in the design is the stress level in the mechanics (eg. max torques on gears…)

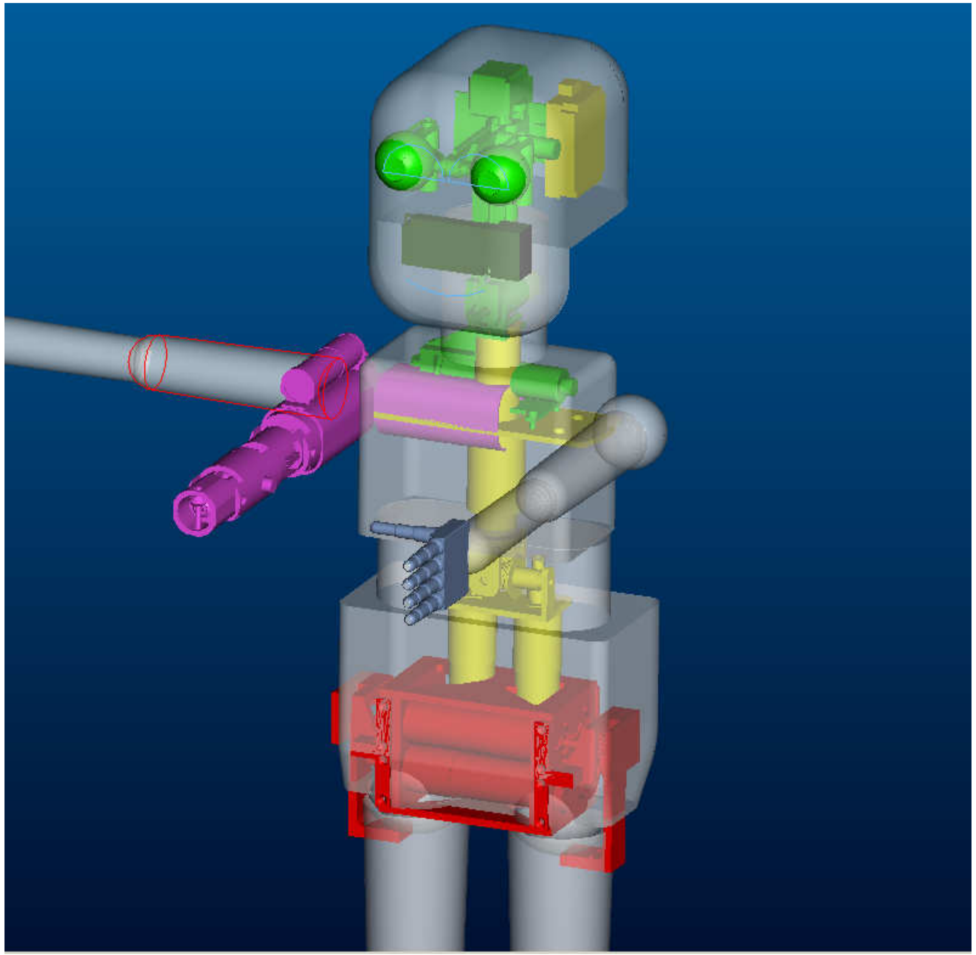
BOTH are phisical limits connected to the available technology

