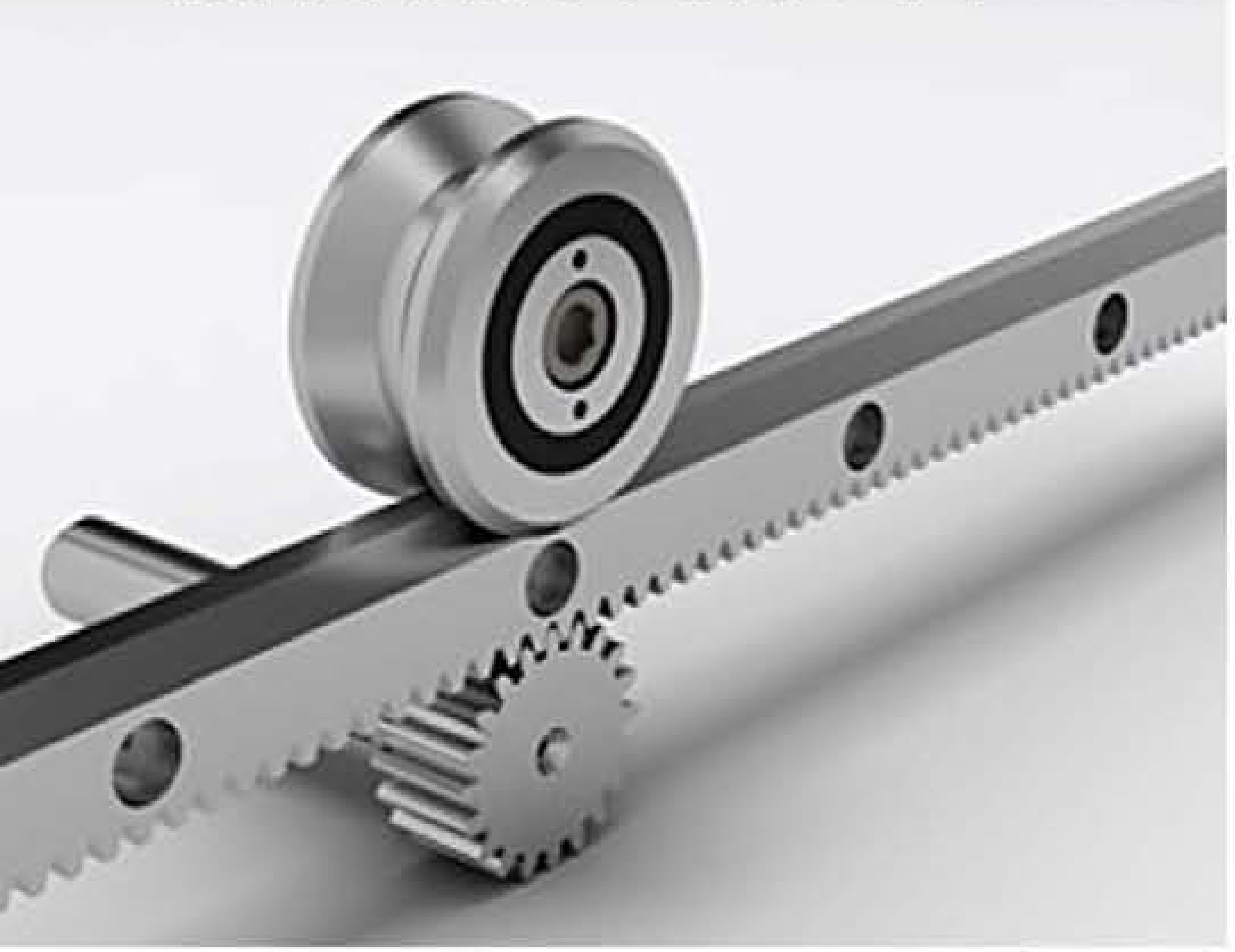
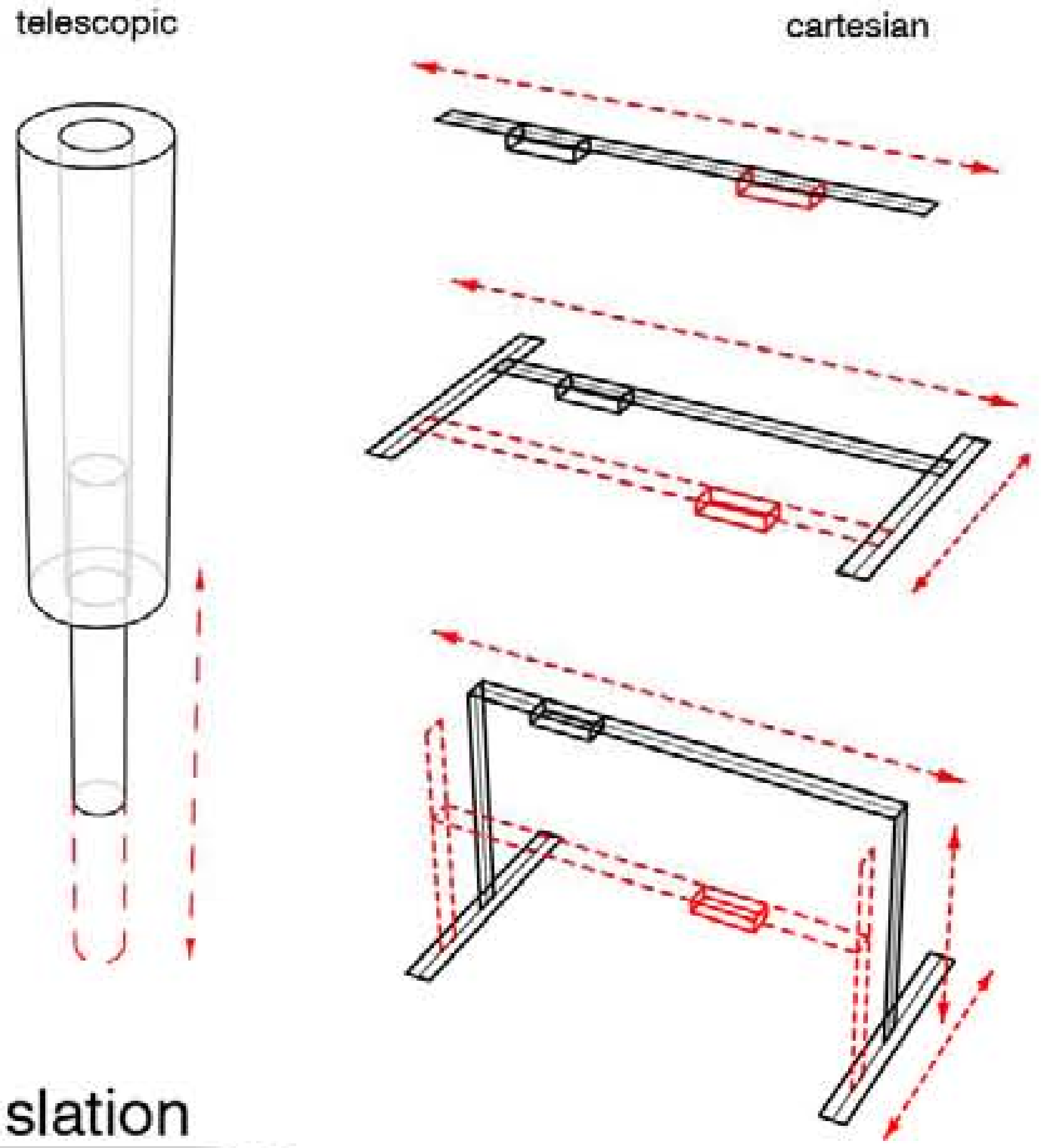
axialmovement+**self**locomotion+**self**configuration+**end**effectors



rotationtrack

scaleapplication



axialtranslation

properties

A Cartesian Coordinate Robot has three linear axes of control (x,y,z). Cartesian coordinate robots with the horizontal member supported at both ends are sometimes called Gantry robots

process

data and power are supplied through belts complimenting axial motion

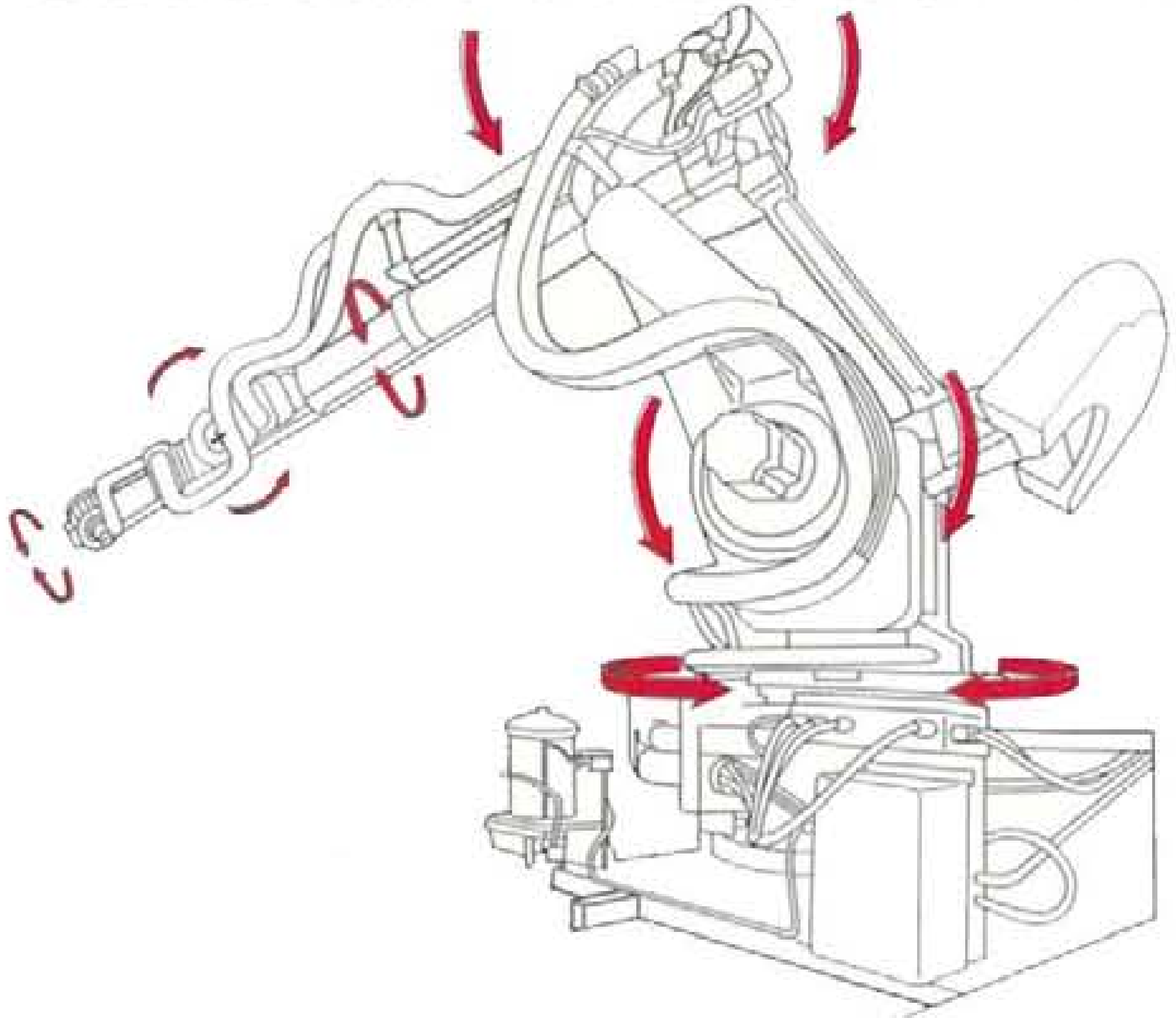
application

utilized at a variety of scales such as printers, CNC machines (laser-cutter, 3-axis mill/router, plasma-cutter), industrial craining

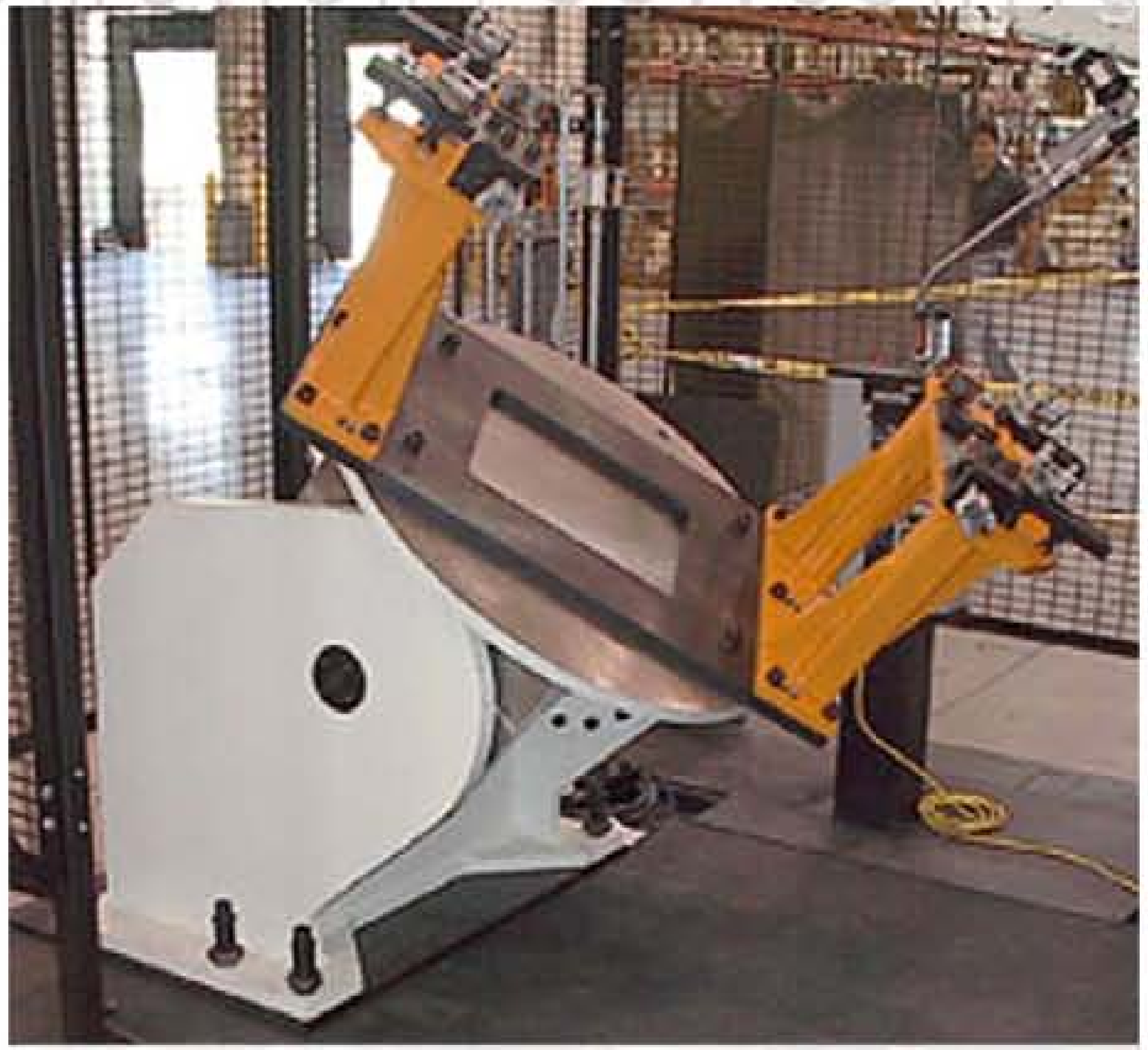
datapower

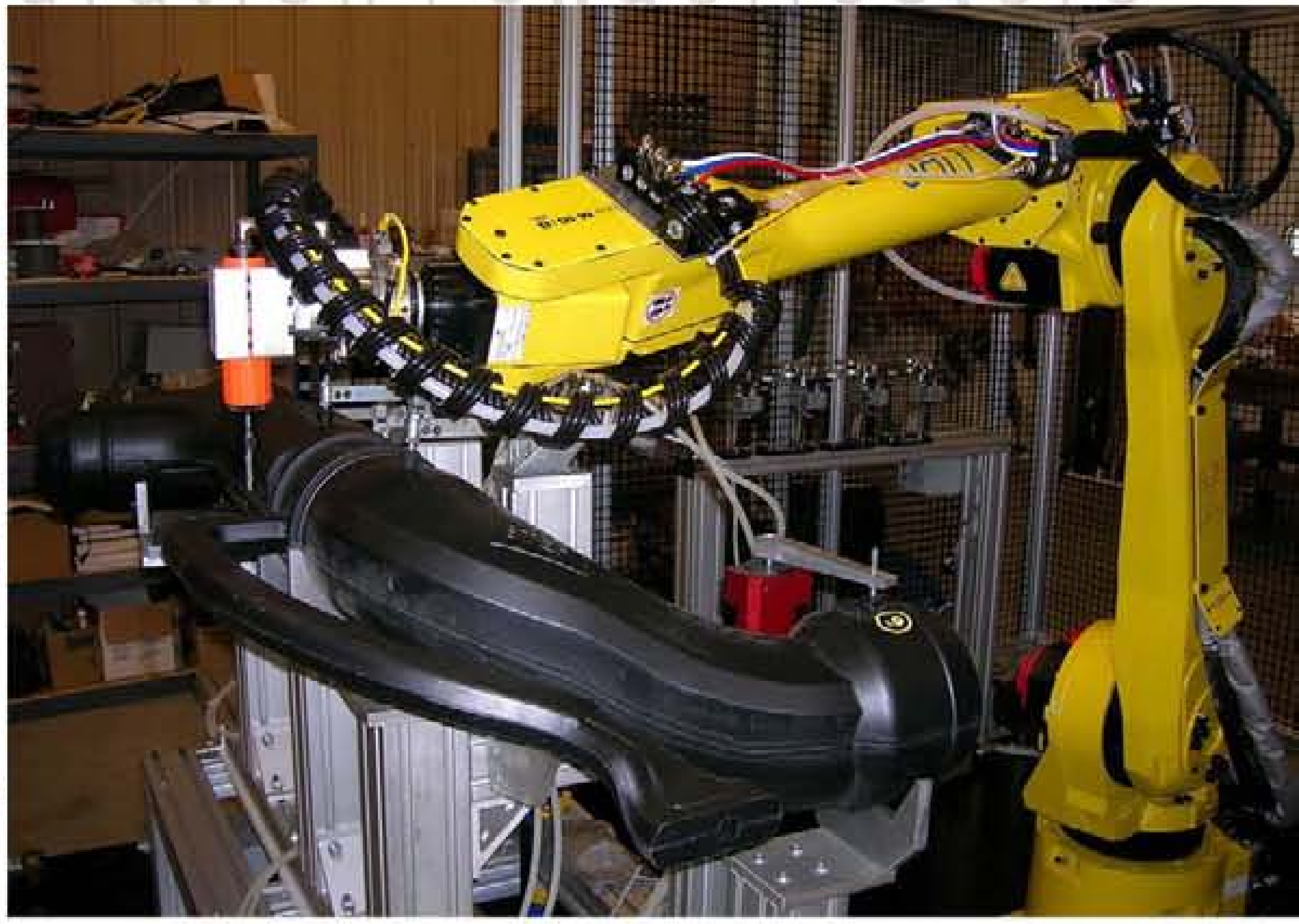
robots+trajectories

suzanbabaa+**harrison**blair+**john**cerone+**artemis**papadatou+**matthew**pauly+**eleftheria**tzanaki



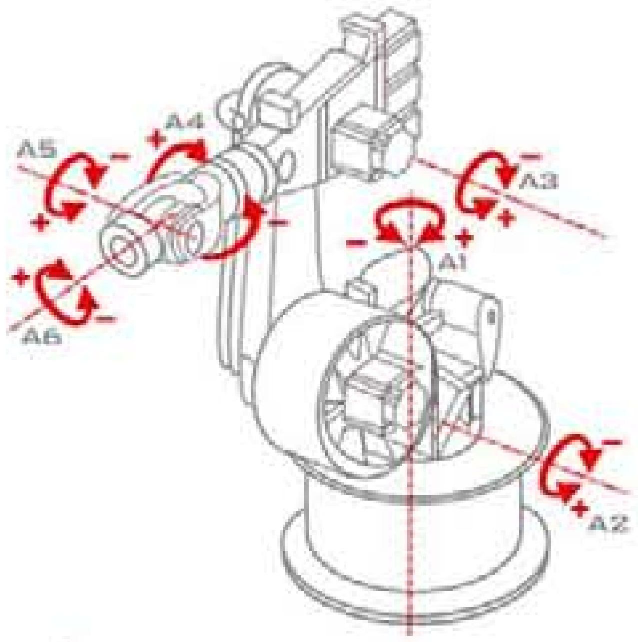
articulatedjoint-arm

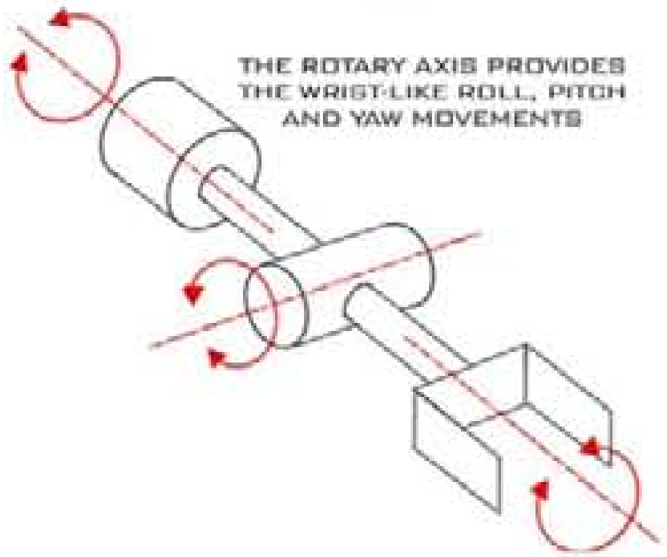




Robot (above) copies motions of surgeon's hands (below)

roboticsurgery





THE ROTARY AXIS PROVIDES THE WRIST-LIKE ROLL, PITCH AND YAW MOVEMENTS

axialrotation

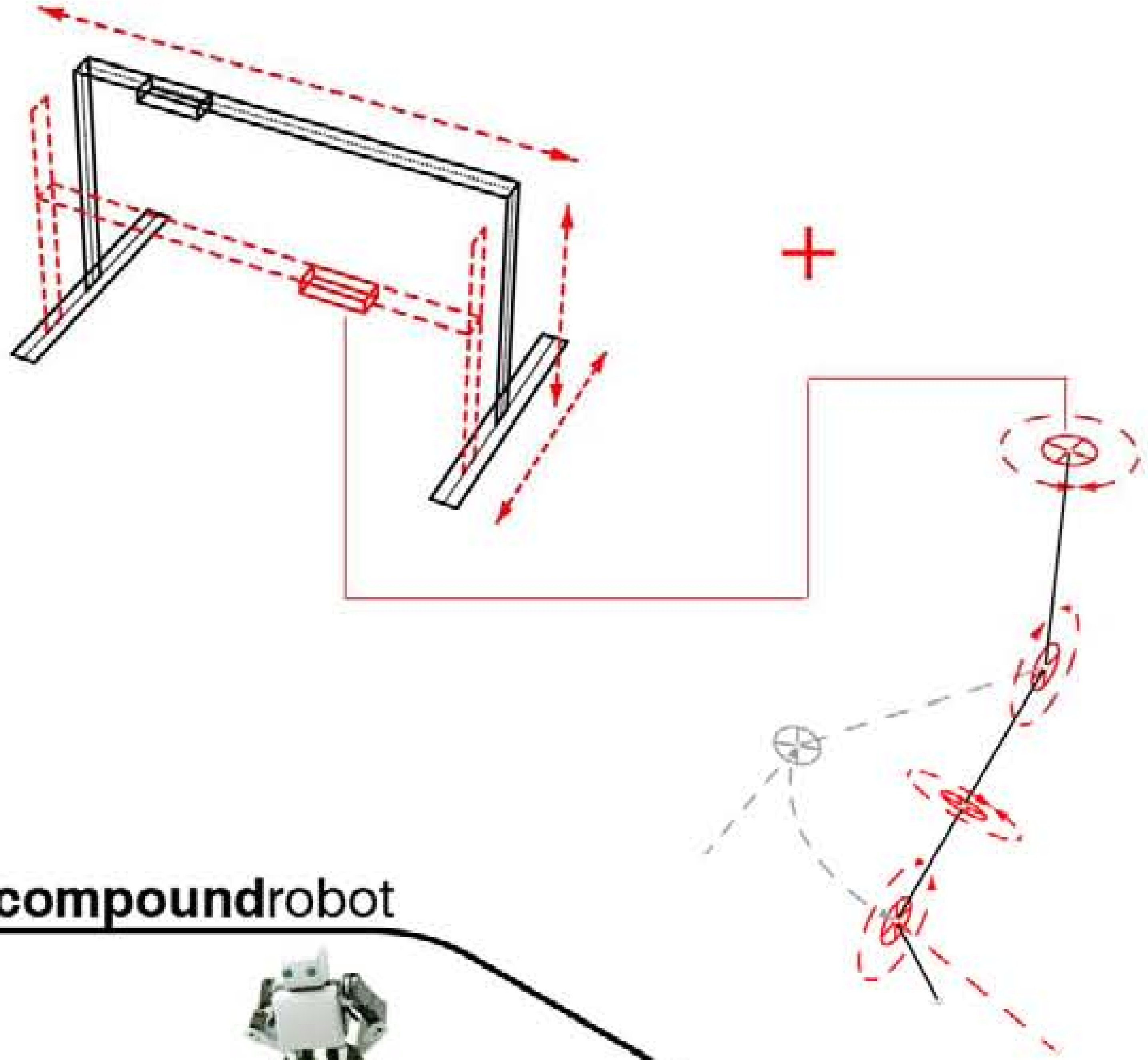
axialmovement + **self**locomotion + **self**configuration + **end**effectors

