RSS Workshop on Minimalism in Design
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From Binary-Actuated Manipulators to Lie Groups

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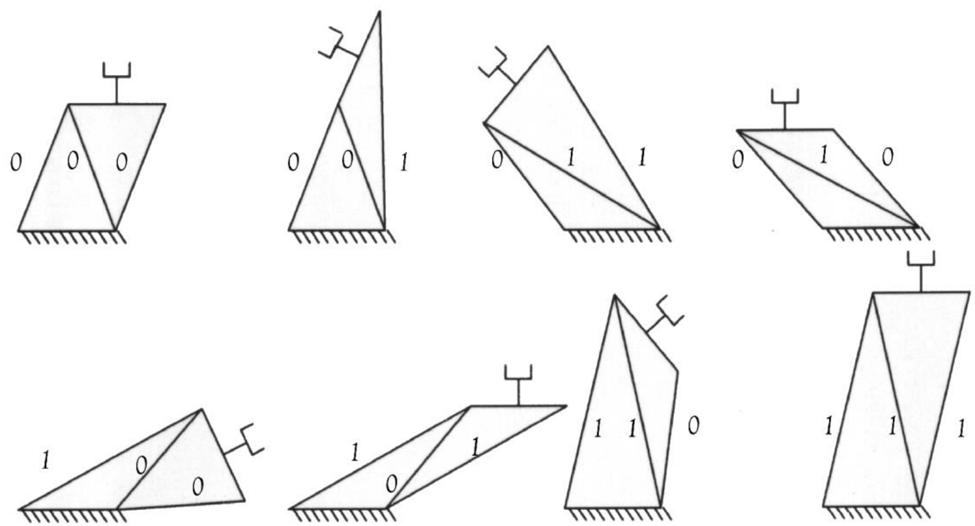
Outline of this talk

- Binary Actuated Manipulators and Workspace Density
- Spherical Motors
- A Modular Manufacturing System
- Robotic Diagnosis, Repair, and Replication
- Acknowledgements: D. Stein, I. Ebert-Uphoff,
  M. Moses, M. Kutzer, J. Davis, K. Wolfe, H. Ma, …

Topic 1:

Binary-Actuated Manipulators

A Binary Manipulator with One Module

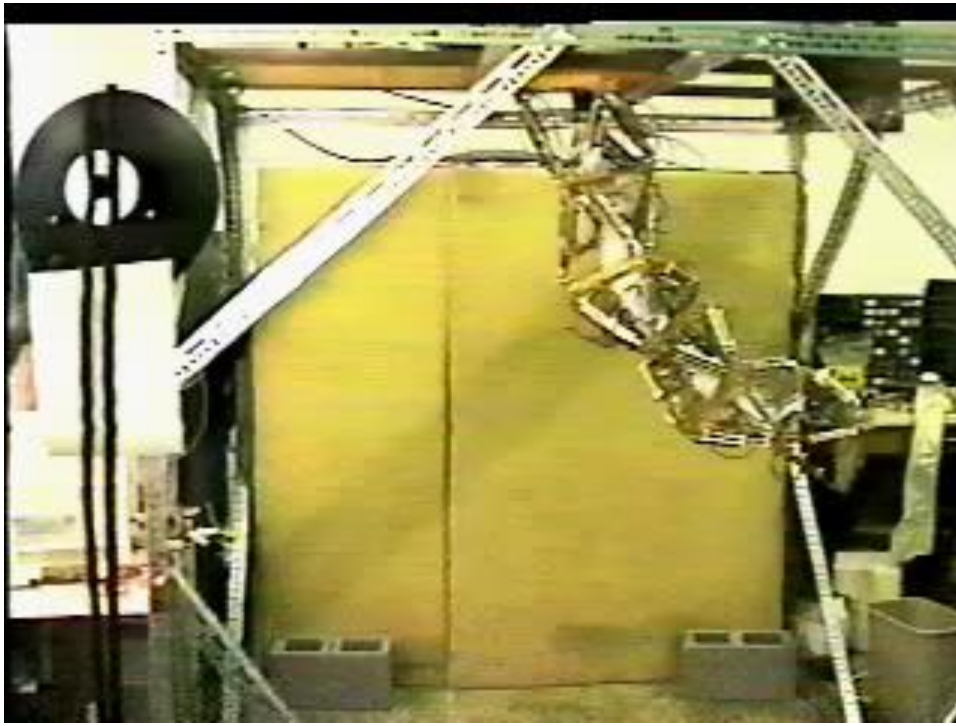


0: retracted state; 1: extended state

Examples of Binary Manipulators

David Stein, VP Siemens

Imme Ebert-Uphoff, CSU

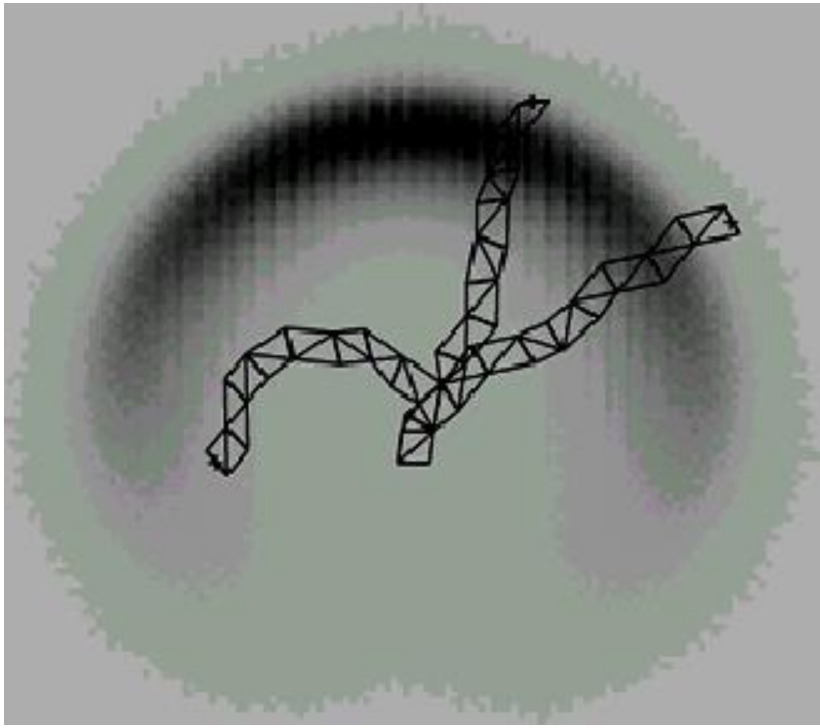


Workspace Density

- It describes the density of the reachable frames in the work space.

- It is a probabilistic measure-ment of accuracy over the workspace.

- f(g) where $$g = \begin{pmatrix} A & a \\ 0^T & 1 \end{pmatrix}$$ is an element of SE(3)



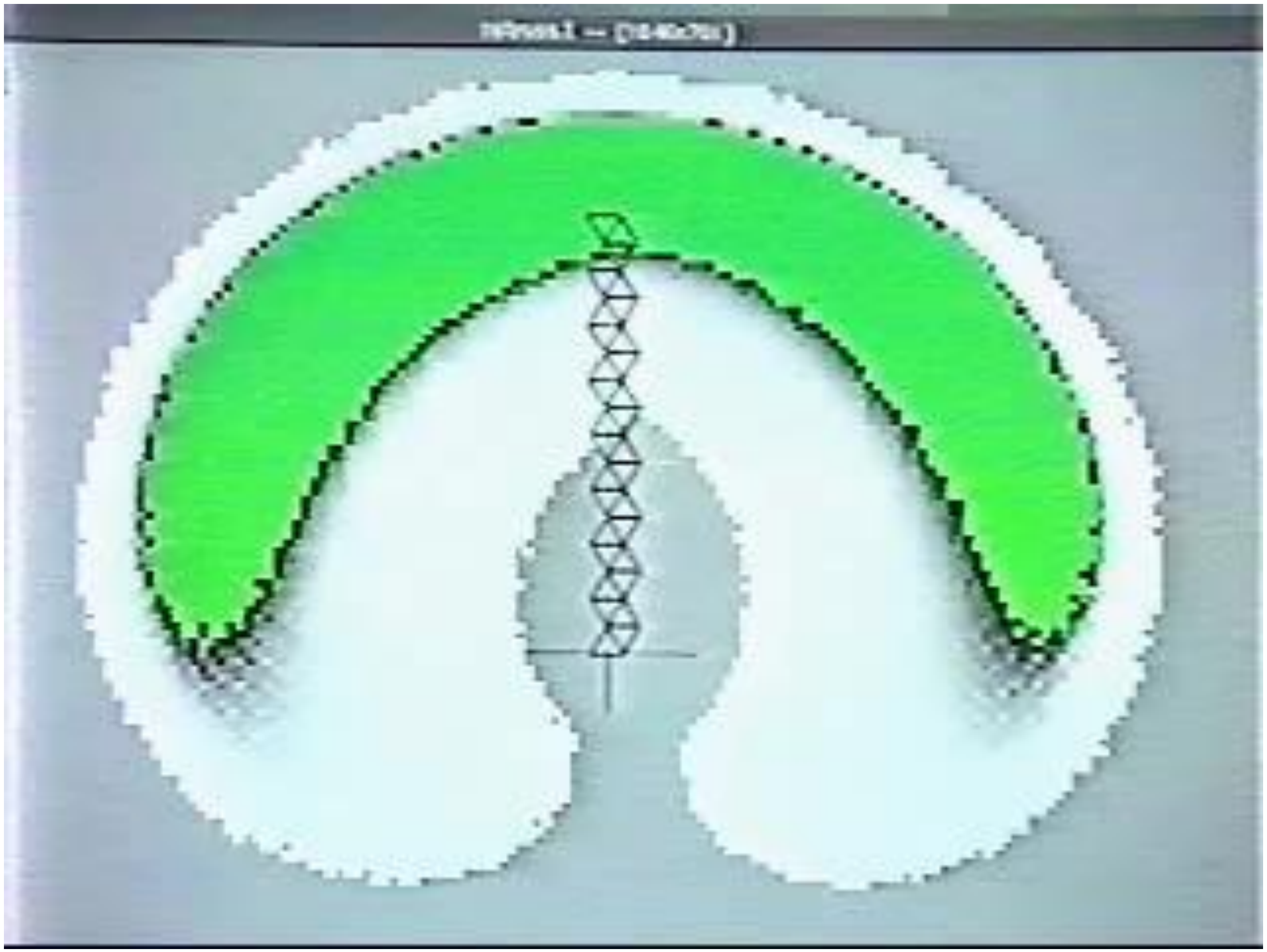
Convolution and the SE(3) Fourier Transform