BEST COMPROMISE SOLUTION NEEDS TO BE DEFINED

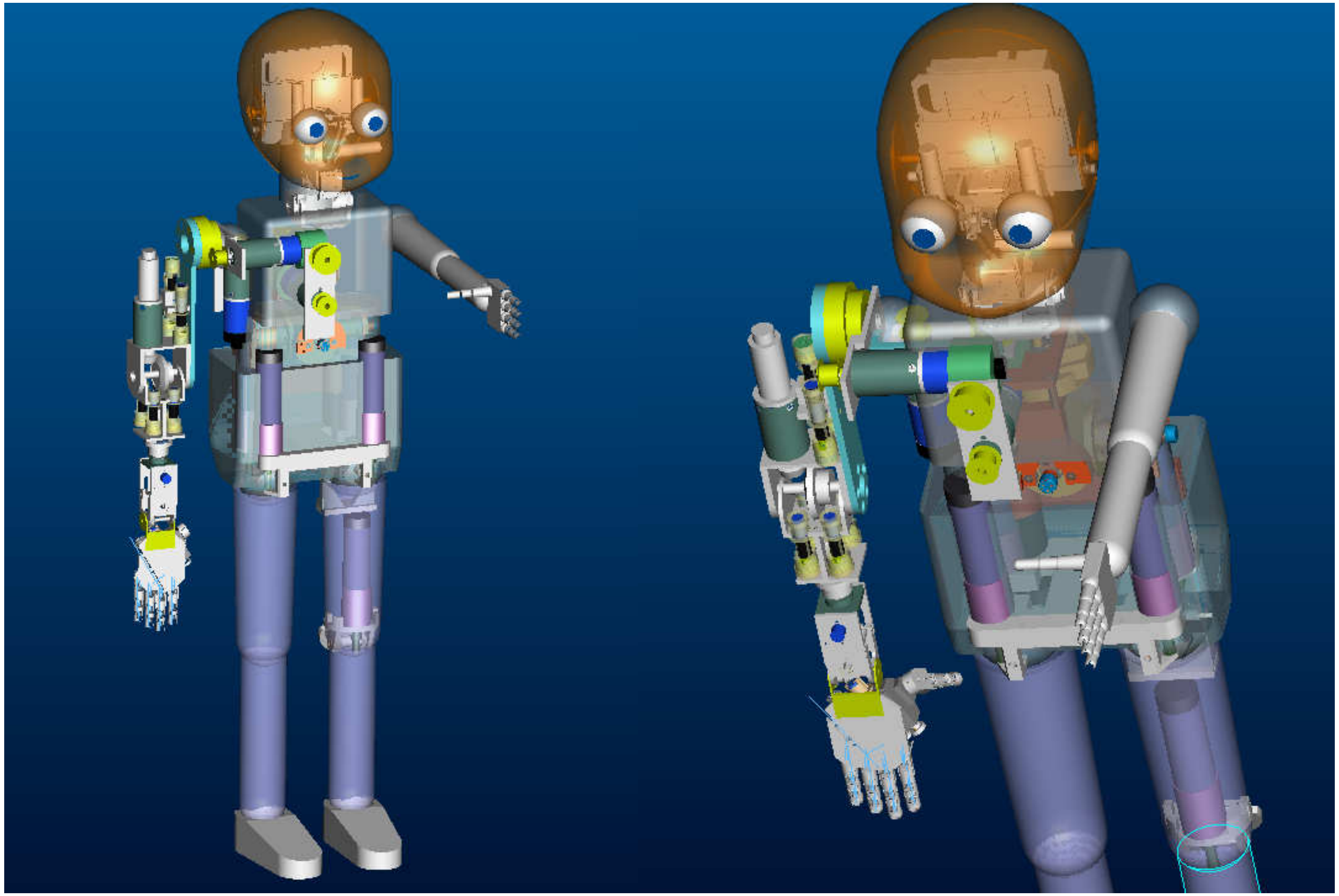
..design evolution and