CYBER-PHYSICAL SYSTEMS AND VARIOUS COMPUTER SCIENCE ISSUES IN SMART AUTONOMOUS ROBOTS

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Outline

- 1. Introduction
- 2. Smart Conveyors
- 3. Distributed Autonomous Robotic Systems
- 4. Conclusions and Perspectives

1. Introduction

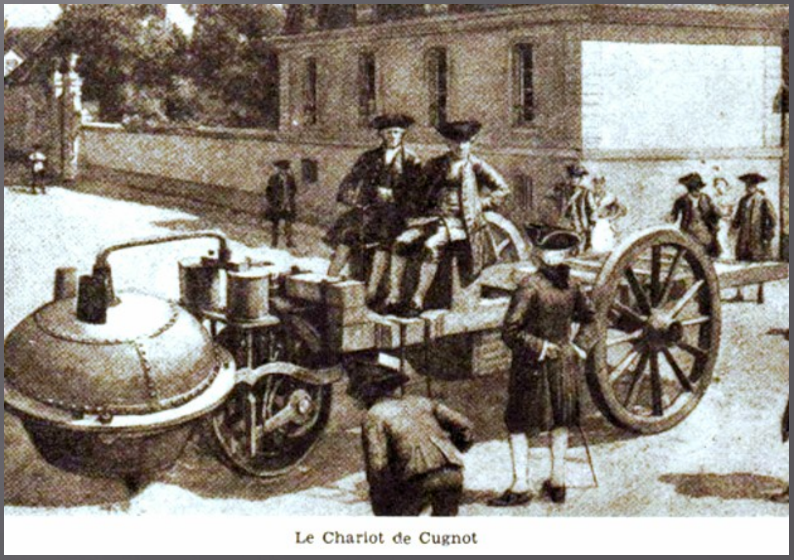
- A new industrial revolution has started;
- 4th revolution.

Fig.1.1 Google car, USA

1.1 The first industrial revolution

- The Industrial revolution (1760 - around 1840);
- from hand production to use of machines and rise of factory system;
- the Age of Steam (1760 - around 1914).

Fig.1.2 Cugnot self-propelled vehicle, France 1770 (4 km/h)



1.2 The second industrial revolution

- Electrification (1860 - 1950)
- Factory, household, city & railway electrification.

Fig.1.3 Arc lamps at Avenue de l'Opera, Paris France in 1878.

1.3 The third industrial revolution

- Computer & communication age (1950 – 2000)
- Processors everywhere;
- Internet has changed the way people communicate and exchange information.
- Messaging applications
(WeChat, WhatsApp, …)
- The Digital Age (1960 -)

Fig.1.4 *5 MB* hard drive being loaded in an airplane by IBM, 1956

1.4 The fourth revolution

- Fusion of physical, digital world and the Internet (2010 -)

Fig.1.5 Assembly system of A380 in Toulouse, France

1.4.1 Internet Of Things

- « IOT: network of items embedded with sensors that are connected to the Internet. »

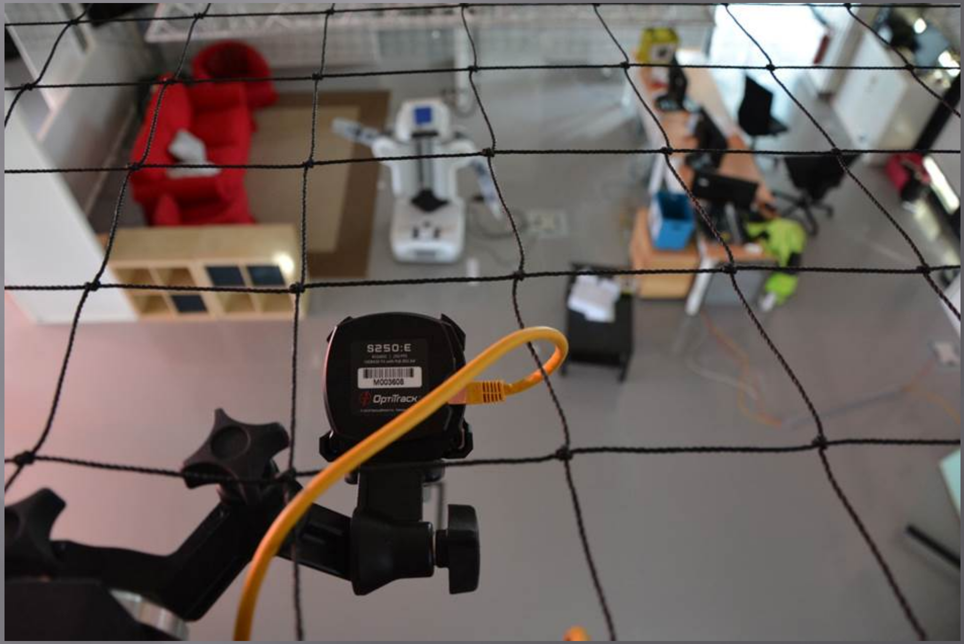


Fig.1.6 Mo-cap and assistance to people at LAAS-CNRS Toulouse

1.4.1 Internet Of Things

- Wireless sensor and actuator networks including Internet of Things (IOT) are changing the way people interact with the physical world.
- These networks have a huge potential for applications ranging from:
- Manufacturing & agriculture (including robotics), transportation, finance, security…

1.4.2 CPS

- Cyber-Physical Systems (CPS): mechanism controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users.
- CPS presents a high combination and coordination between physical and computational elements for critical applications
- Interdisciplinarity: mechatronics, cybernetics, telecommunications & systems sciences.

1.4.3 Ubiquity

- The information about the physical environment is ubiquitously available:
  - Weather report, position of shuttles or trucks on roads, position of tractors in a farm, luggages at airport or people in the street.
- Information tends also to be embedded in the physical environment:
  - Intelligent highways.

1.4.4 Smart Hearth

- More than a classical industrial revolution.
- The societies and physical world tend to be a large self-organizing systems of growing complexity also called: **Smart Earth.**
- This includes in particular:
  - Smart systems & autonomous cars;
  - Smart factory;
  - Smart cities;
  - Smart world.

1.4.5 Smart cities

- Examples of Smart cities
- Melbourne (Australia), Rio de Janeiro (Brasil), Madrid (Spain) Amsterdam (the Netherlands)…
- Upcoming cities:
- Xiongan (China), Dijon (France).
- Companies involved:
  - IBM, Bouygues, EDF, Suez, Berger Levrault…

2. Smart Conveyors

- Smart systems in manufacturing industry.
- Sorting, conveying, positioning parts.

2.1. New trends in computing

- New numerical revolution.
  Advances in parallelism and networking.
  Convergence of several domains like distributed computing and parallel computing.
  New concepts like cloud computing and virtualization, volunteer computing, GPU computing …

2.1. New trends in computing

- Internet Computing (broader, covers all computing paradigms over the Internet) → HTC.
- We need new parallel and distributed algorithms like parallel deep learning;

2.1. New trends in computing

- Where is Intelligence?

  Embedded Intelligence (embedded systems)

  drawback: cost.

  Distributed Intelligence (cyber-physical systems).

  Hosted Intelligence (cloud).

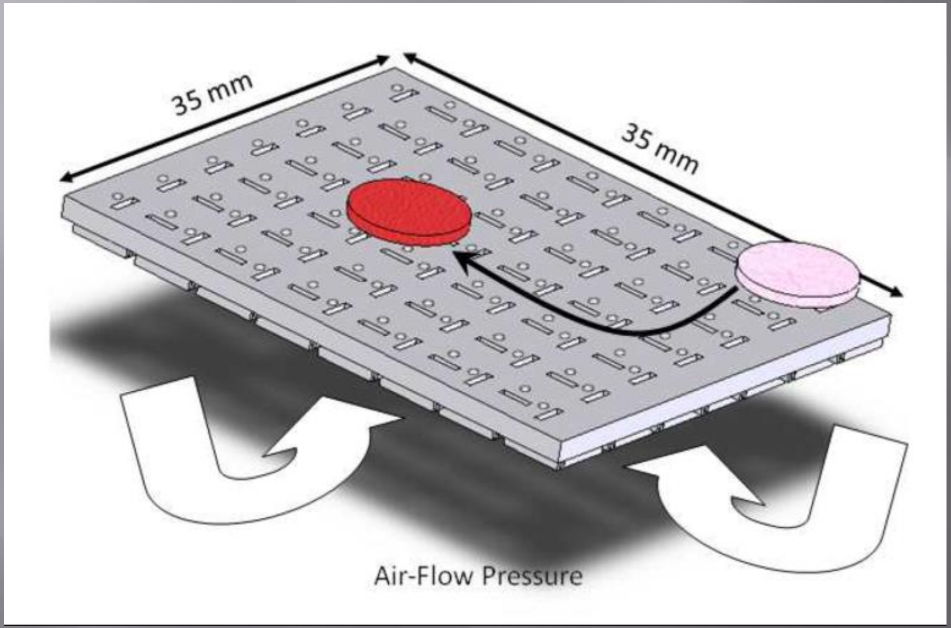
2.2 Smart Surface

- Illustration of modern industrial manufacturing processes:
- Carrying safely and without alteration small objects (critical applications).
- Smart conveyors with distributed intelligence.
- Modular systems
- **Smart Surface Project**

ANR 06 ROBO 0009, 2007 – 2010.