$$(f_1 * f_2)(g) = \int_G f_1(h) f_2(h^{-1} \circ g) dh$$

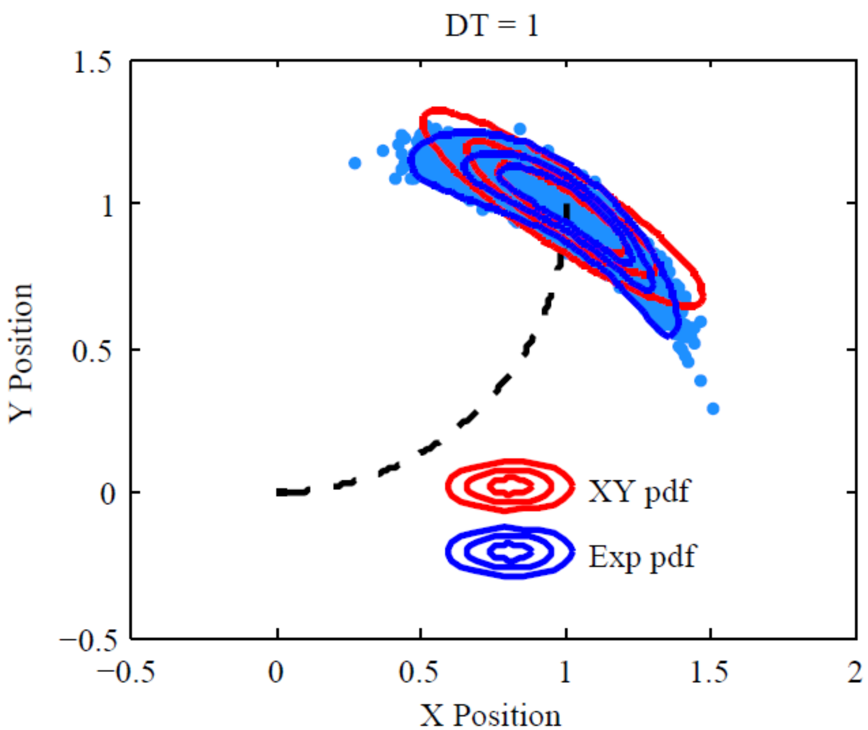
$$F(f_1 * f_2) = F(f_2) F(f_1)$$

Chirikjian, G.S., Kyatkin, A.B, Harmonic Analysis for Engineers and Applied Scientists, Dover, 2016

Inverse Kinematics Simulations



Ebert-Uphoff, I., Chirikjian, G.S., ``Inverse Kinematics of Discretely Actuated Hyper-Redundant Manipulators Using Workspace Densities,'' Proc. 1996 IEEE Int. Conf. on Robotics and Automation, pp. 139-145, April 1996.

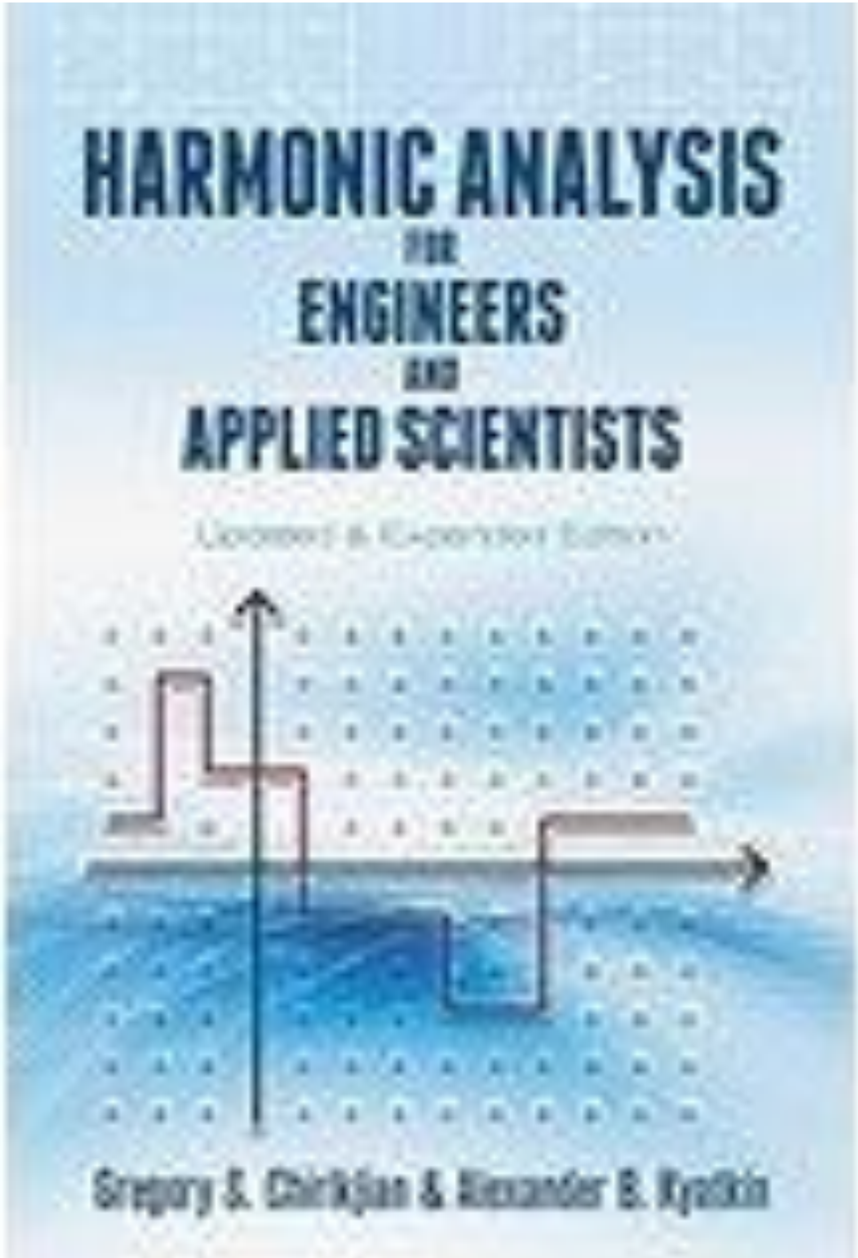


A. Long, K. Wolfe, M. Mashner, G. Chirikjian, ``The Banana Distribution is Gaussian" RSS 2012

$$\int_G \log^\vee\left(\mu^{-1}\circ g\right) f(g)dg = \mathbf{0} \qquad \Sigma = \int_G \log^\vee(\mu^{-1}\circ g)[\log^\vee(\mu^{-1}\circ g)]^T f(g)dg$$