concurrent design

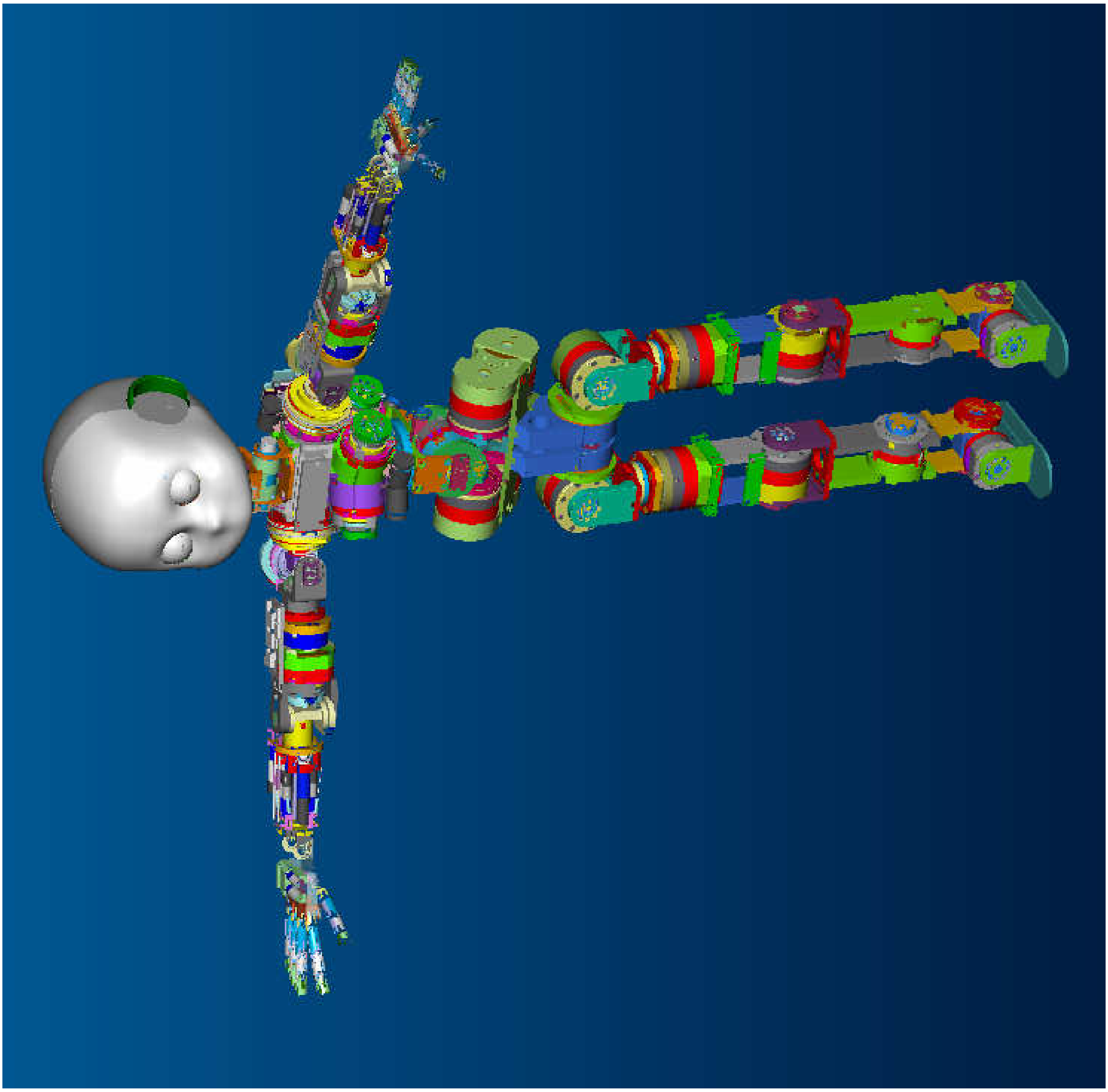
..the integration task:first attempt (march 05)