gantrymounted

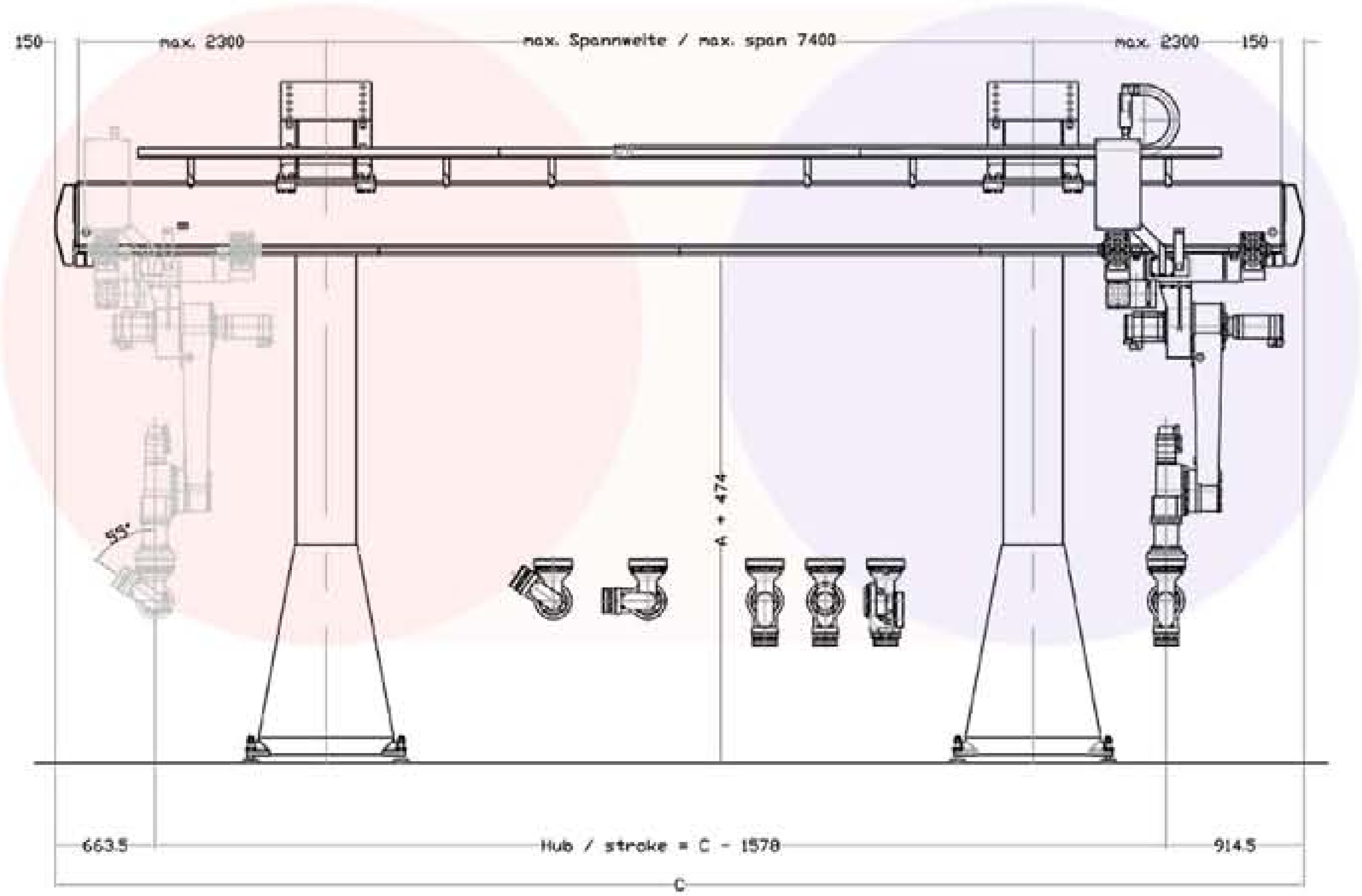
trackmounted

inconjunction

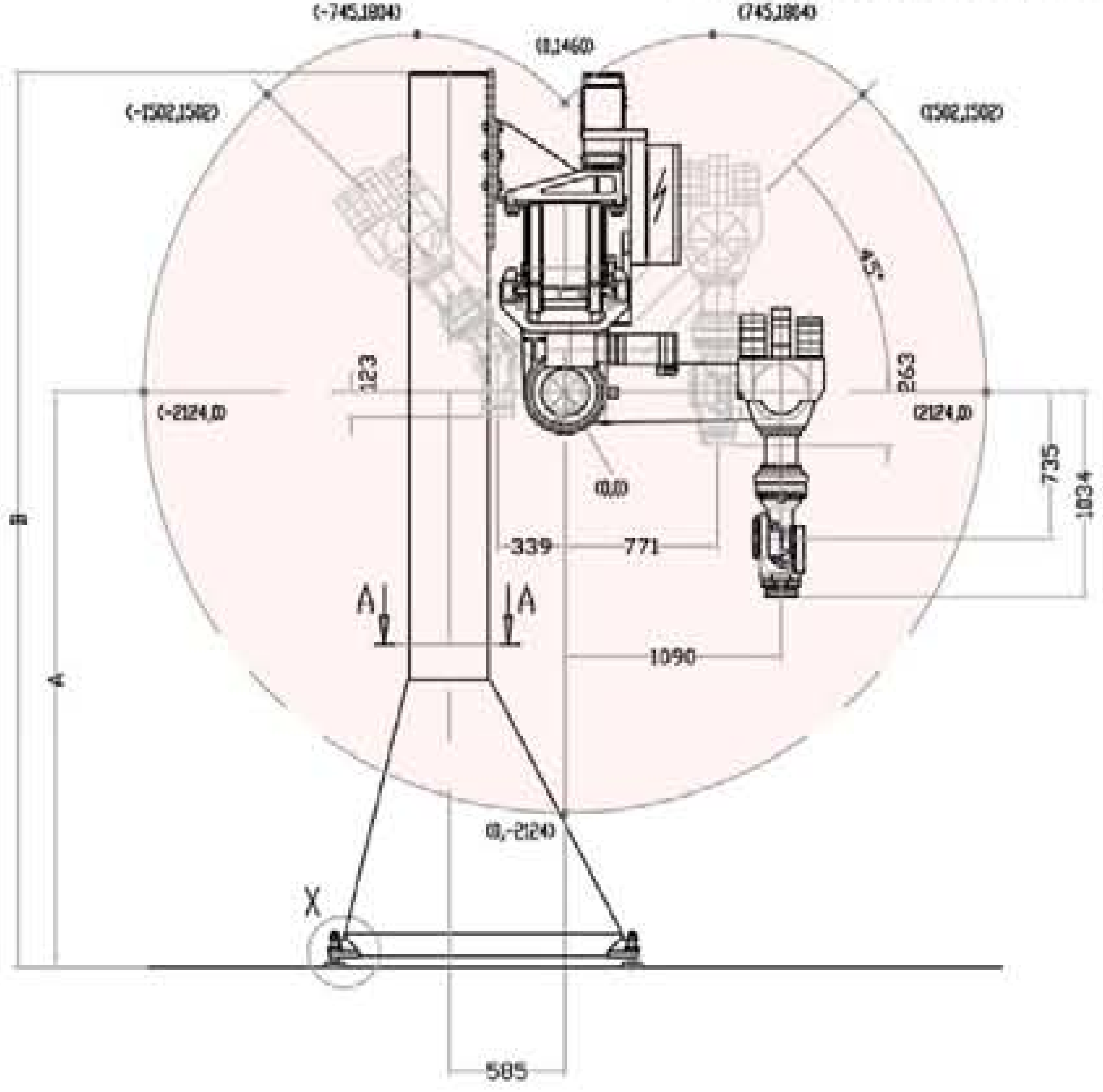
combineprocess



compoundrobot



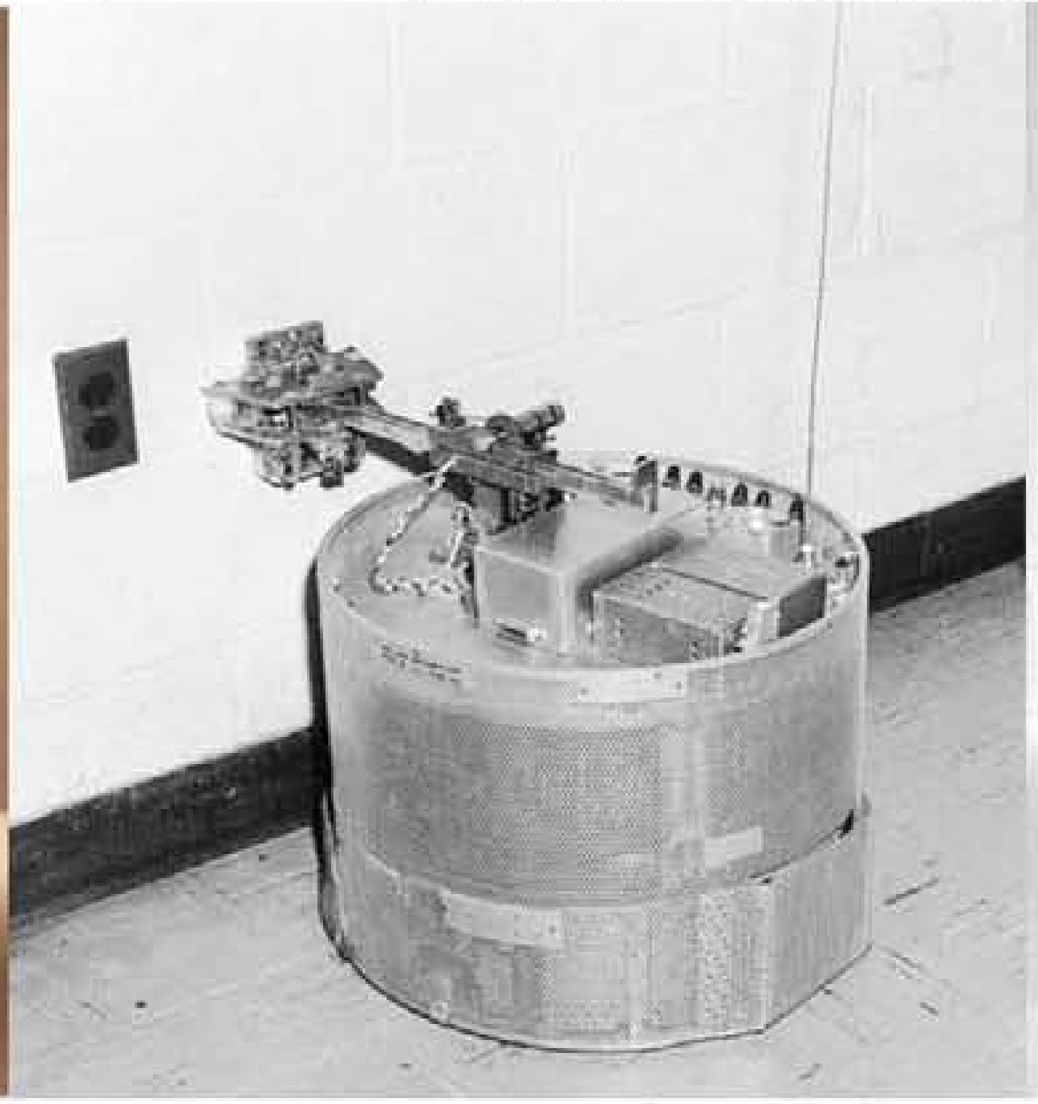
workenvelope



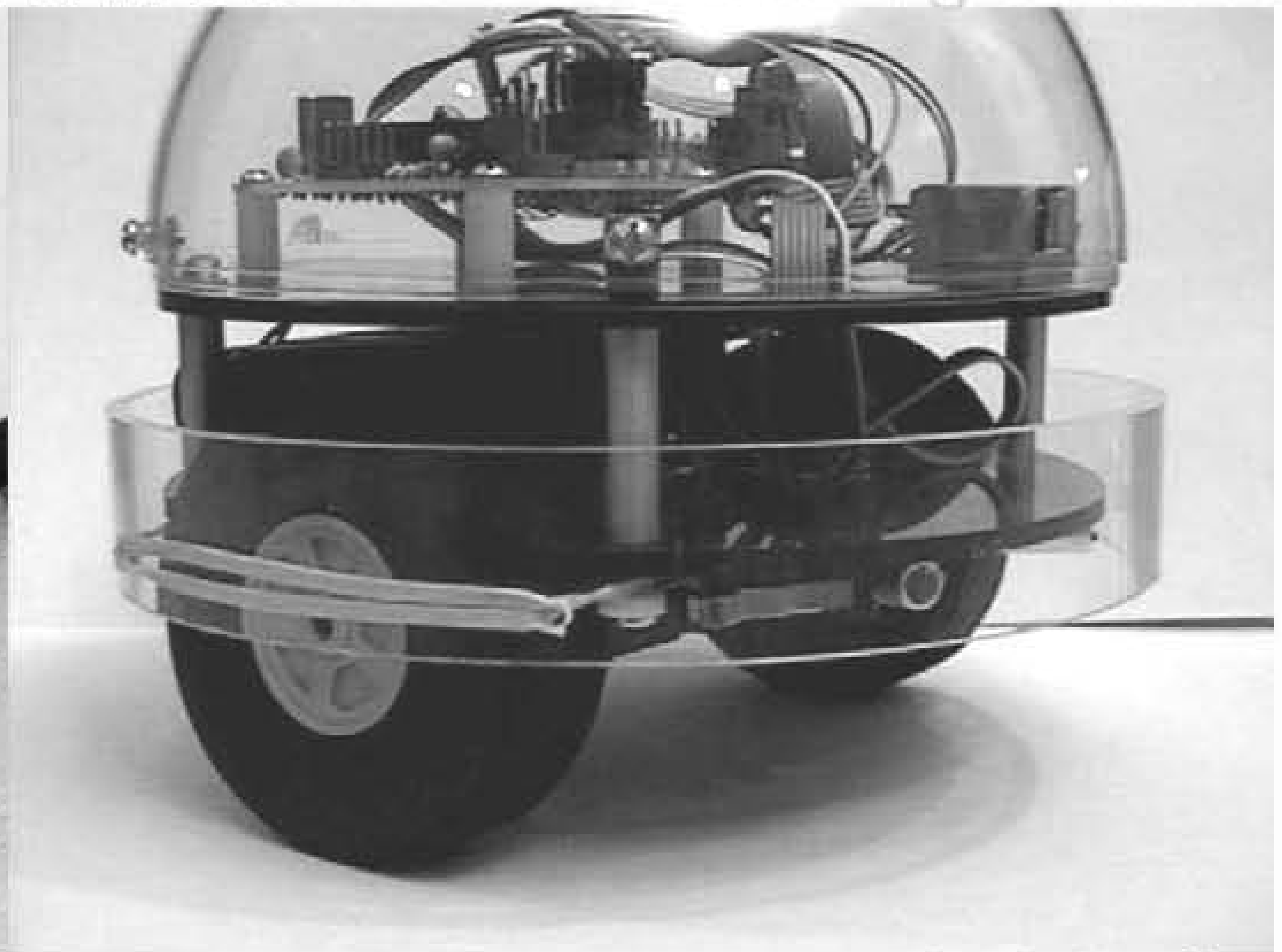
robots+trajectories

suzanbabaa+**harrison**blair+**john**cerone+**artemis**papadatou+**matthew**pauly+**eleftheria**tzanaki

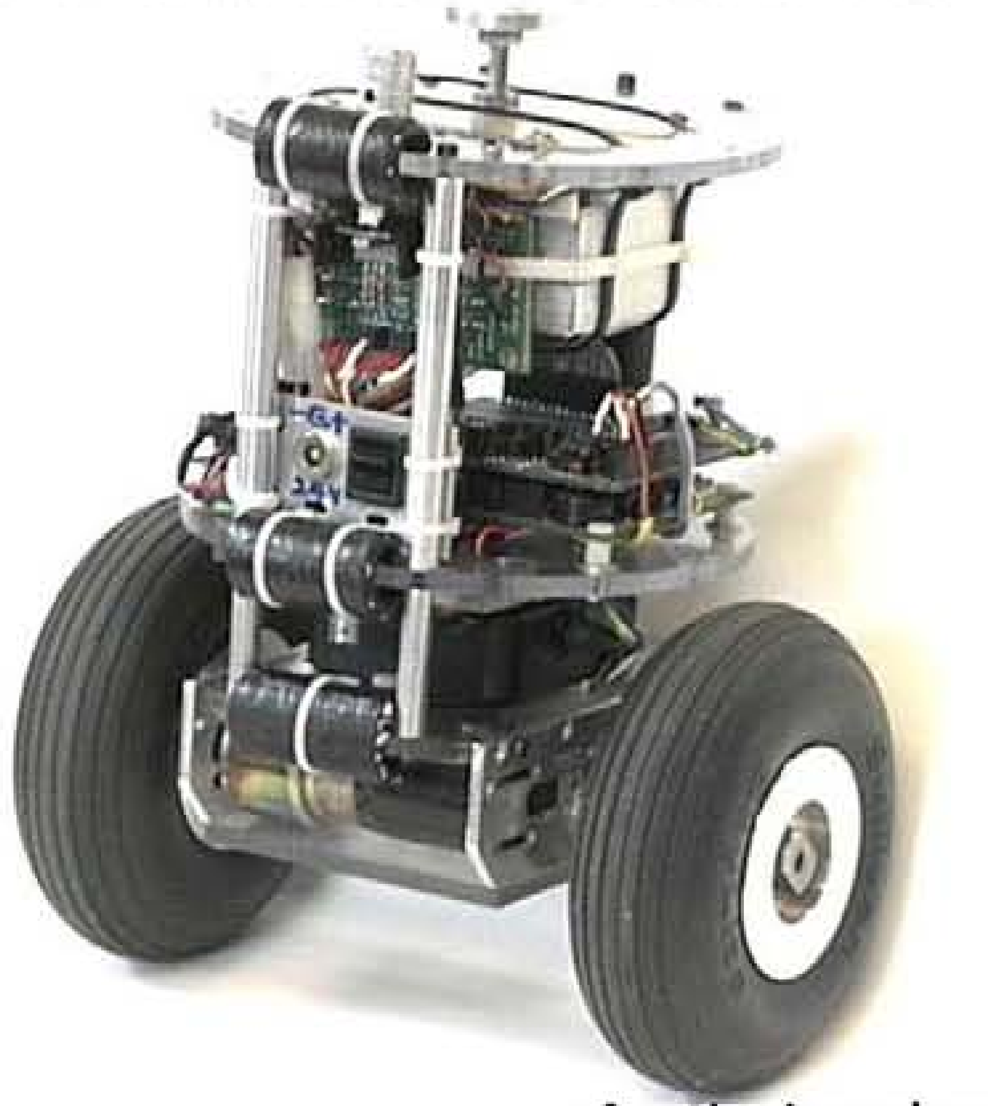
scifidrwho



hopkinbeast

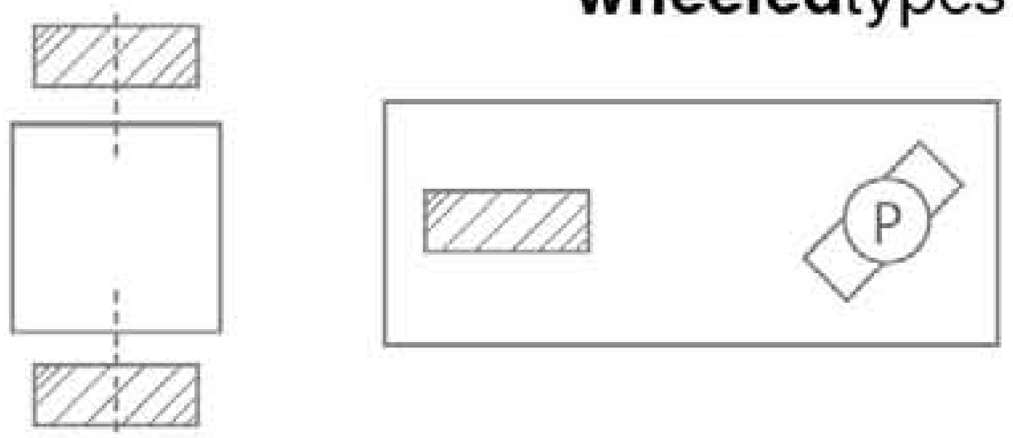


botbalancing



nbotbalancing

wheeledtypes



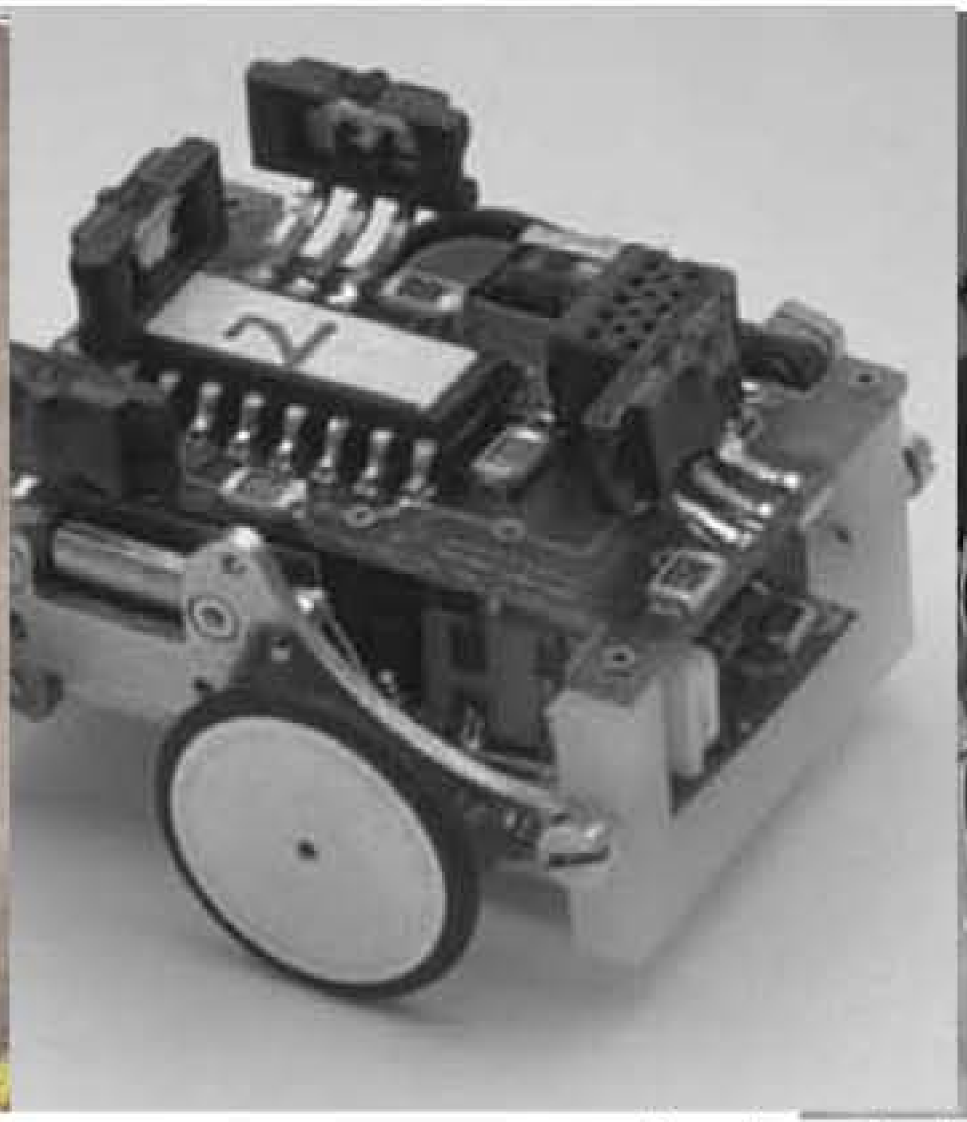
properties

Two wheeled robots provide the simplest means of travel. It also provides the greatest flexibility of rotational motion out of any wheeled robot. The difficulty comes in balance. In the past the weight was distributed below the axle of the drive wheels. Recent developments allow the robot to compensate and continuously remain stable with a center of gravity above the axle (think Segway).

The possibilities of motion are high, but a two wheeled robot cannot traverse difficult terrain. It is also not efficient for heavy loads (unless it is a point load).

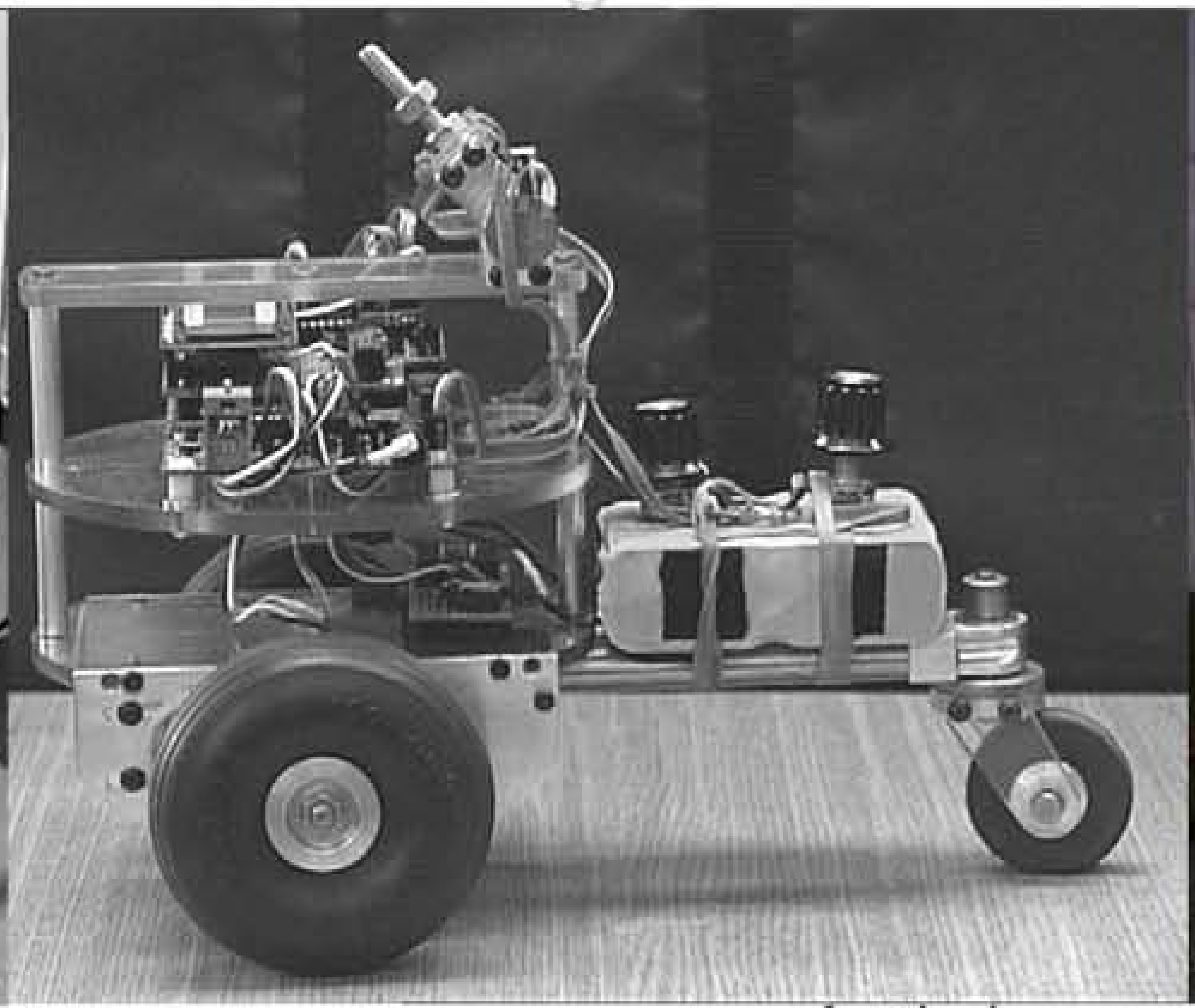
twowheeled

scifistarwars



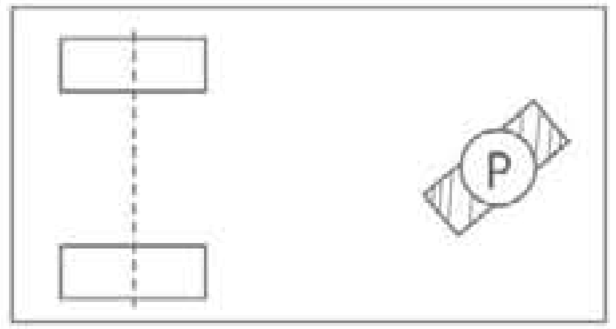
genericwheeled

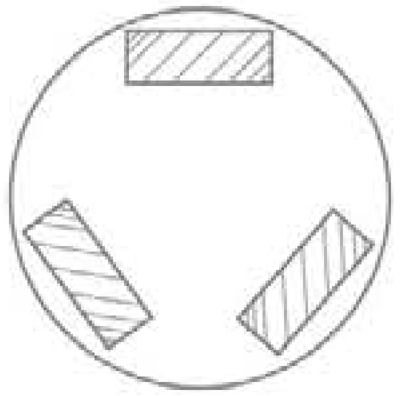
nomadscout

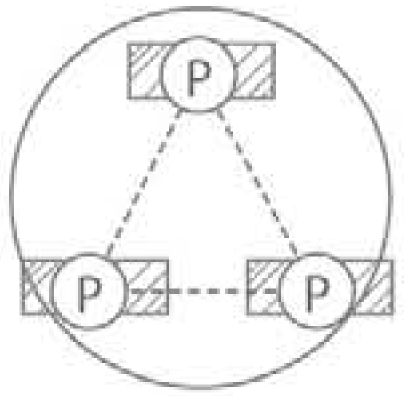


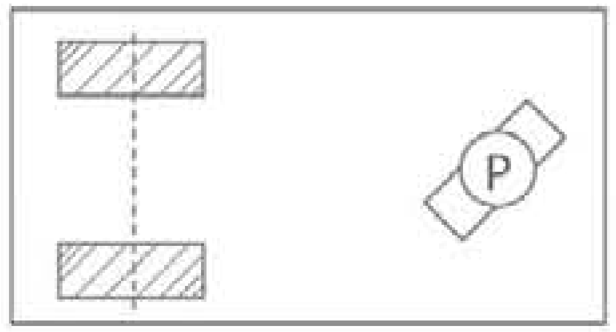
nbotbalance

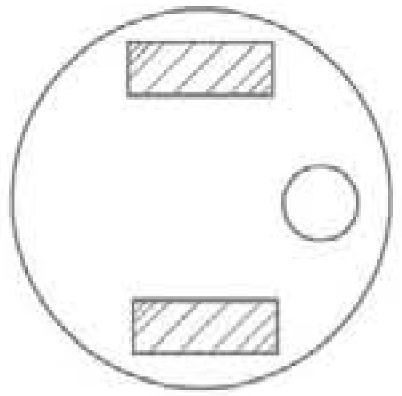
neptunesingledrive











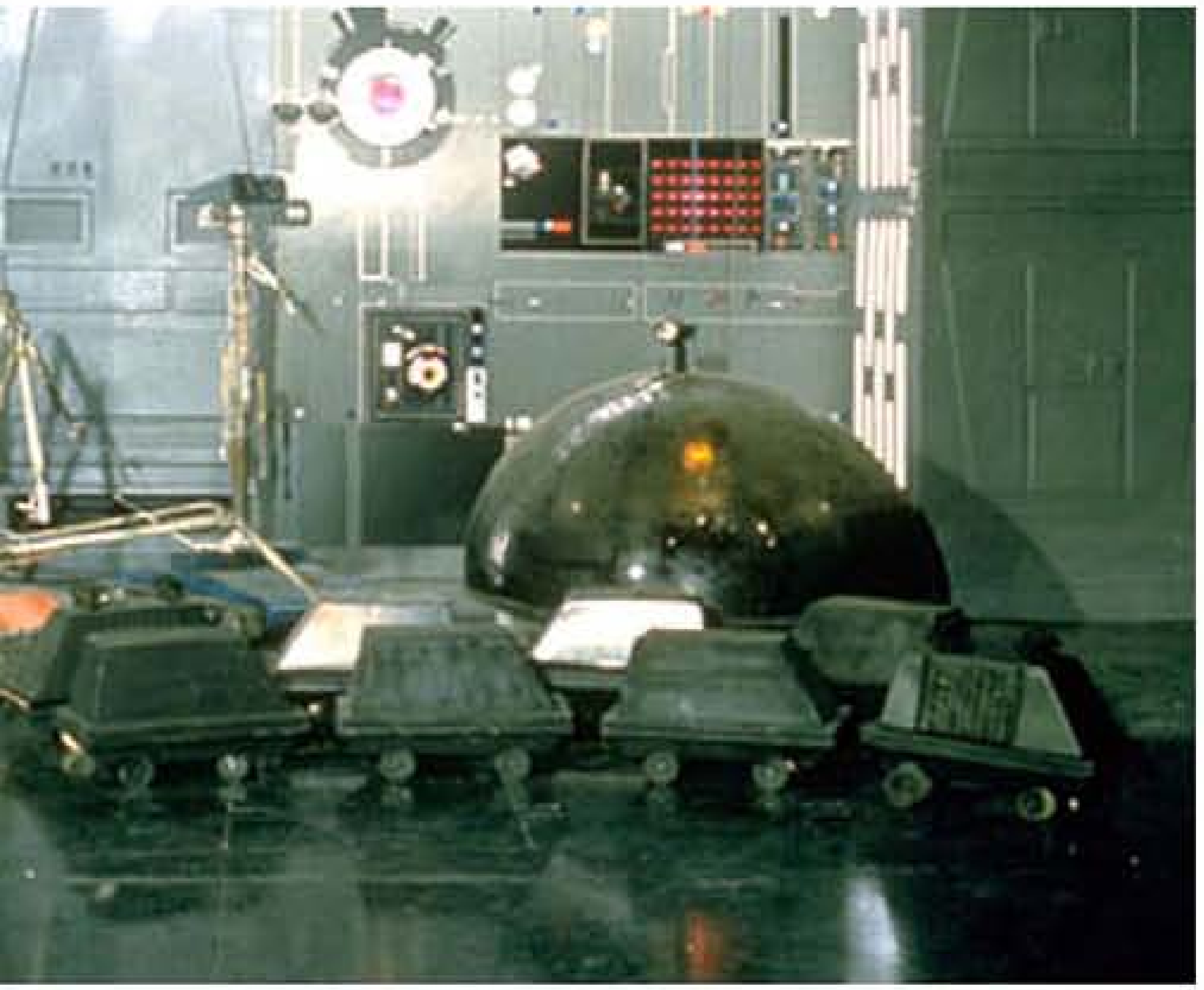
threewheeled

diagrammovement

poperties

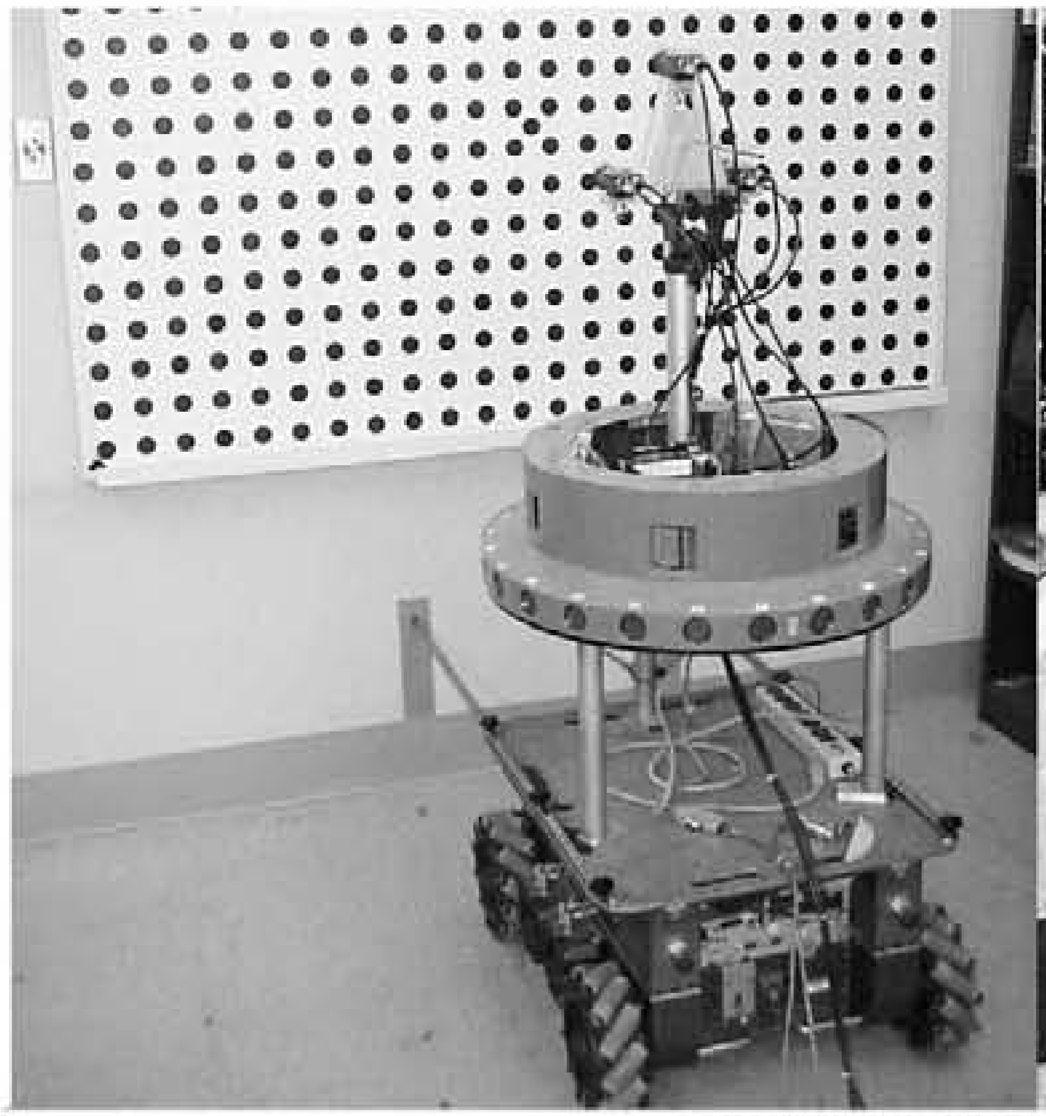
In three wheeled robots, generally there is at least one drive wheel, and at least one stabilizing wheel or contact point. The benefits of t three wheel system is the superior balance and lower energy and computation. T

While three wheeled robots have superior stability; they lack mobility of some two wheeled designs, and the load capacity of a four wheeled (or more) design