$$f(g;\mu,\Sigma) = \frac{1}{c(\Sigma)}\exp\left[-\frac{1}{2}\mathbf{y}^T\Sigma^{-1}\mathbf{y}\right] \qquad \mathbf{y} = \log(\mu^{-1}\circ g)^\vee$$

Relevant Literature

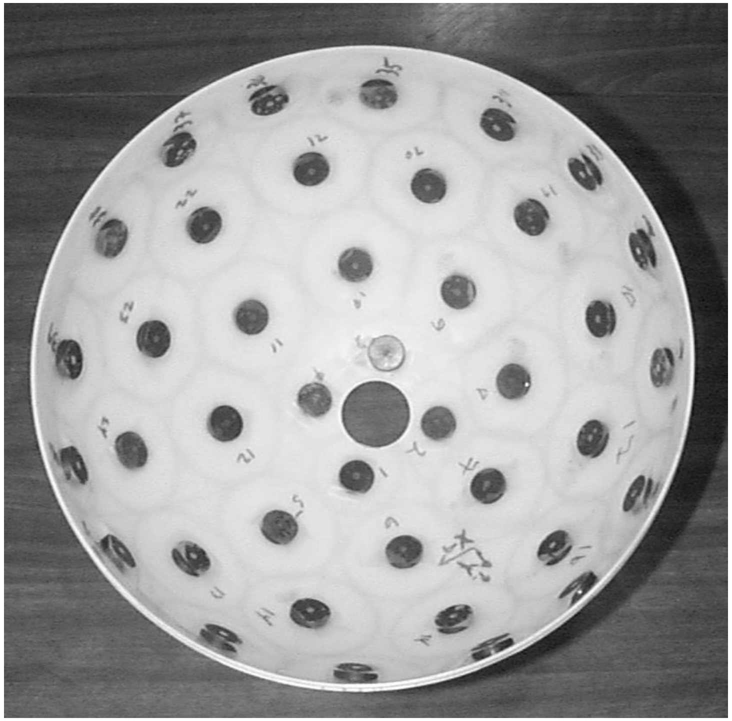


Topic 2:

Spherical Motors and Encoders

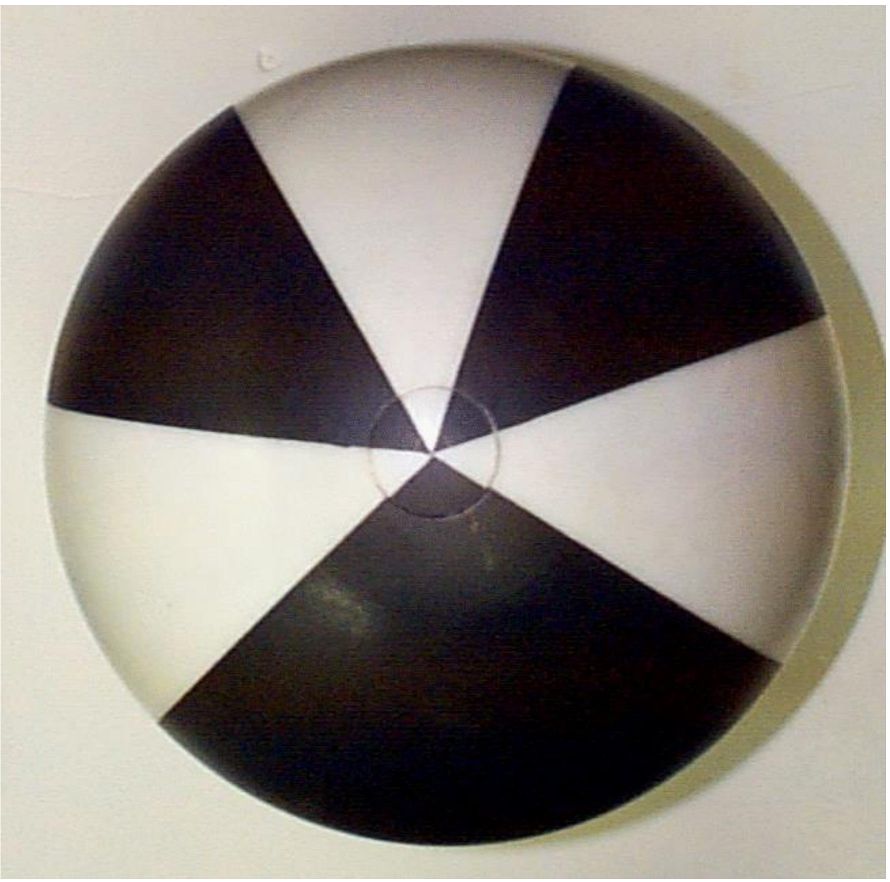
Our Prototype Motor

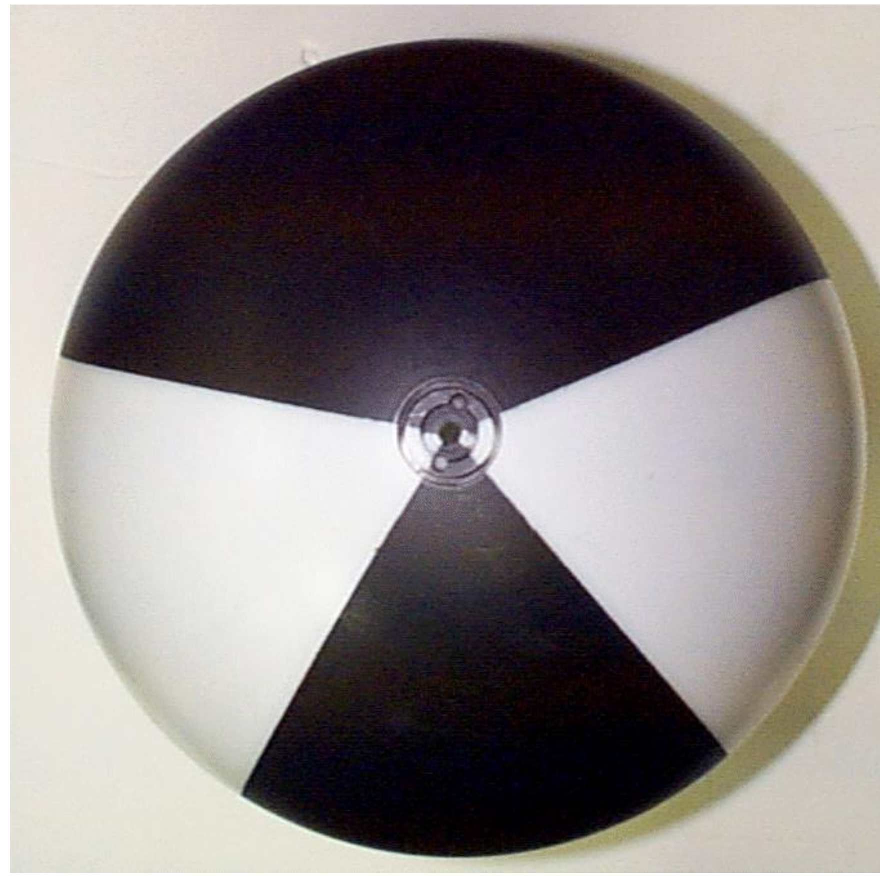
Stator



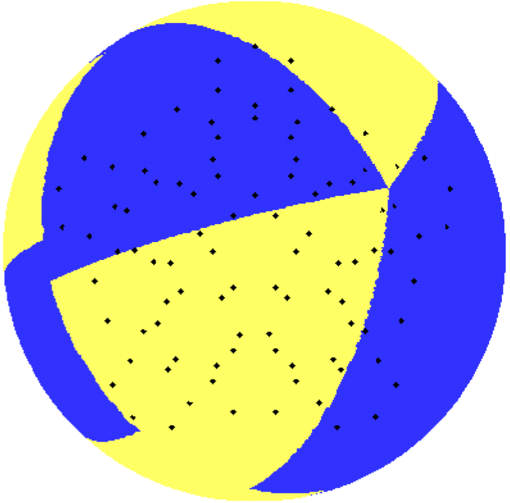
Rotor

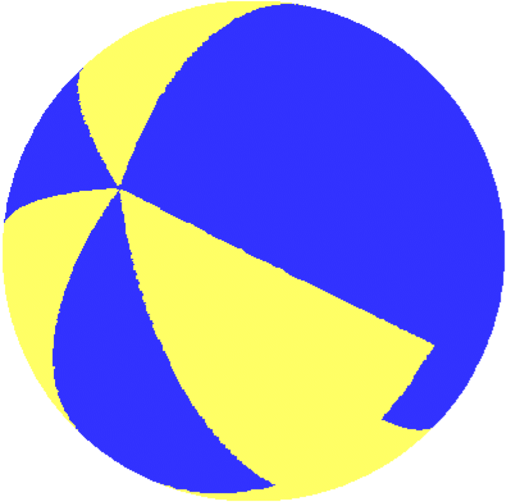
The Encoder

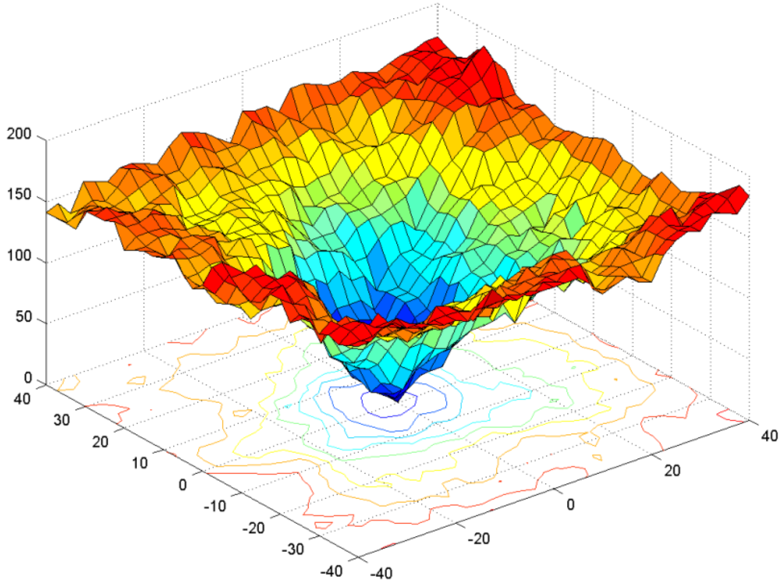




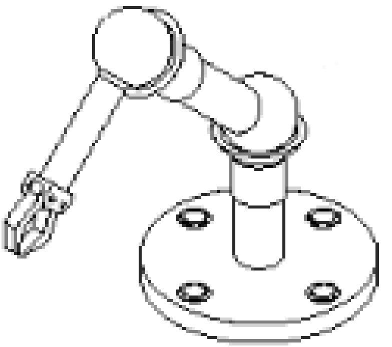
Operating Principles of the Spherical Encoder