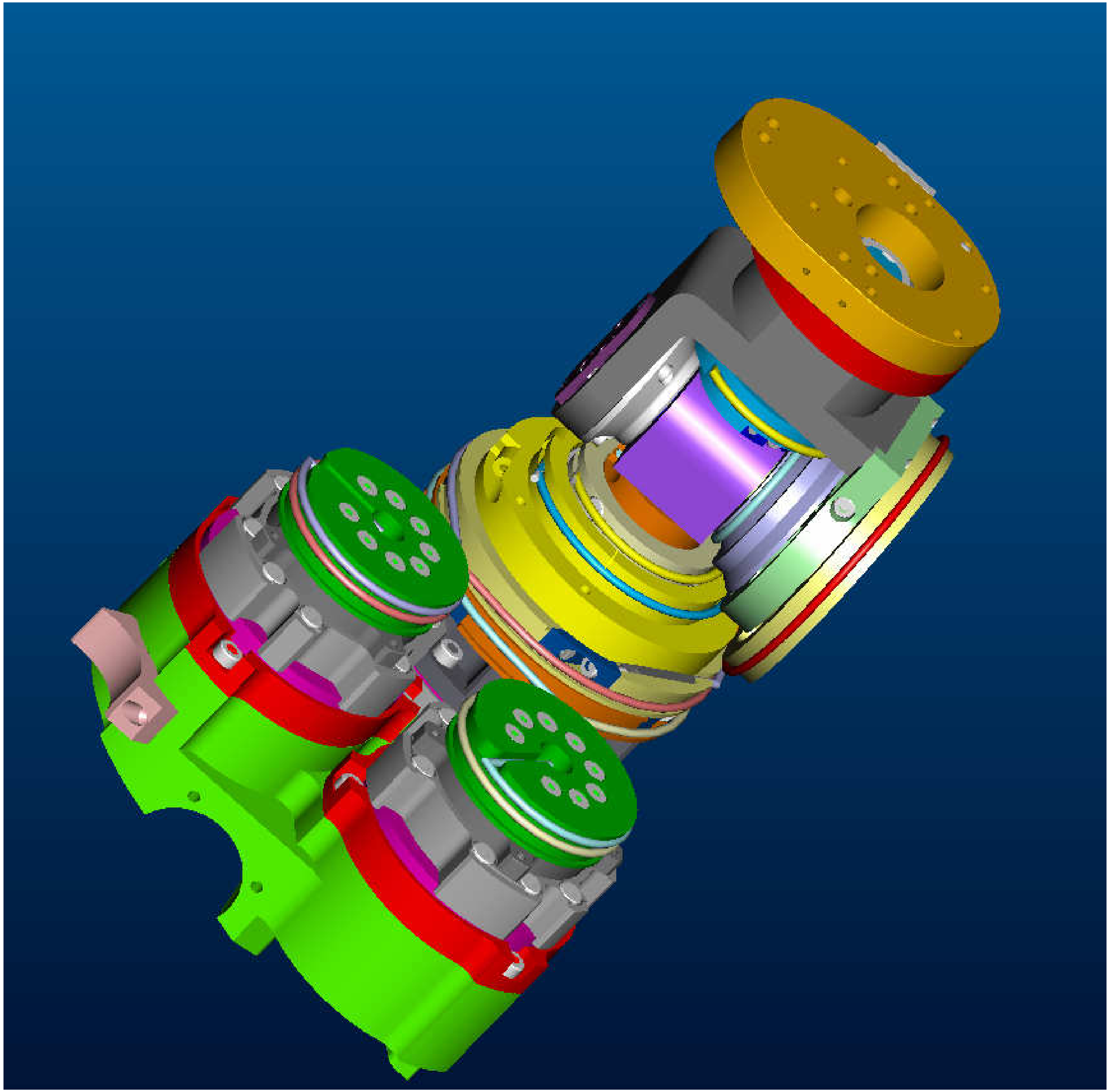


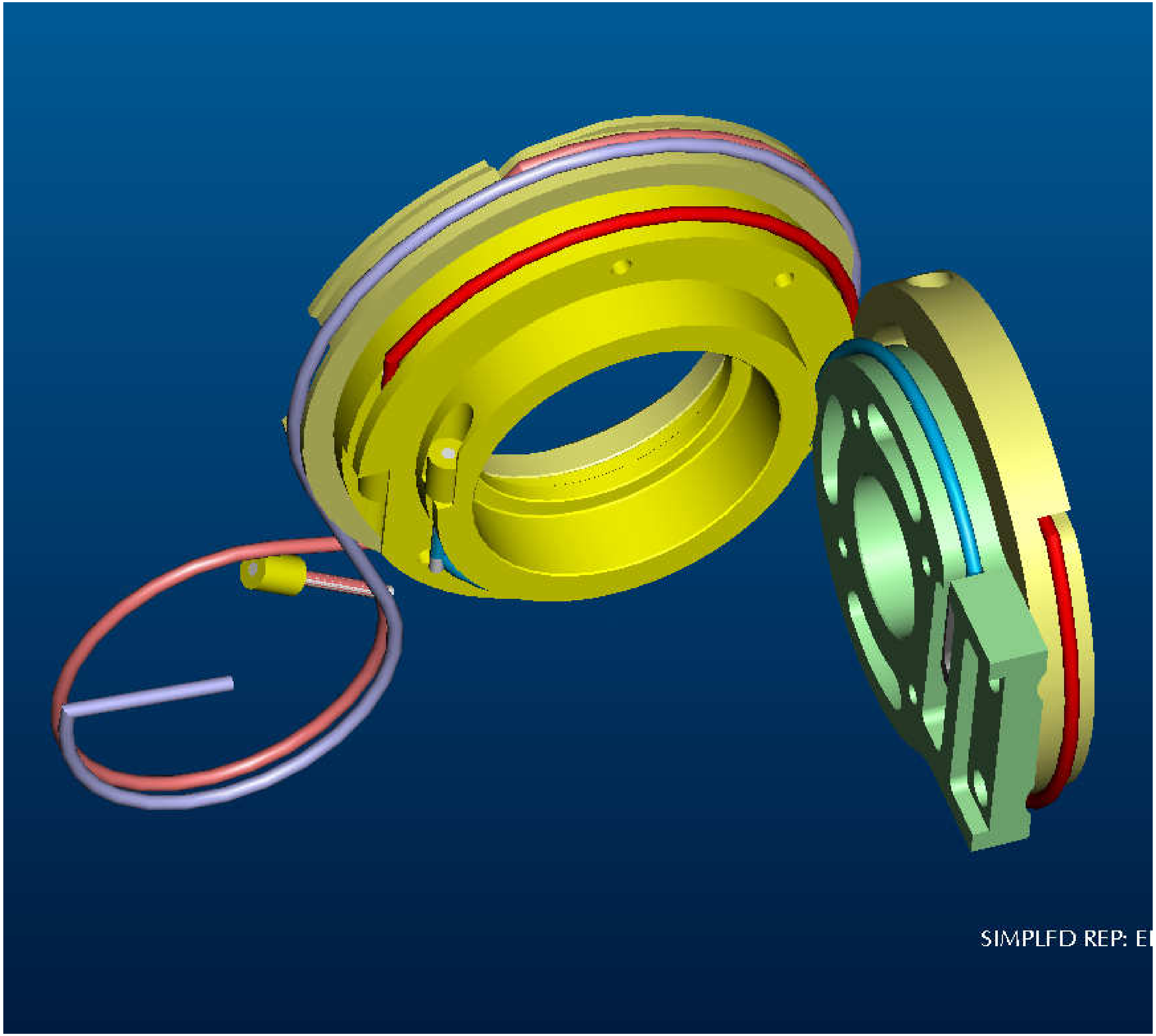
..the integration task (july 05)



Final result..2007 circa..



