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RobMAT

Modelling of Modular Robot Configurations Using Graph Theory

José Baca, Ariadna Yerpes, Manuel Ferre, Juan A. Escalera, and Rafael Aracil
Universidad Politécnica de Madrid
jbaca@etsii.upm.es

HAIS'08
3rd International Workshop on HYBRID ARTIFICIAL INTELLIGENCE SYSTEMS

TOPICS

- Introduction to Modular Systems
- RobMAT Architecture
- Describing Modular Robot Configurations
- Conclusion

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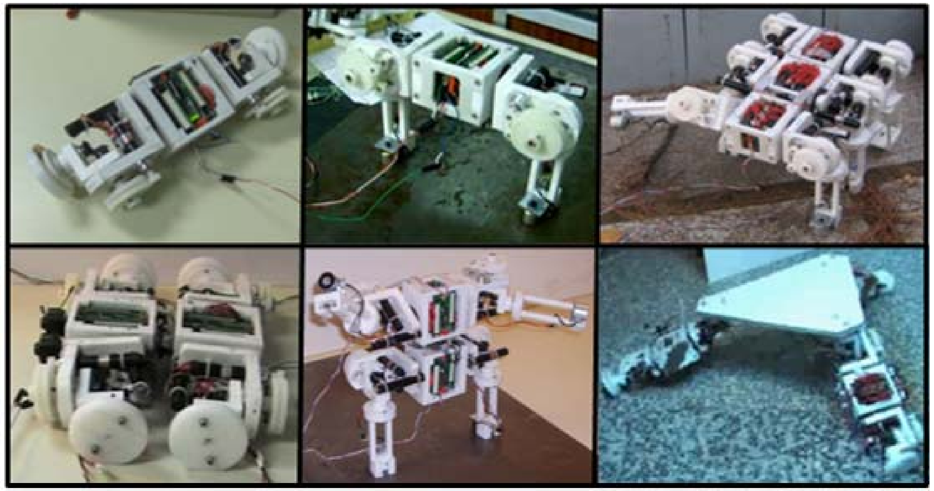
Modular robots are systems that are able to change their configuration when connected to more modules or when rearranged in order to perform a variety of tasks.

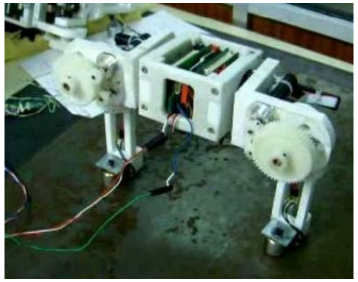


Nowadays, different designs of modular robots have been considered so as to give a solution to varied fields like versatility, adaptability, robustness, costs, etc.

M-Tran

Superbot

Atron



RobMAT

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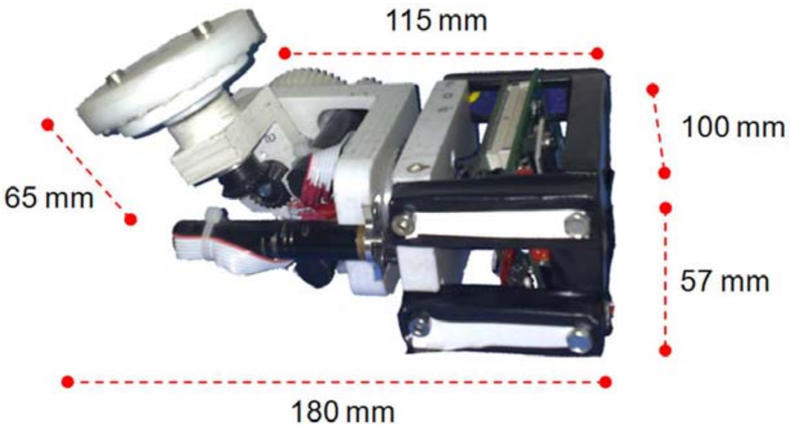
RobMAT: Module