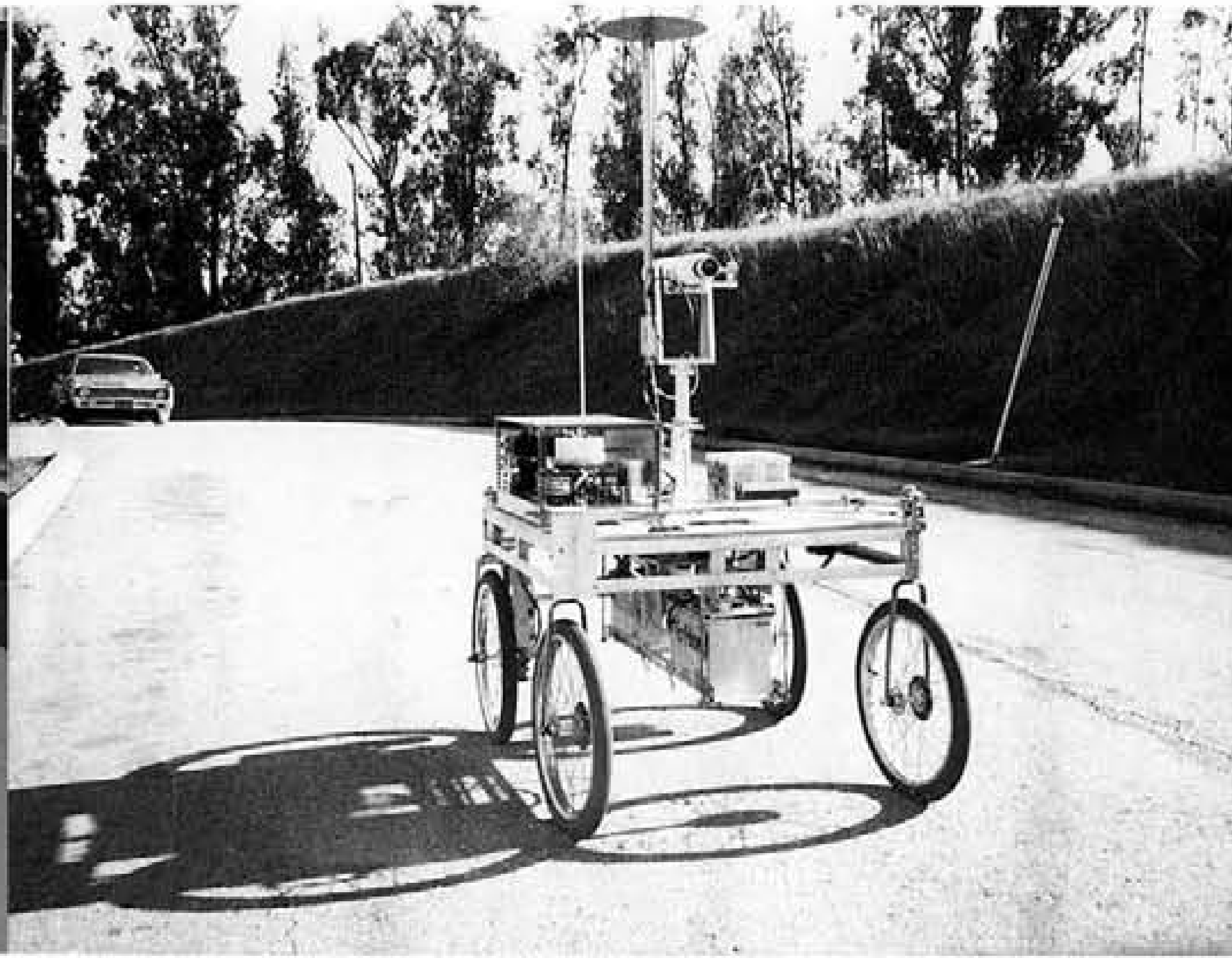


scifistarwars

nomadxr4000

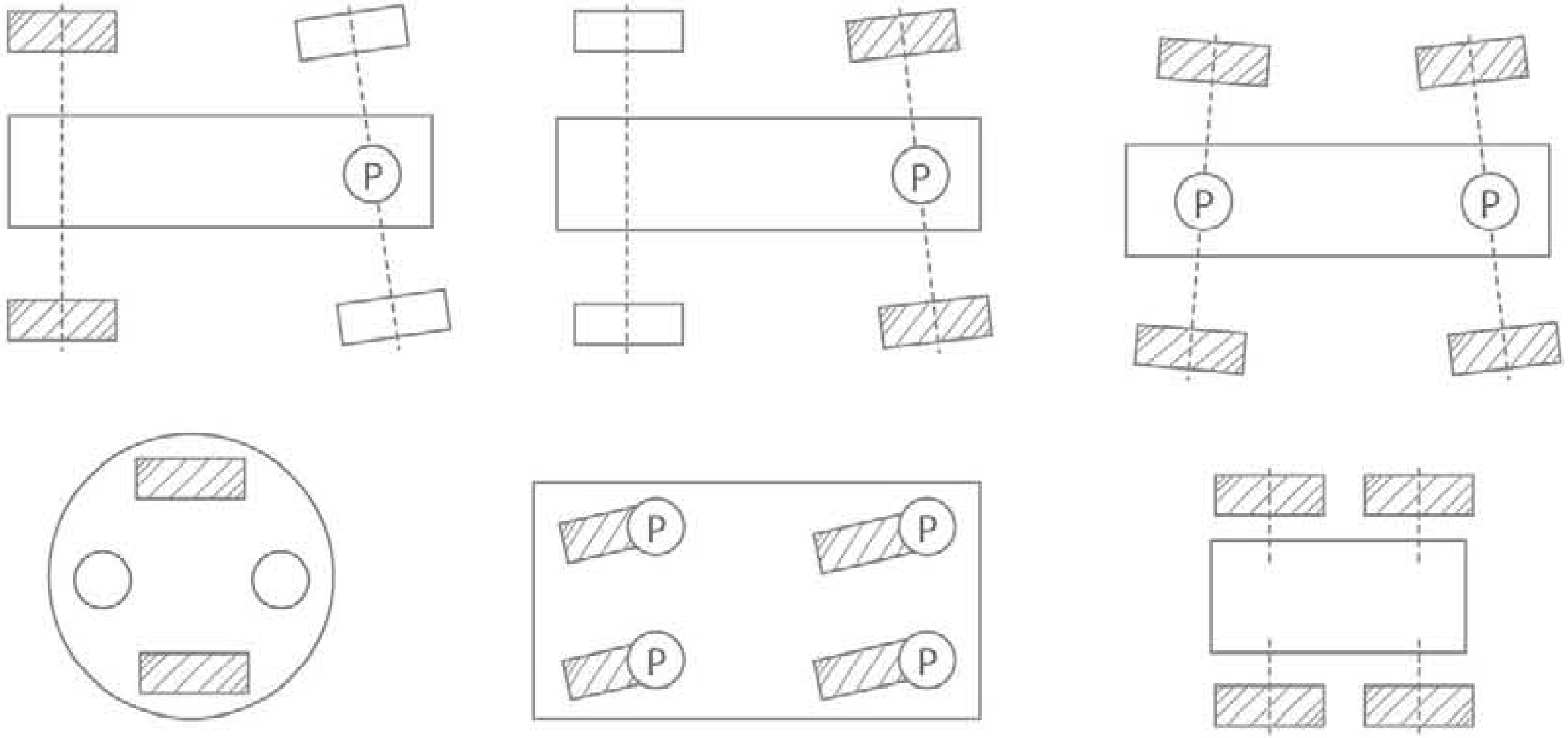


cmuuranus



stanfordcart

fourwheeled



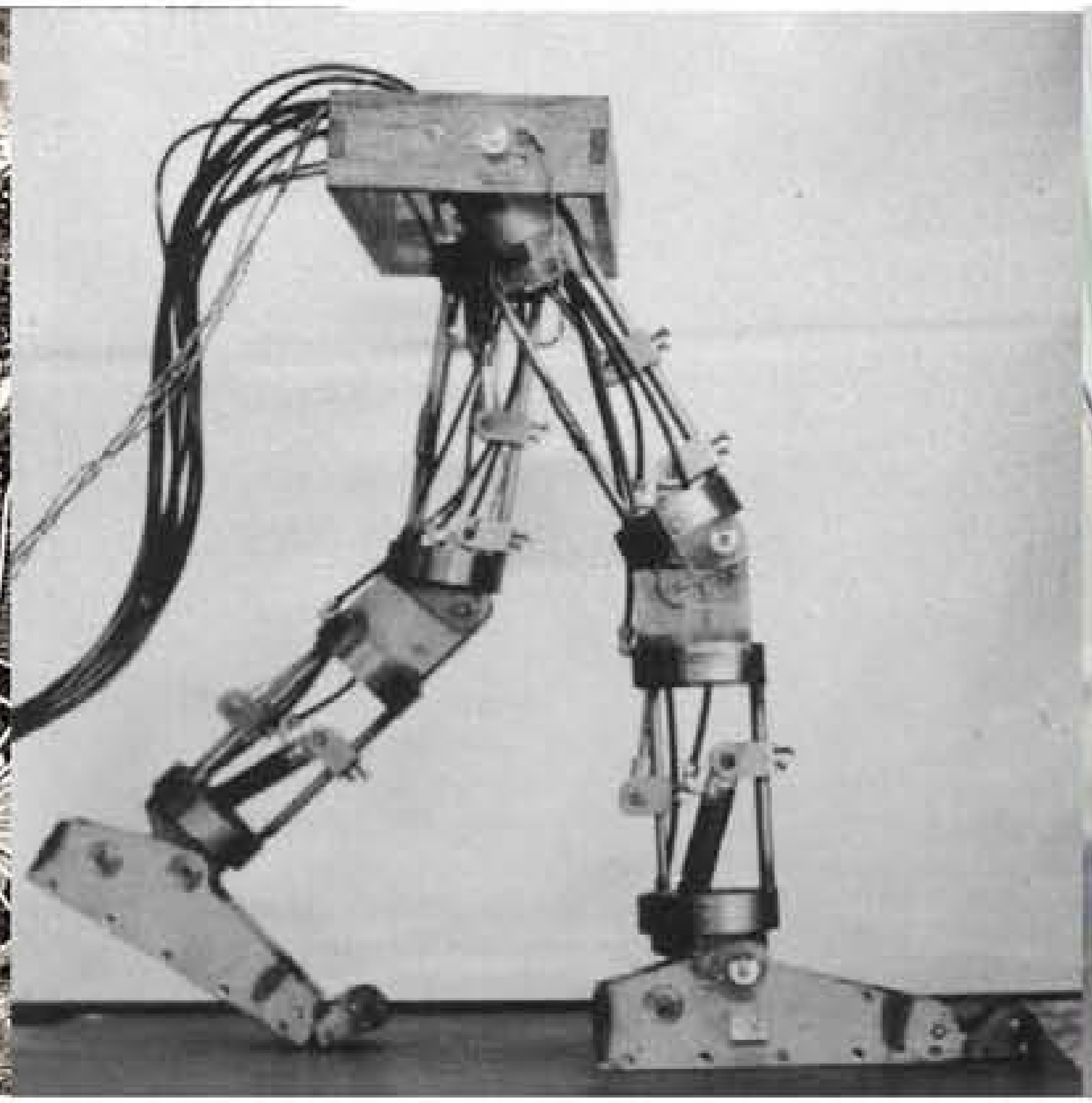
diagrammotion

properties

The four wheeled robot is probably the easiest for us to understand. We are surrounded by four wheeled mechanisms. Cars, trucks, trailers, etc. They provide more efficient stability than a two or three wheeled robot. Depending on the type of wheel (castors, fixed, etc.) the four wheeled robot can have relatively free mobility.

The four wheeled robot, as well as all the wheeled category, provide efficiency and speed. The problem arises when they encounter diffiecult terrain. This is the realm where legged robots are superior.

scifisteamman



w3thebeginning

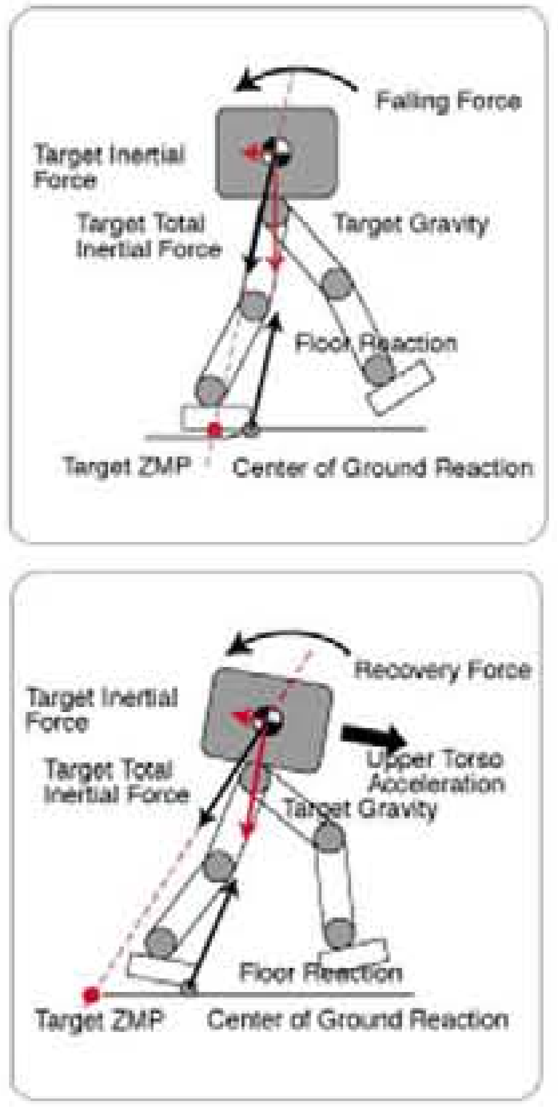
asimoserves

asimofront

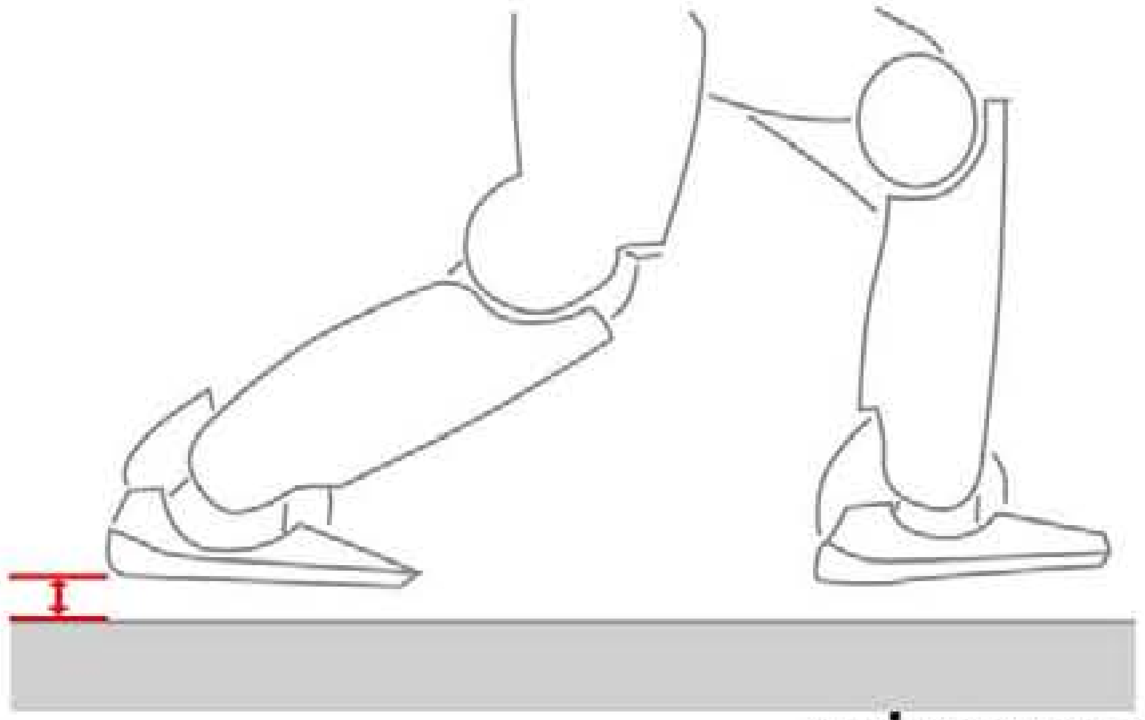
properties

Bipeds are the face of robotics. A humanoid robot is the holy grail of robotics. Two legs offer a flexibility of motion not available to quadrapods and hexapods. The flexibility comes at a price as the bipod must constantly balance itself, relying on heavy computation.

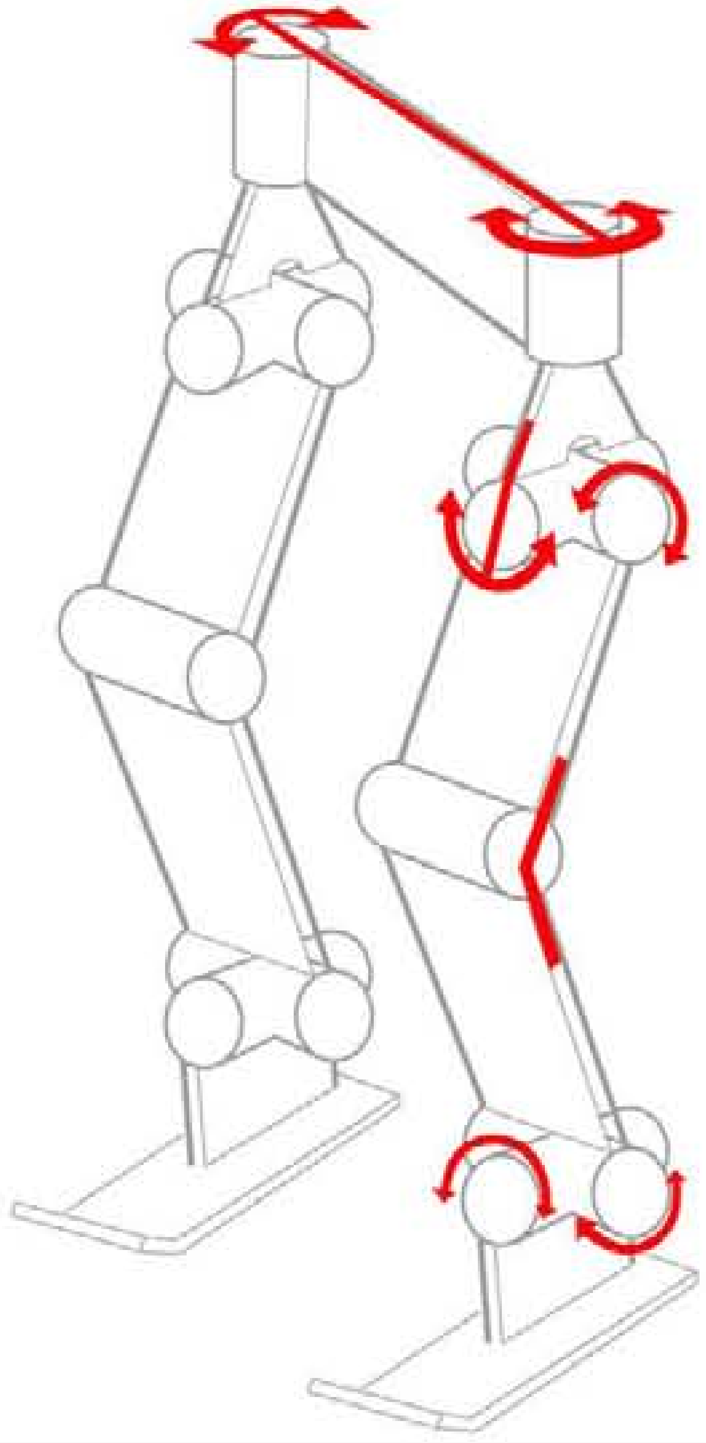
The anthropomorphic qualities of the bipeds are the most intriguing aspect. They have been dreamt about for 150 years. They are still limited by technological constraints.



forcesmotion

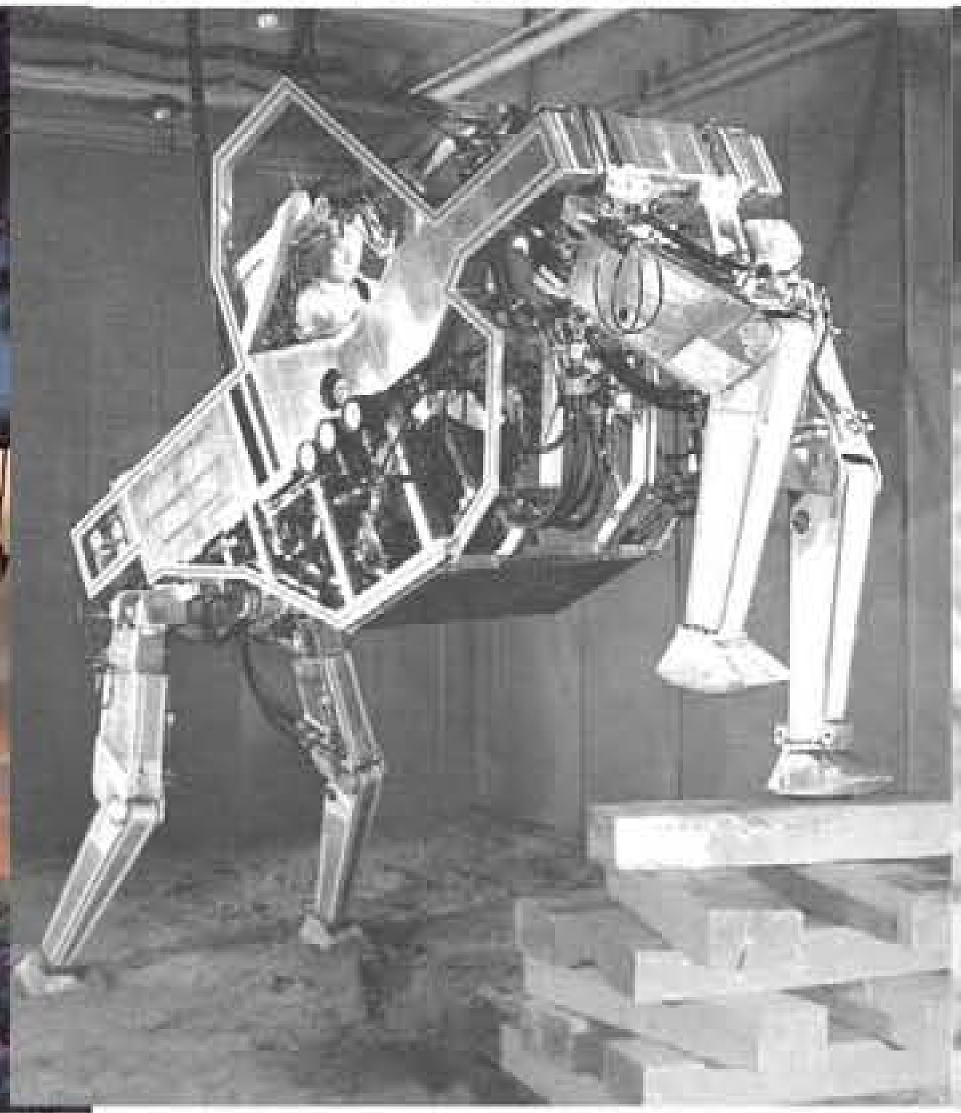


asimoruns



biped

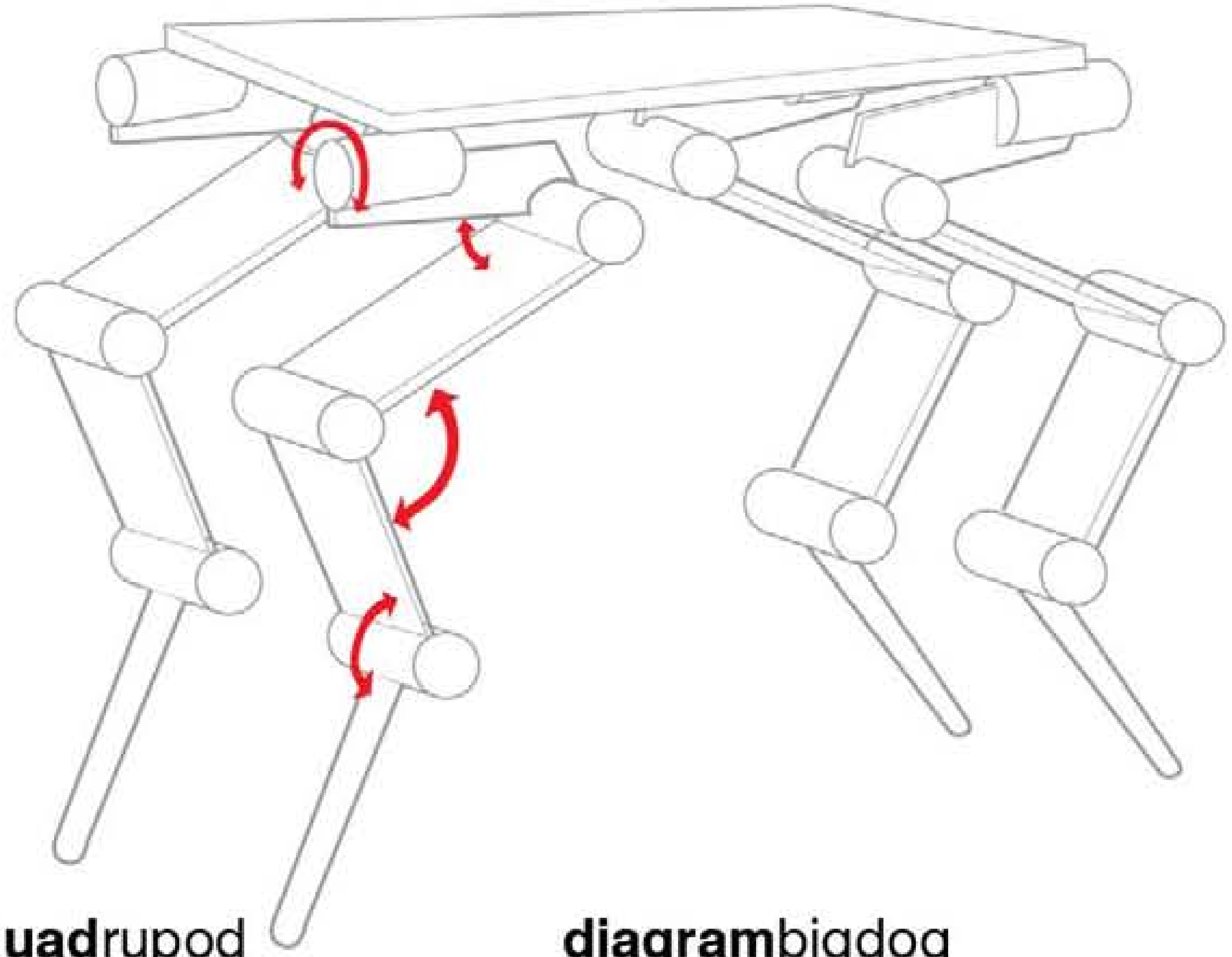
howl'smovingcastle



gewalkingtruck

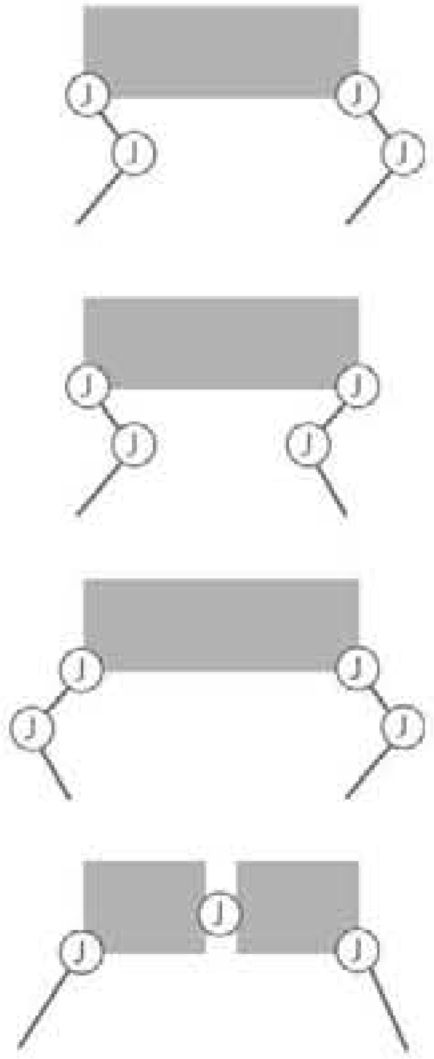
bigdogbalancing

bigdogdetailed



quadrupod

diagrambigdog

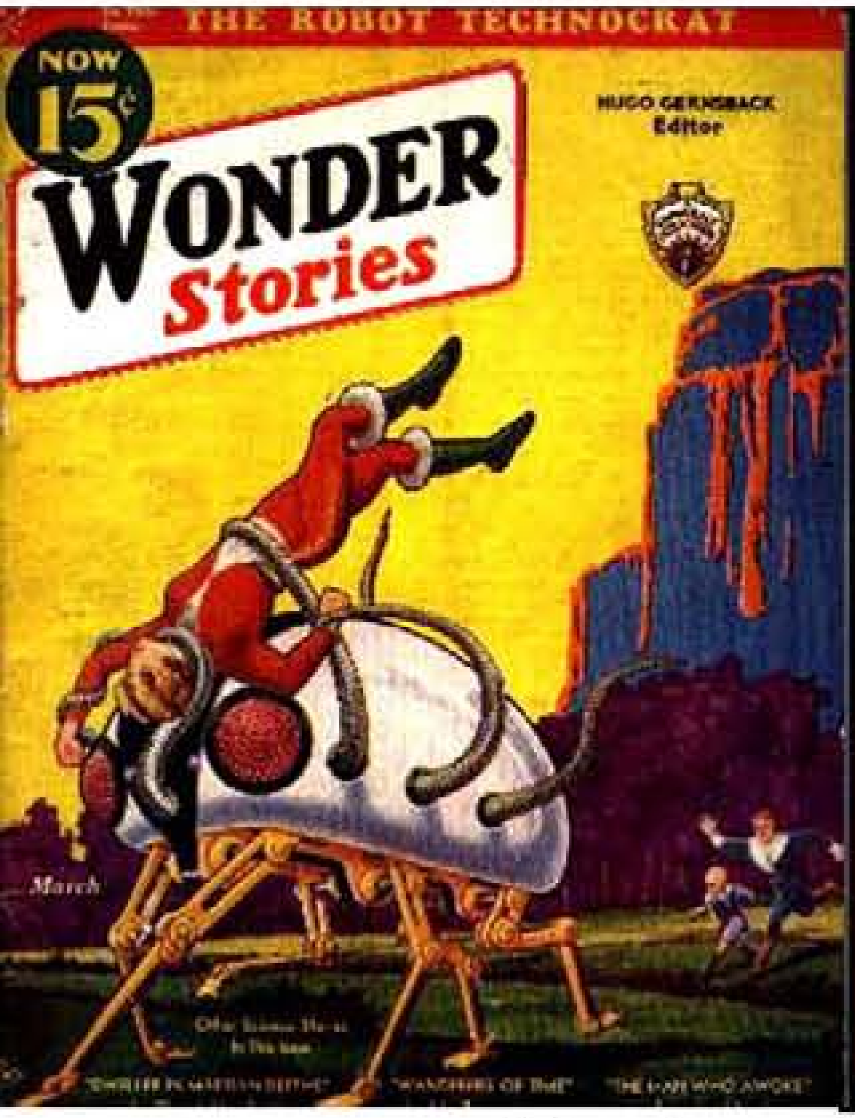


walkingtypes

properties

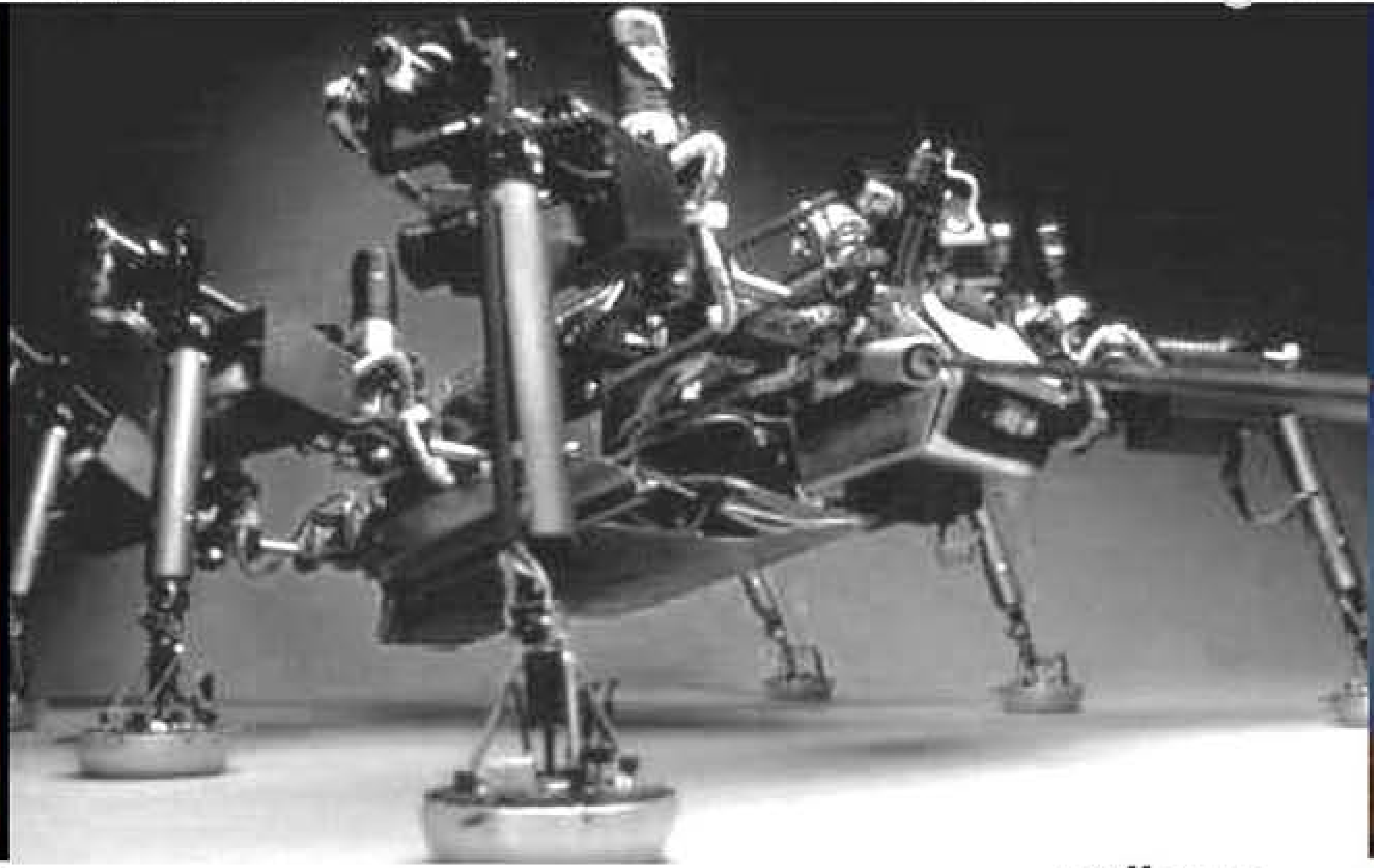
Four-legged robots provide a speed and greater terrain flexibility than hexapods. The difficulty is in the balancing system to attain the high speeds.