2.2 Smart Surface

- The Smart Surface conveyor



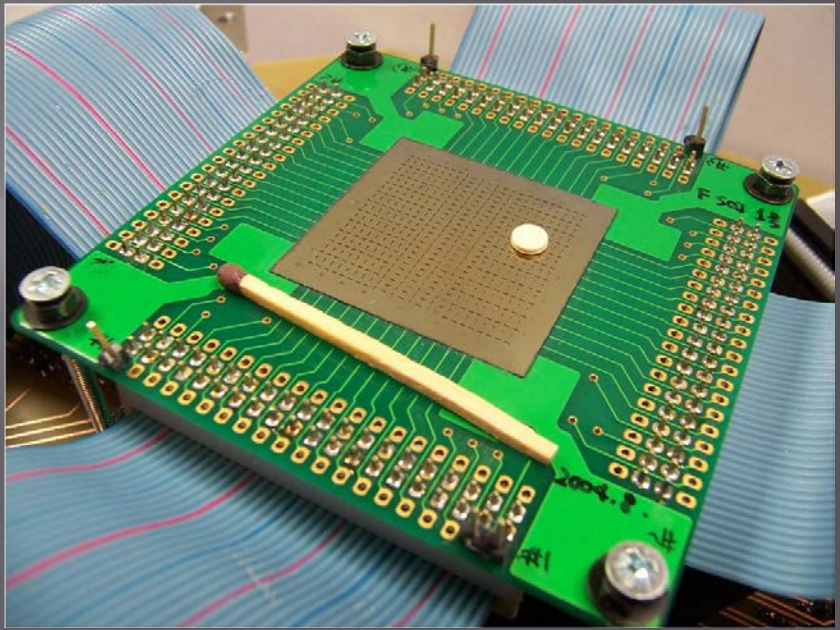


Fig. 2.1 Smart Surface

2.2 Smart Surface

- Goal: design of an area of cells with sensors, actuators and processors.

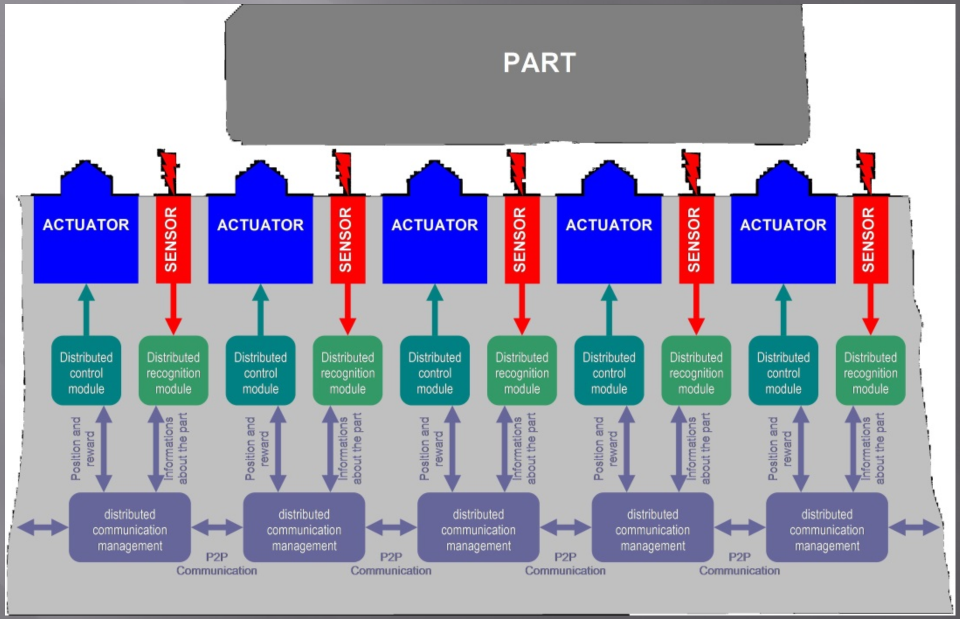


Fig 2.2 Smart Surface design

2.2 Smart Surface

- Few sensors (one per cell).

  Poor definition of the item on the surface.
- Distributed iterative algorithms for state acquision of the smart surface.
- Asynchronous iterative algorithms.
- Convergence results.
- Detection of the convergence test.

  Method of Bertsekas (activity graph & acknowledgment of messages).

2.3 Distributed Part Differentiation

- Distributed methods for part differentiation.
- Assumption 1: limited number of types of parts.
- Assumption 2: there is at most one part on the smart surface.

2.3 Distributed Part Differentiation

- Criteria:

  contour-based differentiation criteria, like

  number of components of vector x_i with value 1 such that there exists

  $x_j = 0, j \in N(i).$

  region-based criteria, like

  number of components of vector x_i with value 1, i.e. surface like criteria.

2.3 Distributed Part Differentiation

- Offline stage: a database that contains the values of criteria used to differentiate parts is produced. Only a limited number of parts that will be called reference parts are considered. The values of the criteria are stored in cells.

2.3 Distributed Part Differentiation

- Offline stage:

  the reference part is rotated several times and is also moved along several cells;

  a matrix of sensor values is generated, the matrix fits the smart surface, i.e. there is one entry per sensor;

  sub-matrices, i.e., masks are generated;

  values of the different criteria are calculated for all masks of the reference part.

  The set of criteria values forms the database.

2.3 Distributed Part Differentiation

- Online stage: cells try to differentiate the part on the smart surface by comparing the criteria values of this part with the values stored in the database.

2.3 Smart Surface Simulator

- Multithreaded Smart Surface Java Simulator (SSS).

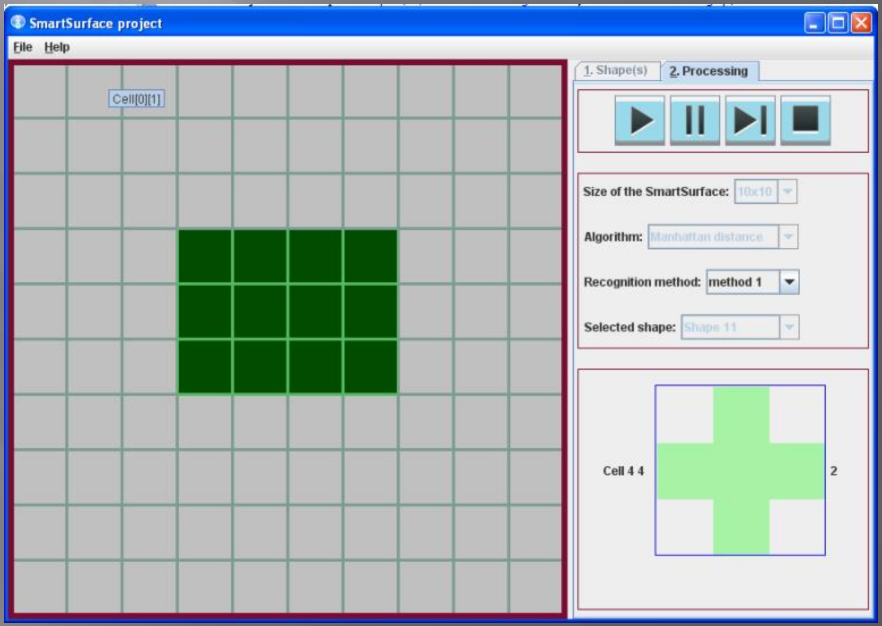


Fig. 2.4 Smart Surface Simulator

3. Distributed Autonomous Robotic Systems

- **<u>Reconfigurable</u>** assembly lines
- Smart modular conveyors with distributed intelligence.
- Critical applications
- ANR project Smart Blocks.

  ANR-2011-BS03-005, 2011 – 2015.

- Distributed Autonomous Robotic Systems
- Modular Reconfigurable Robots (MRR)

3.1. Smart Block Project

Goal: build module with:

- Sensors on each side (blocks).
- Sensors on top (parts).
- Electro-permanent magnet-based motion actuators (block motion).
- 2D pneumatic MEMS actuator array (moves parts on top).
- Processing unit.
- Communication ports.

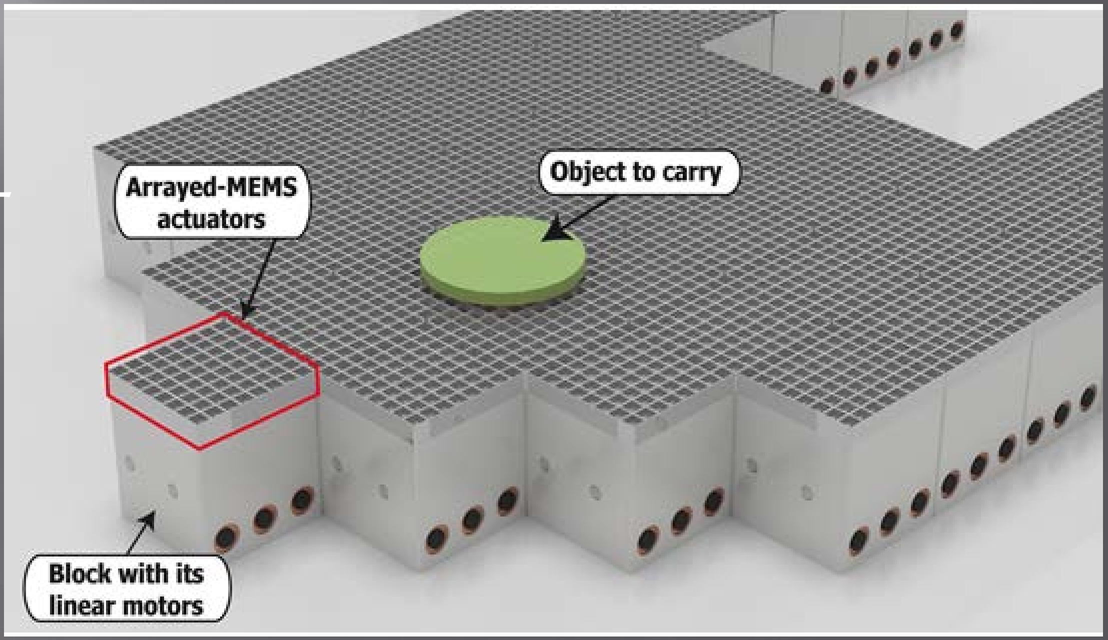


Fig.3.1 The modular surface

3.1. Smart Block Project

centimeter scale micropart conveyor.

Self reconfigurable. MEMS-based modular surface.

Semiconductors manufacturing, micromechanics, pharmaceutical .