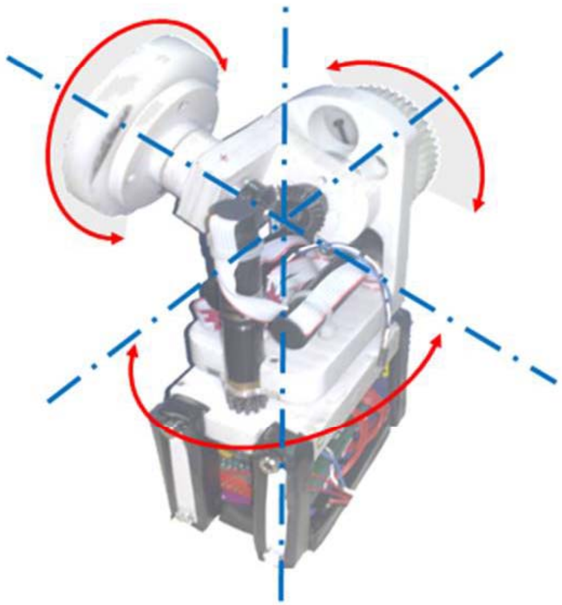
The **module**:

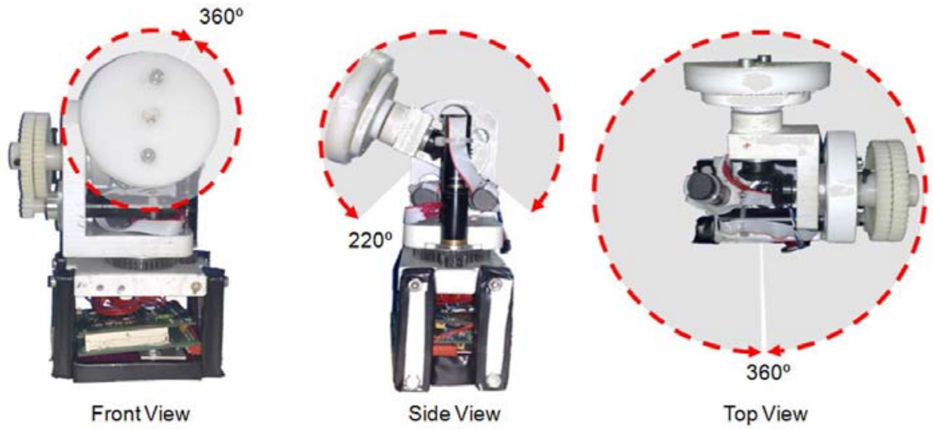
- Simplest component.
- Capacity of movement.
- Capacity of Communication.

The robot attempts to obtain a balance between in the complexity of design and degree of functionality.

RobMAT: Module

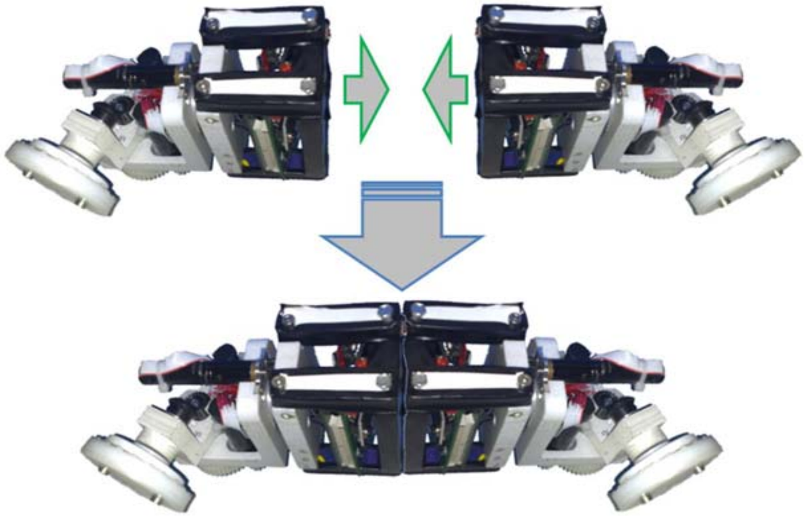
The module has an actuated central part that provides 3 degrees of freedom. The axis of each D.O.F. intersects in one point and thus the atom has an actuated spherical joint.