A higher computation power and energy consumption is needed than hexapods, but it can potentially be faster than hexapods and handle heavier loads than bipods



scififrankrpaul

scificoncept



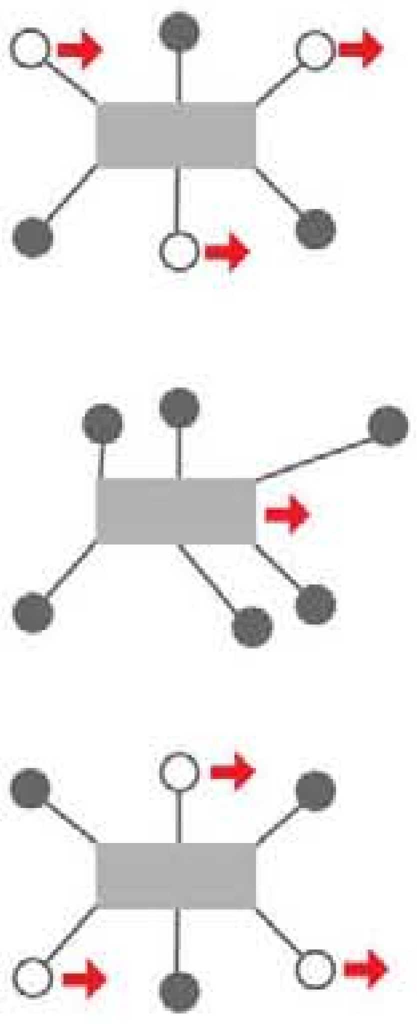
attilatwo

genghisgait

properties

Six-legged configurations are popular because of their static stability during walking. This allows for a simple balancing system inherent in its motion. The hexapods always have at least three points in contact with the ground at any one time.

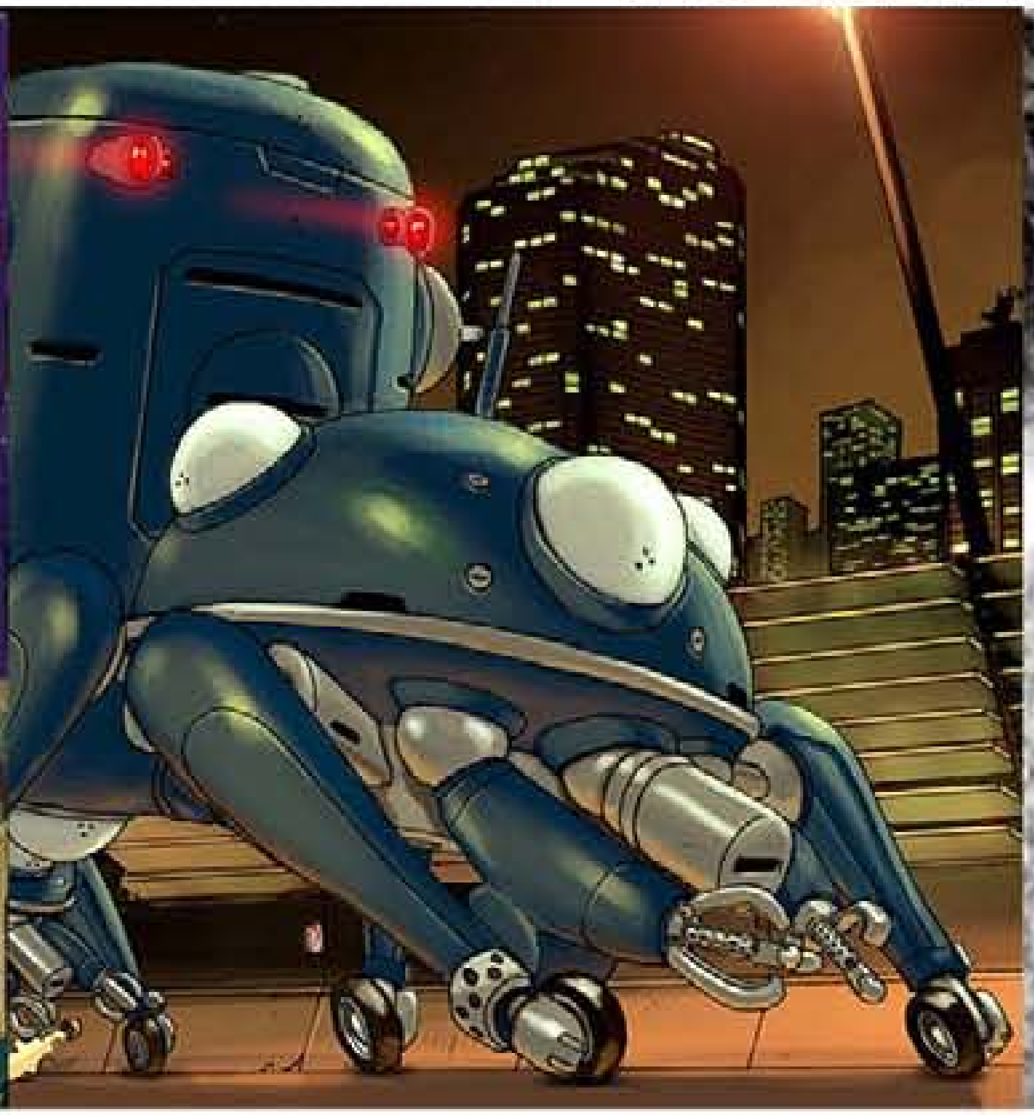
The natural stability of six legs allow for less energy consumption and less computation, but it does not allow for the possible flexibility or speed of other legged robotics



diagrammovement

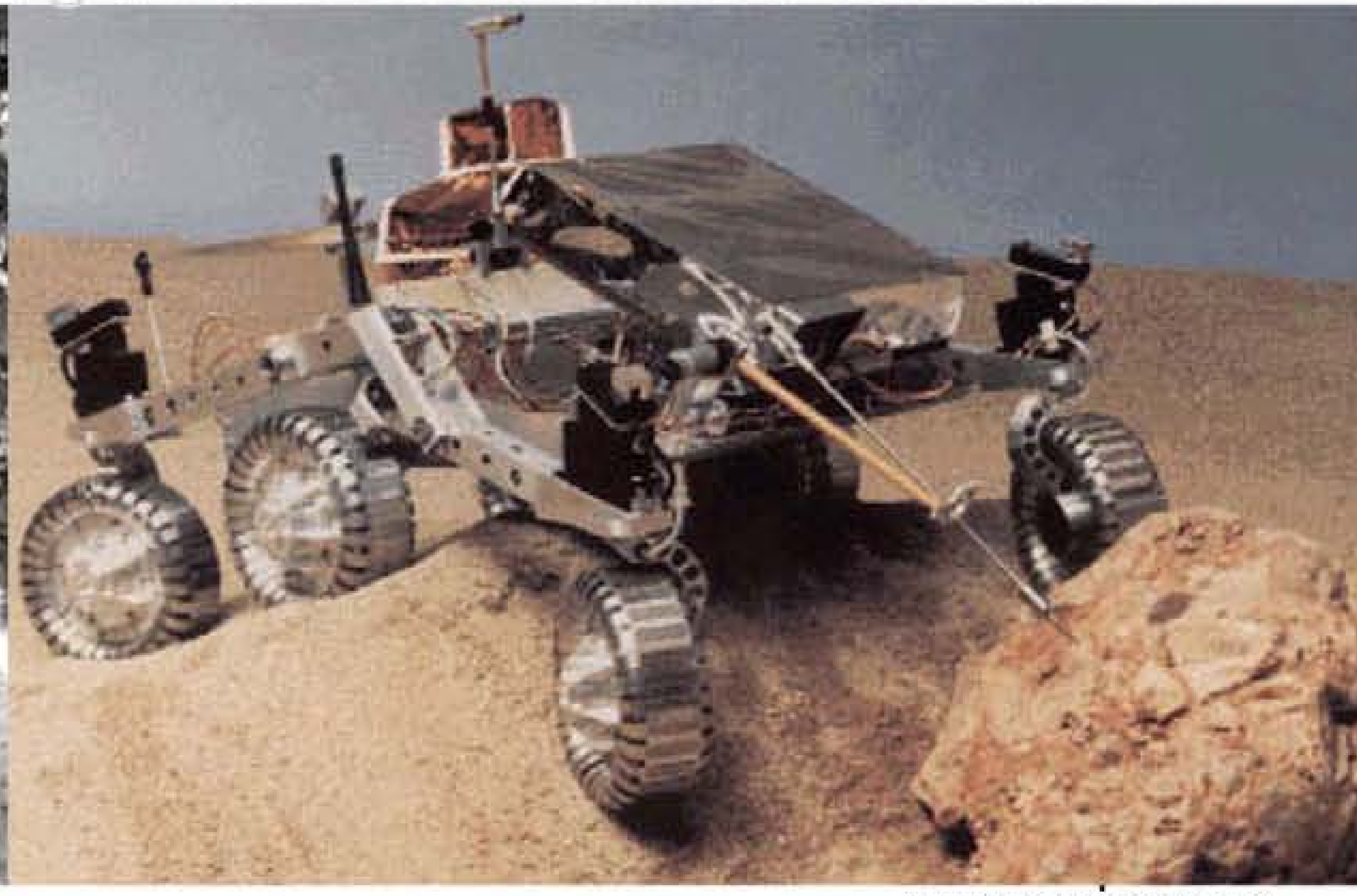
hexapod

scififrankrpaul



scifighostinshell

shrimpallterrain



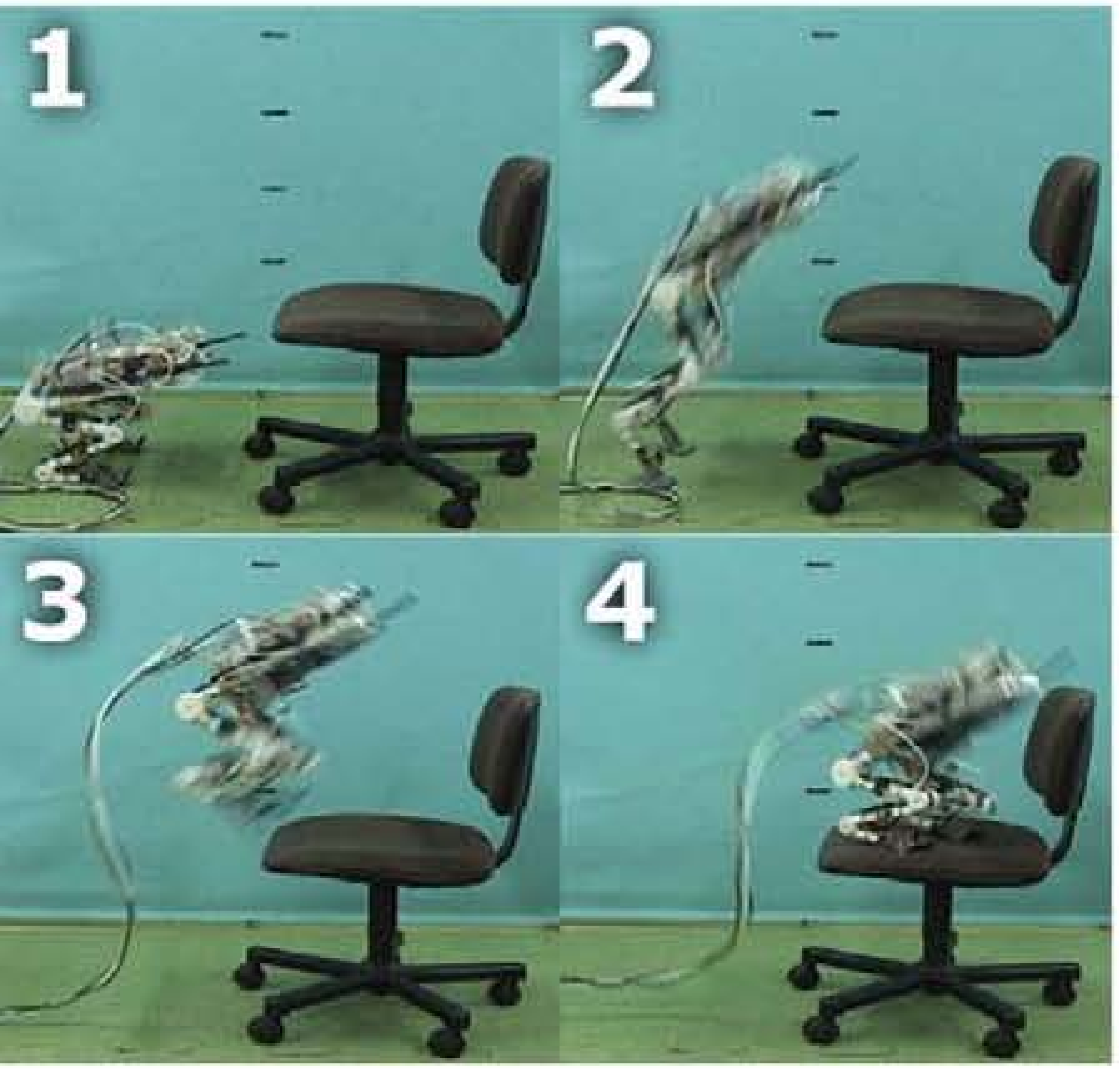
marssojourner

properties

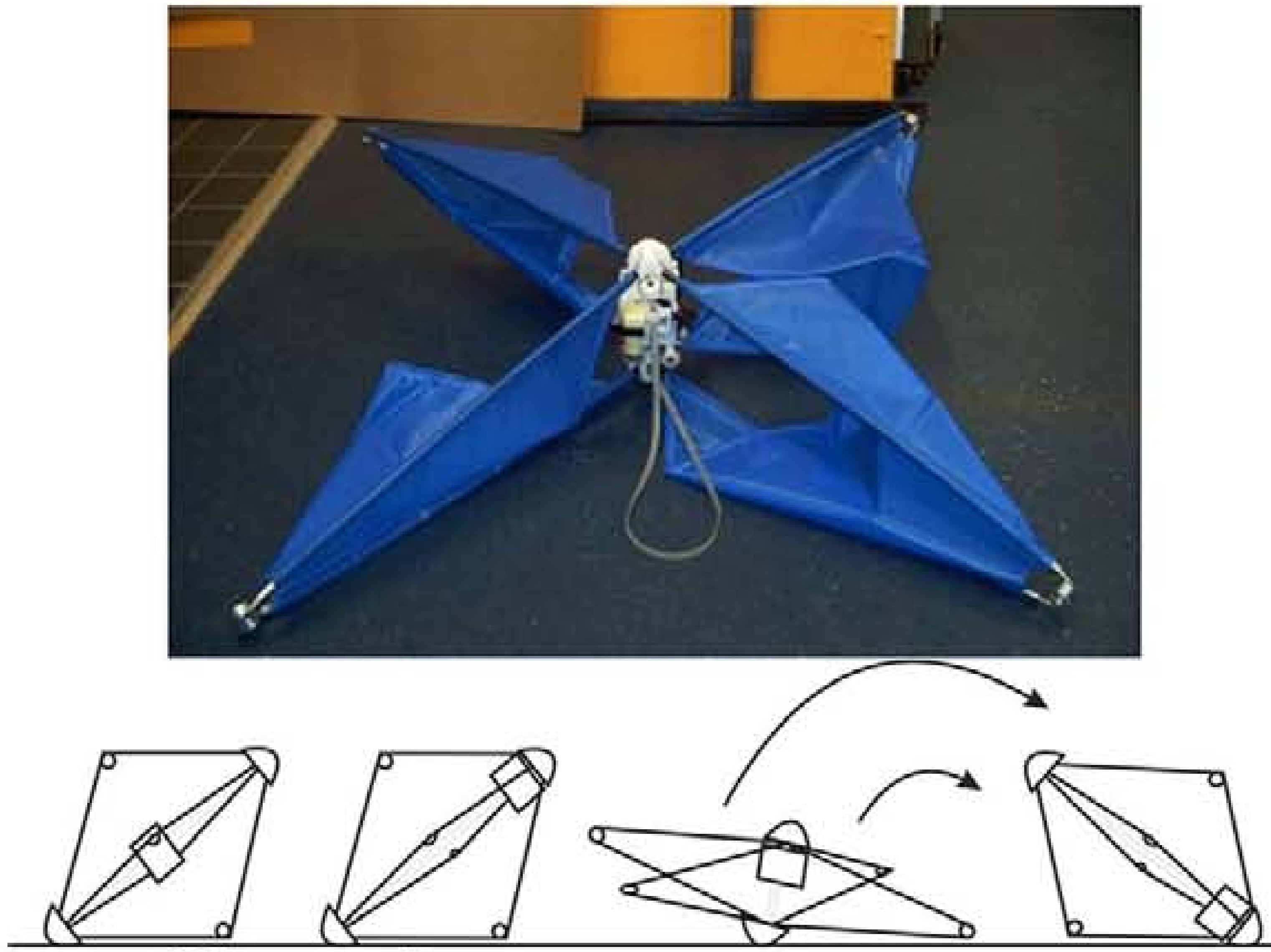
When leg systems are combined with wheels, a more efficient robot can be developed. The legs provide the flexibility for difficult terrain. The wheels provide speed and efficiency on simple terrain.

The only drawbacks of a hybrid system would be the difficulty of computation and energy consumption. This is the reason there have been so few realworld applications of a hybrid locomotion system.

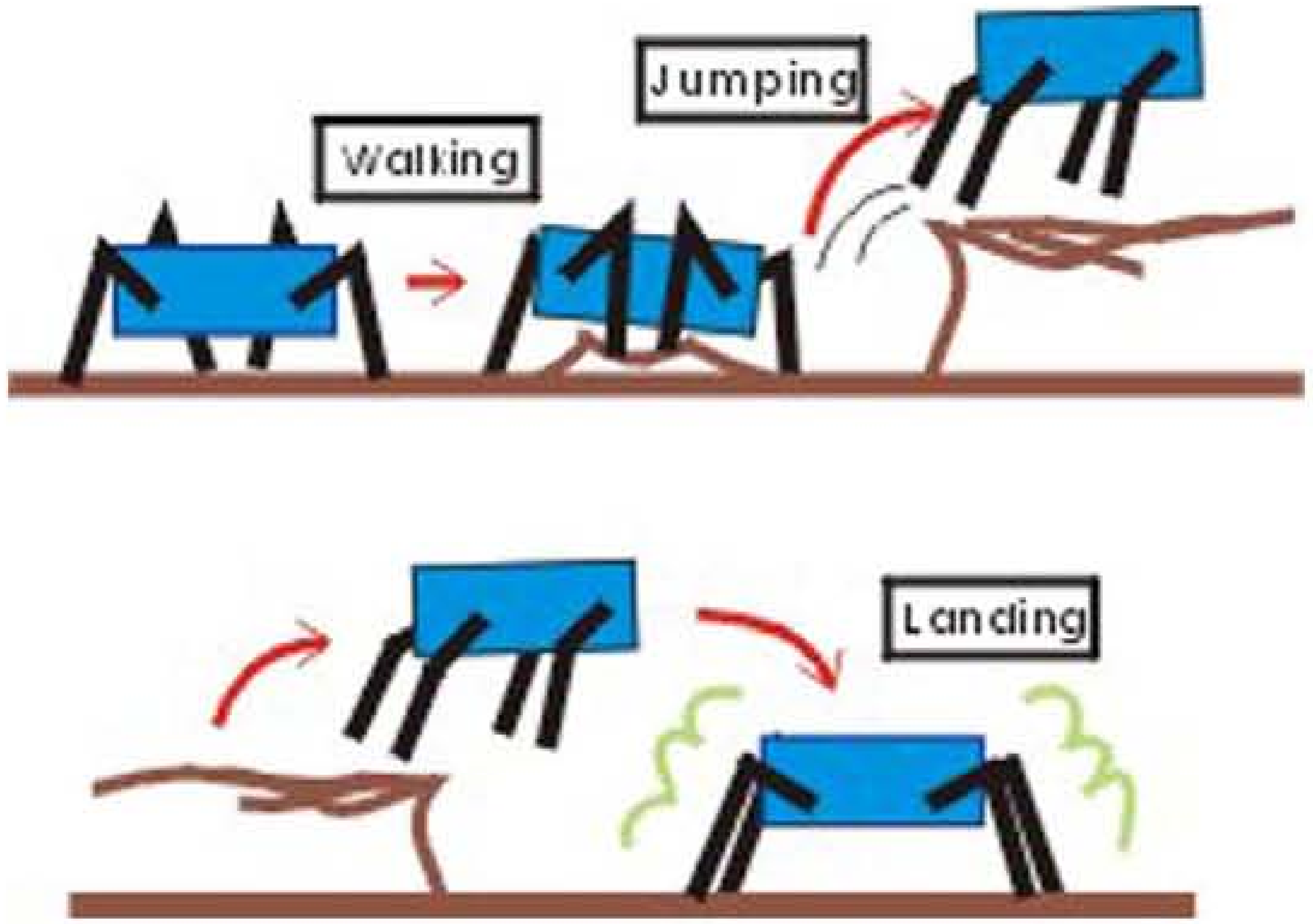
hybridwheel-leg



legged jumping robots



'Glumper'



sub-category(jumping)

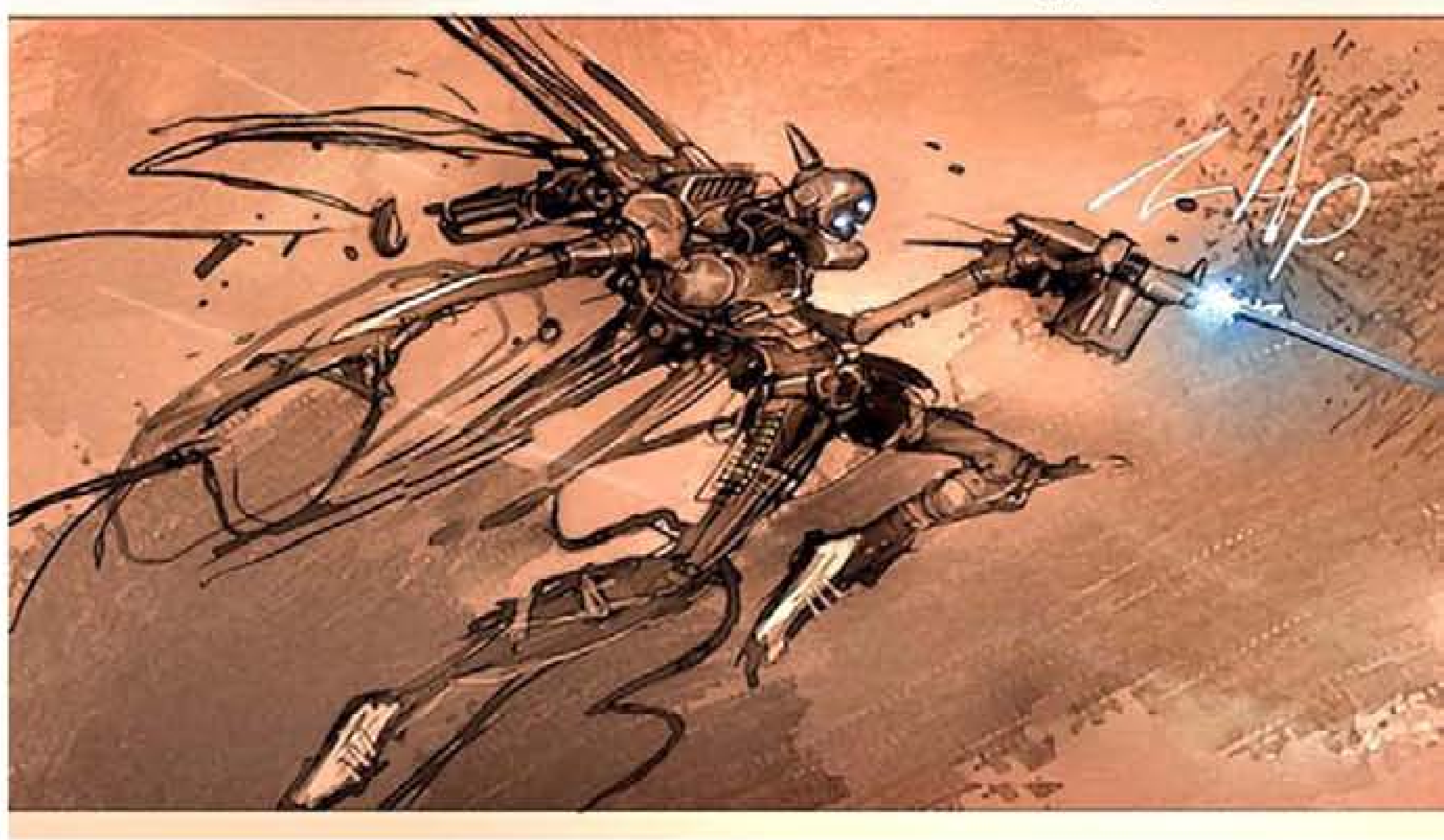
description

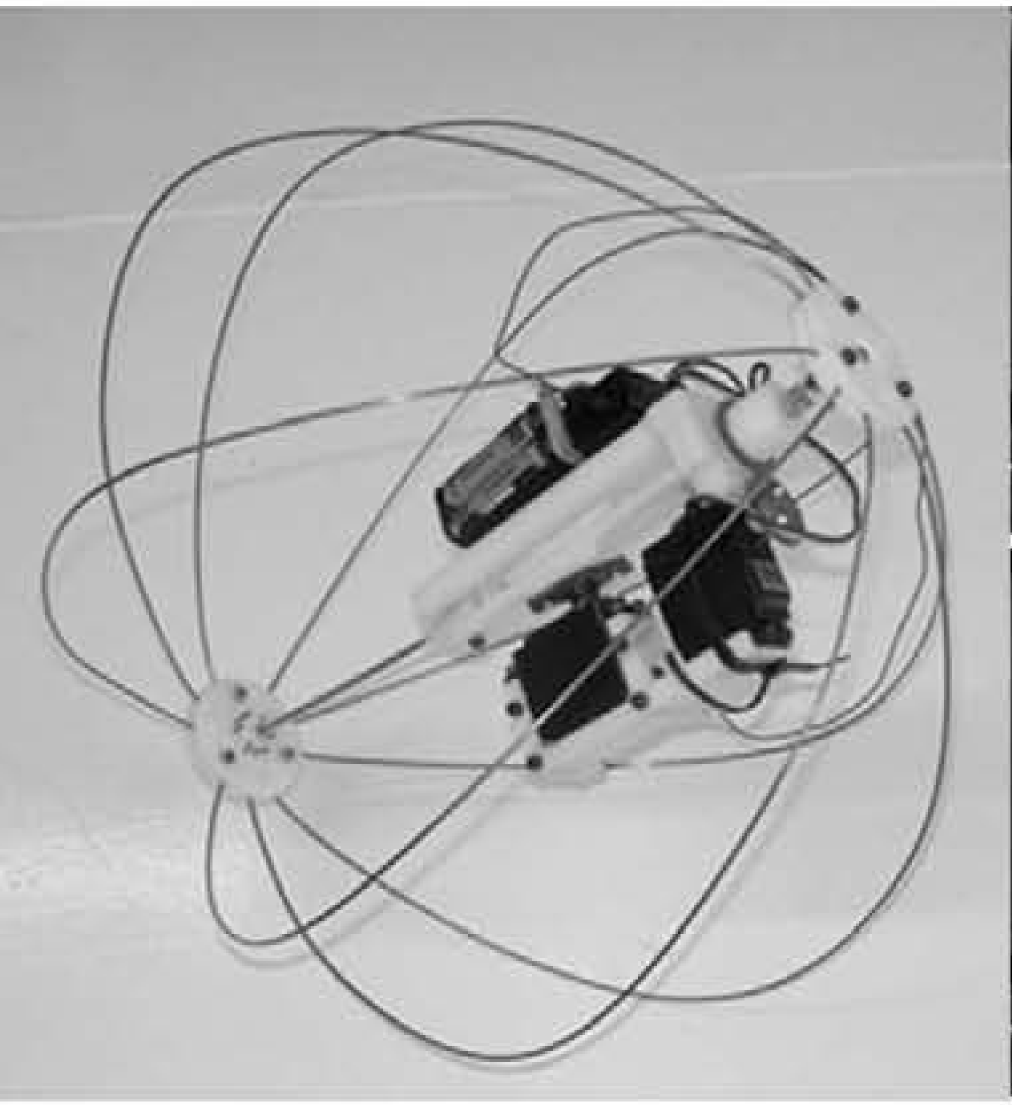
Legged robots

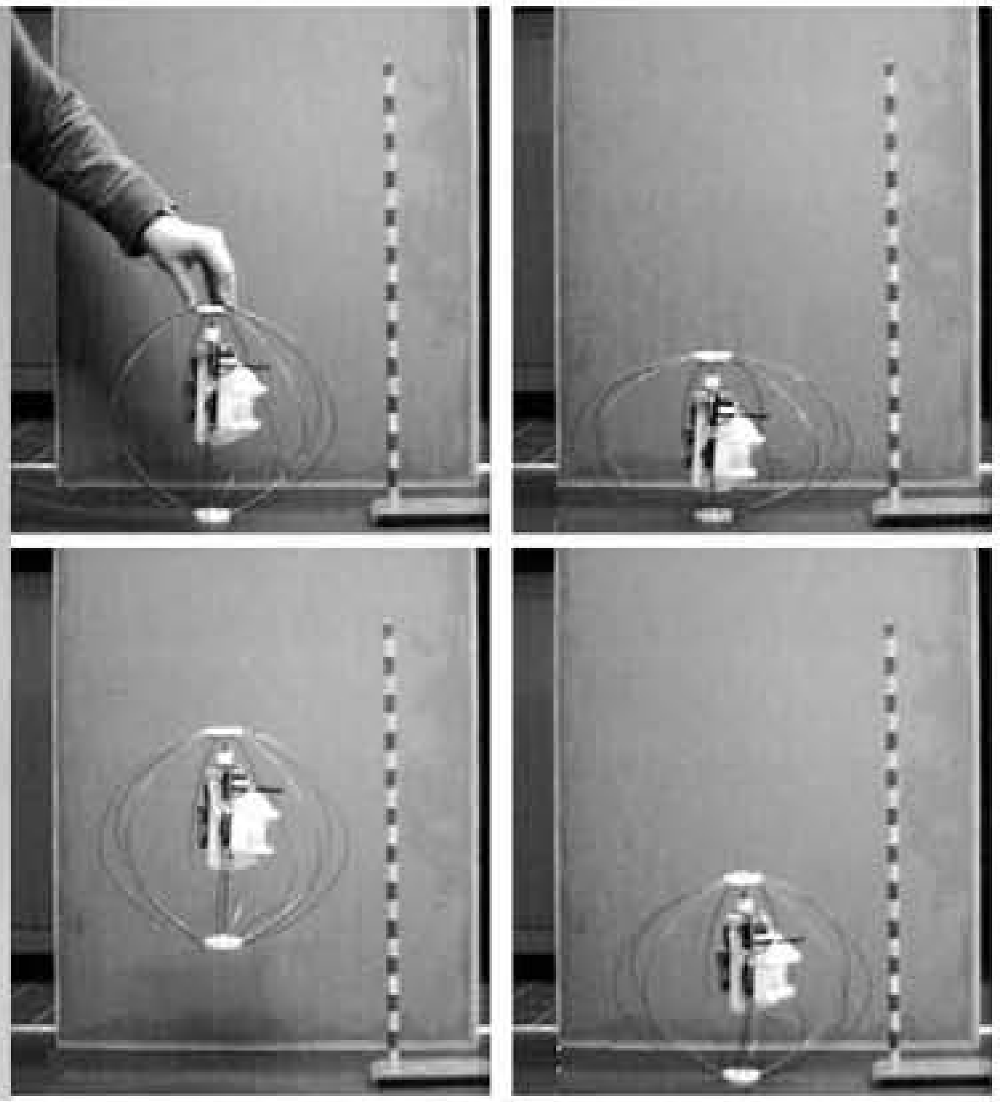
a. The robot is bipedal with 6 pneumatic muscles on each leg for 6 degrees-of-freedom. It utilizes this artificial musculosceletal system to perform explosive motion jumping as high as 50% the robot's height and landing smoothly. The musculoskeletal system is inspired by biological systems.
It is controlled by an off-board PC and supplied by compressed air for the muscles and electrical power.

b. The legs mechanism consists of joints with cylinders that drive at very high speed during jumping motion. Jumping movement is performed with air supply.
It has very high terrain adaptability and mobility.
It can move around areas with many high steps and obstacles.