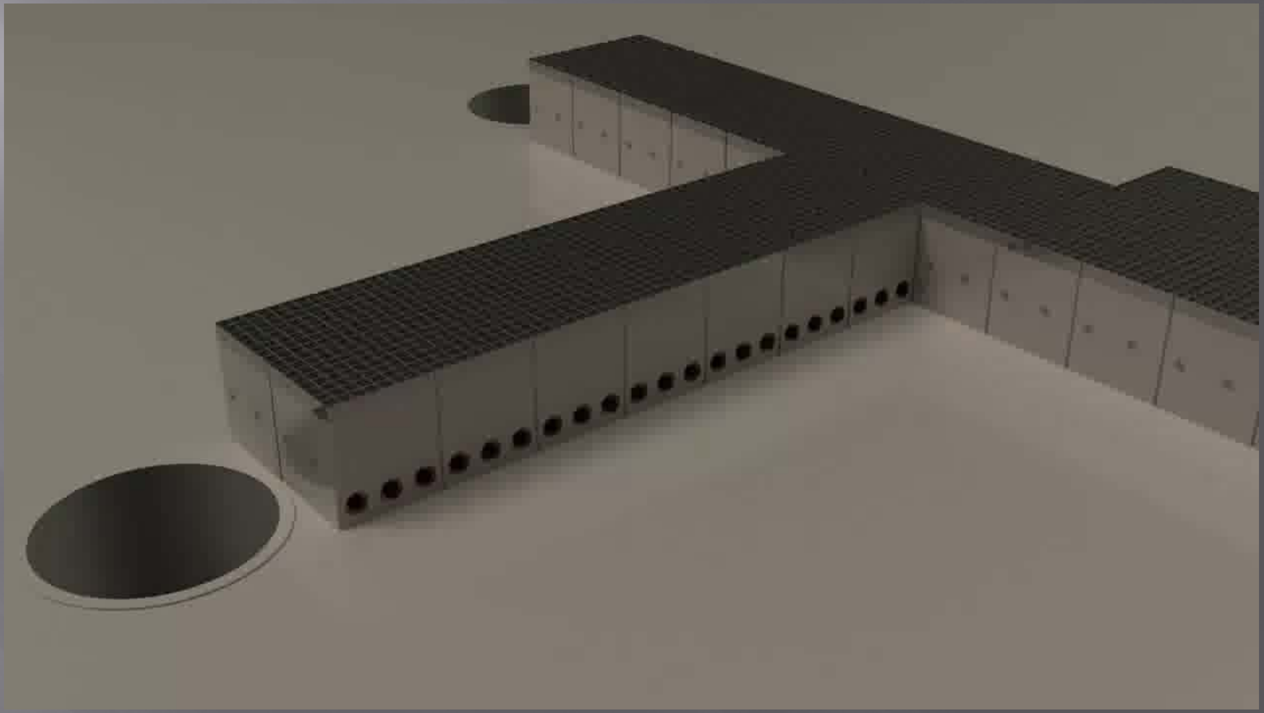


Fig.3.2 The reconfigurable smart blocks modular conveyor

3.2 Discrete Model

2D Grid Topology.

Node: center of the square that can be occupied by a block.

Input, Output, Blocks.

Metrics: hop Count.

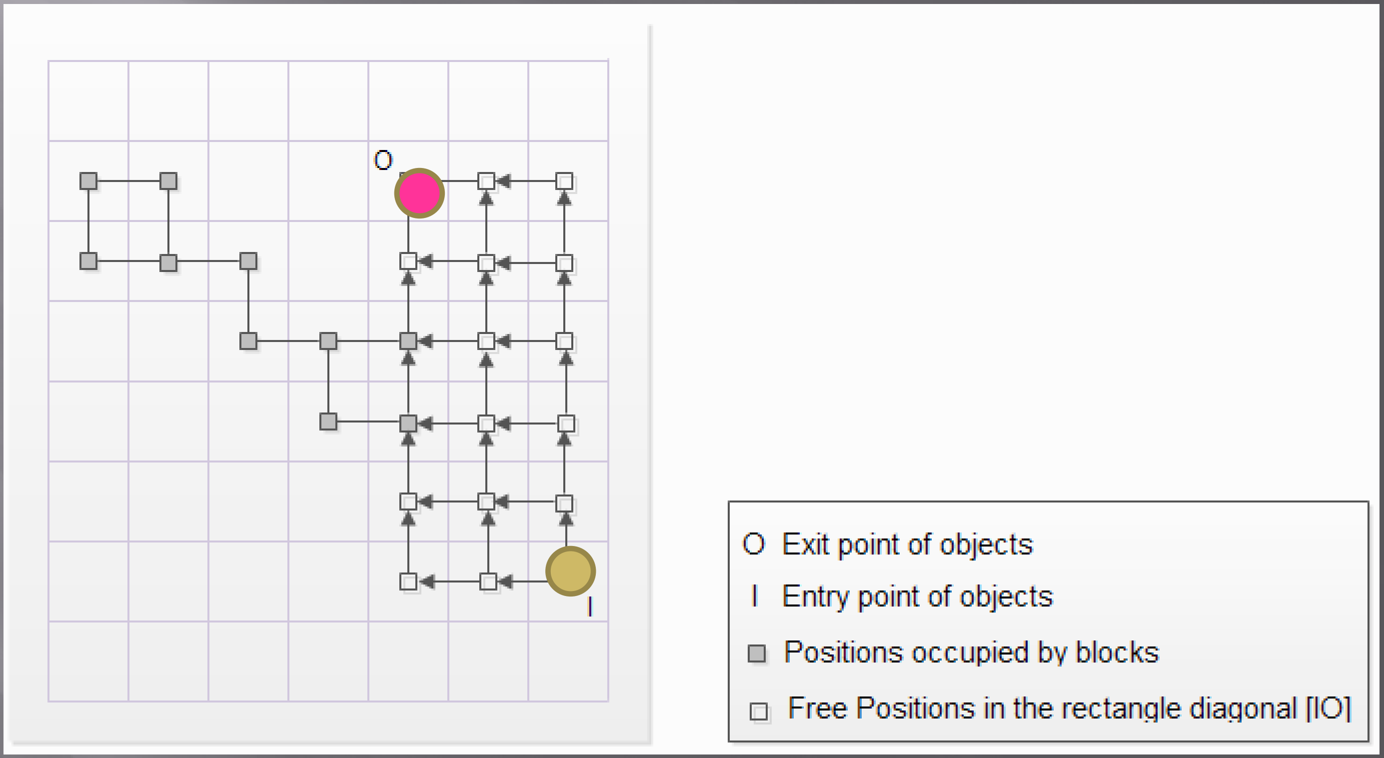


Fig. 3.3 The discrete model of the modular surface

3.3 Block Motion

Relies on contact with other blocks.

Rectilinear block moves.

Elementary block moves.

One hop move.

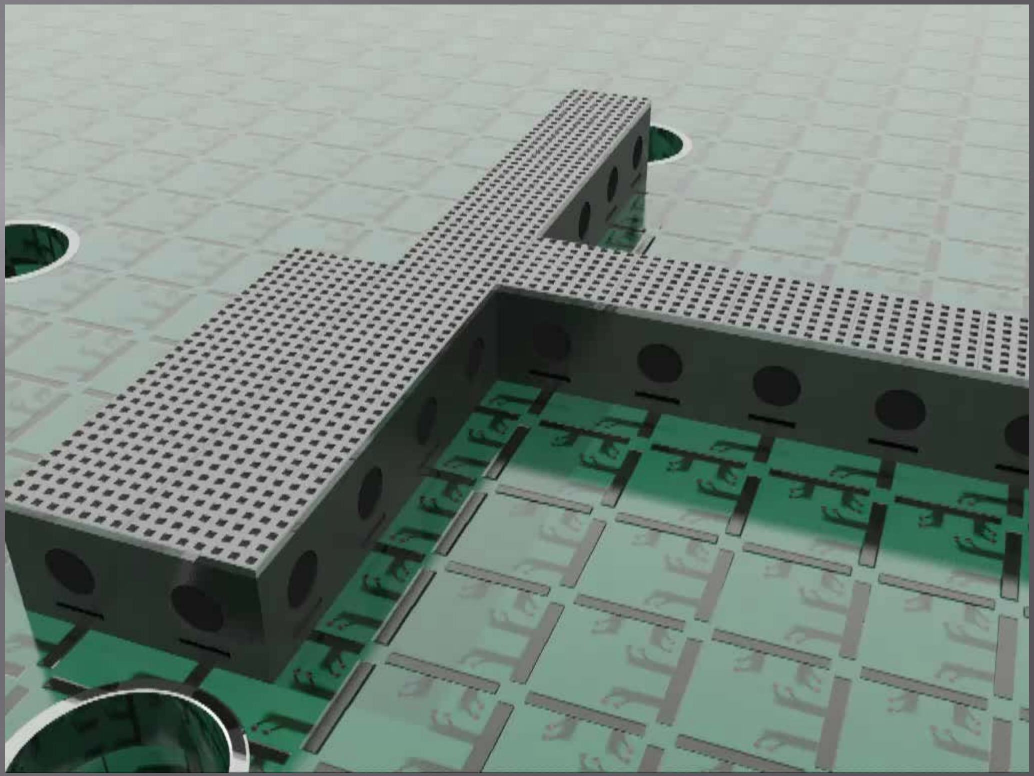


Fig. 3.4 Rectilinear block motion

3.4 Distributed Algorithm

- Distributed Intelligence well suited to cyber-physical systems.
- Blocks cooperate to optimally build a shortest path between the entering point of parts and their exit point on the surface.
- Discrete trajectory optimization; distributed algorithm for the reconfigurable modular surface.
- Distributed election ;
- Scalability, flexibility and optimality.

3.4 Distributed Algorithm

- Quickly set up a modular conveyor with mimimal distance between *I* and *O*.
  - It computes the shortest path between *I* and *O* using a strategy based on minimum hop count.
  - Heuristics tends to minimize the number of block moves in order to build the shortest path.
  - Scalable approach based on distributed asynchronous iterative elections.

3.5 Recent work (2016-2017)

- Hardware;

  Challenges in miniaturization.
- Software;

  New distributed heuristics.