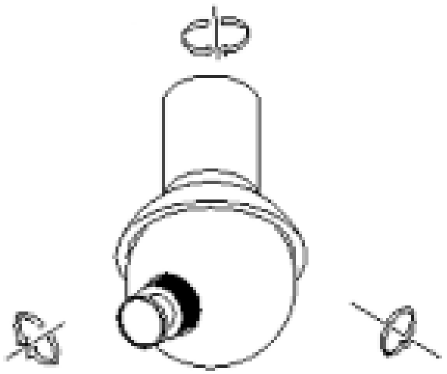


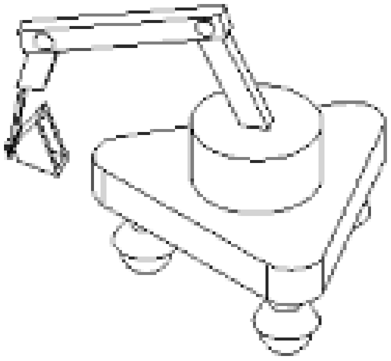


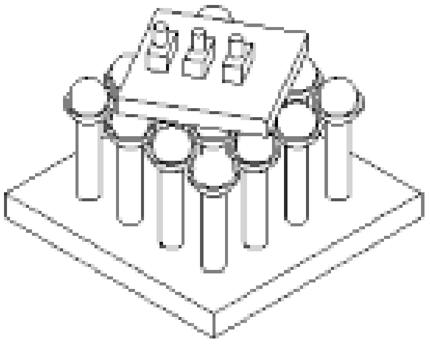


Potential Applications









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1) G. S. Chirikjian, Stochastic Models, Information Theory, and Lie Groups, Vol. 1, 2, Birkhauser, 2009,2011.

2) G.S. Chirikjian, A.B. Kyatkin, Engineering Applications of Noncommutative Harmonic Analysis, CRC Press, 2001.

3 Stein, D., Scheinerman, E.R., Chirikjian, G.S., ``Mathematical models of binary spherical-motion encoders, IEEE-ASME Trans. on Mechatronics 8 (2): 234-244, 2003

Topic 3:

A Modular Manufacturing System

An architecture for universal construction via modular robotic components

Matthew S. Moses received the Ph.D. degree in mechanical engineering from Johns Hopkins University, Baltimore, MD, in 2011. He is currently a consultant for industry.

Hans Ma received the B.S. degree in mechanical engineering from Johns Hopkins University, Baltimore, MD, in 2012. He is currently a graduate student in the Department of Mechanical Engineering at Johns Hopkins.

Kevin C. Wolfe received the B.S.M.E. degree in mechanical engineering from The College of New Jersey, Ewing, in 2007 and the M.S.E. and the Ph.D. degrees in mechanical engineering from Johns Hopkins University, Baltimore, MD, in 2009 and 2012, respectively. He is currently a research engineer at the Johns Hopkins University Applied Physics Laboratory.

Robotics and Autonomous Systems 62 (2014) 945–965

An architecture for universal construction via modular robotic components

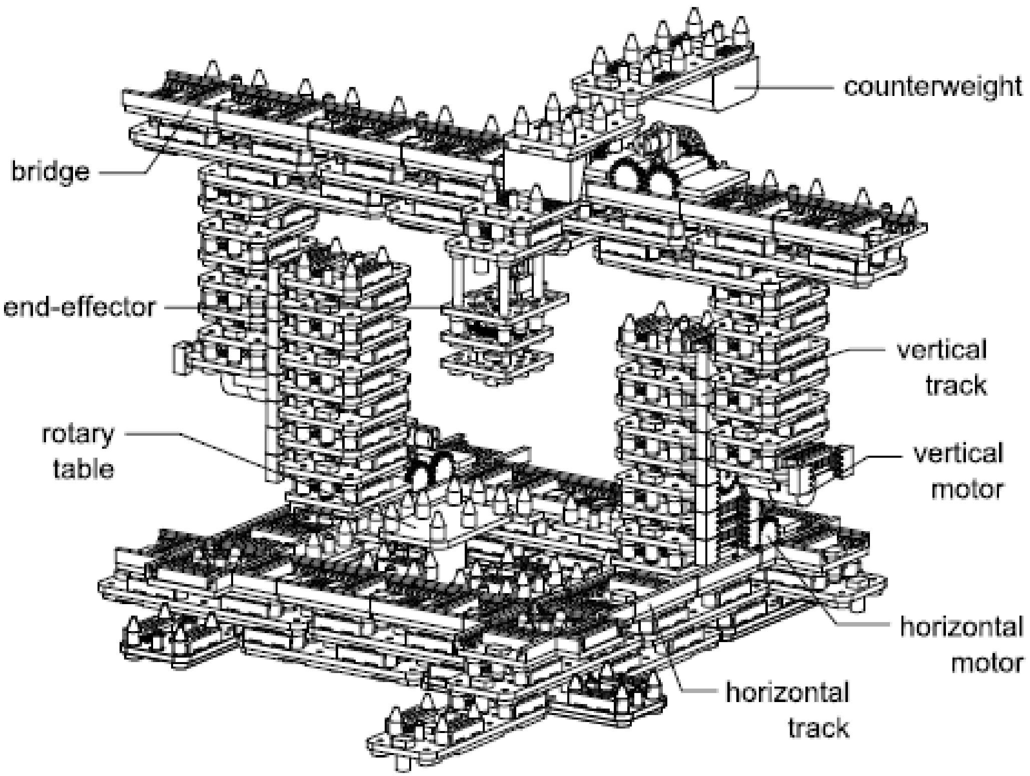

Fig. 1. The constructor is a general purpose 3-axis manipulator, with access to a rotary table for part re-orientation. The constructor workspace allows it to assemble indefinite extensions of track.