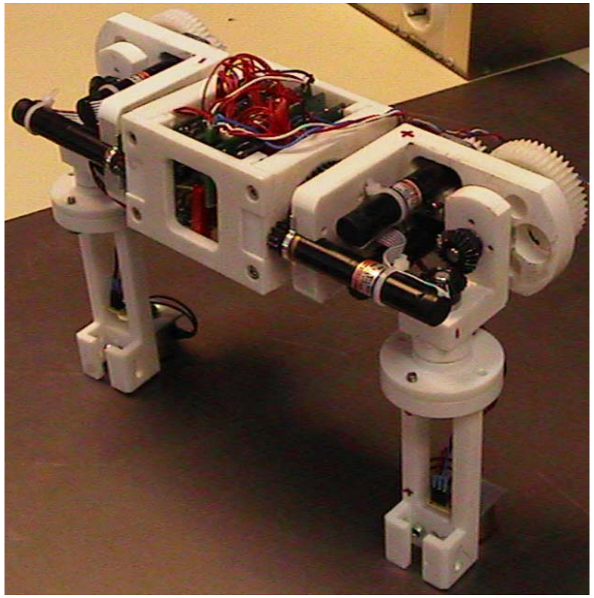




RobMAT: Molecule

Molecule: Joining of two or more modules



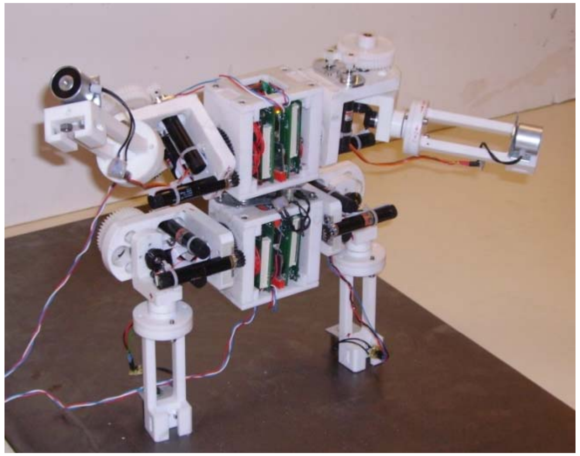
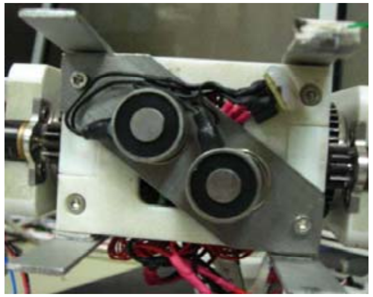
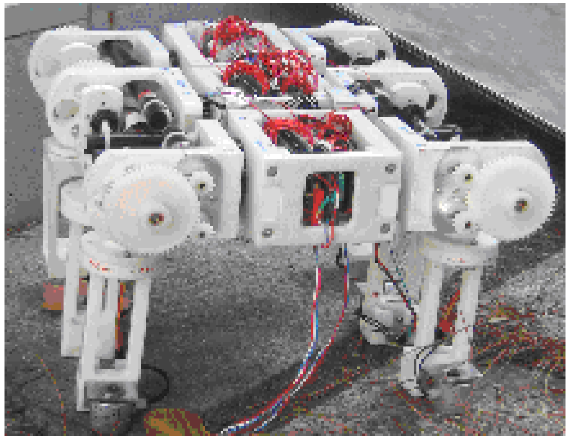


RobMAT: Molecule

Each molecule has a connector which allows docking between or among them.

Increase of degrees of freedoms:

- •Better object manipulation.
- •Different forms of displacement.

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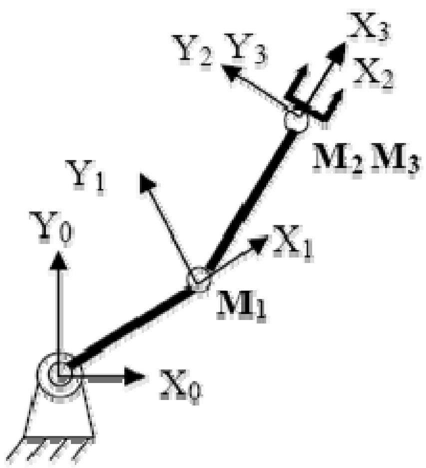
The model of a robot is very important in order to obtain the workspace and to determine its functionality.

Defined Robot:

It is just a matter of following a systematic procedure.