3.5.1 E.P. Magnets

- Electro Permanent magnet

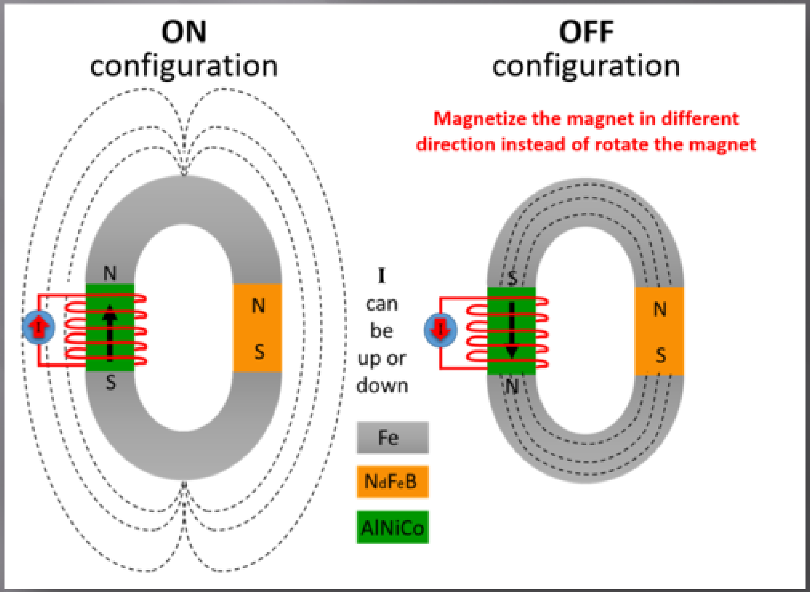


Fig. 3.5 Principle of EP magnets

3.5.2 Semi Electro Permanent Magnet

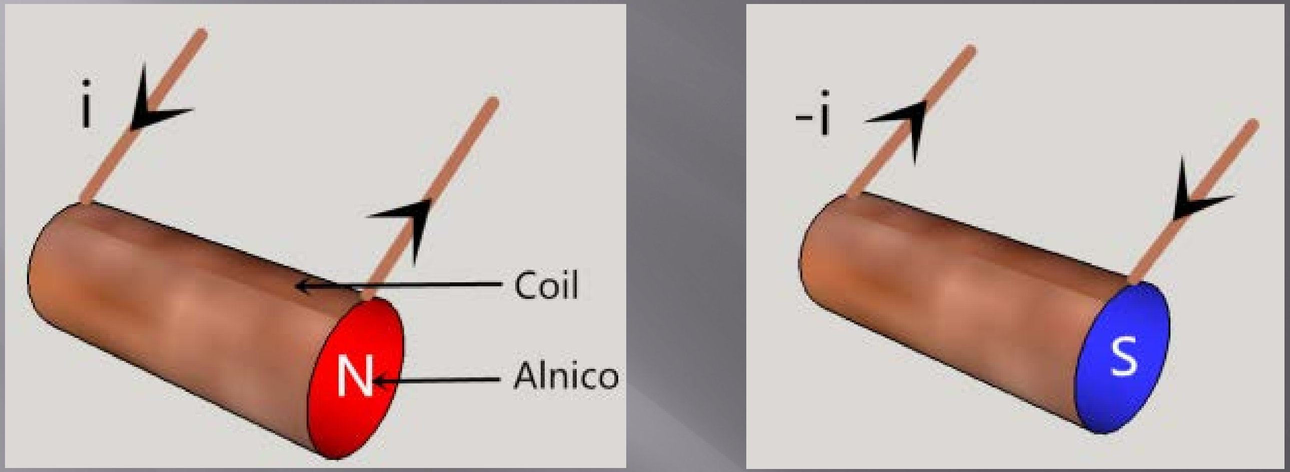
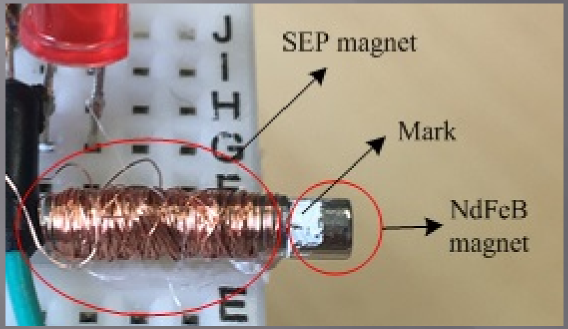
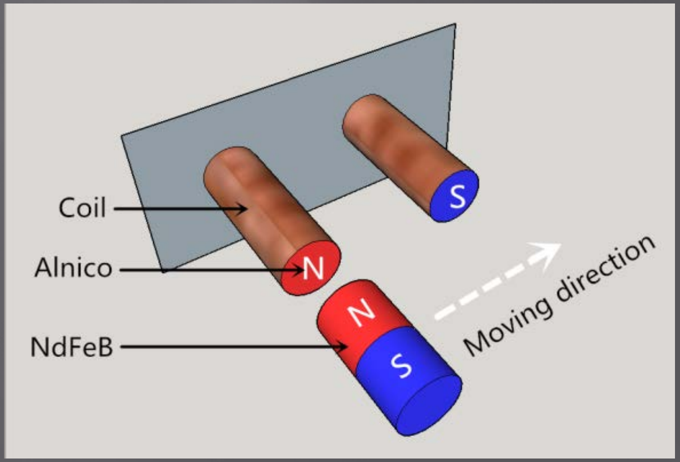


Fig. 3.6 Principle of SEP magnets

Fig. 3.7 Permanent magnet is the rotor





3.5.2 Semi Electro Permanent Magnet

- ❑Permanent magnet is the rotor
- ❑One system for
  - ➢ Motion function
  - ➢ Connection function saving energy.

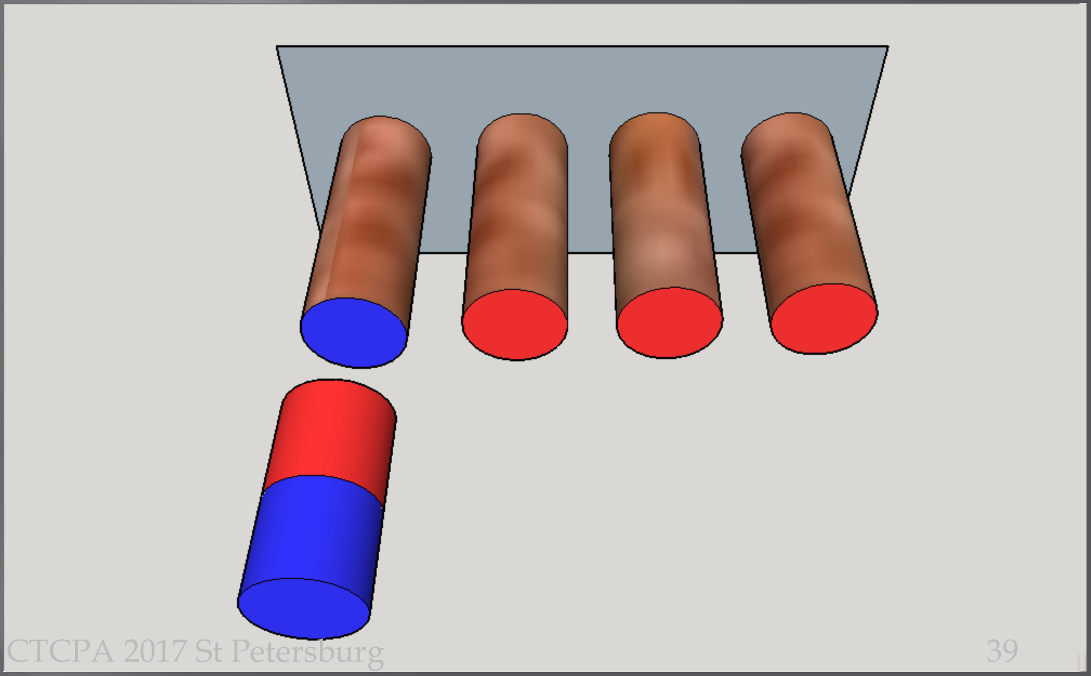
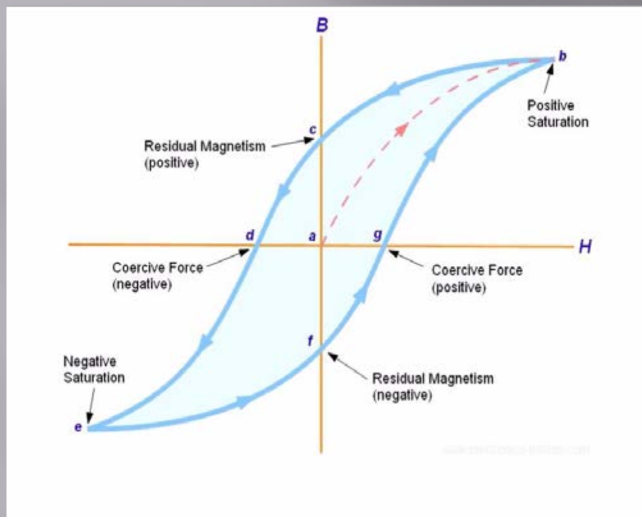
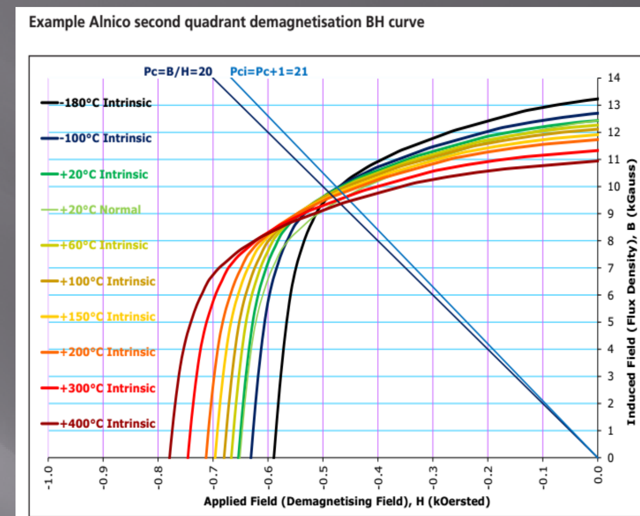