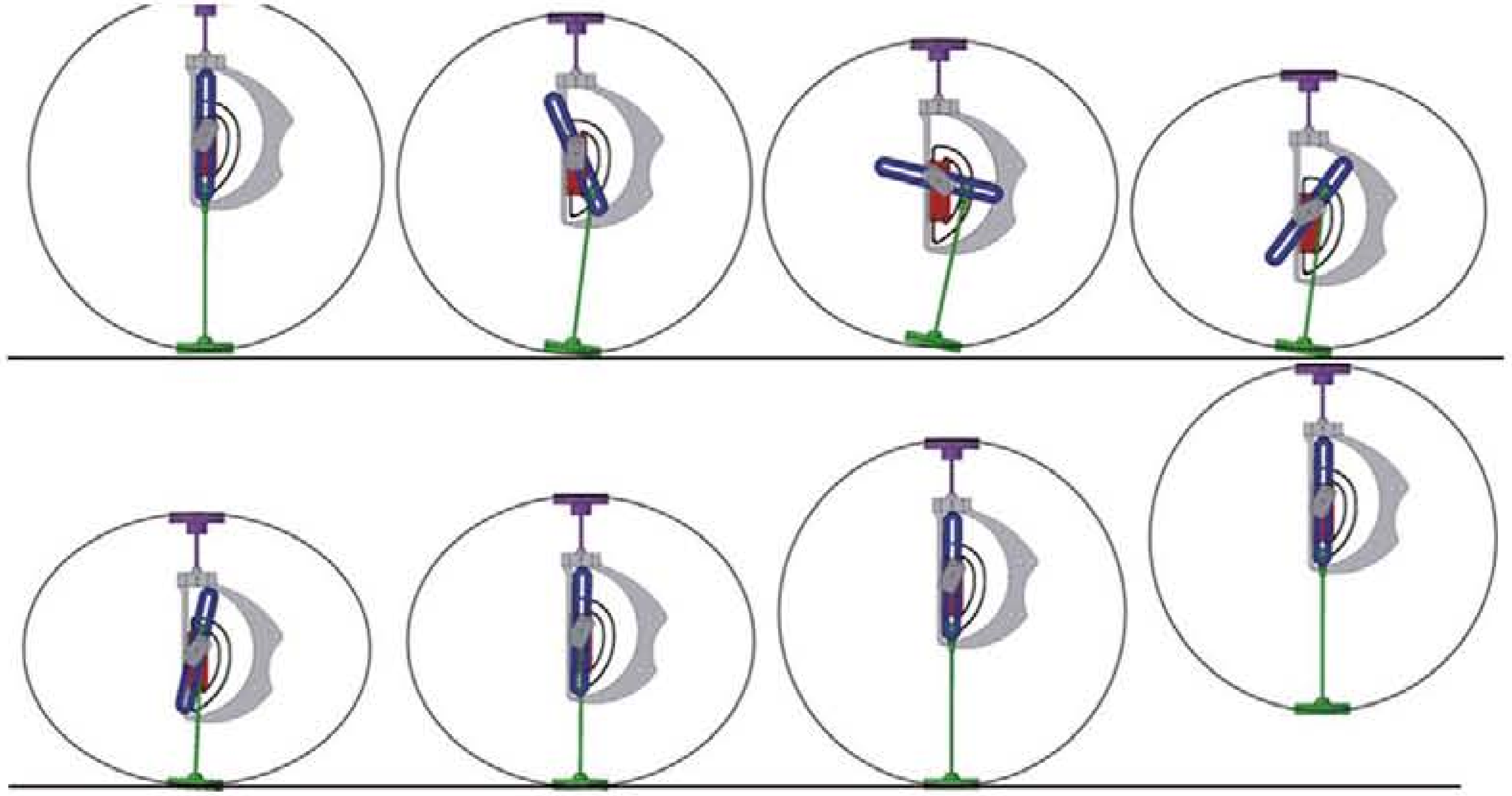
c. 'Glumper' (inspired by animals)
The robot jumps and then glides. It has 4 long legs, each with a torsion spring 'knee' at its midpoint, distributed perpendicularly between a 'head' and a 'foot'. A triangular membrane mounted between each leg element and along the axis of the robot acts as its gliding wings.



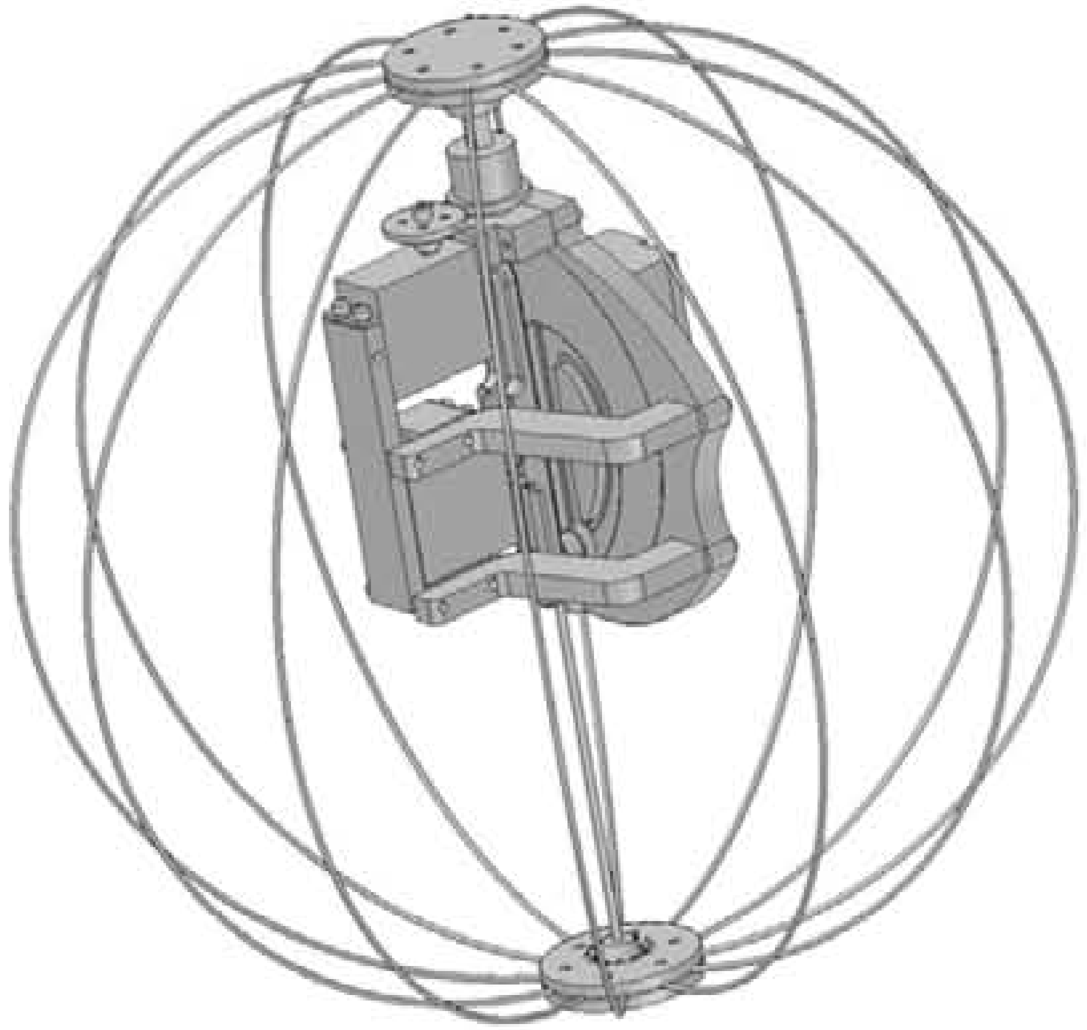




jumping performance



Pictorial representation of the compression phase and the jumping phase of Jollbot



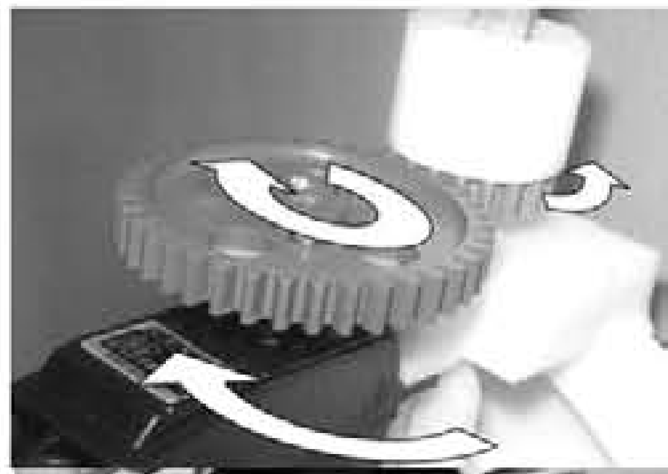
sub-category(jumping)

description

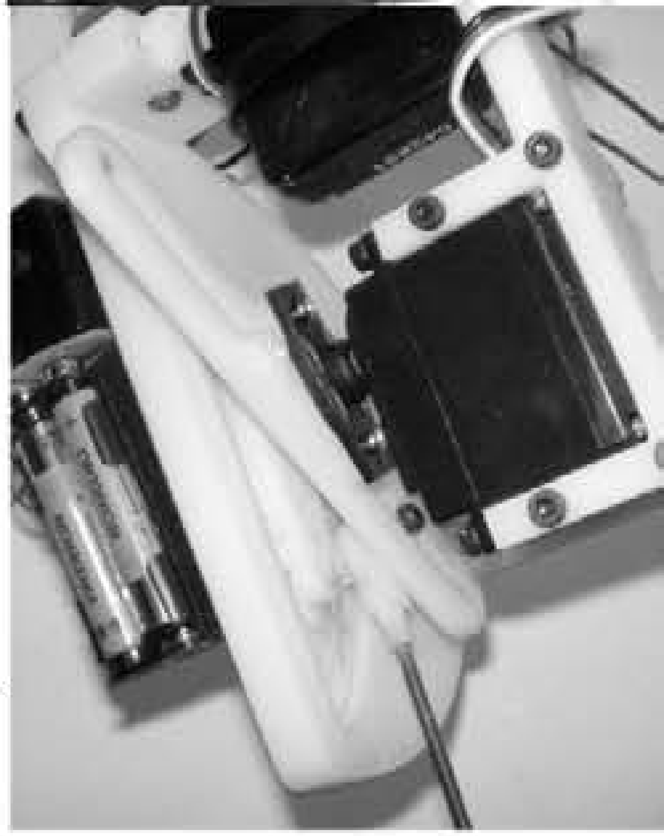
Combined jumping and rolling motion results in its name, the Jollbot. The main skeletalstructure comes from the metal semi-circular hoops. These hoops are the springs that provide the energy for jumping and rolling.
Compressing the sphere along a central axis, joining the mounting points of the hoops, energy is stored within the outer structure. Energy is rapidly released and provide lift to the robot. When jumping it raises its center of gravity by 0.22m and clears a height odf 0.18m.
A catch mechanism ensures it remains in its position until next jump.

application

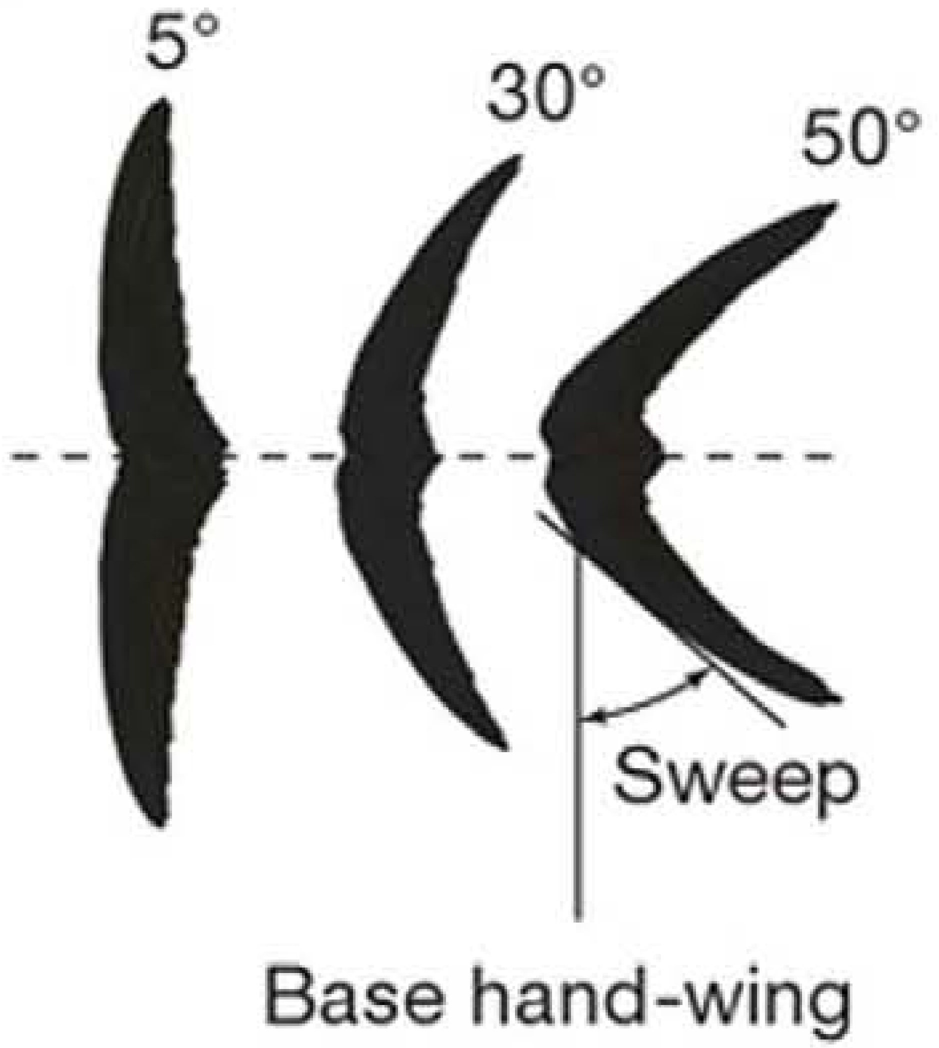
- -It has demonstrated some of the highest jumps for an autonomously powered robot so far engineered.
- -It will help astronauts, cause jumping is good locomotion across terrain
- -light in weight to maximize their own performance
- -higher damage tolerance
- -can store energy

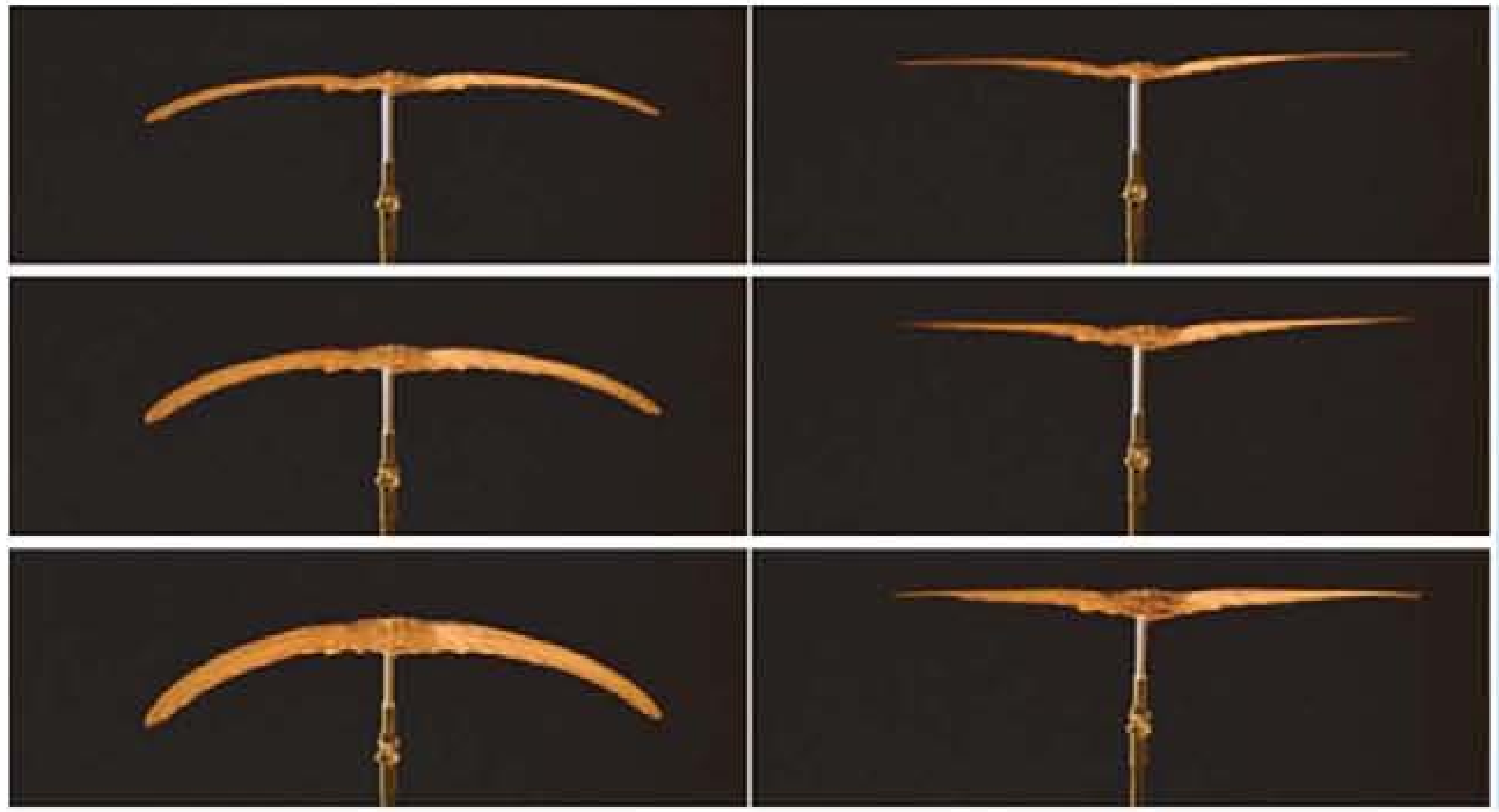


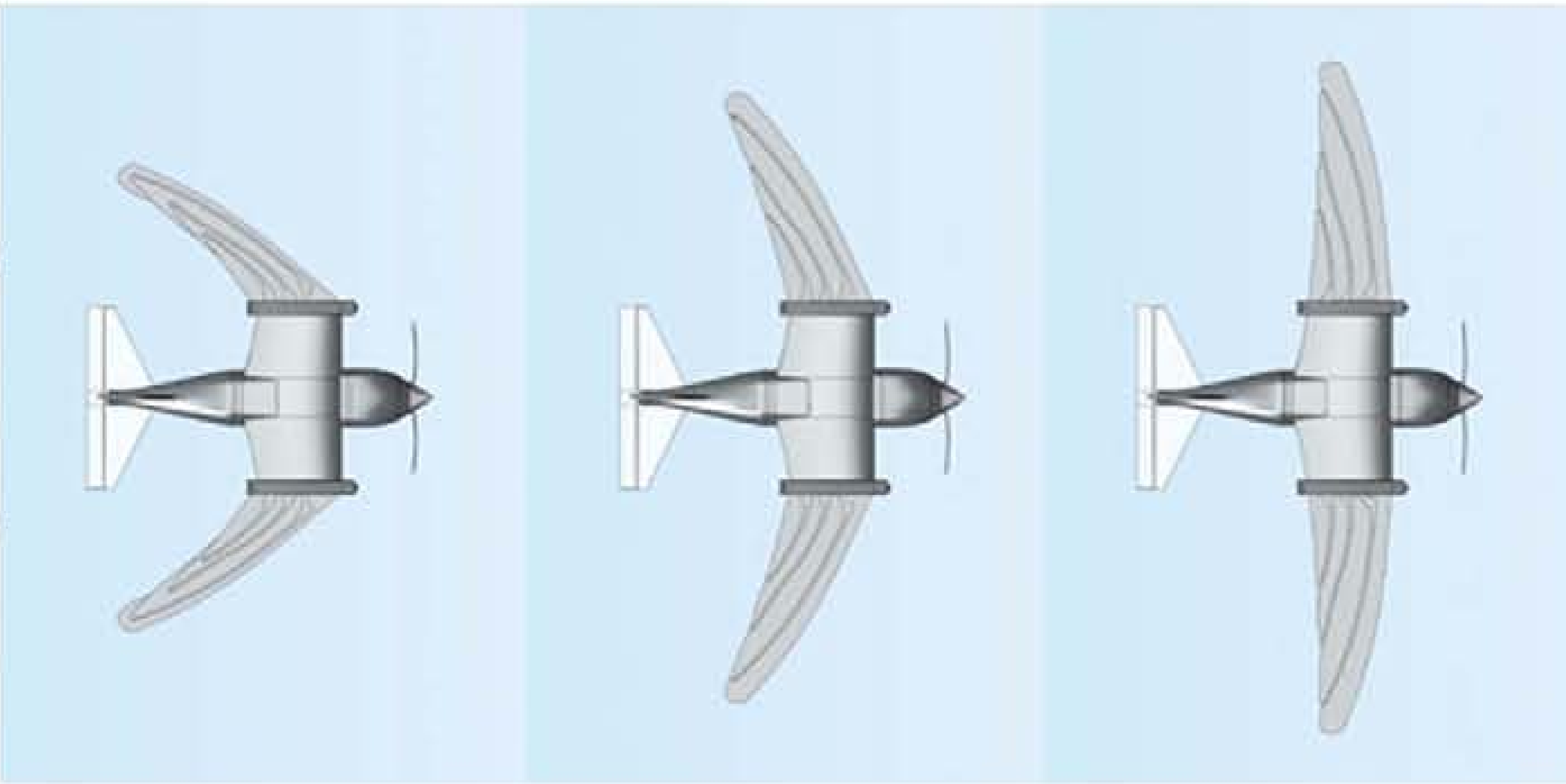
Jollbot jump direction and rolling mechanism



Photograph showing detail of guide, face cam and slider roller in Jollbot.



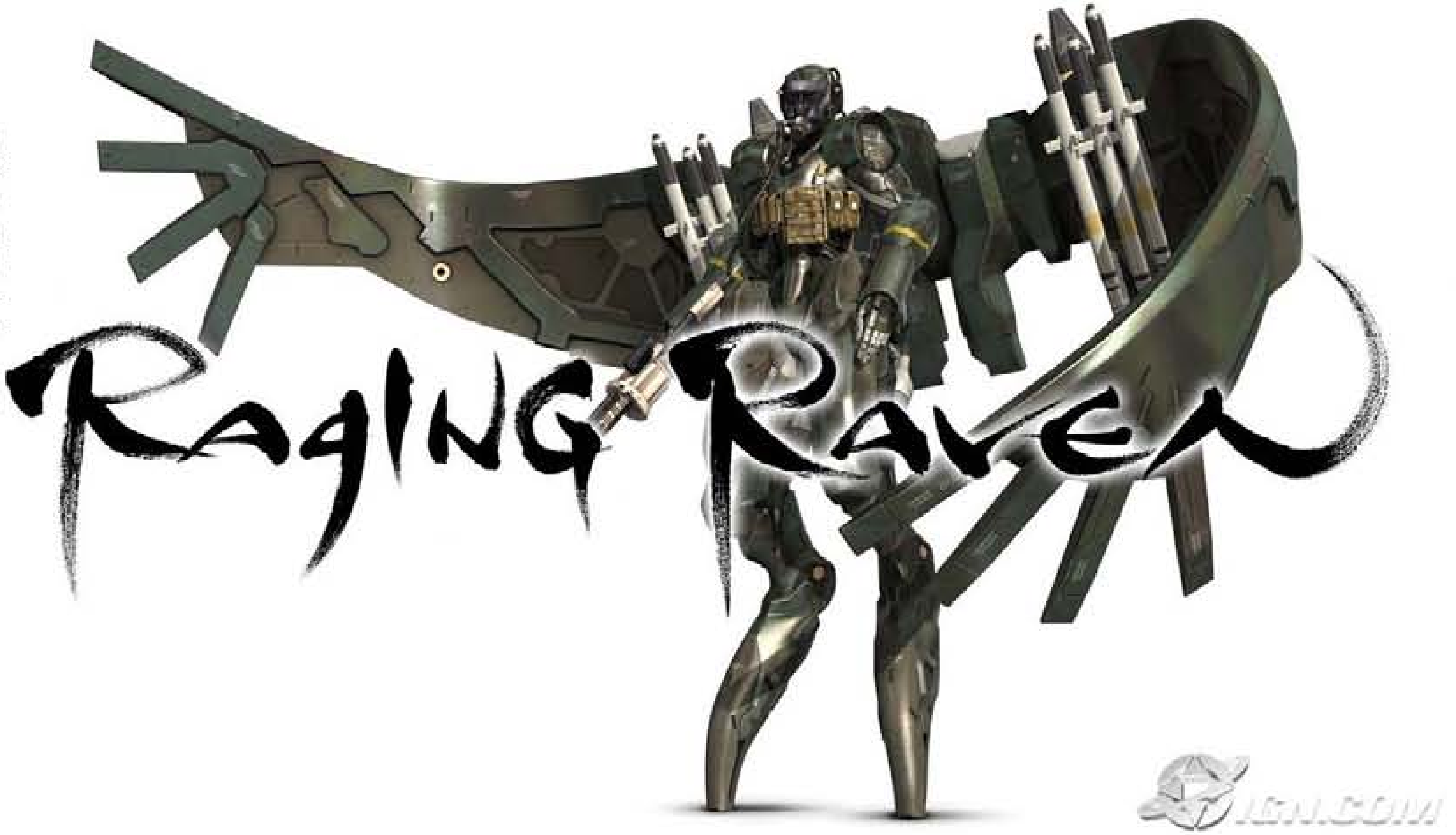




description

Roboswift: bird sized airplane that flies like a swift
The unique morphing wing-design features are taken from the swift. Morphing means the wings can be swept back and forth in flight by folding feathers over each other, thus changing the wing shape and reducing the wing surface area. Roboswift also steers by morphing its wings. Doing so it can perform optimally, flying efficiently and highly maneuverable at very high and low speeds and more agilely than fixed-wing aircrafts.
The propeller that powers the plane folds back during gliding to minimize air drag.

It is used to perform surveillance missions.

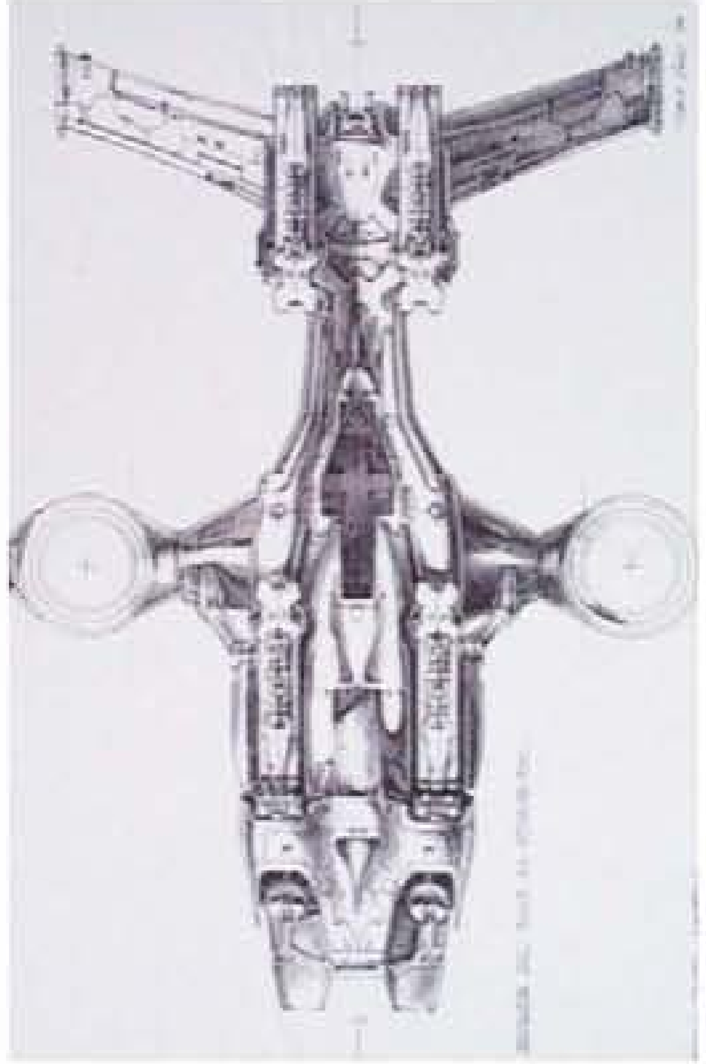


military robot:the predator

unmanned AutoCopter

autonomous aerobotes for exploration of Titan and Venus

the Blimp



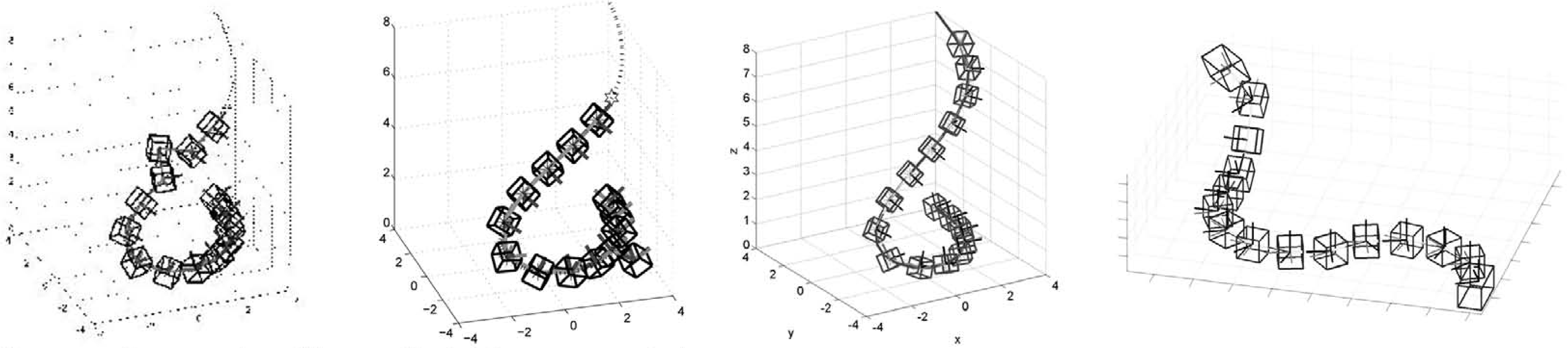
sub-category(autonomous flying)

description

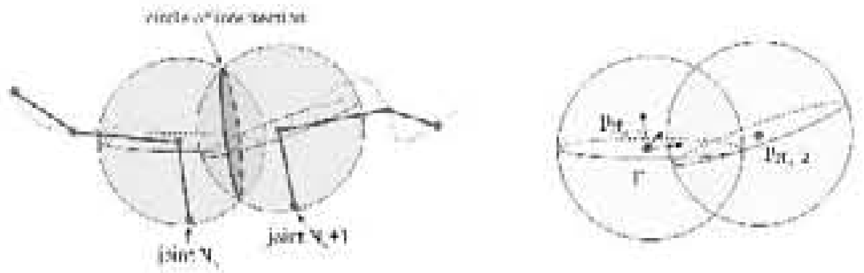
a. The predator : it is a remote-controlled light aircraft, that remains undeatected by radars.