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architecture for universal construction via modular robotic An components

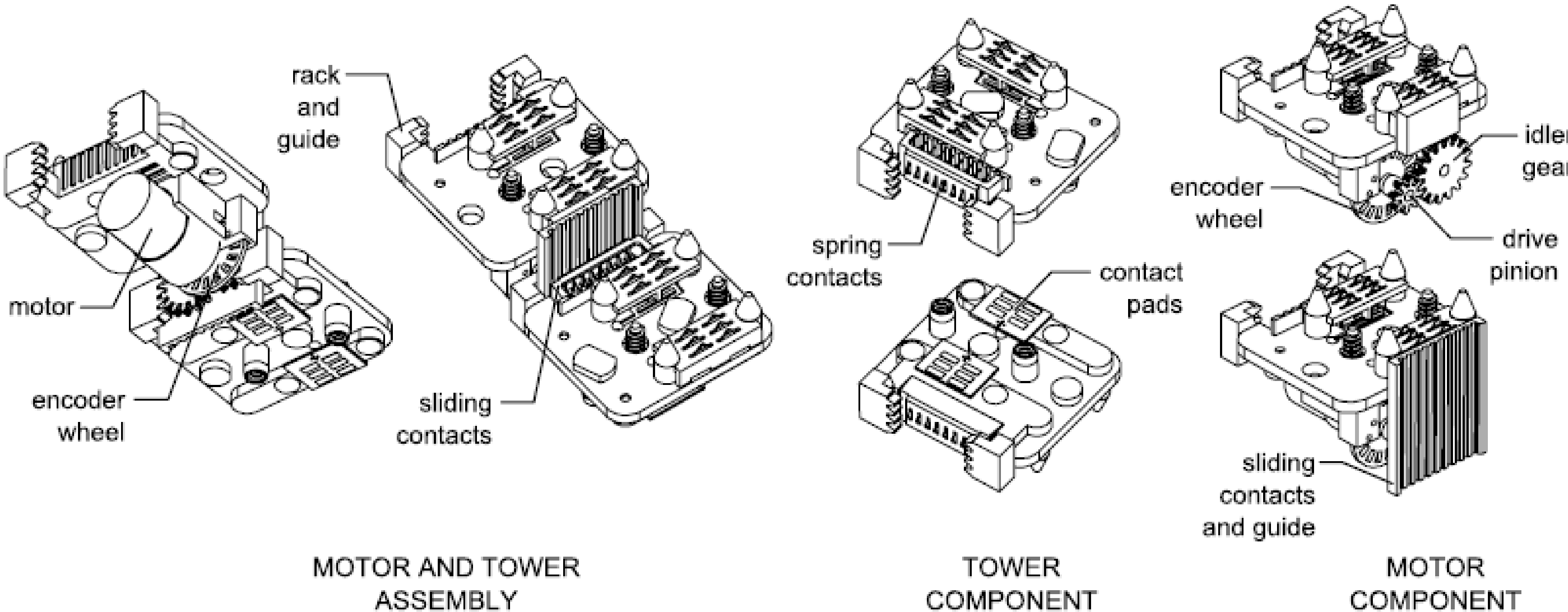

Fig. 18. Key features of the vertical motor and track components. These are Part Types 15 and 12, respectively, as seen in Fig. 2.