With a defined robot, the number of degrees of freedom, length of links, masses and geometry are normally well defined and constant, facilitating their modelling.



Datos:

$L_1 = L_2 = 0.8$ m

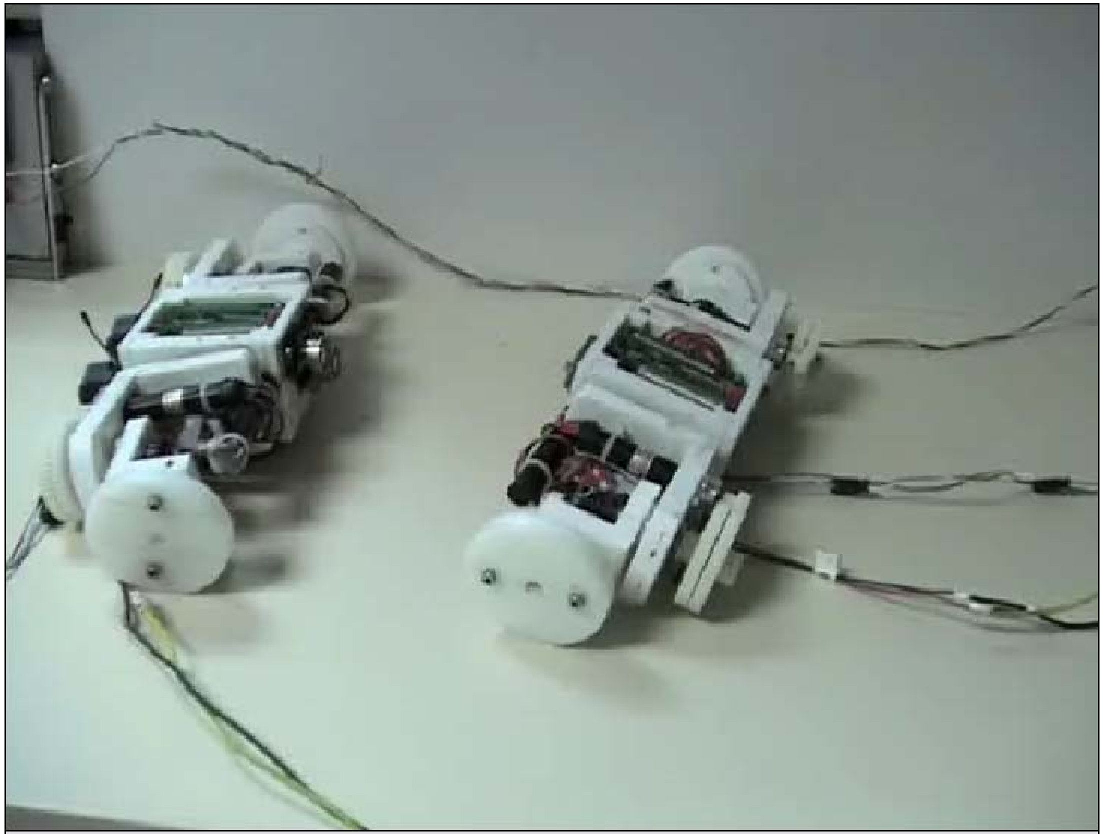
$M_1 = 4.7$ Kg; $M_2 = 2.6$ Kg; $M_3 = 1.1$ Kg

$G = 9.8\ m/s^2$

${}^1p_{C1}=[0,0,0]'$; ${}^2p_{C2}=[0,0,0]'$; ${}^3p_{C3}=[0,0,0]'$;

$${}^{C1}I_1=[0];\ {}^{C2}I_2=[0];\ {}^{C3}I_3 = \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.1 & 0 \\ 0 & 0 & 0.1 \end{bmatrix} (kg/m^2)$$

RobMAT



reconfig.avi

Modular Robot:

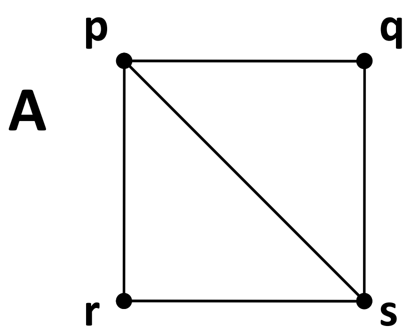
•**It complicates the robot's kinematics and dynamic modelling.**