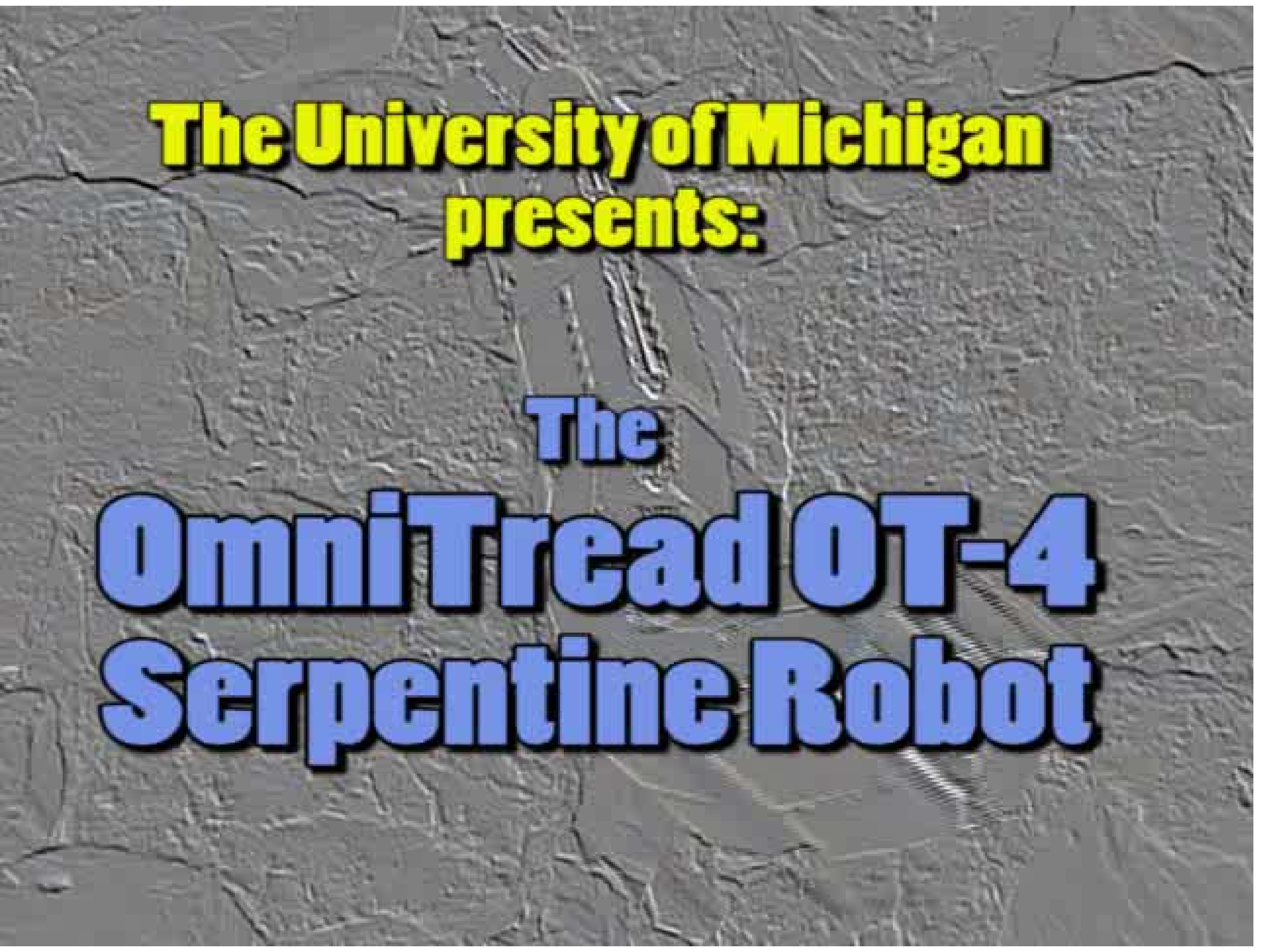
b. AutoCopter: it is a military robot with a neural networked-based automatic flight control system. It works with computer and is gasoline powered.

c. the Blimp: evolving aerial robot that is controlled in thrust and can slip sideways. it is controlled by a computer and powered by batteries.



Diagrammatic examples of the way the joints are connected





description

Living snakes have 4 major gaits:
1. lateral undulation
2. concertina gait
3. sidewinding
4. rectilinear motion

Designers of snakelike, nonlegged robots have adopted one or another of these methods to provide mobility for their machines.

behavior

The snake-shaped serpentine robot is propelled along by **moving treads** that cover 80 percent of its body. These treads prevent the snakebot from stalling or becoming stuck on rough terrain because, similar to a tire touching a road, t the treads propel the robot forward like a tire touching a road.

A human operator controls the snakebot via a **joystick** and **umbilical cord**, which also provides electric power, which sends commands to specially designed software. A smaller, but more self-contained version that is now under development will carry on - board power for one hour of tetherless operation

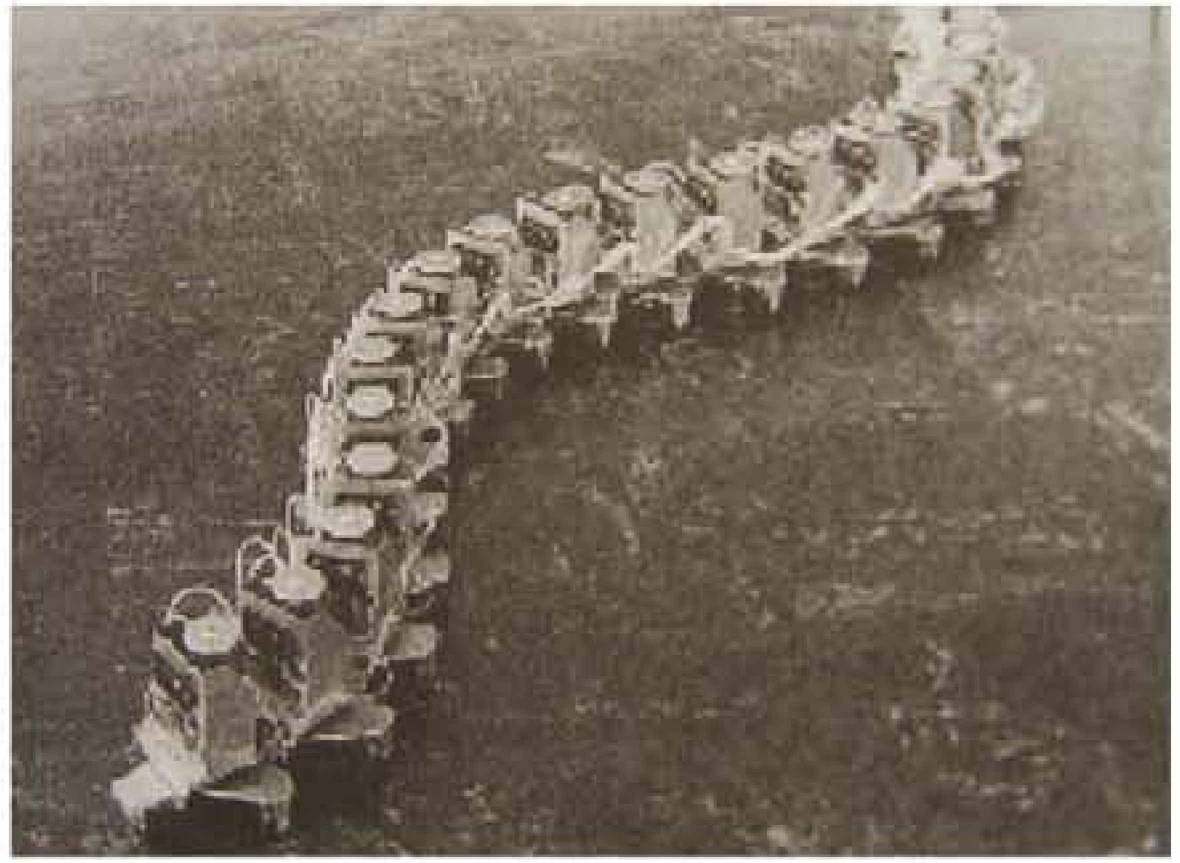
application

The serpentine (snake) robot can be used for **hazardous inspections or surveillance** in **industrial** or **military applications**. Other uses can be for inspection of pipelines, for medical applications for both diagnostic and surgical purposes.

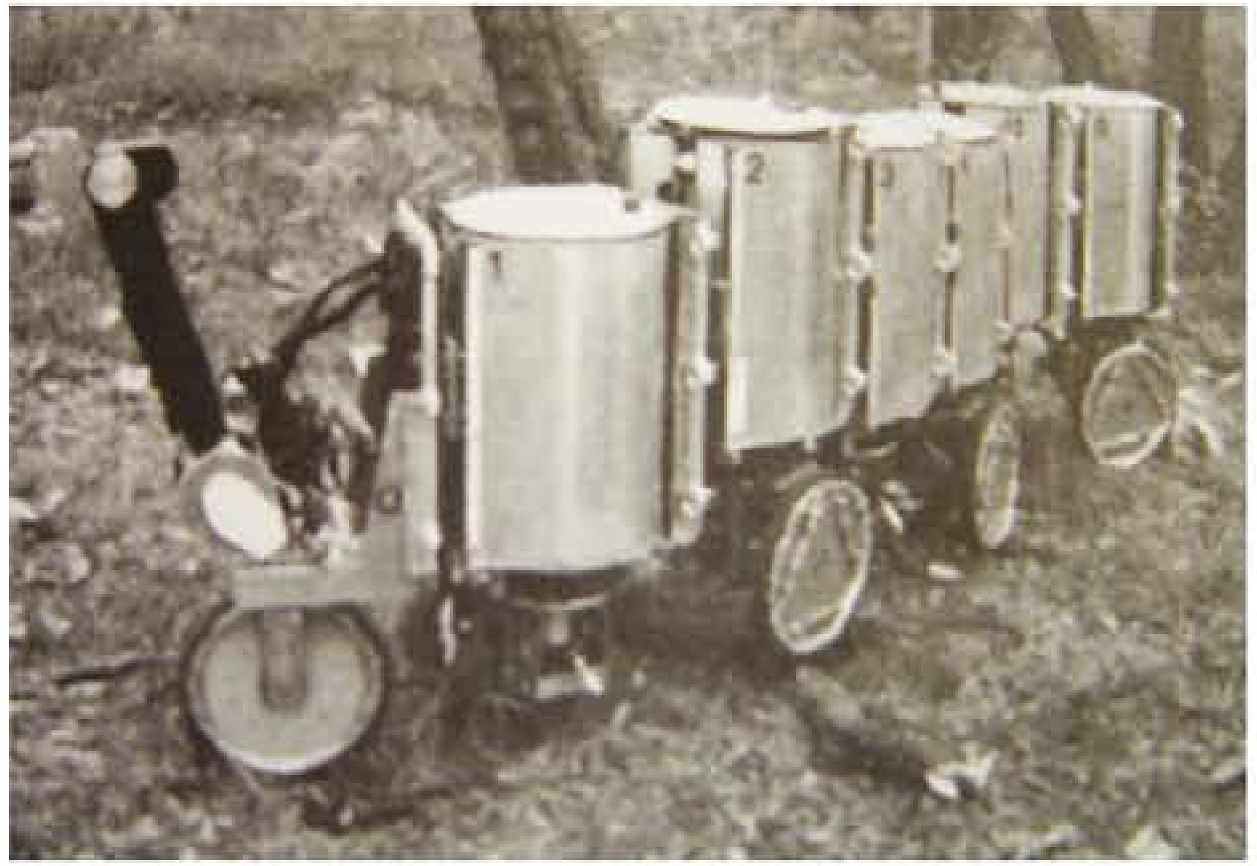
application

sub-category (serpentine / snake robotics)

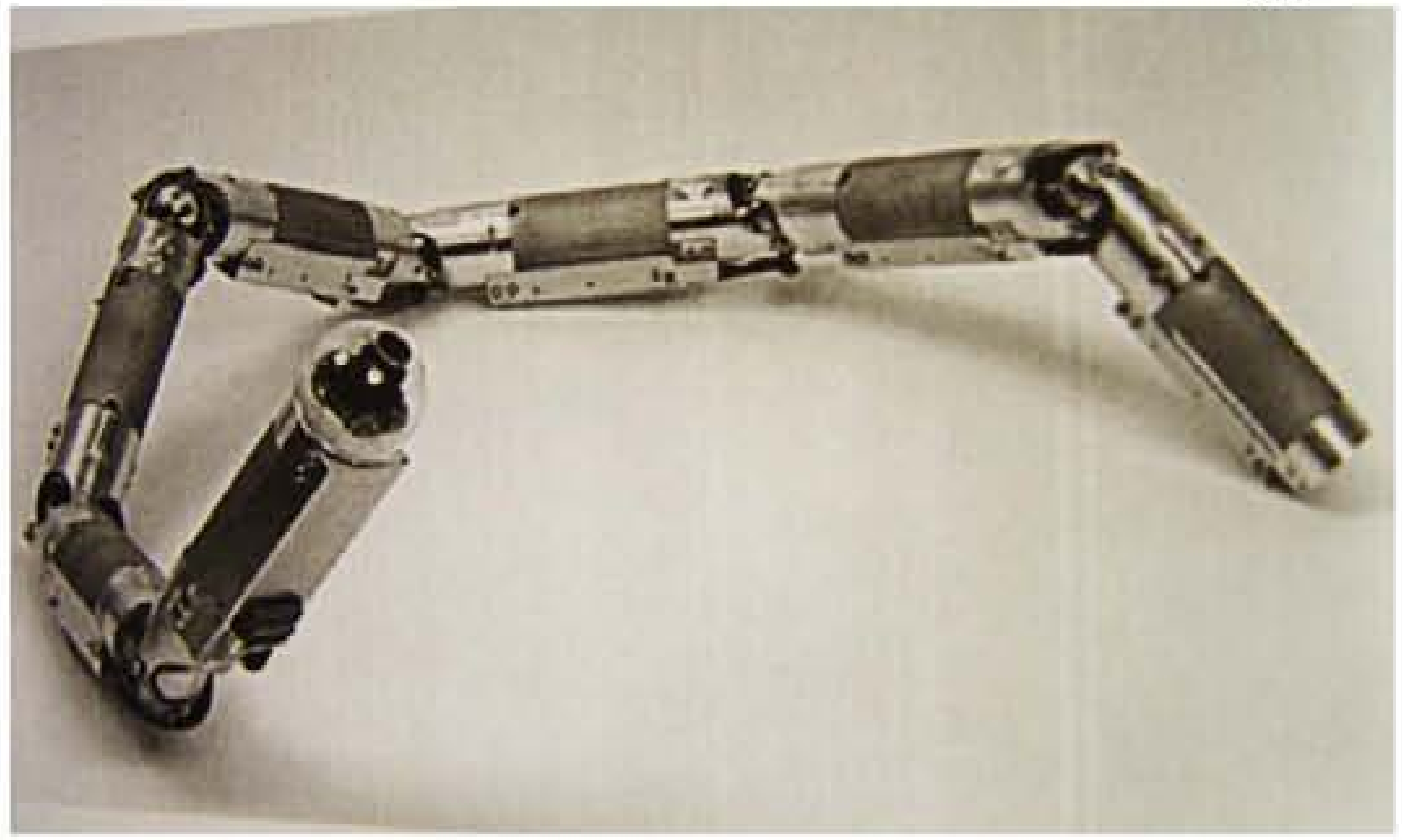
Different types



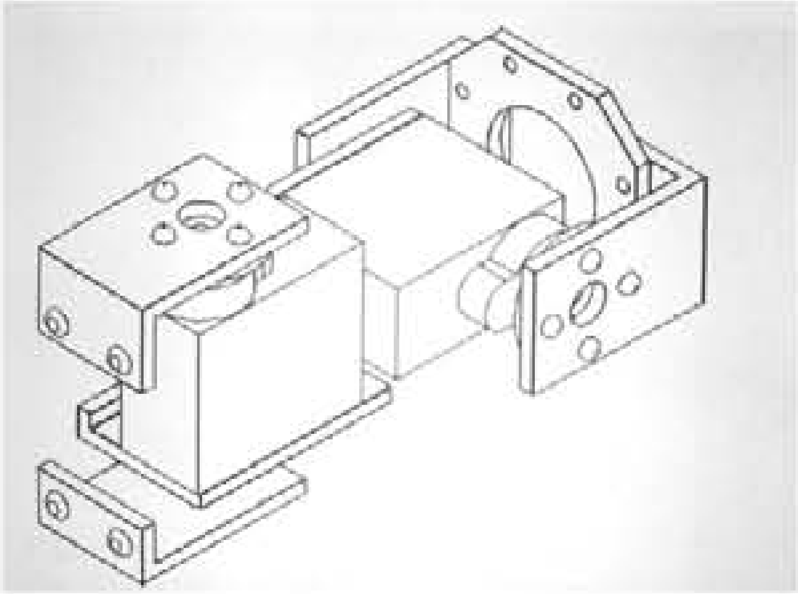
Hirose snake robot with adaptive cord mechanism



Snake robot that is capable of adjusting to terrain variations by means of relative vertical movement



Robot with a mechanism strong enough to enable it to lift one or more of its segments.



Typical Linkage that is used in order to connect 2 pieces of the snace robot.

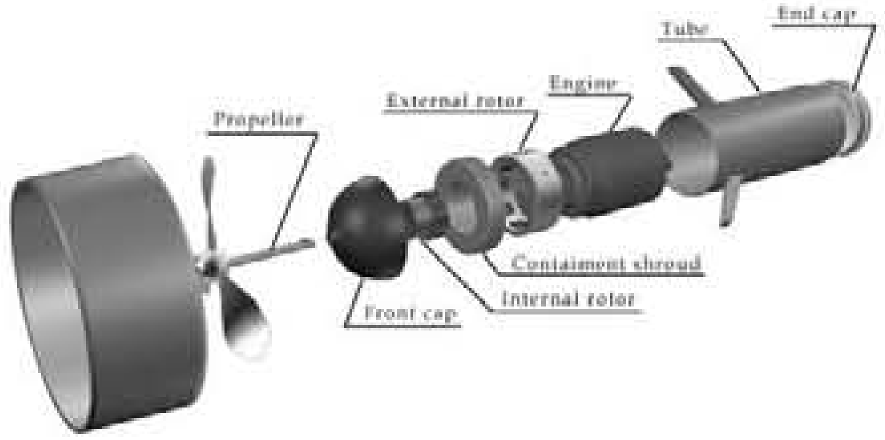
This Crawling Robot is a tetrahedron, which is a pyramid with three sides and a base. The tetrahedral pyramid shape is a fundamentally stable structure and the simplest space-filling solid.

HOW DOES A TETRAHEDRON ENGAGE IN LOCOMOTION?
The short answer is by moving the center of mass in a direction just off to the side of a target in the direction of a tetrahedral side until the tetrahedron tips over in that direction, and then moving the center of mass in the direction of an adjacent tetrahedral side just off to the other side of the target until the tetrahedron tips over in the other direction. The center of mass is moved off-center by lengthening and tilting above ground struts in the direction of alternating adjacent sides, creating a flip/flop motion.

sub-category (serpentine / snake robotics)

1. Submarines _ vehicles autonomous

Underwater robotic vehicles equipped with thrusters



description

Underwater vehicles differ from ground-based vehicles in a number of ways:

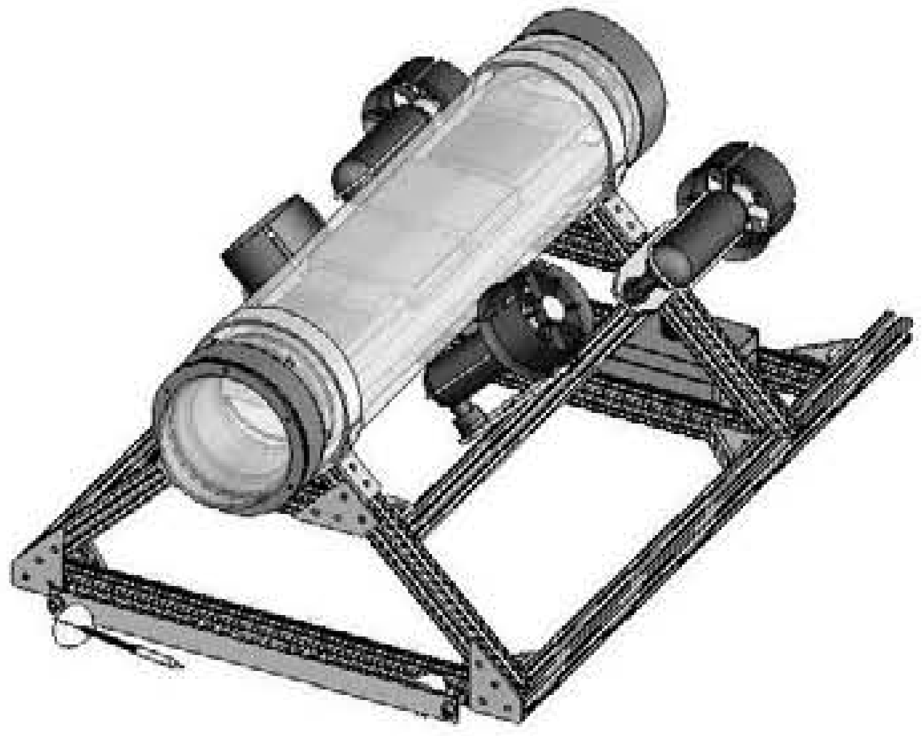
1. The vehicle must move in all three coordinate directions.

2. The density of water in which they move changes as a function of depth, and with it, the control characteristics of the vehicle change as well.

3. With increasing depth the water pressure on the vehicle increases.

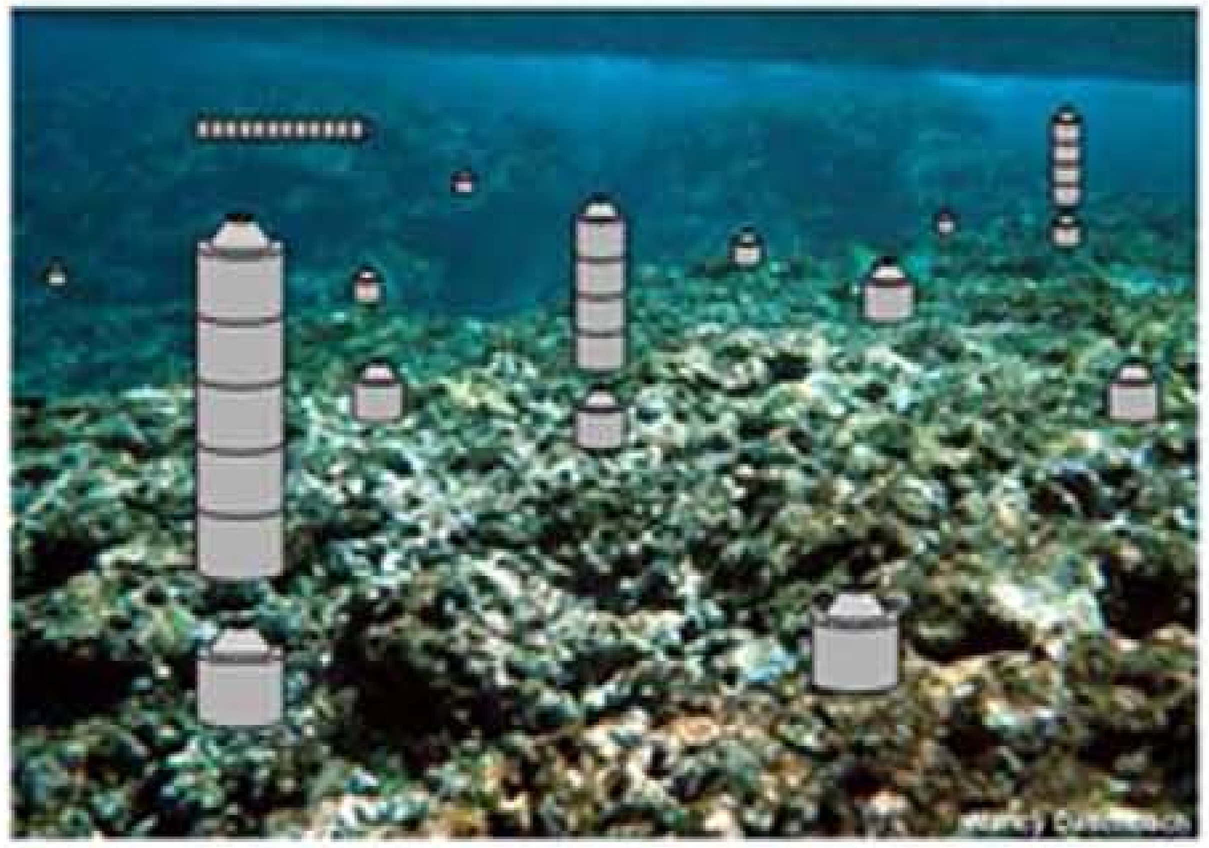
4. The dynamics of underwater vehicles are highly nonlinear, thus making simple linear control nearly impossible.

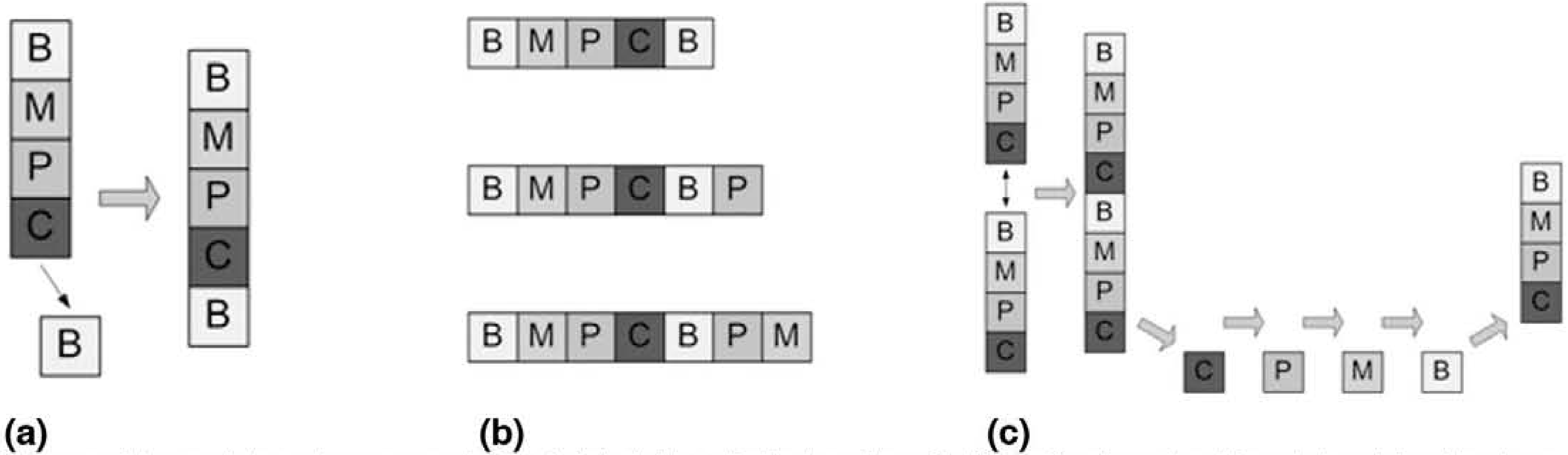
5. The vehicles must be sufficiently waterproof to safeguard all the on-board instumentation.



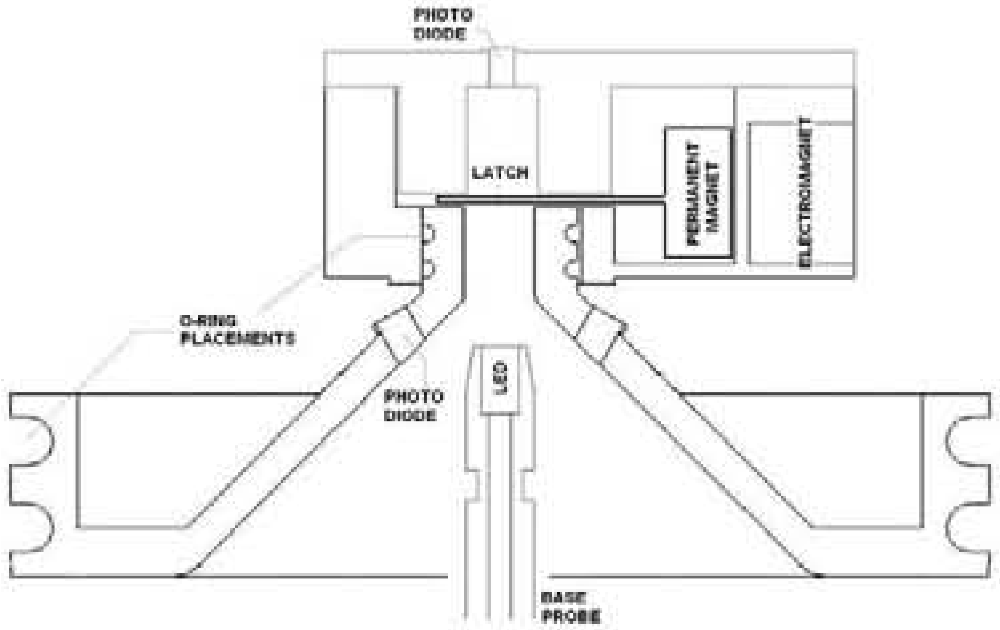
sub-category(underwater)

1. Submarines _ vehicles autonomous modular





The concept is a modular system composed of a set of stackable, cylindrical modules with different functions. A working robot contains at least one of the four module types: buoyancy ('B'), motor ('M'), power ('P'), and computation ('C'). As shown in (a), a robot can dock with a module resting on the sea floor, adding that module to its configuration. Additional modules increase the capability of the robot. Adding a buoyancy module, (b) top, allows the robot to move horizontally with increased efficiency; adding an extra power module, (b) center, increases lifetime and thus autonomy; and an additional motor module, (b) bottom, increases maneuverability and speed. A module deployment sequence is shown in (c), with two robots docking, followed by the placement of the modules of the lower robot on the sea floor.

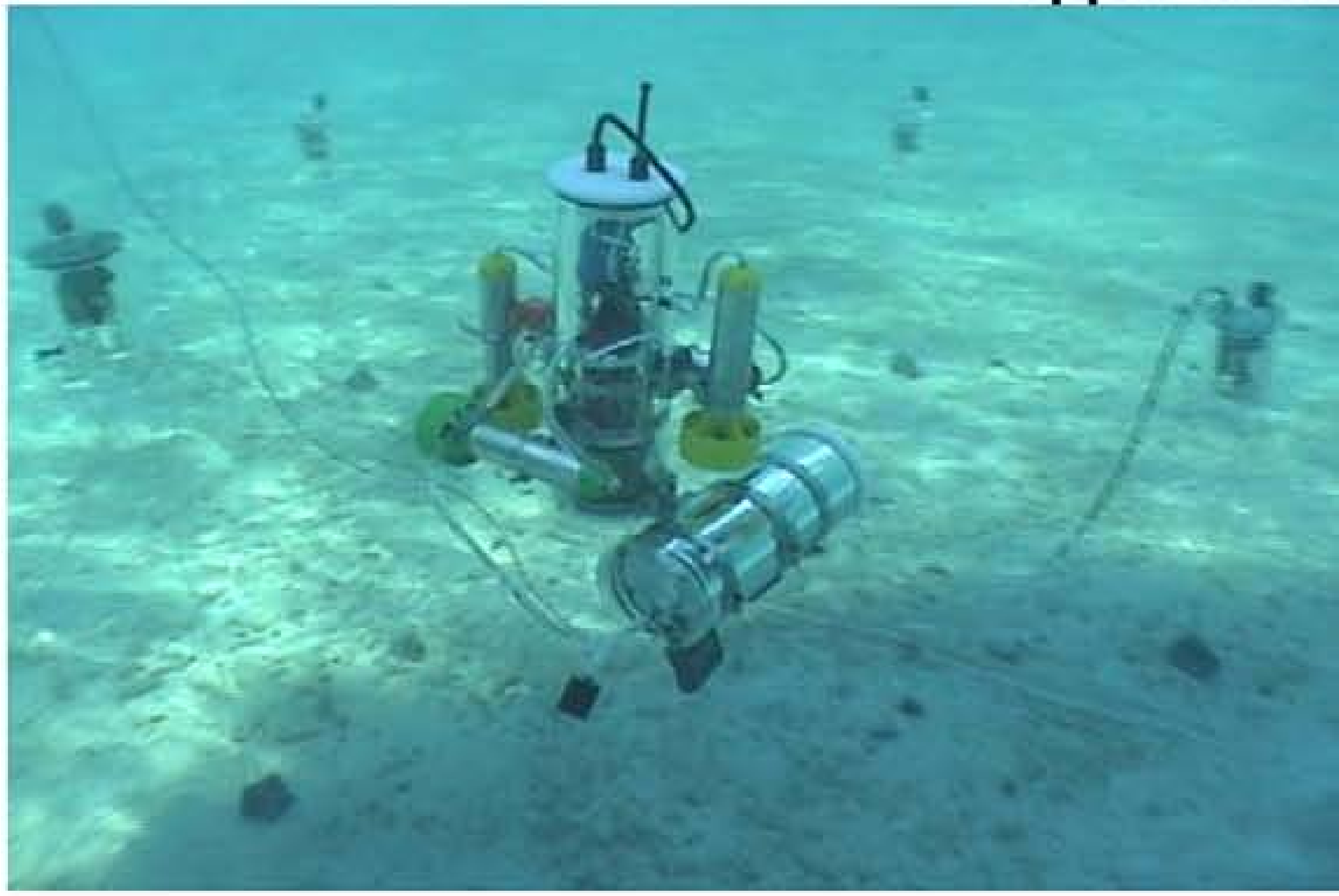


Detail: The mechanics of the docking and latching mechanism in crosssection.The latching plate with a variable-width hole, viewed from above.

description

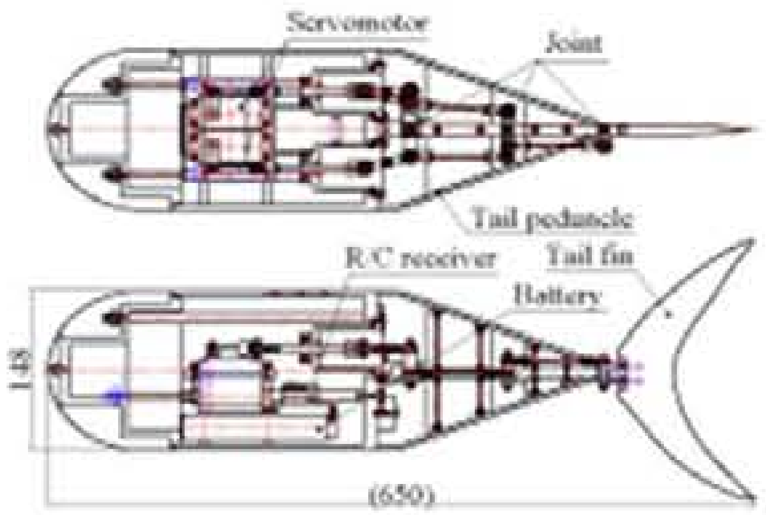
Autonomous underwater robots that are modular and can establish ad-hoc underwater networks. Such robots will permit the exploration and monitoring of underwater environments, allowing applications such as long-term monitoring of underwater habitats, monitoring and surveillance of ports, modeling the impact of weather and ground activities (such as manufacturing and agriculture) on the water quality, and underwater geochemical prospecting. Each of these applications requires a long term underwater presence that can cover a large area and adapt to triggers in the environment, positioning and repositioning the robot or adjusting the sampling rate.