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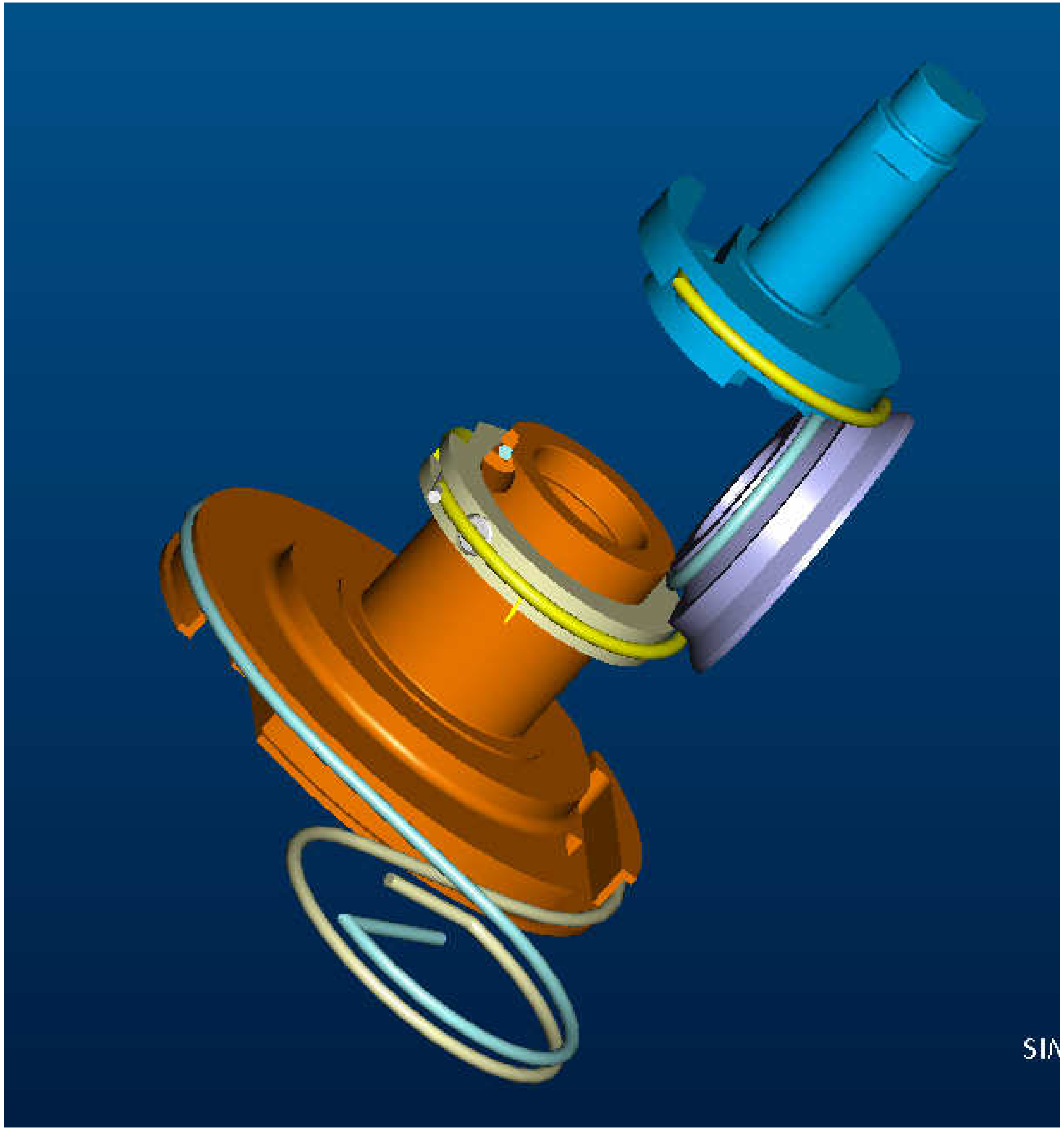