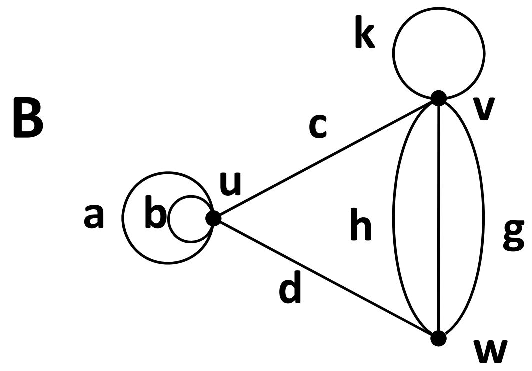
• The changing configuration of molecules means that, unlike other robots, modelling in advance is not applicable.

Therefore, an algorithm is required to **automatically generate the model for any configuration** during the execution of each step of a task.

Graph Theory:

A **graph** G=(V,E) is a mathematical structure consisting of two finite sets V and E.
The elements of V are called **vertices** (or **nodes**), and the elements of E are called **edges**.
Each edge has a set of one or two vertices associated to it, which are called its **endpoints**.





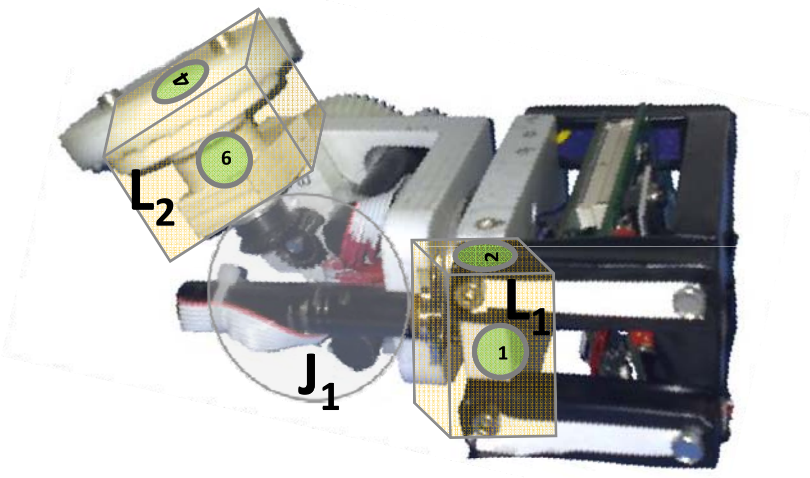
V_A= {p, q, r, s} and E_A= {pq, pr, ps, rs, qs}

V_B= {u, v, w} and E_B= {a, b, c, d, f, g, h, k}

Graph Theory into Modular Robots:

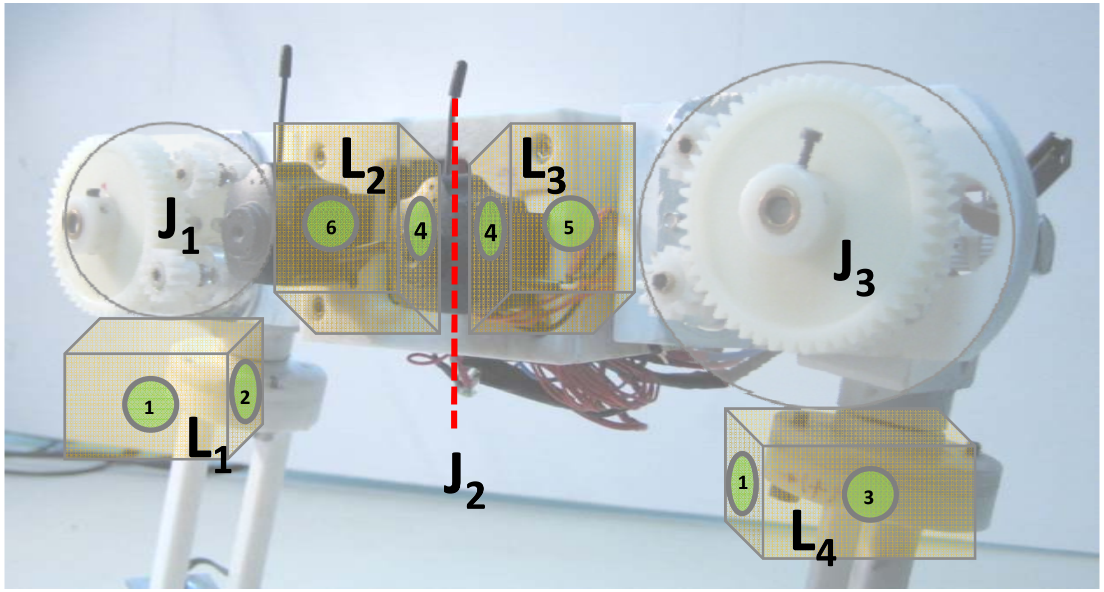
If we consider RobMAT as a homogenous robot, without considering the tools it can handle, the analogy will be the following:

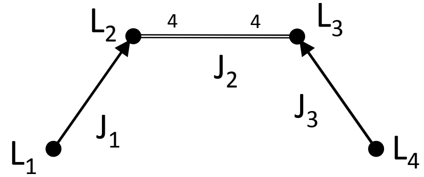
Vertices = **Links** (each prism next to the spherical joint).
Edges = **Joints** (connector and spherical joint).



Graph Theory into Modular Robots:

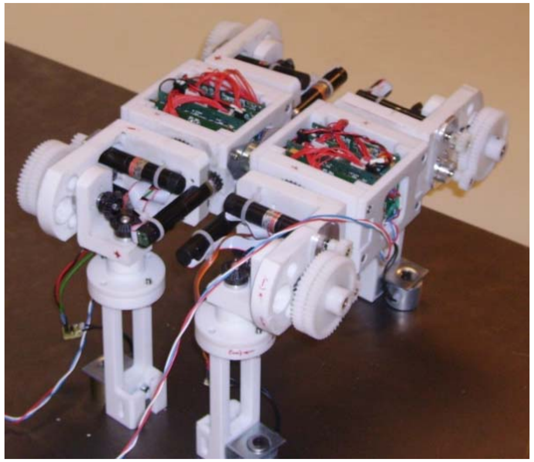
Another element to be taken into account when representing module chains is the linking point between modules, which is called the **port.** Basically, a connector can have more than one place or port to join with another connector.

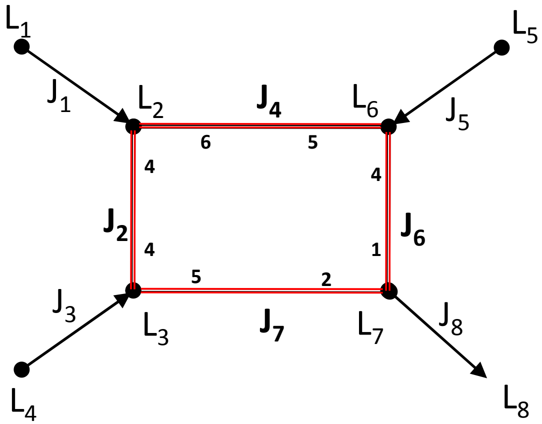




Two module configuration graph

Four module configuration graph

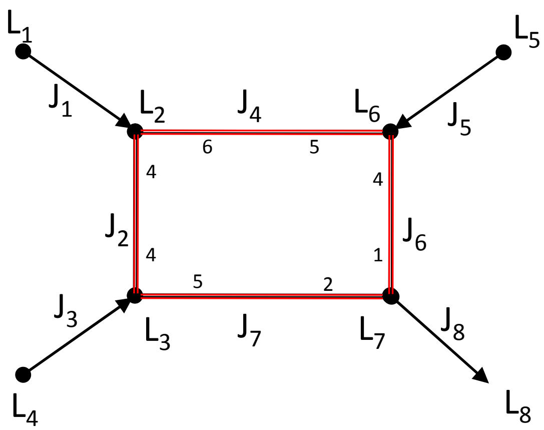




It can be noticed the joints created at each module union (J_2, J_4, J_6, and J_7) and the graph shows the representing link port number.

All this information is set forth in the Assembly Incidence Matrix AIM, so that it can be easily included in algorithms.