Fig. 3.8 Rotor in action

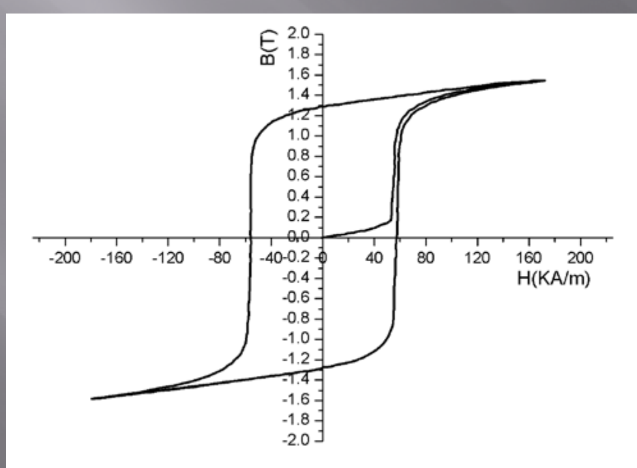
3.5.2 Semi Electro Permanent Magnet



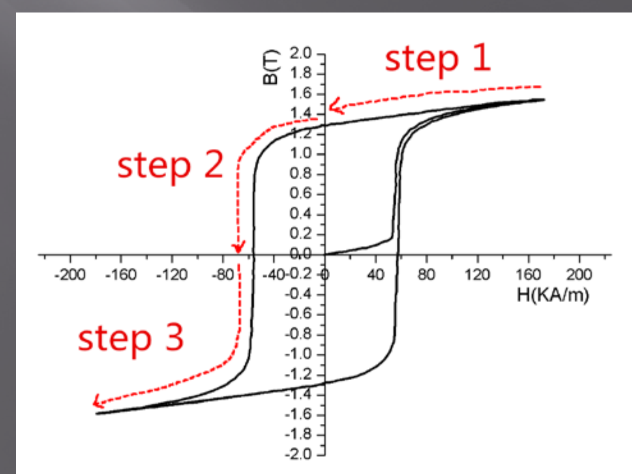
a) BH curve



b) Alnico5 second quadrant demagnetisation BH

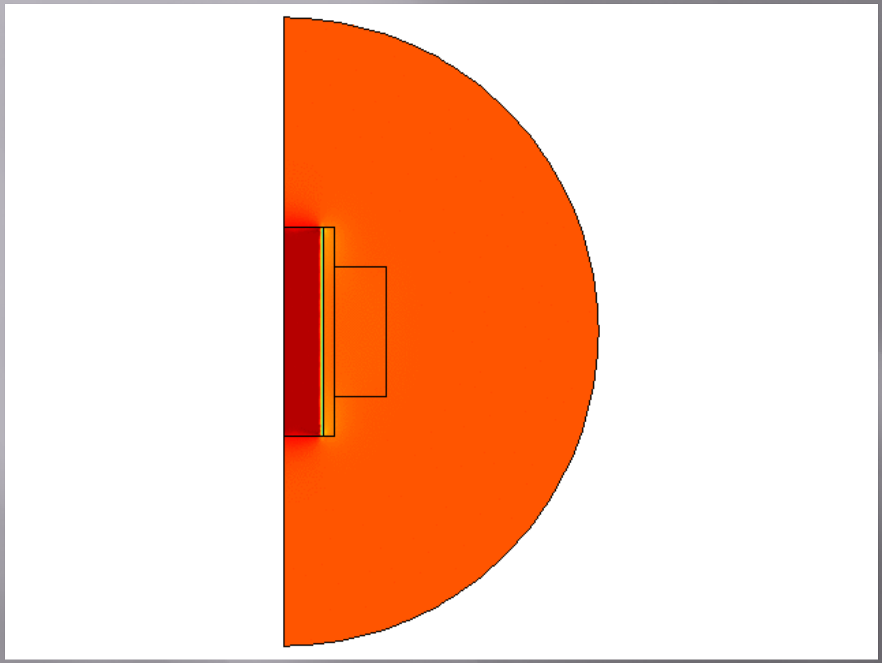


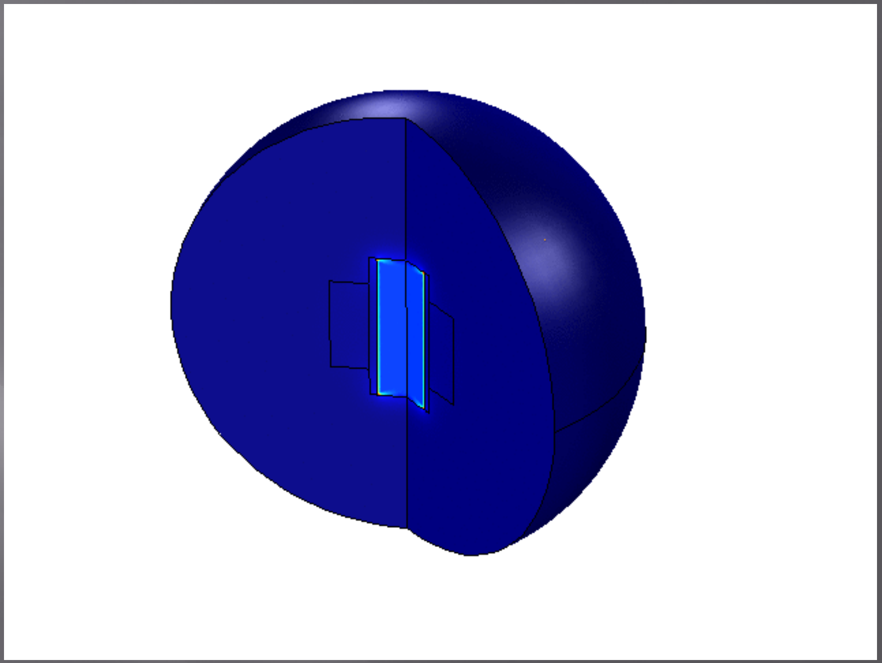
c) Alnico5-7 full quadrant demagnetisation BH curve, Alnico5-7≈Alnico5



d) Process of magnetization direction reverse

3.5.2 Semi Electro Permanent Magnet





a) 2D Fig. 3.8 Magnetic flux density b) 3D

- Process of elimination of magnetism.
- Simulation via Comsol MultiPhysics.

  Guidance for design.

3.5.3 Circuit Design

- Circuit

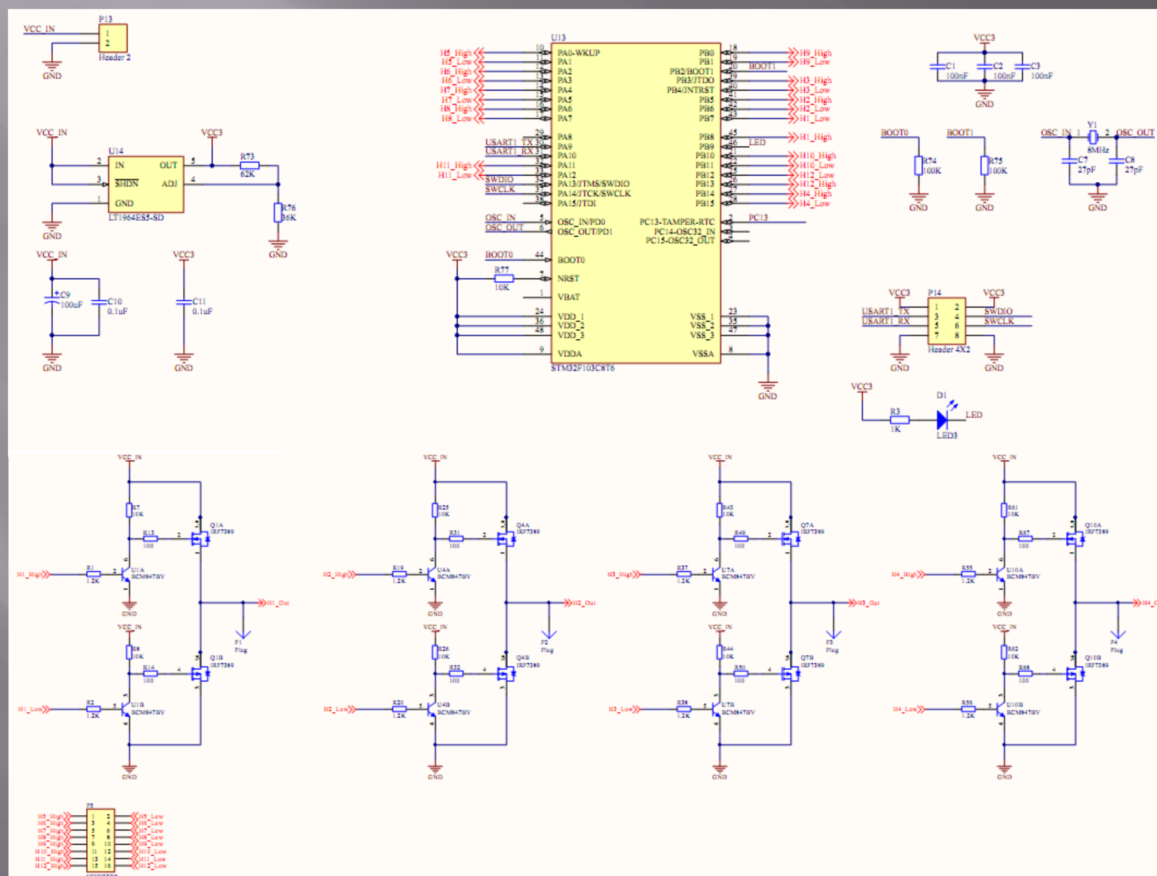
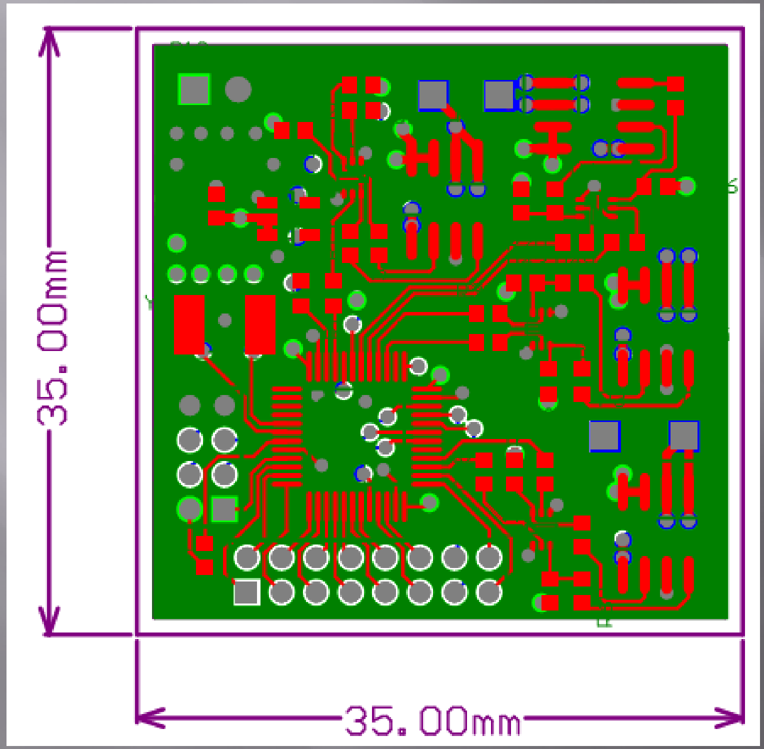