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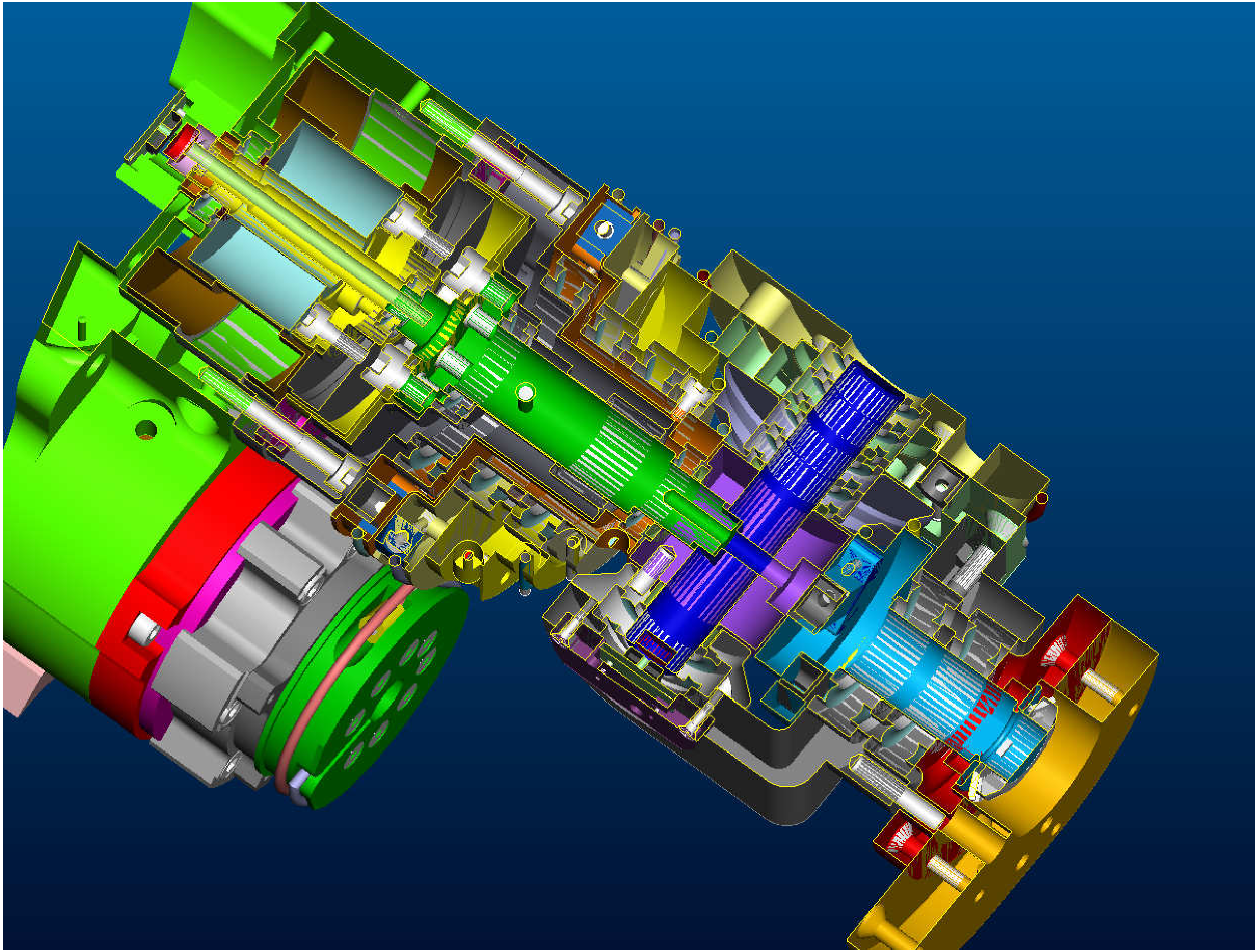
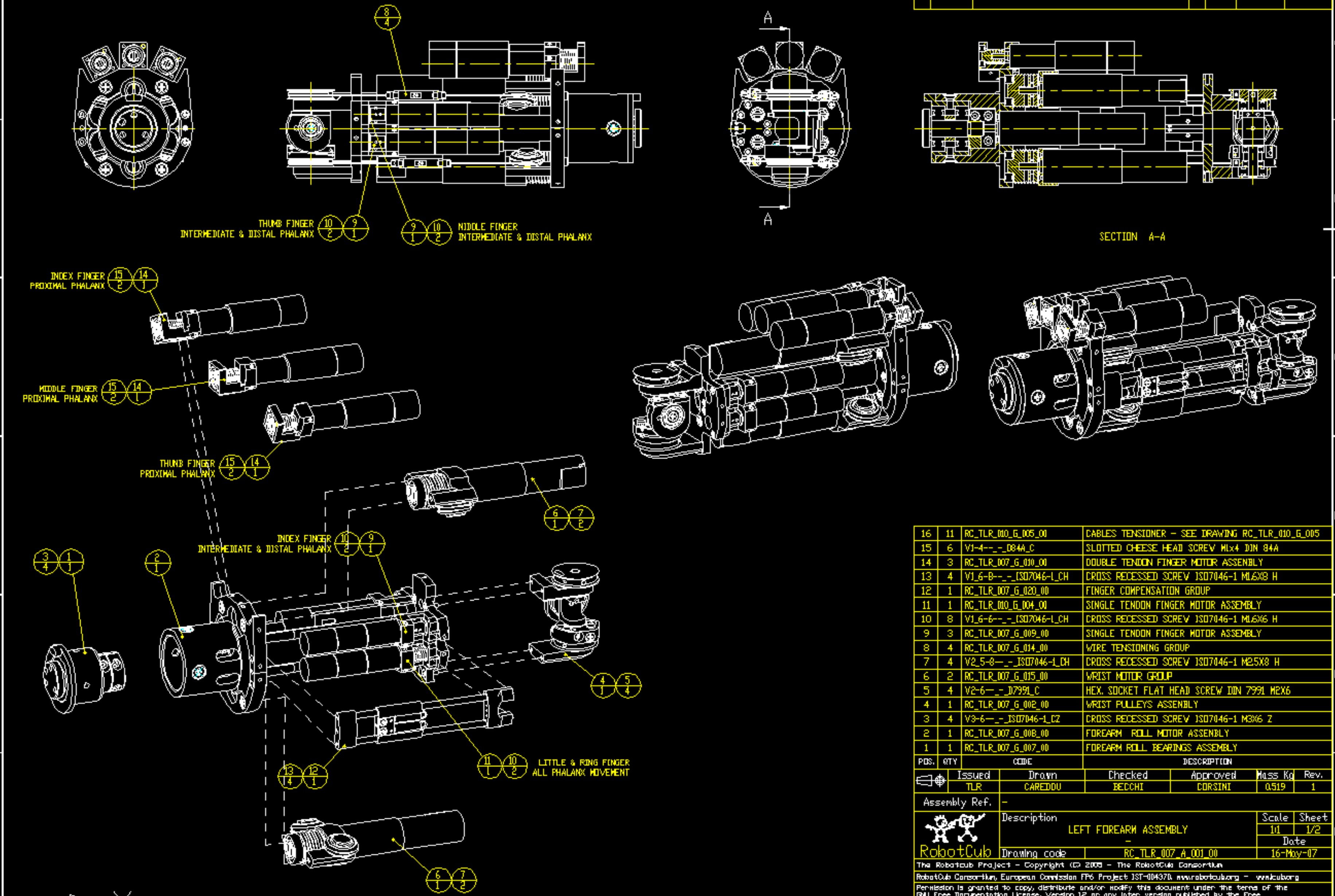