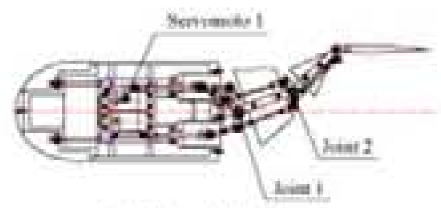
application



sub-category(underwater)

1. Biogically inspired Underwater Robotics




(a) Motion of tail peduncle

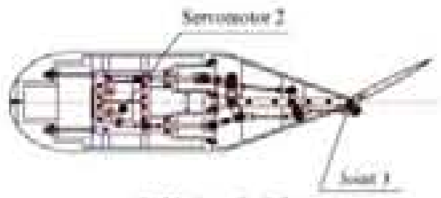

(b) Motion of tail fin

Fig. 3 Link mechanism

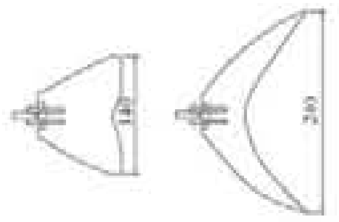

(a) Pike-type tail fin (b) Tuna-type tail fin

Fig. 4 Tail fins

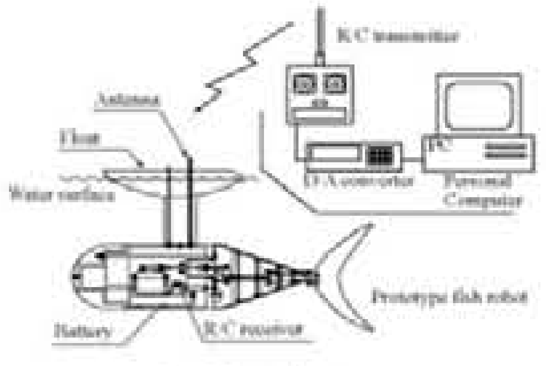


Fig. 5 Control system

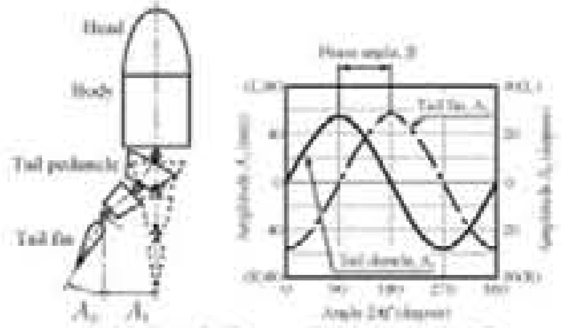
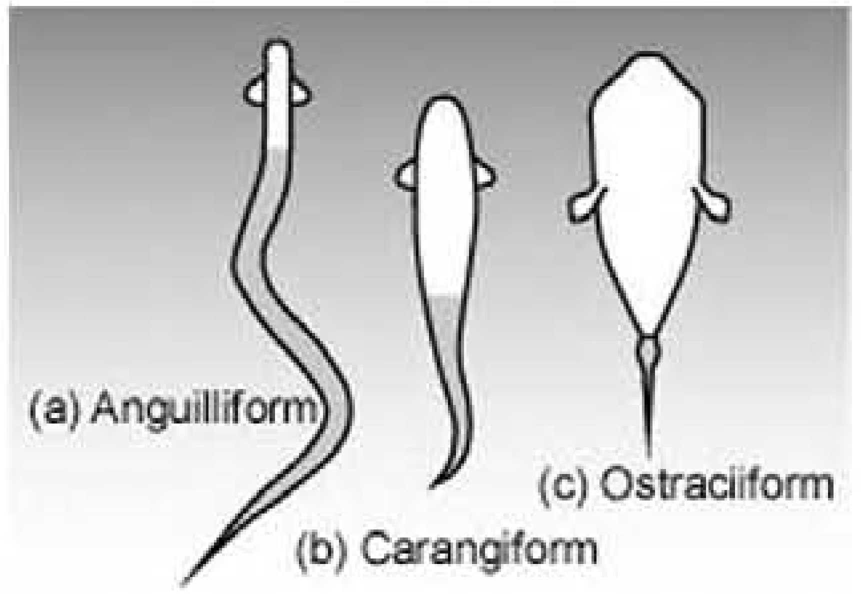
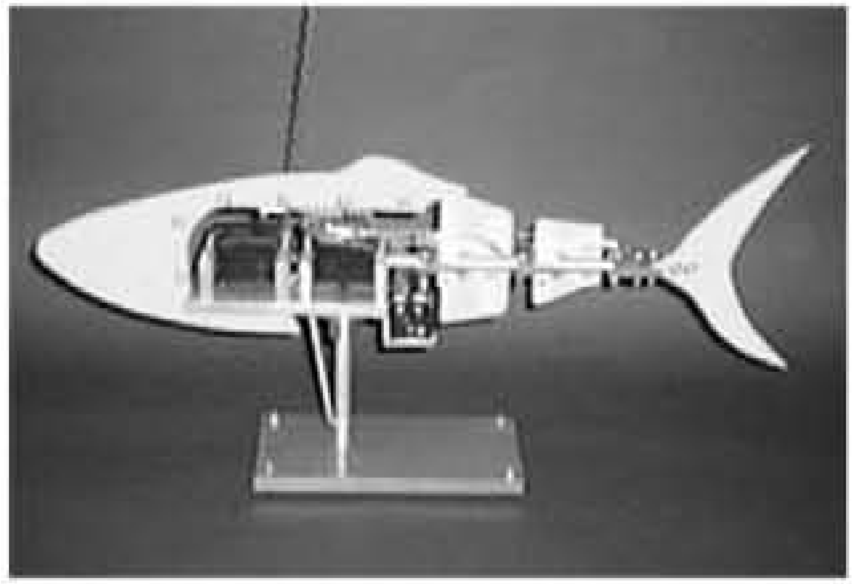

(a) Motion of tail (b) Motion at K_a=0.7

Fig. 6 Outline of moving pattern

application

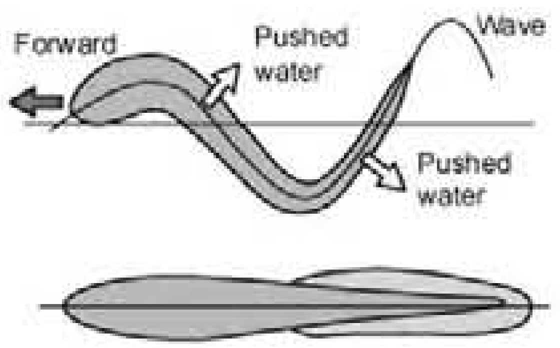




description

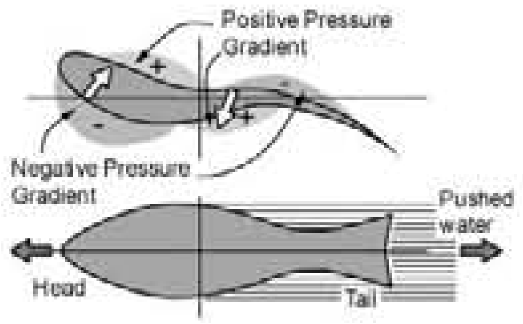
(A) Change Wave

Fish using this method are propelled by a muscle wave in the bdy of the animal which progresses from head to tail. This causes the fish to be propelled by the action of its body upon the water. In order to get propulsive force, it is needed that velocity of the wave is faster than forward speed of the fish, and amplitude of the tail part is bigger than that of the head part.



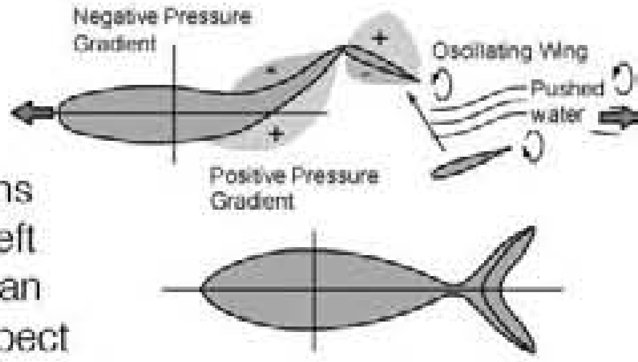
(B) Body Foil

Trout and Salmon are fish typical of those using this swimming method. These fish push water away behind them with using both oscillation of a tail fin and motion of a body. (a) of the figure to the right shows pressure distribution by the motion of body conceptually. There are positive and negative pressure gradients, or we may have to say them action -reaction force, their total force then becomes propulsive force.



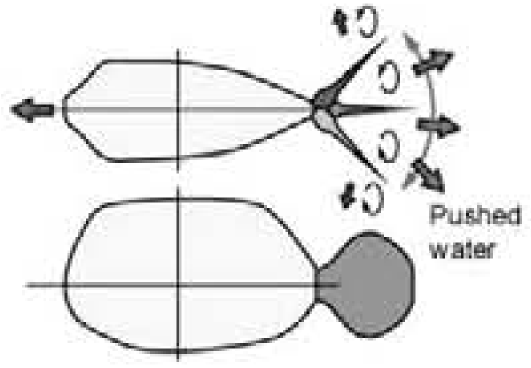
(C) Oscillating Wing

Fish using this method derive nearly all of its propulsive force from an oscillating wing-shaped tail fin. The motion of the oscillating wing is combined heaving motion and feathering motion of the tail fin, and has about 90 degrees of phase angle between the heaving and the feathering of the tail fin. Tuna and Bonito use this method. Cetaceans also use this method, although they wave their tails up and down, not left and right. These fish has a crescent and wing-shaped tail fin. As its span is long and its chord is short, the tail fin has high aspect ratio. High aspect ratios are associated with very high lift performance in wings, propellers, helicopter rotors, high-speed motorboat propellers and hydrofoils



(D) Oscillating Plate

Fish using this method oscillate only a tail fin alike a plate without moving the body. The direction of water pushed by the Oscillation Plate may disperse to left or right, not behind the fish. As the result, this propulsive method has weak points at swimming speed and propulsive efficiency.



The GOLEM Project Cornell Computational Synthesis Lab

The evolutionary process iteratively selects fitter [determined by its locomotive ability] machines, creates offspring by adding, modifying, and removing building blocks using a set of operators, and replaces them into the population.

parameters

Variables -
robot = <vertices> <bars> <neurons> <actuators>

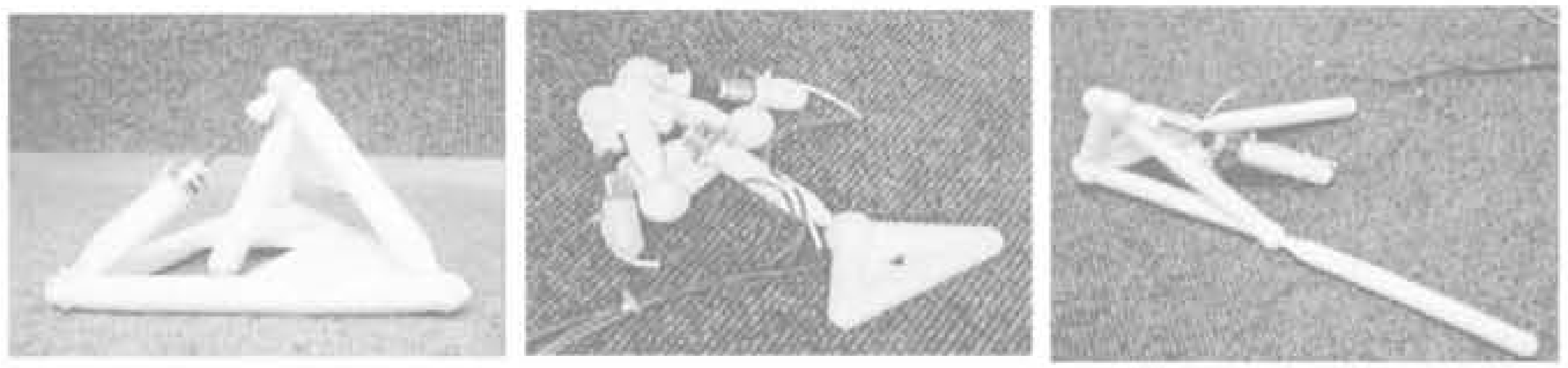
verticies = <x,y,z>
bar = <vertex 1 index, vertex 2 index, relaxed length, stiffness>
neuron = <threshold, synapse coefficients of connections to all neurons>
actuator = <bar index, neuron index, bar range>

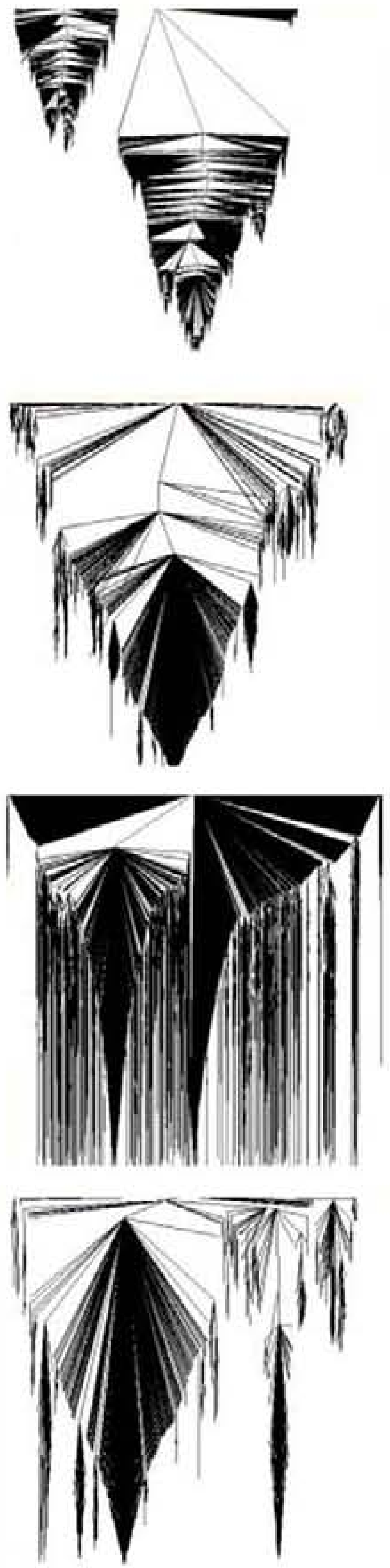
Target - Maximize net distance that center of mass moves over 12 cycles of neural control

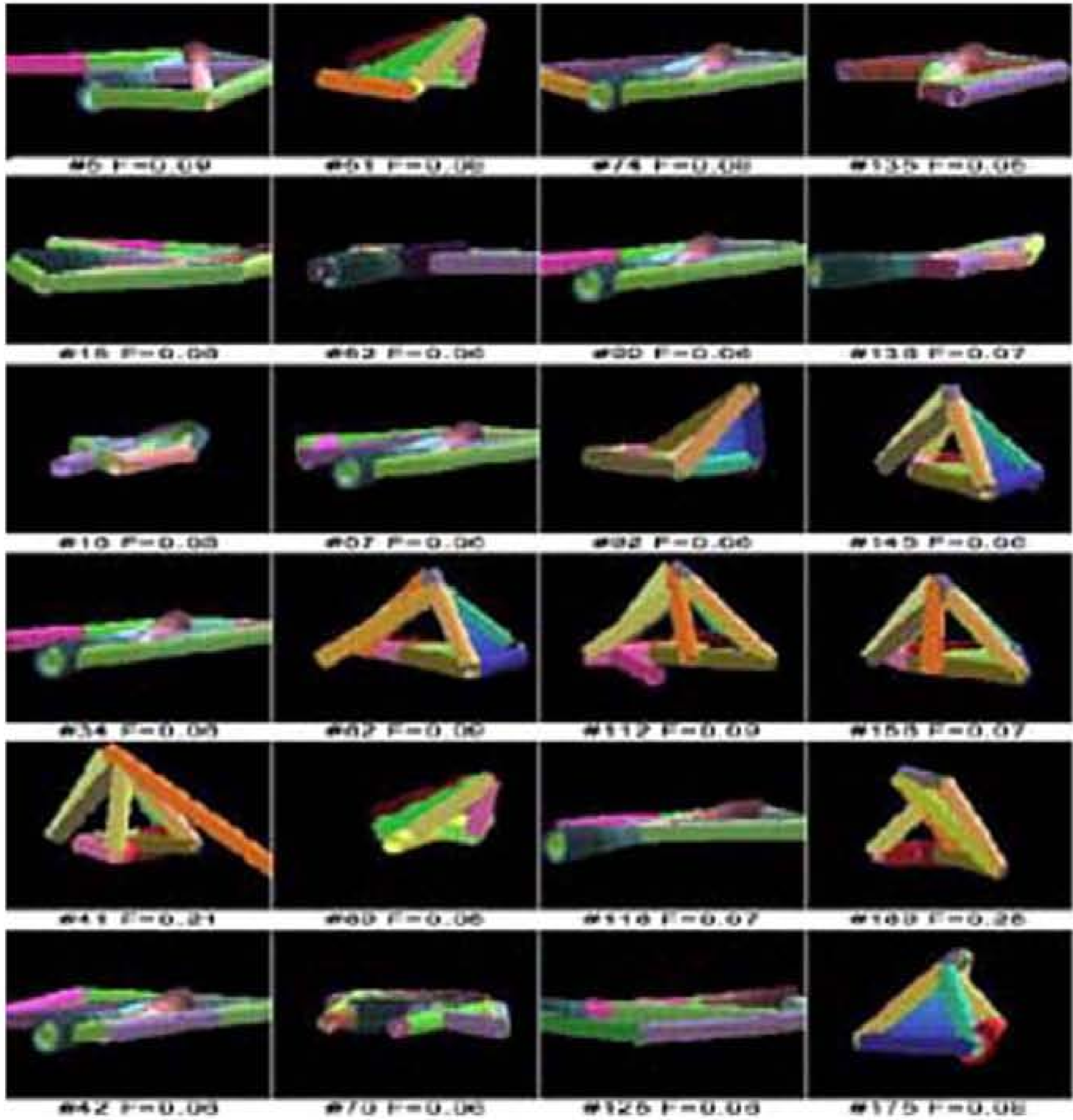
Process-
Create 200 null individuals

1) Apply at least 1 mutation	(probability of occurance)
mutate length of bar or synaptic weight	(0.1)
add/remove dangling bar or unconnected neuron	(0.01)
split vertex and add bar/split bar and add vertex	(0.03)
attach/detach neuron bar	(0.03)

2) Simulate and rate mechanics of control
3) Replace 1 individual w/ new robot (tree diagrams reflect different criteria for doing so)
4) repeat x 300-600







Molecube Cornell Computational Synthesis Lab

Robot evolves buildable morphologies and assembles its modular components into these forms.

parameters

Module Types:

Swivel blocks: rotation
fixed polarities

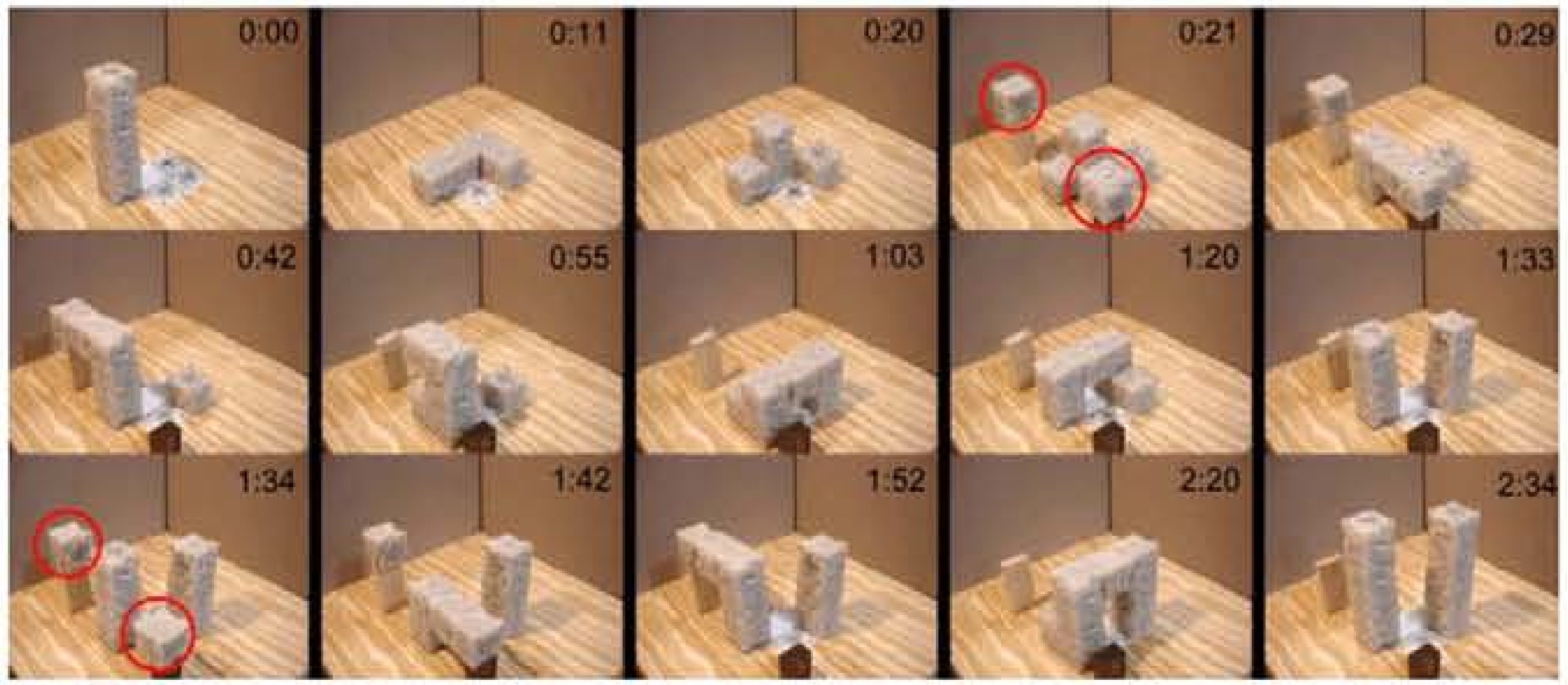
Effector blocks: no rotation
N, S, off, magnets settings

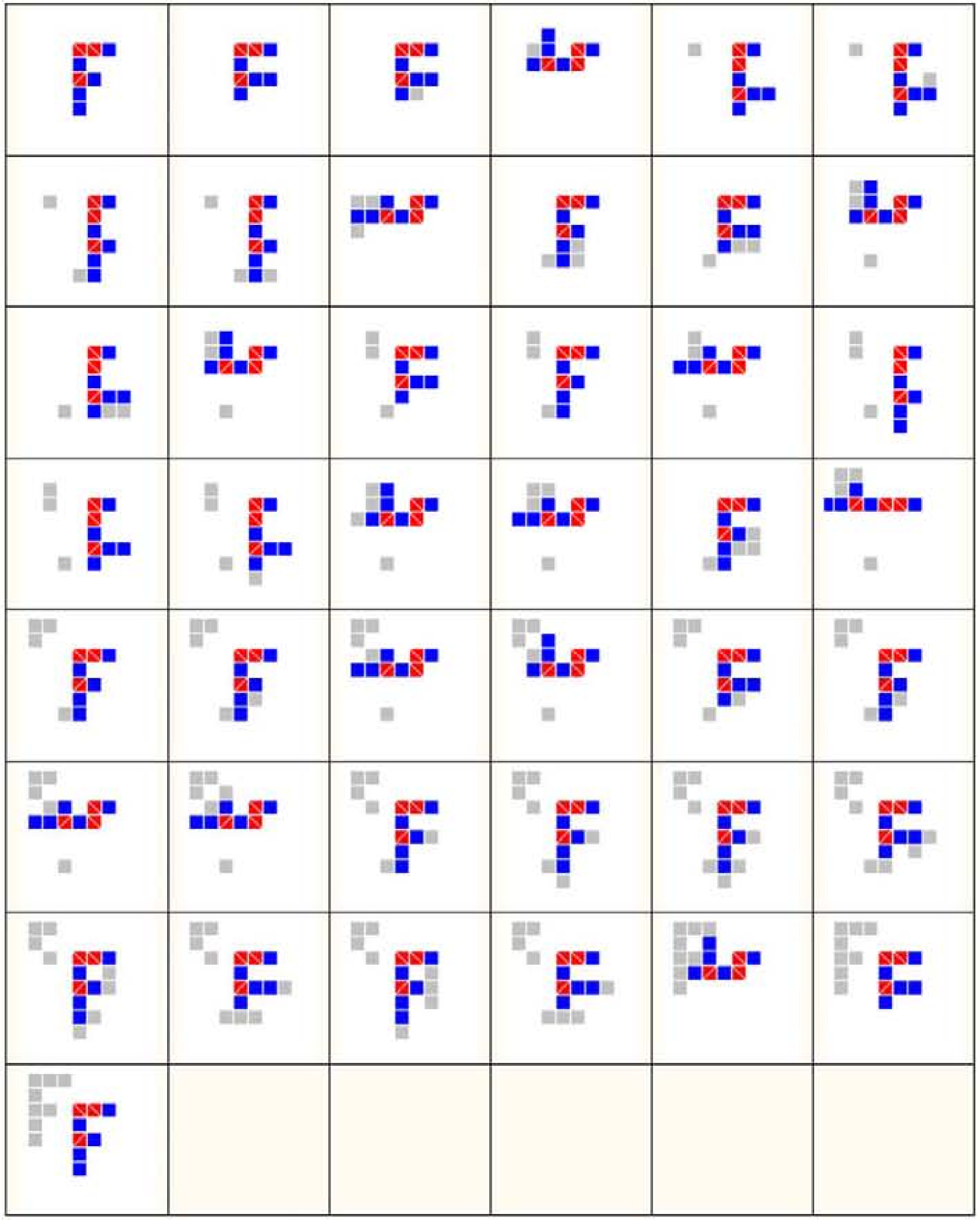
Targets: Construct 2 identical assemblies

Evolve morphology which machine can reach
Evolve sequence which will construct morphology
Fewer motions
Fewer basepoints

Avoid:

Collision
Unintentional magnetic bonding



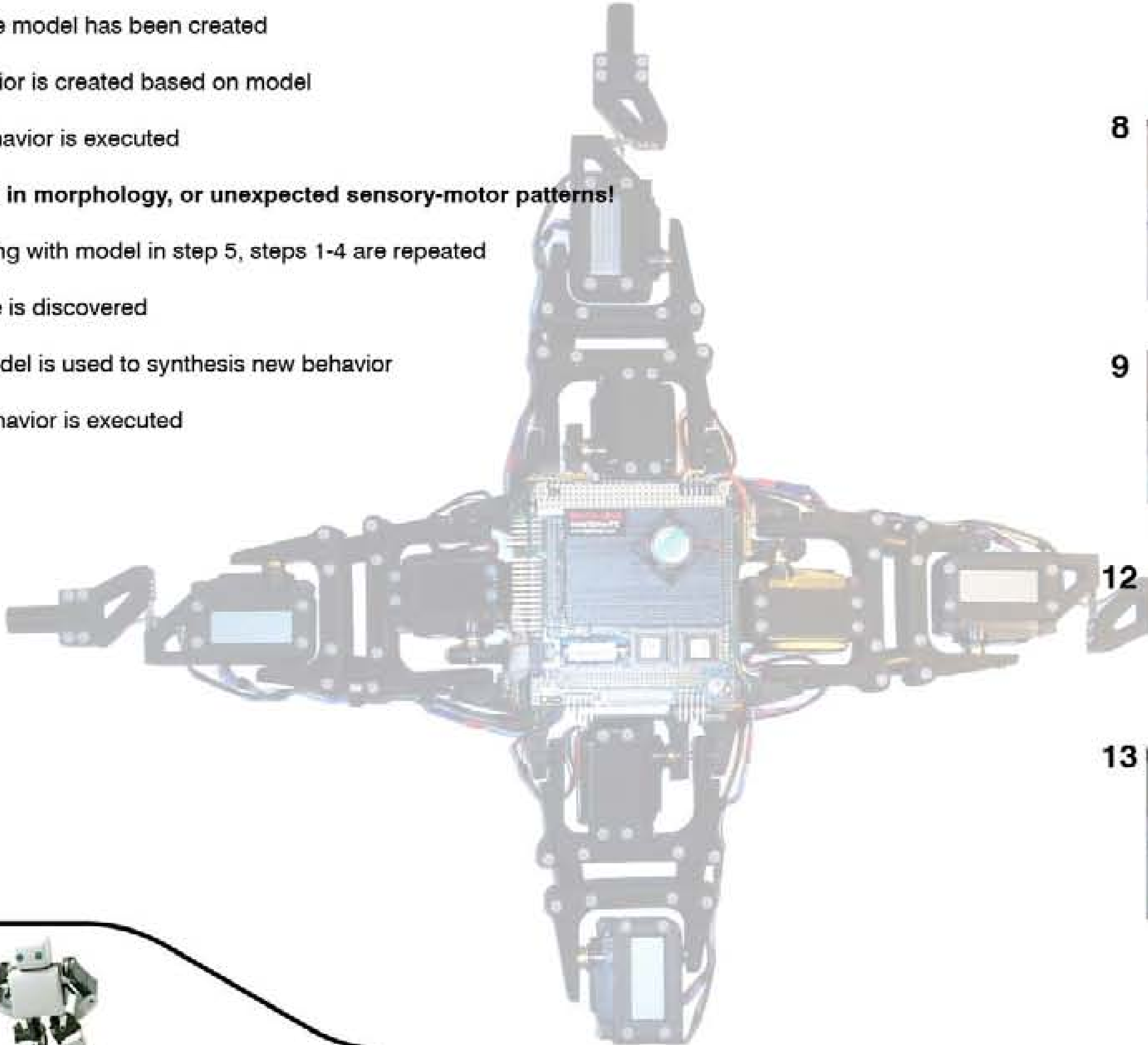


Starfish Robot Cornell Computational Synthesis Lab

A robot discovers its own morphology through recursive modeling and testing, adjusting its models and behavior as its morphology changes

algorithmic components

1) Arbitrary motor action provides sensory data
2) 5 self-models explain causal relationship between actuation and data
3) *Which action will address the greatest disagreement between (the predicted sensory signals of) these models?*
4) This action is performed
5) Repeat x 16
6) Accurate model has been created
7) A behavior is created based on model
8) This behavior is executed
9) **Change in morphology, or unexpected sensory-motor patterns!**
10) Beginning with model in step 5, steps 1-4 are repeated
11) Damage is discovered
12) New model is used to synthesis new behavior
13) New behavior is executed

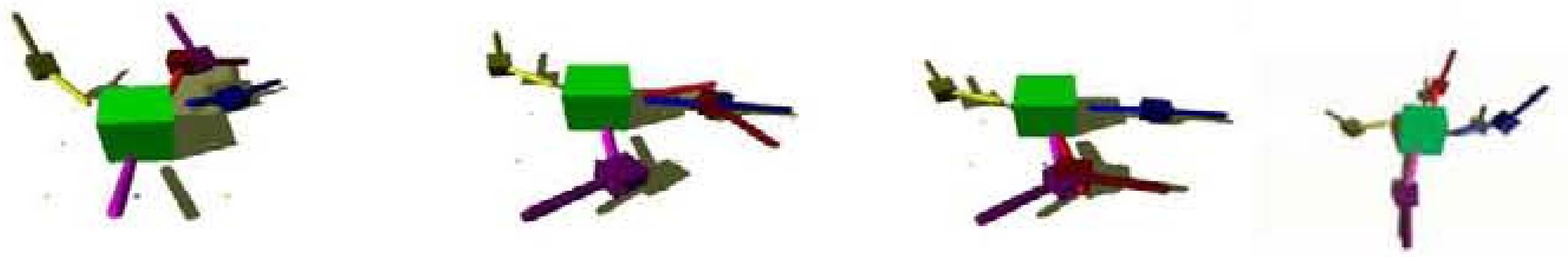


1

2

4

5



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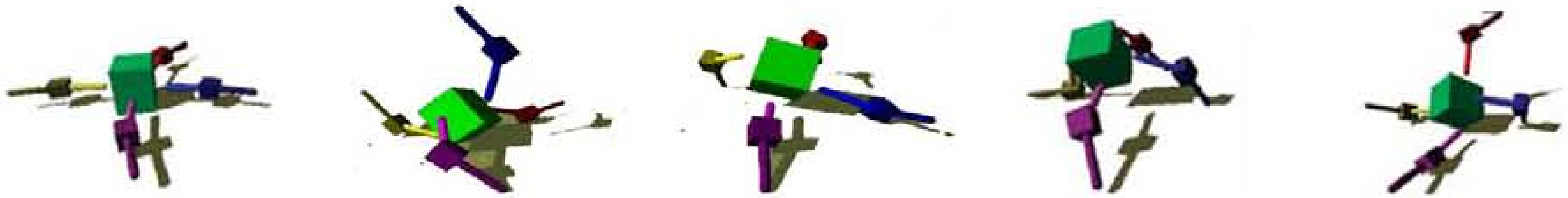