Fig. 3.9 Circuit of the main board

3.5.3 Circuit Design



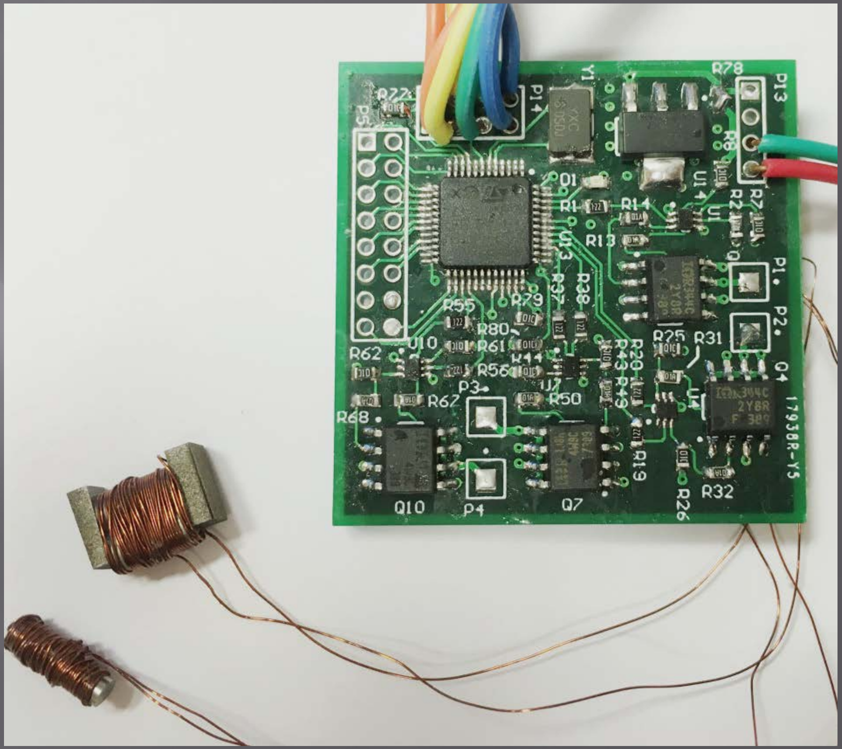


Fig. 3.10 PCB and main board for controlling the modules

3.5.4 New Block Design

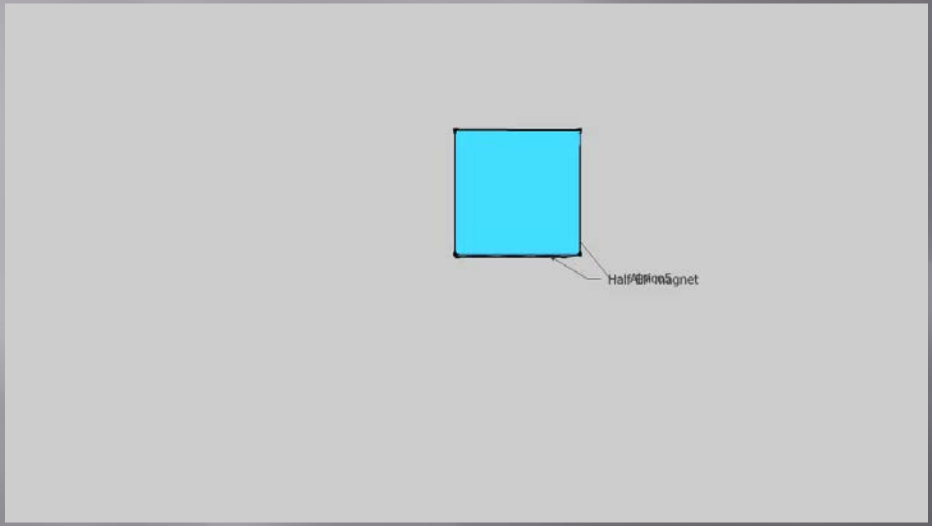


Fig. 3.11 a) Block design

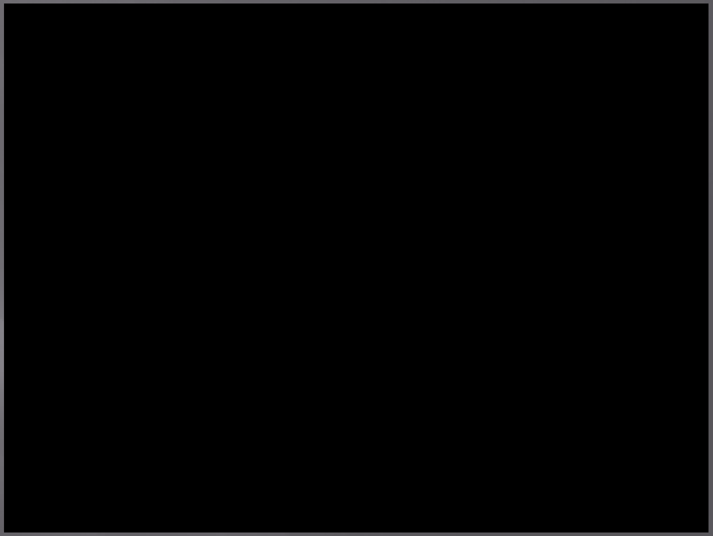


Fig. 3.11 b) Block test

3.5.5 Tests

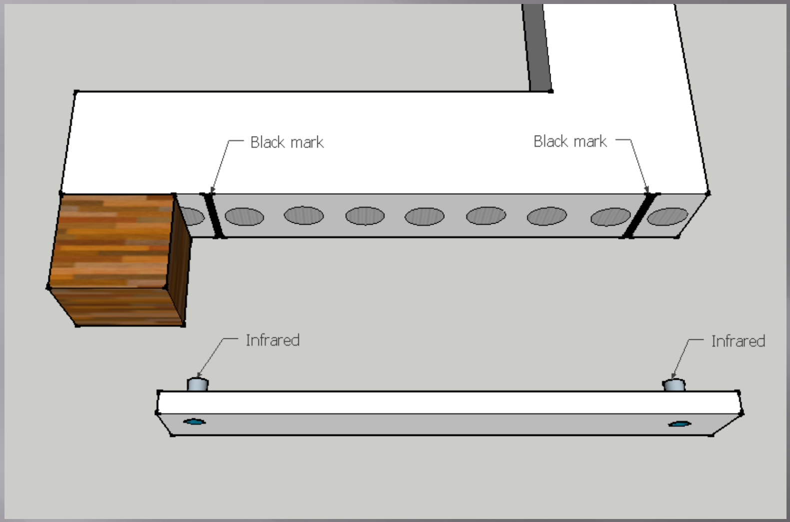


Fig 3.12 a) Speed test
Prepare for distributed algorithm

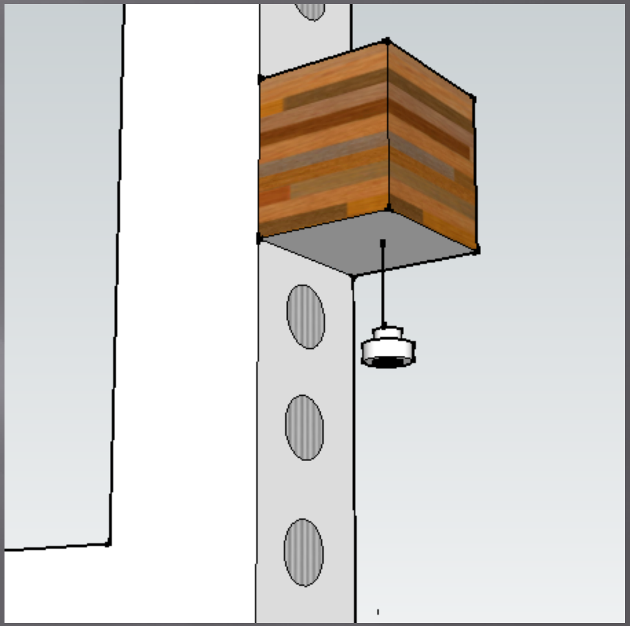


Fig 3.12 b) Holding force test
Prepare for 3D motion

3.5.5 Tests

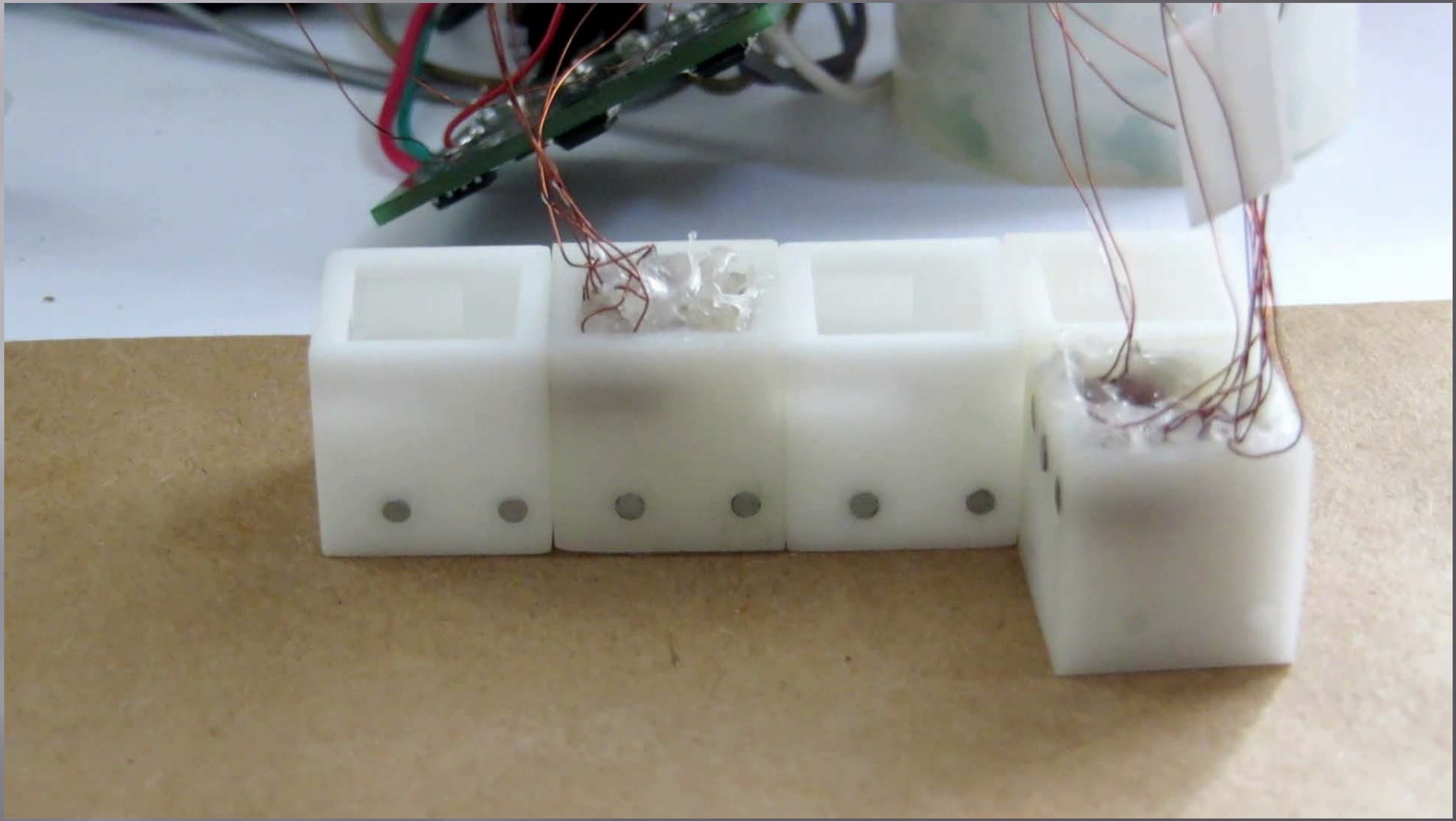


Fig. 3.13 Rectilinear motion

3.5.5 Tests

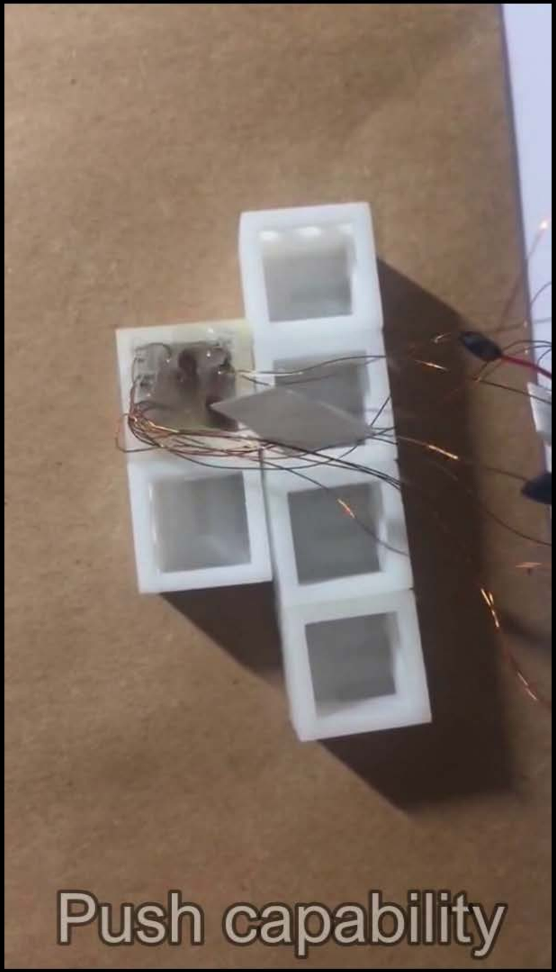


Fig. 3.14 Push and pull motion

3.5.6 Distributed algorithm & Simulator of Smart Modules