Rev.	Reviewer	Description	Zone	Date	Drawn	Checked
1	TLR	CHANGED WRIST PITCH & YAW CABLES		21/09/07	PINO	BECCHI



POS.	QTY	CODE	DESCRIPTION
16	11	RC_TLR_010_G_005_00	CABLES TENSIONER - SEE DRAWING RC_TLR_010_G_005
15	6	V1-4--_-_D84A_C	SLOTTED CHEESE HEAD SCREW M1x4 DIN 84A
14	3	RC_TLR_007_G_010_00	DOUBLE TENDON FINGER MOTOR ASSEMBLY
13	4	V1_6-8--_-_ISO7046-1_CH	CROSS RECESSED SCREW ISO7046-1 M1.6X8 H
12	1	RC_TLR_007_G_020_00	FINGER COMPENSATION GROUP
11	1	RC_TLR_010_G_004_00	SINGLE TENDON FINGER MOTOR ASSEMBLY
10	8	V1_6-6--_-_ISO7046-1_CH	CROSS RECESSED SCREW ISO7046-1 M1.6X6 H
9	3	RC_TLR_007_G_009_00	SINGLE TENDON FINGER MOTOR ASSEMBLY
8	4	RC_TLR_007_G_014_00	WIRE TENSIONING GROUP
7	4	V2_5-8--_-_ISO7046-1_CH	CROSS RECESSED SCREW ISO7046-1 M2.5X8 H
6	2	RC_TLR_007_G_015_00	WRIST MOTOR GROUP
5	4	V2-6--_-_D7991_C	HEX. SOCKET FLAT HEAD SCREW DIN 7991 M2X6
4	1	RC_TLR_007_G_002_00	WRIST PULLEYS ASSEMBLY
3	4	V3-6--_-_ISO7046-1_CZ	CROSS RECESSED SCREW ISO7046-1 M3X6 Z
2	1	RC_TLR_007_G_008_00	FOREARM ROLL MOTOR ASSEMBLY
1	1	RC_TLR_007_G_007_00	FOREARM ROLL BEARINGS ASSEMBLY

Issued	Drawn	Checked	Approved	Mass Kg	Rev.
TLR	CAREDDU	BECCHI	CORSINI	0.519	1

Assembly Ref. -

RobotCub

Description: LEFT FOREARM ASSEMBLY -

Scale 1:1 | Sheet 1/2

Drawing code: RC_TLR_007_A_001_00 | Date 16-May-07

PART 5 : ..is a robot really useful??

Configuration	Model	Axes	Payload (kg)	Reach (mm)	Repeatability (mm)	Speed
Articulated	Fanuc M-410i	4	155	3139	+/–0.5	axis 1, 85 deg/sec axis 2, 90 deg/sec axis 3, 100 deg/sec axis 4, 190 deg/sec
	Nachi 8683	6	200	2510	+/–0.5	N/A
	Nachi 7603	6	5	1405	+/–0.1	axis 1, 115 deg/sec axis 2, 115 deg/sec axis 3, 115 deg/sec
	Staubli RX90	6	6	985	+/–0.02	axis 1, 240 deg/sec axis 2, 200 deg/sec axis 3, 286 deg/sec
Type 1 SCARA	AdeptOne	4	9.1	800	+/–0.025	(est.) 1700 mm/sec
	Fanuc A-510	4	20	950	+/–0.065	N/A
Type 2 SCARA	Adept 1850	4	70	1850	X,Y +/–0.3 Z +/–0.3	axis 1, 1500 mm/sec axis 2, 120 deg/sec axis 3, 140 deg/sec axis 4, 225 deg/sec
	Staubli RS 184	4	60	1800	+/–0.15	N/A
Cartesian	PaR Systems XR225	5	190	X 18000 Y 5500 Z 2000	+/–0.125	N/A
	AdeptModules	3	15	X 500 Y 450	+/–0.02	axis 1, 1200 mm/sec axis 2, 1200 mm/sec axis 3, 600 mm/sec
Cylindrical	Kohol K45	4	34	1930	+/–0.2	axis 1, 90 deg/sec axis 2, 500 mm/sec axis 3, 1000 mm/sec
Spherical	Unimation 2000 (Hydraulic, not in production)	5	135		+/–1.25	axis 1, 35 deg/sec axis 2, 35 deg/sec axis 3, 1000 mm/sec