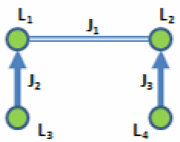
The **Assembly Incidence Matrix** (AIM) is a (N+1)x(M+1) matrix with N vertices (v) and M edges (e). This matrix is formed by giving to each entry a_{ij} the number of the port that joins v_i and e_j, or 0 when no linking appears. The extra column (M+1) indicates the link type, while the extra row (N+1) shows the joint type.



$$AIM = \begin{array}{c} \begin{array}{ccccccccc} J_1 & J_2 & J_3 & J_4 & J_5 & J_6 & J_7 & J_8 & \end{array} \\ \left(\begin{array}{ccccccccc} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & p \\ 1 & 4 & 0 & 6 & 0 & 0 & 0 & 0 & p \\ 0 & 4 & 1 & 0 & 0 & 0 & 5 & 0 & p \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & p \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & p \\ 0 & 0 & 0 & 5 & 1 & 4 & 0 & 0 & p \\ 0 & 0 & 0 & 0 & 0 & 1 & 2 & -1 & p \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & p \\ s & c & s & c & s & c & c & s & 0 \end{array} \right) \end{array} \begin{array}{l} \\ L_1 \\ L_2 \\ L_3 \\ L_4 \\ L_5 \\ L_6 \\ L_7 \\ L_8 \\ \end{array}$$

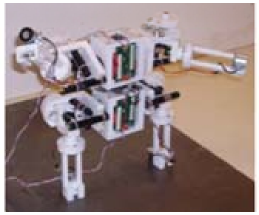
Each configuration can be represented by graphs and with this a mathematical way to describe the structure generated.

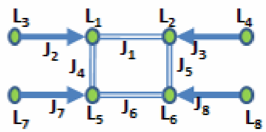
Two Modules Configuration



	J1	J2	J3
L1	1	1	0
L2	1	0	1
L3	0	1	0
L4	0	0	1
TOJ	c	s	s

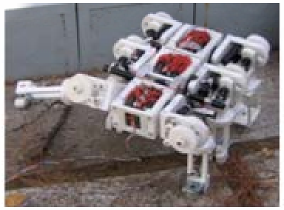
Four Modules Configuration

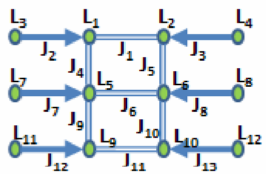




	J1	J2	J3	J4	J5	J6	J7	J8
L1	1	1	0	1	0	0	0	0
L2	1	0	1	0	1	0	0	0
L3	0	1	0	0	0	0	0	0
L4	0	0	1	0	0	0	0	0
L5	0	0	0	1	0	1	1	0
L6	0	0	0	0	1	1	0	1
L7	0	0	0	0	0	0	1	0
L8	0	0	0	0	0	0	0	1
TOJ	c	s	s	c	c	c	s	s

Six Modules Configuration





	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13
L1	1	1	0	1	0	0	0	0	0	0	0	0	0
L2	1	0	1	0	1	0	0	0	0	0	0	0	0
L3	0	1	0	0	0	0	0	0	0	0	0	0	0
L4	0	0	1	0	0	0	0	0	0	0	0	0	0
L5	0	0	0	1	0	1	1	0	1	0	0	0	0
L6	0	0	0	0	1	1	0	1	0	1	0	0	0
L7	0	0	0	0	0	0	1	0	0	0	0	0	0
L8	0	0	0	0	0	0	0	1	0	0	0	0	0
L9	0	0	0	0	0	0	0	0	1	0	1	1	0
L10	0	0	0	0	0	0	0	0	0	1	1	0	1
L11	0	0	0	0	0	0	0	0	0	0	0	1	0
L12	0	0	0	0	0	0	0	0	0	0	0	0	1
TOJ	c	s	s	c	c	c	s	s	c	c	c	s	s

Once a configuration can be described in a mathematical formulation the corresponding kinematical model can be obtained.