- Principle of a new distributed iterative algorithm

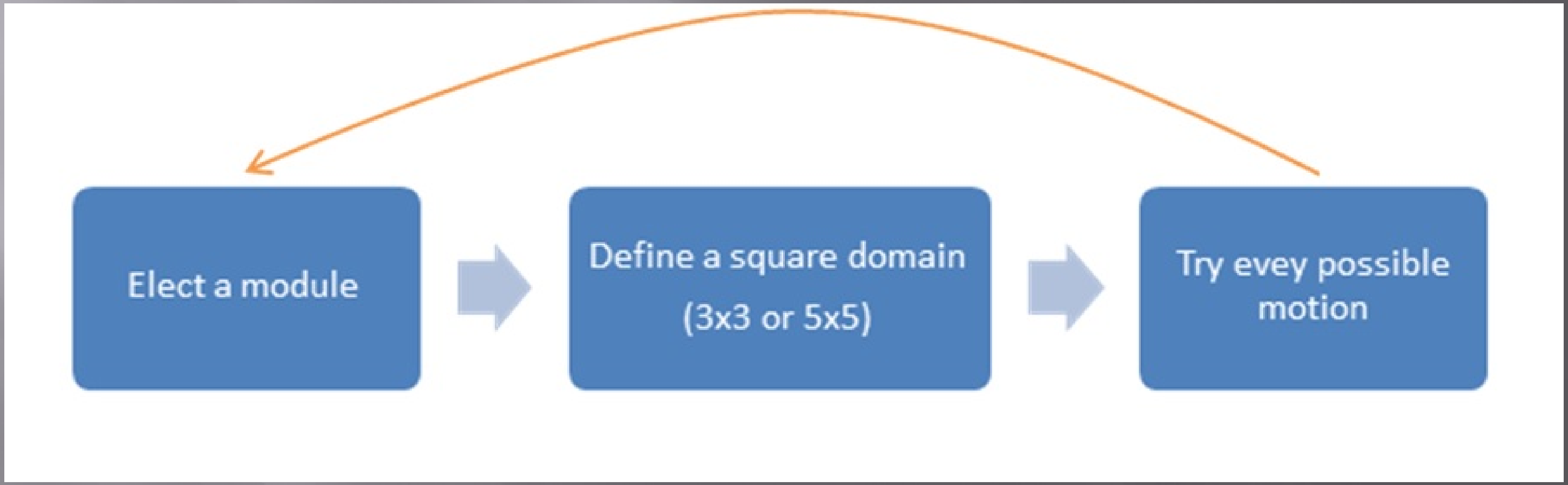


Fig. 3.15 Distributed iterative algorithù

3.5.6 Distributed algorithm & Simulator of Smart Modules

- New distributed algorithm

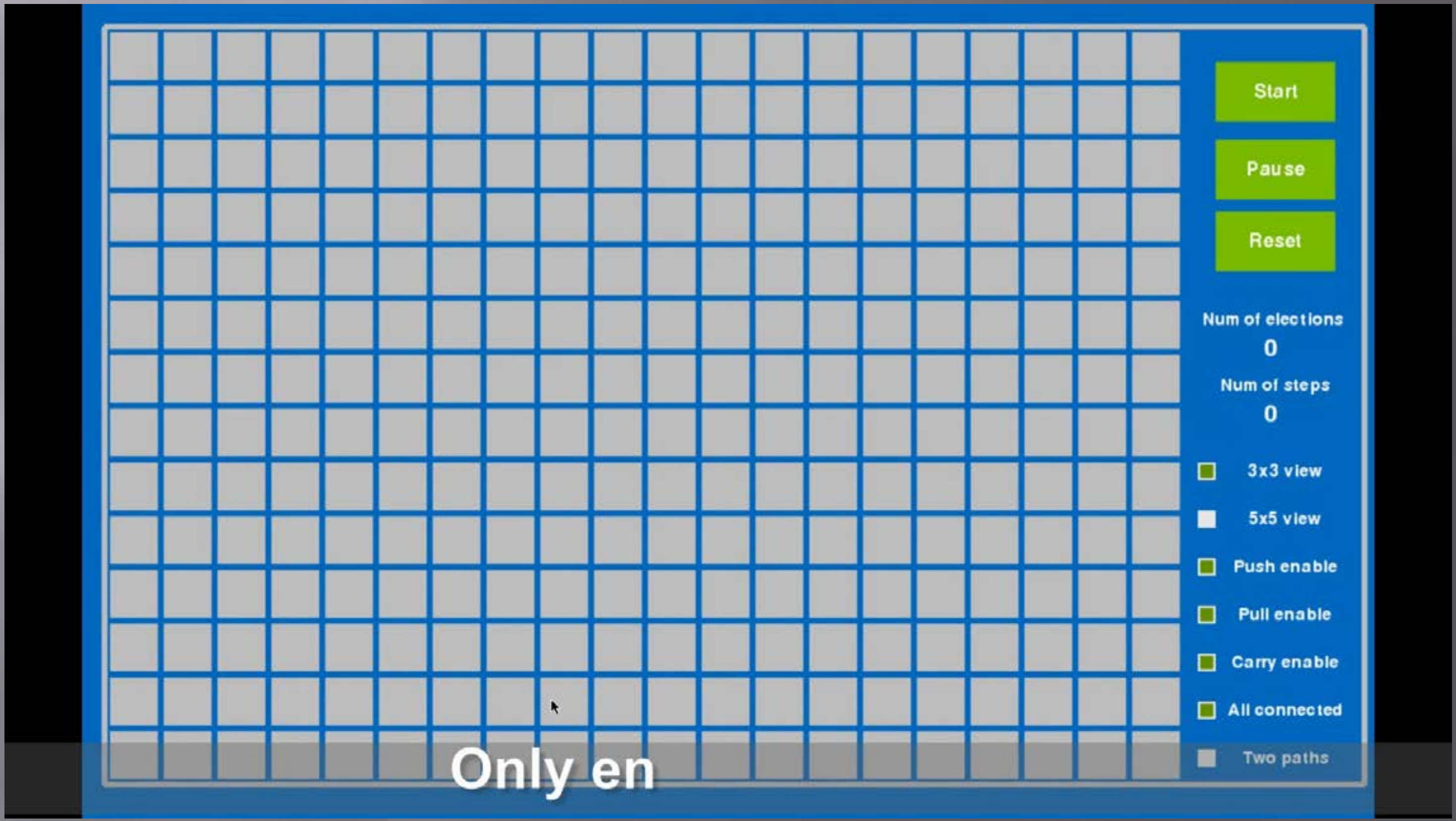


Fig. 3.15 distributed algorithm & SSM

3.5.6 Distributed algorithm & Simulator of Smart Modules

- New distributed algorithm

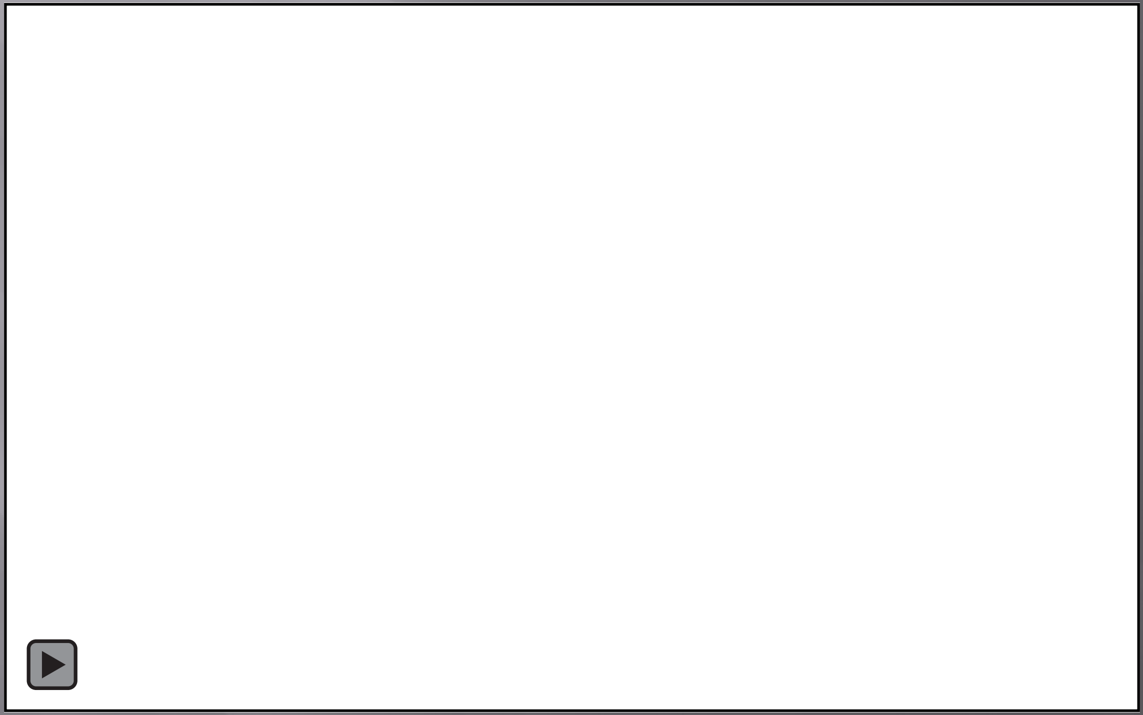
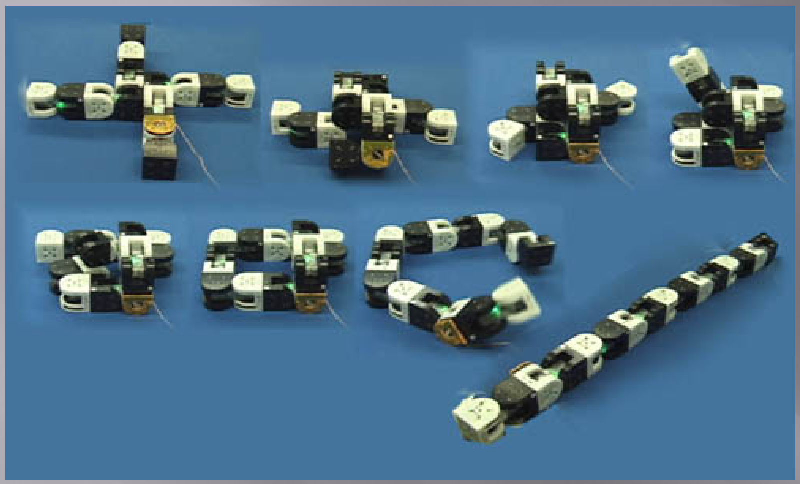
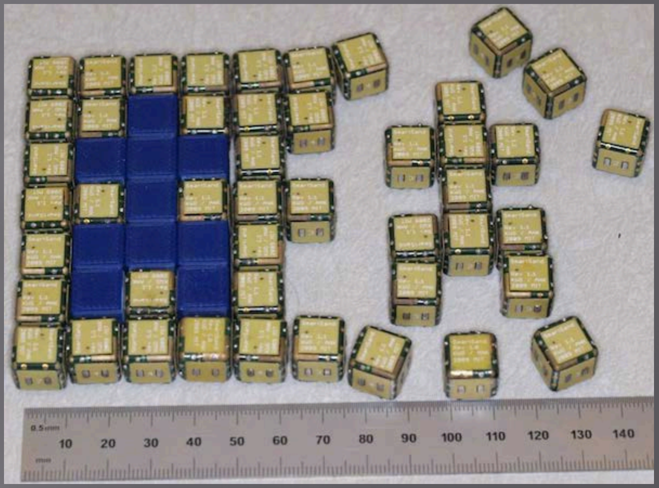


Fig. 3.16 distributed algorithm & SSM

3.6 Other Modular Reconfigurable Robots



MTRAN III __ AIST (Japan)



Robot Pebbles__MIT

CUBELETS__ Modular Robotics

MRS__ Czech Technical University

4. Conclusions & Perspectives

- Design and development of distributed modular robotic system