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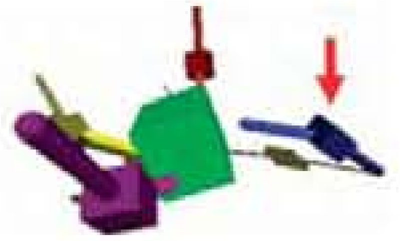

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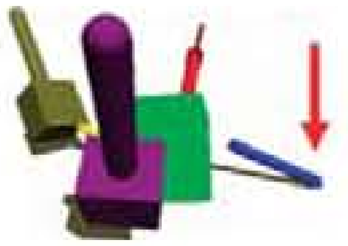

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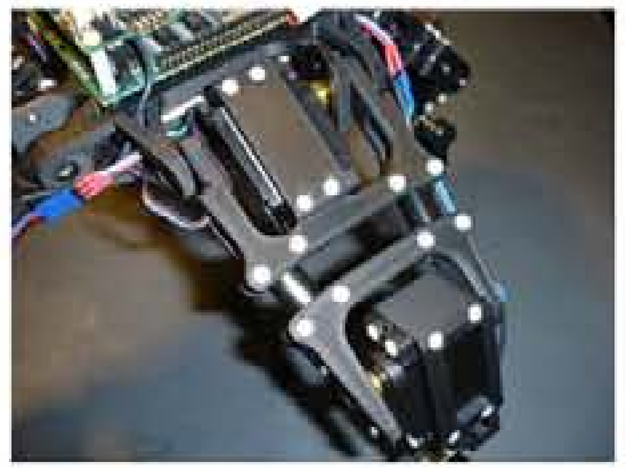


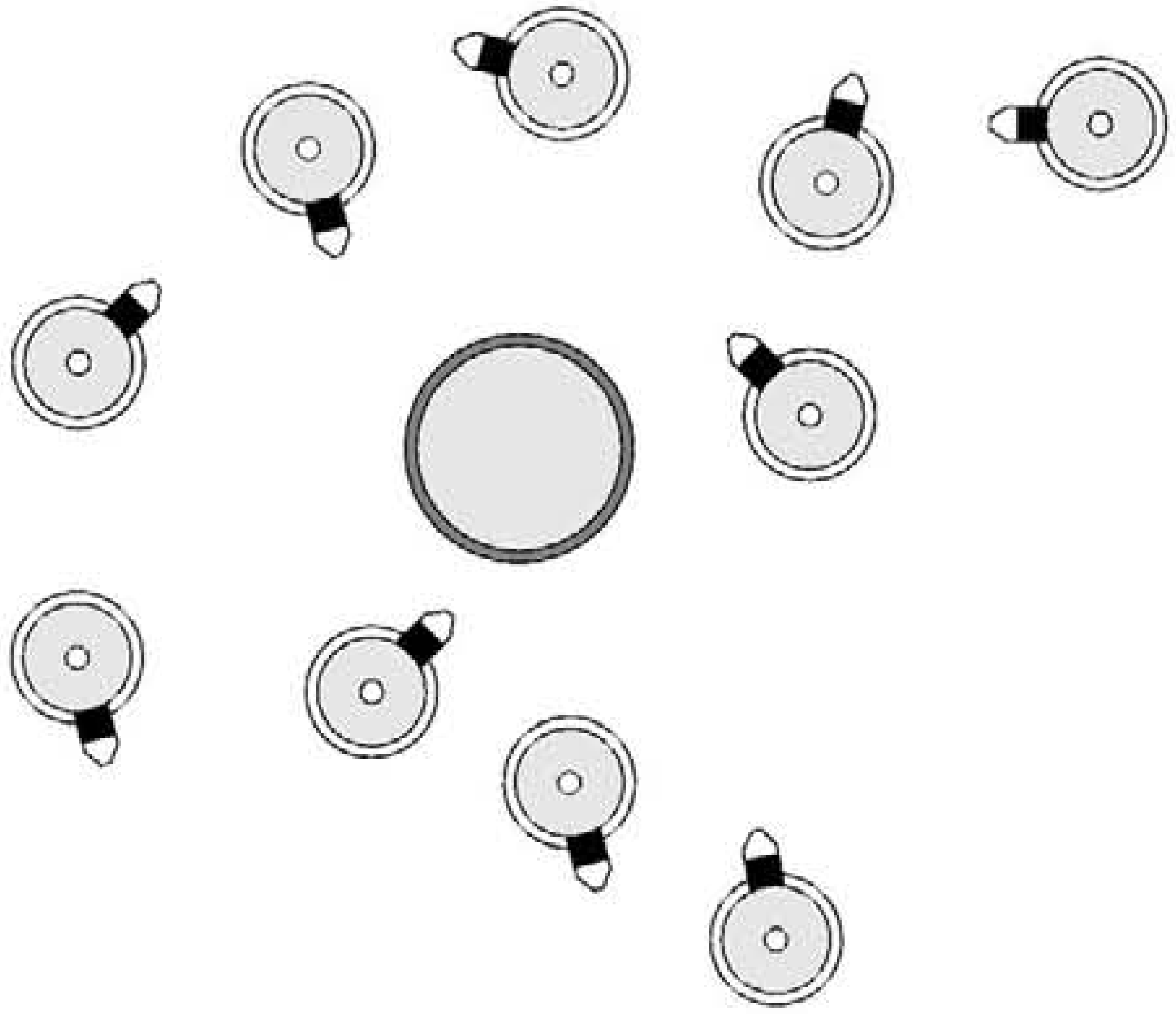
13

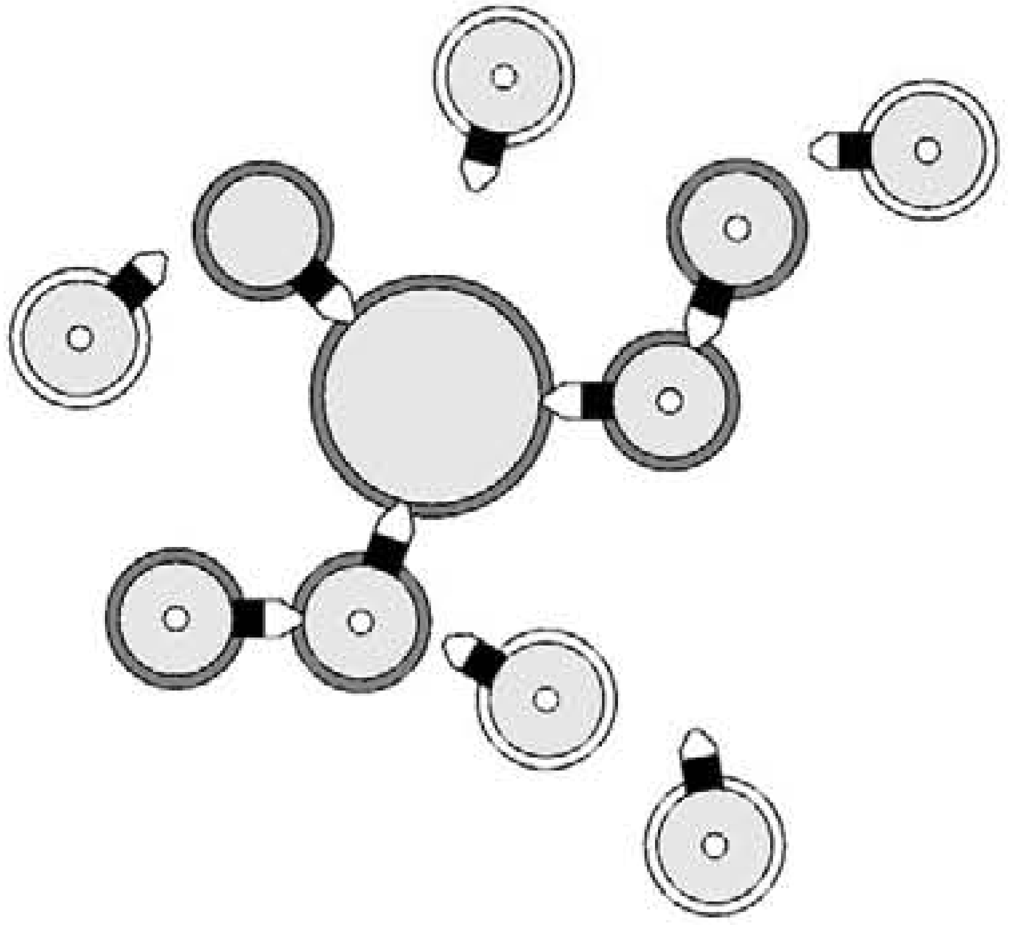
Source: Bongard, J. et al. Resilent Machines Through Continuous Self-Modeling. Science 314. 1118-1121

starfish

Swarmbots Information Society Technologies

Robots signal to each other (using color LEDs) in order to perform group behaviors



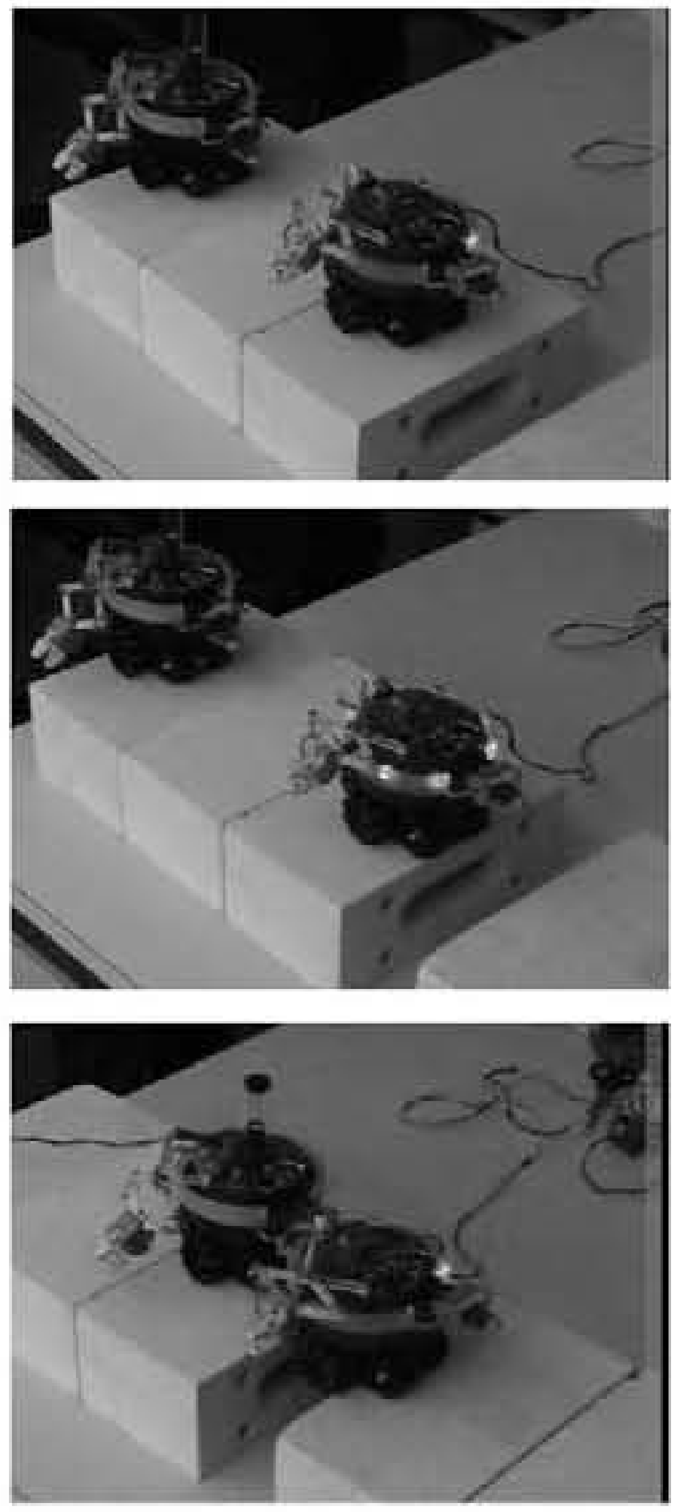


algorithmic components

Algorithm 1: The assembly module

```
activate color ring in blue
repeat
    feature extraction (camera)
    sensor readings (proximity)
    $(i1, o2, o3) <-- f(i1, i2, i3, i4)$

    if ($o3 > 0.5$) ^ (grasping requirements fulfilled) then
        close gripper
        if successfully connected then
            activate color ring in red
            halt until timeout reached
        else
            open gripper
        endif
    endif
    apply ($o1, o2$) to traction system
```

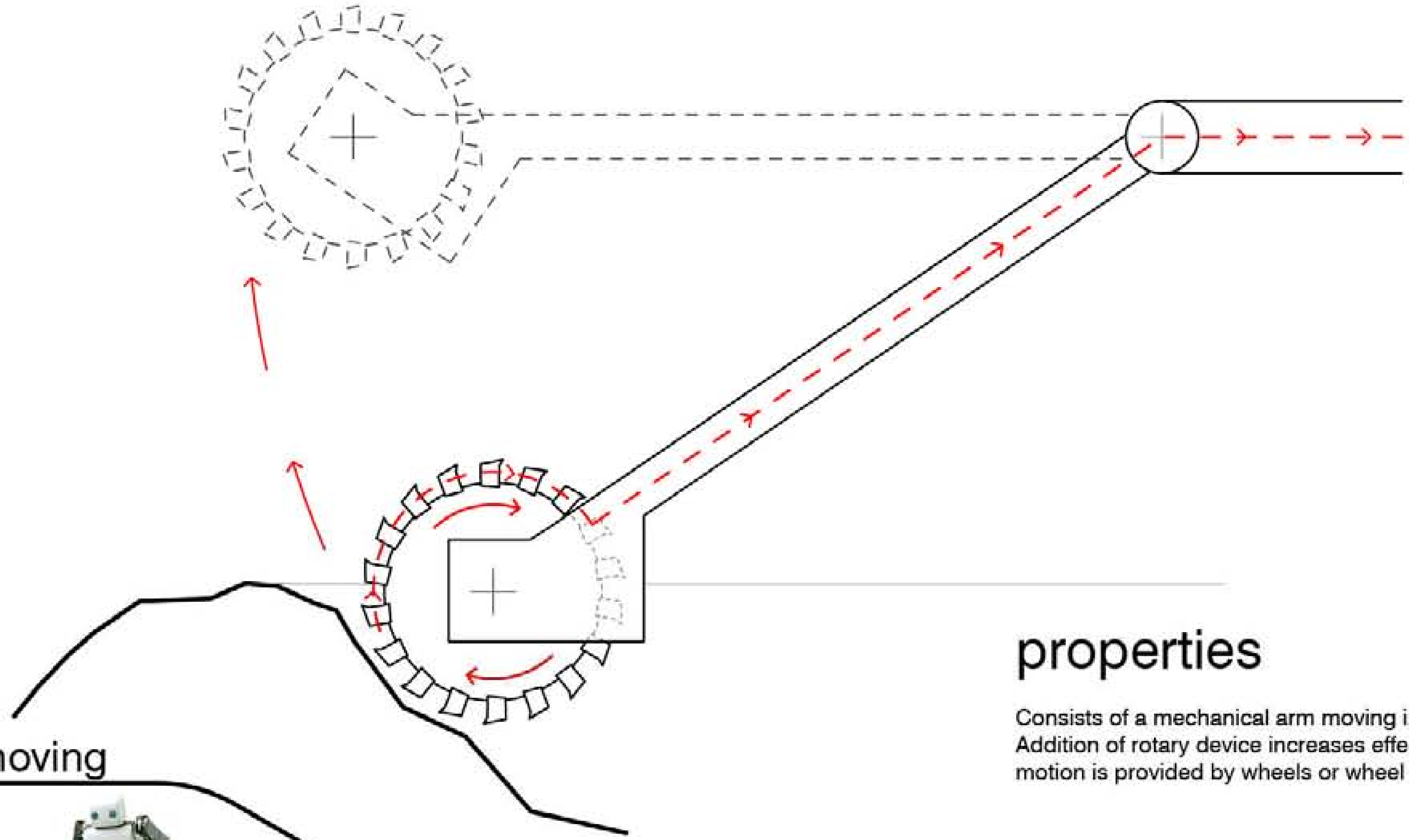


Source: Grob, R. et al. Autonomous Self-Assembly in Swarm-Bots. IEEE Transactions on Robotics 22. 1115-1130

bobcattractor

trenchdigger

bagger255mine excavator



earthmoving

properties

Consists of a mechanical arm moving in a single plane of motion. Addition of rotary device increases effectiveness of digging. Locomotion is provided by wheels or wheel and track systems.

applicationearth moving

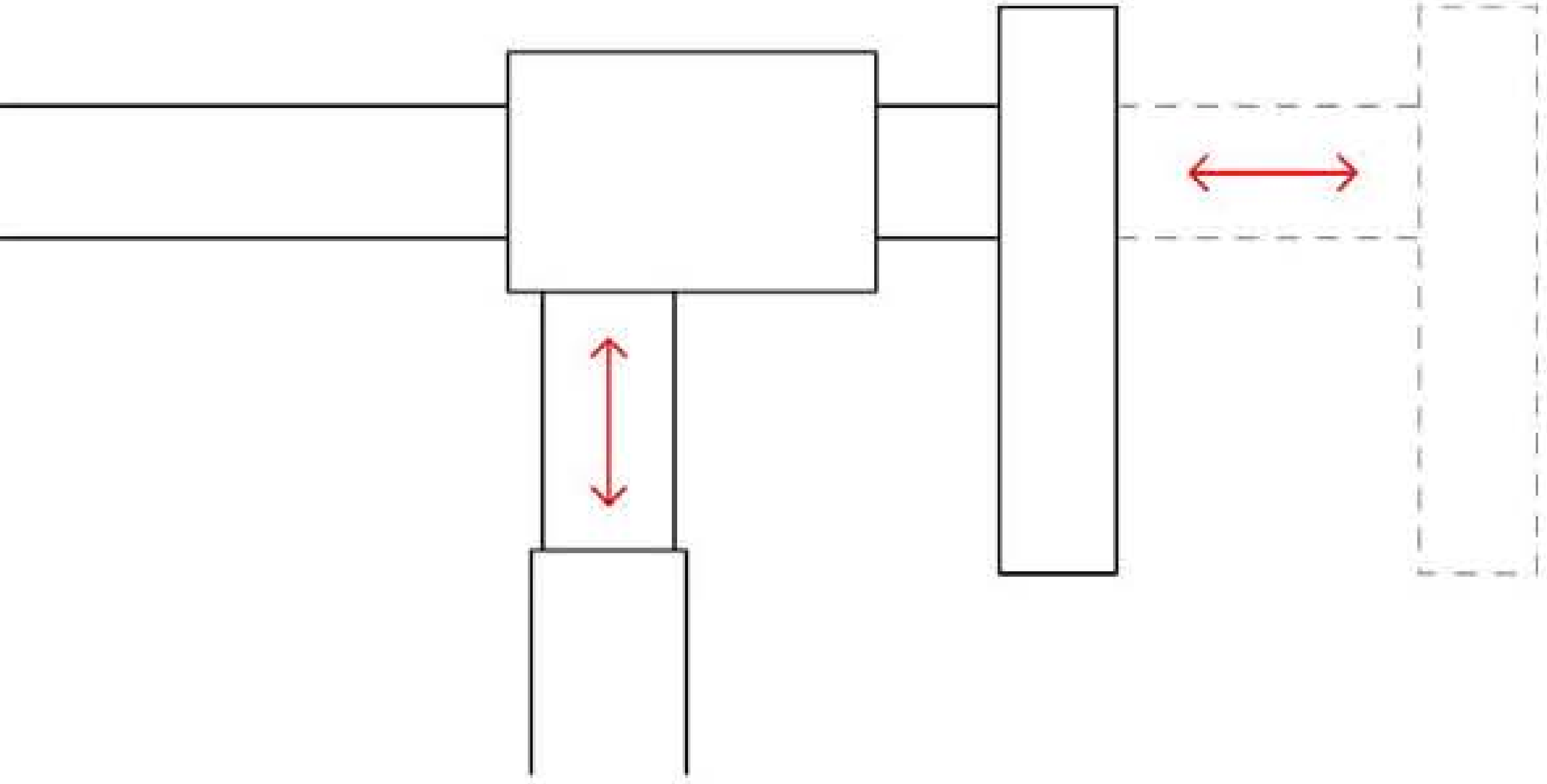
axialmovement + selflocomotion + selfconfiguration + **endeffectors**

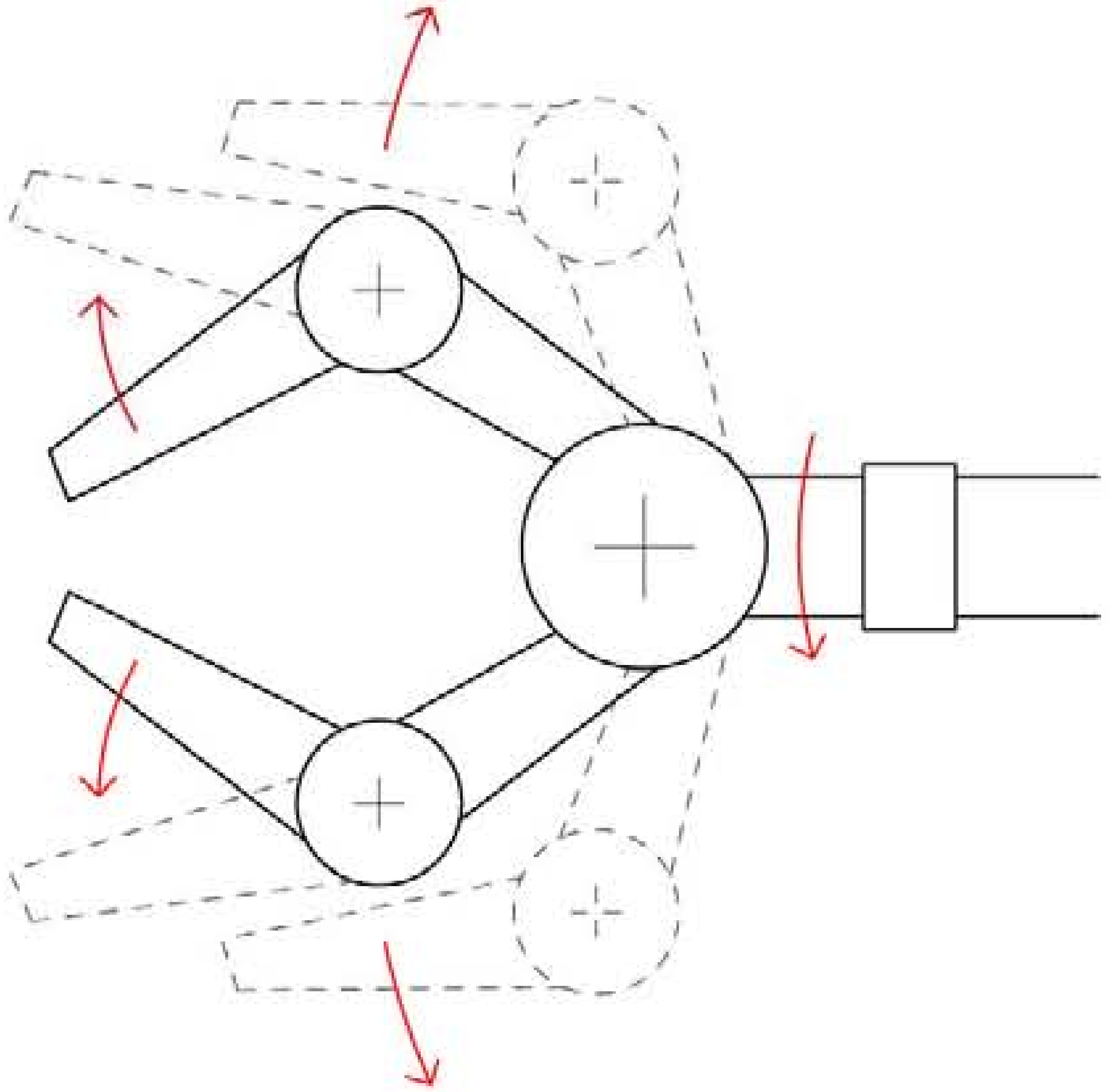
surgicalmanipulator

industrialmanipulator

cncbender

multi-purposemanipulator



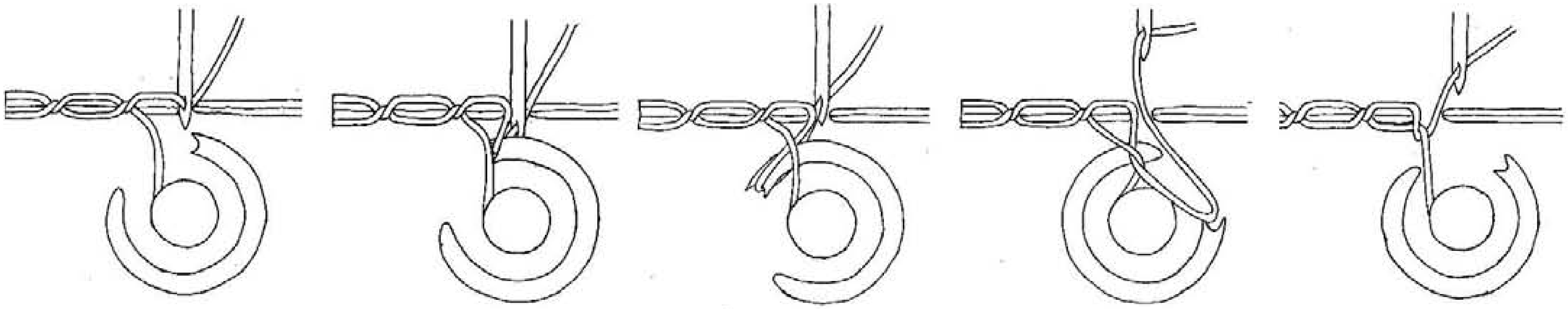


applicationcnc bender

manipulating


manualweaving


commercialseawing machine



weaving

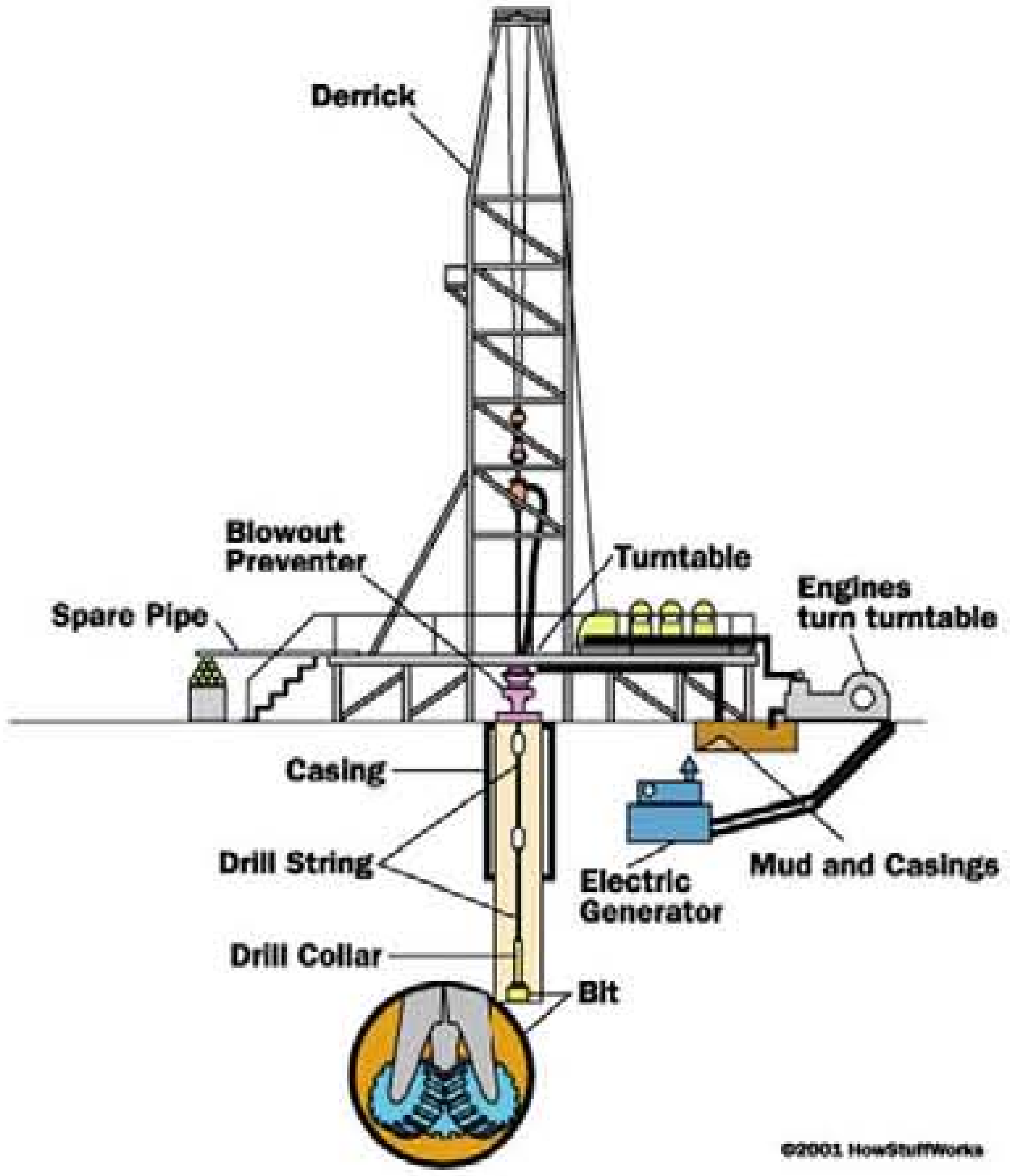
industrialloom

handdrill

tabledrill press

oil rigdrill string

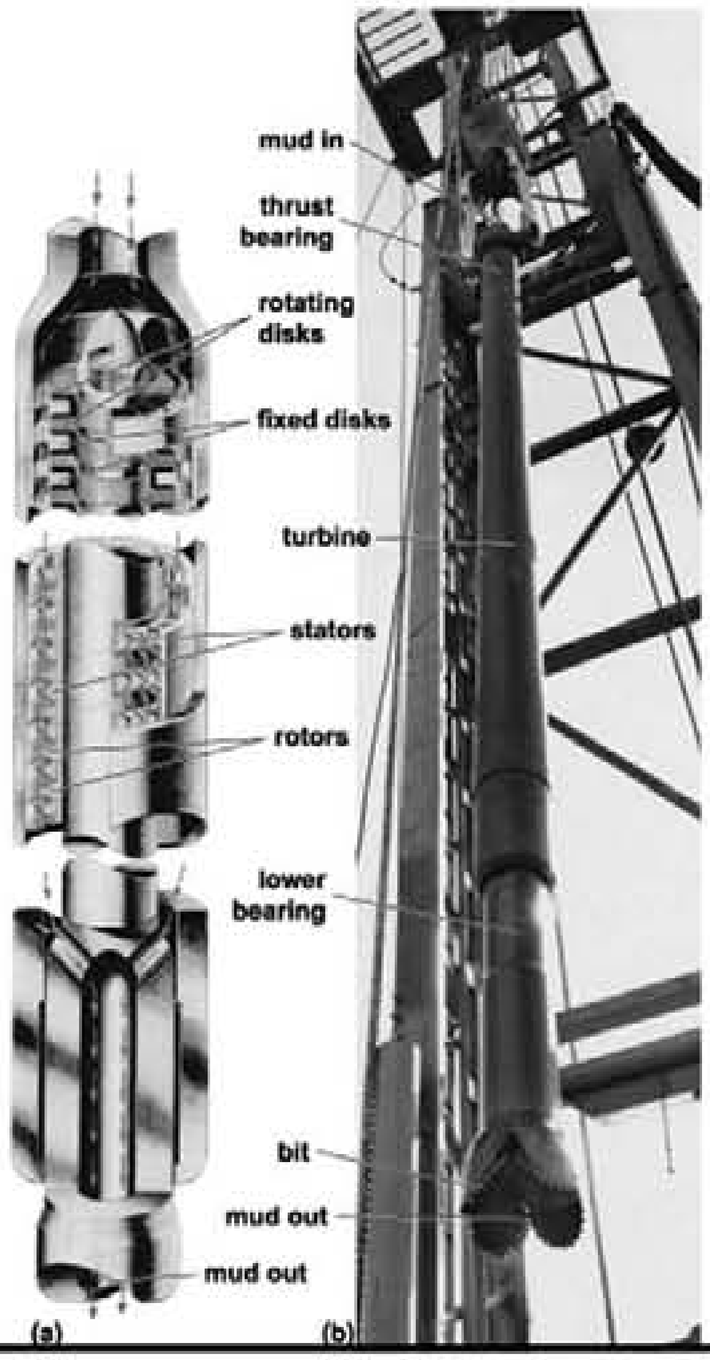
oil rigdrill bit



drilling

properties

Moves vertically and uses rotary motion about the z-axis.



applicationearth moving