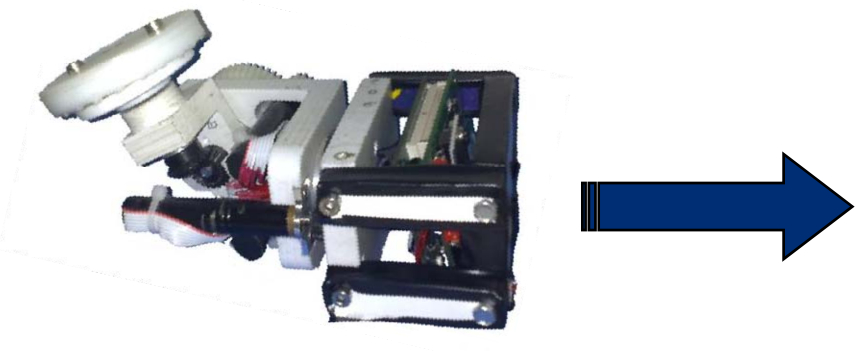
1.- Using POE and Graph Theory, the **module kinematics model** can be determined.

- Screw Theory.

  This allows treating prismatic and rotational joints in the same expressions without specific changes.

- Product of exponentials (POE).

  Using POE the forward kinematics equation of an open chain robot can be uniformly expressed.



$$H_0^e(q_1,q_2,q_3) = e^{\hat{S}_1 q_1} e^{\hat{S}_2 q_2} e^{\hat{S}_3 q_3} H_e^0(0)$$

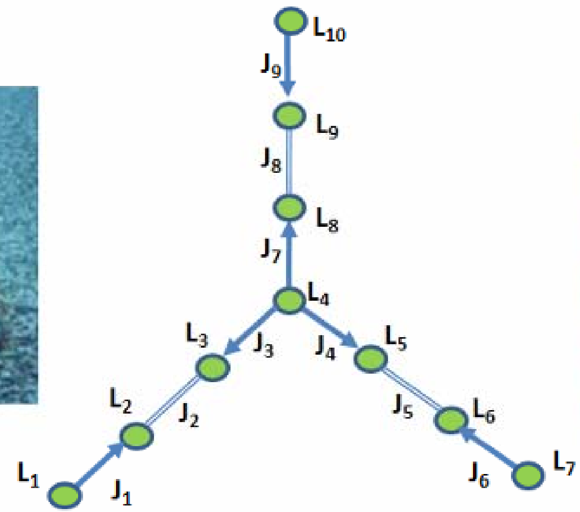
$$\hat{S}_1 = \begin{pmatrix} w_1 = (0,0,-1) \\ v_1 = (0,0,0) \end{pmatrix} \quad \hat{S}_2 = \begin{pmatrix} w_2 = (0,-1,0) \\ v_2 = \left(-\frac{L}{2},0,0\right) \end{pmatrix} \quad \hat{S}_3 = \begin{pmatrix} w_3 = (1,0,0) \\ v_3 = \left(0,-\frac{L}{2},0\right) \end{pmatrix}$$

$$H_0^e = \begin{pmatrix} 0 & 0 & 1 & \frac{L}{2} \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & \frac{L}{2} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

2.- The **molecule kinematics** can be obtained by combining several module kinematics.

- An arbitrary module is designated as root, and position/ orientation is propagated from this root to every end-side module through the modules in the molecule.

To automate this process, it is important to know how modules are connected to each other. Depending on where the module port is attached, orientation and/or position changes will or will not be required.



	J1	J2	J3	J4	J5	J6	J7	J8	J9
L1	1	0	0	0	0	0	0	0	0
L2	1	1	0	0	0	0	0	0	0
L3	0	1	1	0	0	0	0	0	0
L4	0	0	1	1	0	0	1	0	0
L5	0	0	0	1	1	0	0	0	0
L6	0	0	0	0	1	1	0	0	0
L7	0	0	0	0	0	1	0	0	0
L8	0	0	0	0	0	0	1	1	0
L9	0	0	0	0	0	0	0	1	1
L10	0	0	0	0	0	0	0	0	1
TOJ	s	c	s	s	c	s	s	c	s

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Conclusion

•The possibility of modelling modular robot configurations can be achieved by graph theory.

•Its study generates a mathematical object so it can be manipulated to perform complex analyzes, like forward kinematics.

•Although it is possible to represent any modular robot structure with graphs, just some configurations will be useful for real applications. Therefore, the search for equilibrium between complexity of the task and modular robot configuration must be achieved.

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