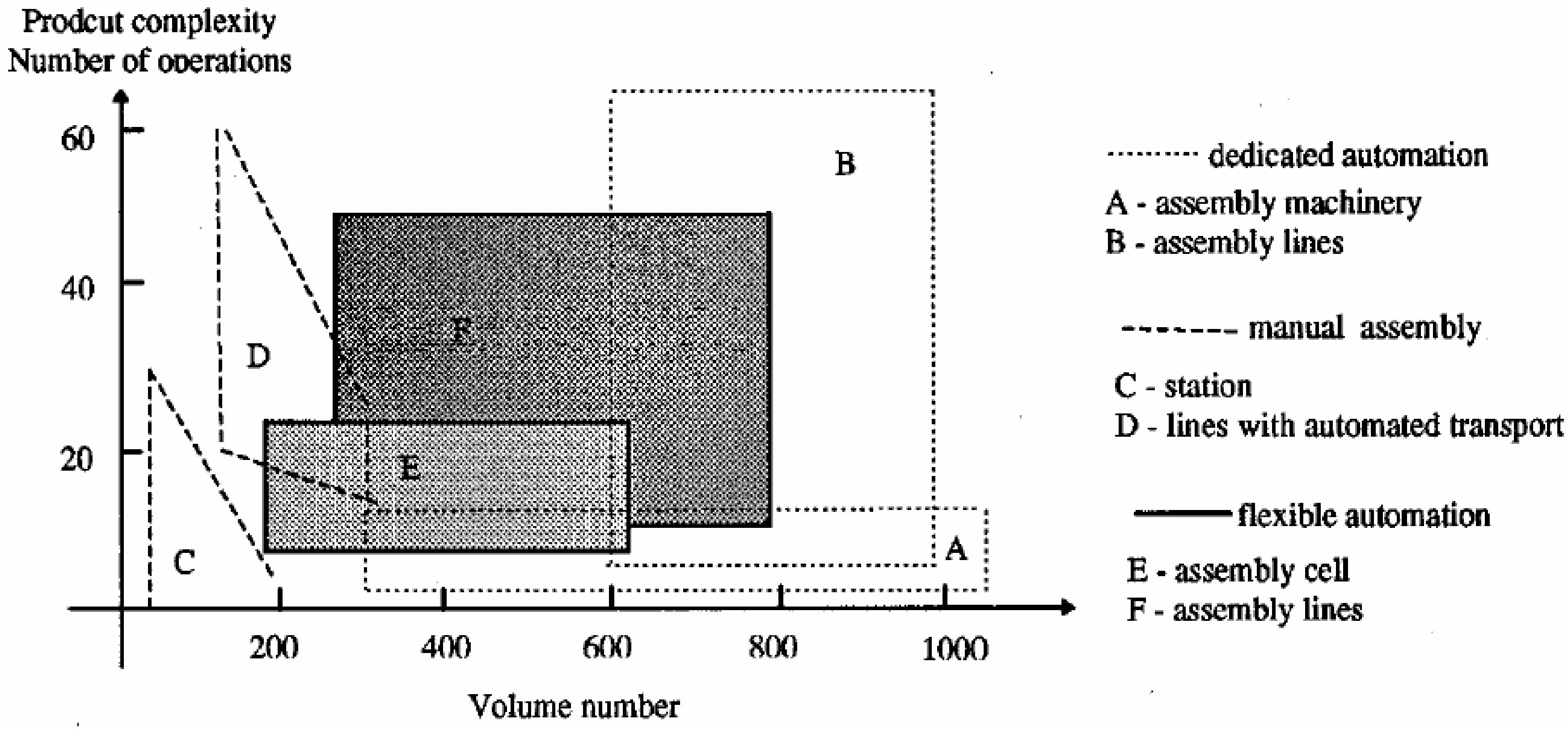

Prodcut complexity
Number of operations
60
40
20
200
400
600
800
1000
Volume number
A
B
C
D
E
F
dedicated automation
A - assembly machinery
B - assembly lines
manual assembly
C - station
D - lines with automated transport
flexible automation
E - assembly cell
F - assembly lines

TABLE 14.10.1 Design Solutions for Robots

Problems in Utilizing Robotics	Design Solutions to Assist Production
Location accuracy and repeatability	Design for vertical assembly; use chamfered edges for mating surfaces; tolerance leeway for mating parts
Part feeding and orientation	Design parts which can be easily fed, provide notches, guide pins, or slots for part orientation; select parts from vendors that will deliver in easy-to-feed packaging
Programming robot and associated equipment	Design simplification; use common parts for different products, part reductions; part families
Application problems with fasteners (screws, washers, and nuts)	Minimize the use of all fasteners; utilize snap fits where possible
Downtime caused by jams and misfeeds due to poor part quality	Select vendors that produce high-quality parts

TABLE 14.10.2 Design Rules for Robotic Assembly

Product should have a base part on which to build assemblies in a top-down, straight-line motion direction
Base should be stable and facilitate orientation
Parts should be able to be added in layers
Use guide pins, chamfers, and tapers to simplify and self-align the layering of parts
All parts should accommodate handling by a single gripper and be comparable with popular feeding methods
Sufficient access is available for the gripper
Avoid the use of bolt-and-nut assembly
Parts should be able to be pushed or snapped together; when screws are necessary for repair, they should all be the same size
High quality parts are used
Vendors deliver parts that are compatible with the selected part feeder mechanism

TABLE 14.10.3 Economic Cost and Savings for Robot Applications

Investment costs	
Robot purchase price	for many applications this is a much smaller part of the costs than expected (25 to 45%)
Other equipment (part feeders, conveyors)	this includes the cost of hardware interfaces
Design of end effector, special fixtures, and other equipment	most applications require the design of a unique end effector and special fixtures
Software design and integration	can be a much higher cost than expected due to the complexity of interfacing different equipment controllers
Installation including facility modifications	usually a small cost for robot system
Technical risk	this is the risk of whether the system will perform up to the specifications in areas such as performance, quality, precision, etc.
Operating costs	
Training	costs of training operators, engineering and maintenance personnel
Product design changes	cost required to modify the robotic software and hardware when design changes or modifications are made to the product
Operating, utilities, and maintenance	typical costs found for most manufacturing equipment
Savings	
Direct labor	labor savings caused by the robotic system
Ergonomic and health	benefits of lower number of job injuries, workers compensation costs, and compliance with OSHA regulations
Quality	improved quality may result due to lower scrap and waste
Precision	robots can often perform tasks at a much higher precision (i.e., lower variability) than manual operations resulting in fewer defects and better product performance

fine
(and good job on robotics..)