- Linear motor
- Design of modules
- Distributed algorithms
- Simulator of Smart Modules

4.1 Future work

- Sensors;
- Communication;
- Fault detection.

4.1 Future work

- Develop more IoT aspects;
- Miniaturization →Cloud computing;
- Hosted intelligence:
  Deep learning;
  Data analysis:
  Quantity of items
  conveyed, faults
- Security.

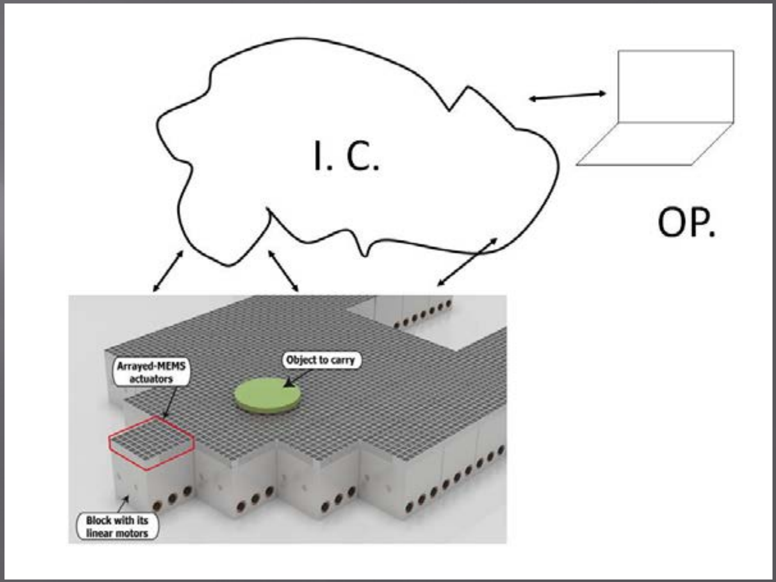


Fig. 3.10 IoT Architecture

4.1 Future work

- Security challenges:
- Access control;
- Dynamicity;
- Interactions;
- Cooperation of modules;
- Sensor design;
- Physical security.
- pharmaceutical industry
- Micromechanics.

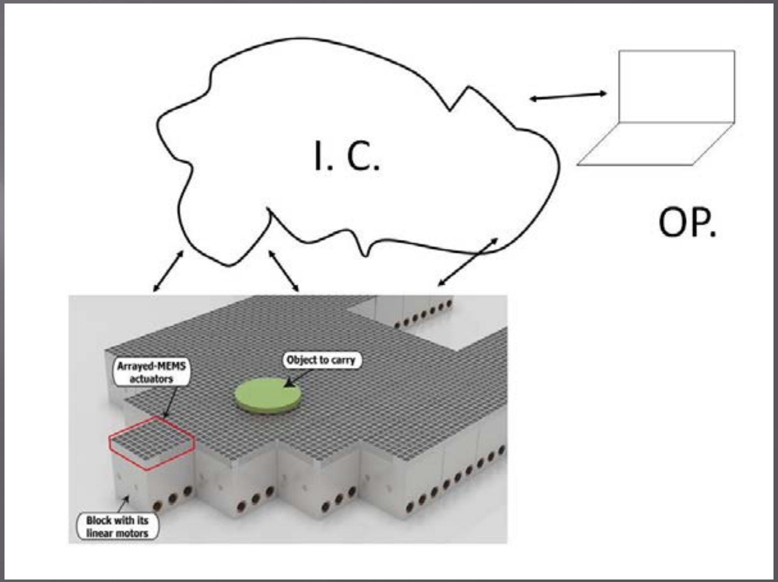


Fig. 3.10 IoT Architecture

4.2 Programmable Matter

4.2 Programmable Matter

- Programmable matter

Intel Carnegie Mellon University