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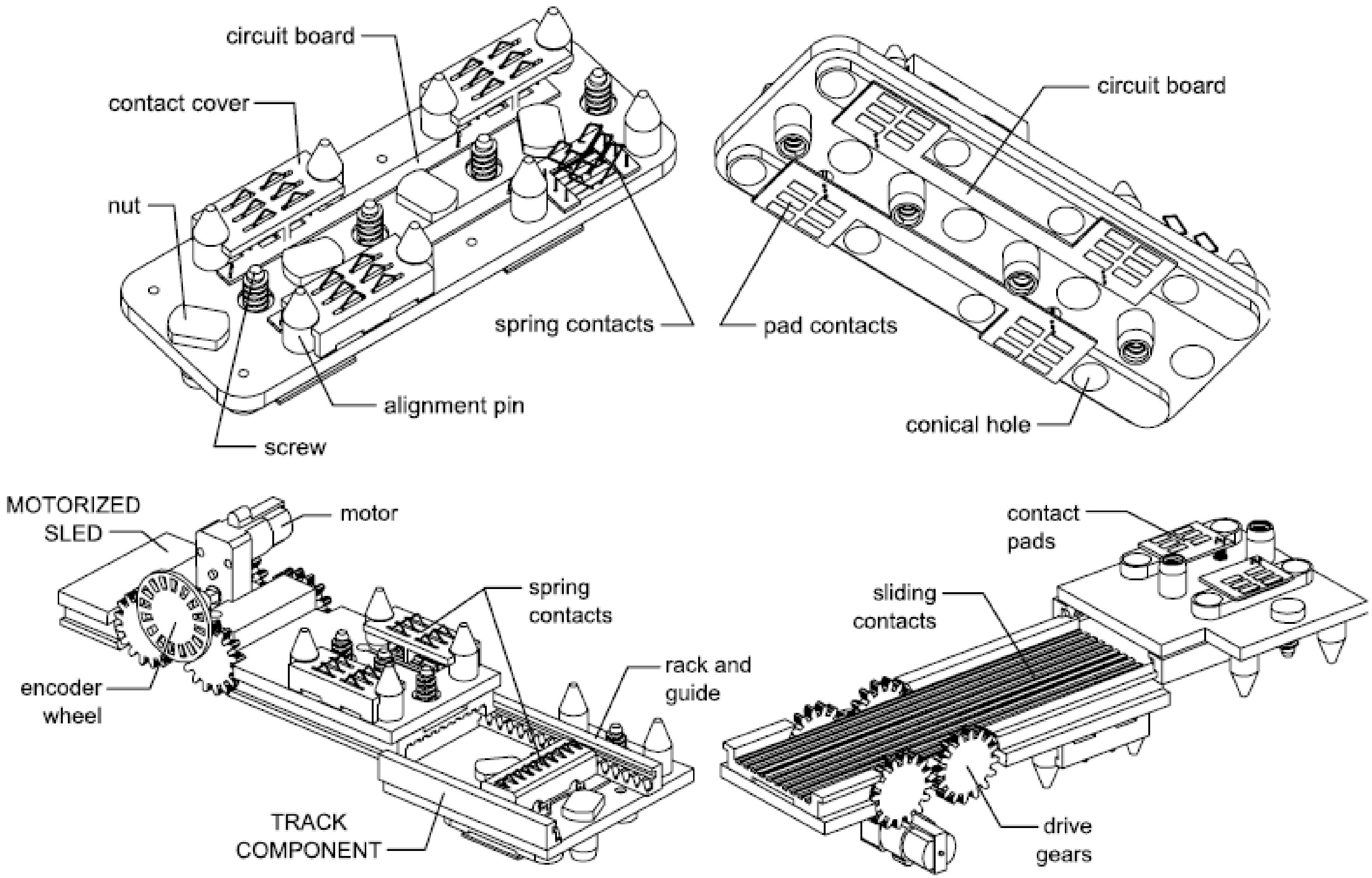
An architecture for universal construction via modular robotic components



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An architecture for universal construction via modular robotic components

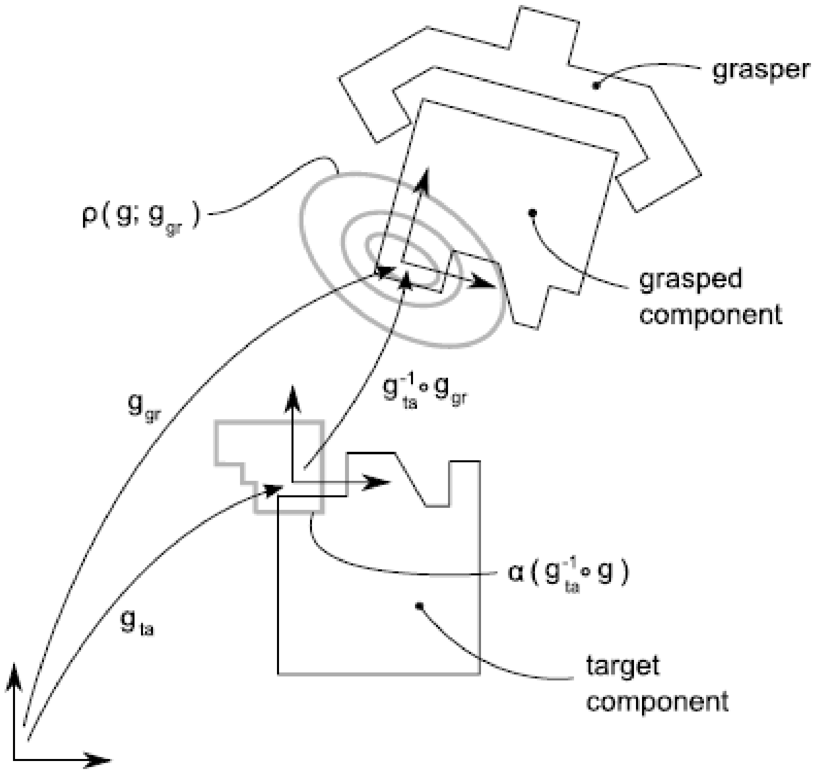

Fig. 8. Uncertainty in positioning of the grasper is represented by a probability density function $\rho(g; g_{gr})$. The function $\alpha(g_{ta}^{-1} \circ g)$ is the probability of a successful connection given a relative displacement between grasper and target. The independent variable is g.

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Principal Kinematic Formula

$\iota(C) \doteq \begin{cases} 1 & \text{if } C \neq \emptyset \\ 0 & \text{for } C = \emptyset \end{cases}$ $\quad gC \doteq \{g \cdot \mathbf{x} | \mathbf{x} \in C\}$ $\quad \mathcal{I}(C_0, C_1) = \int_G \iota(C_0 \cap gC_1)\, dg$

Given planar convex bodies C_0 *and* C_1

$$\mathcal{I}(C_0, C_1) = 2\pi[A(C_0) + A(C_1)] + L(C_0)L(C_1)$$

Given convex bodies C_0 *and* C_1 *in* $\mathbb{R}^3$

$$\mathcal{I}(C_0, C_1) = 8\pi^2[V(C_0) + V(C_1)] + 2\pi[A(C_0)M(C_1) + A(C_1)M(C_0)]$$

Relevant Literature

Topic 4:

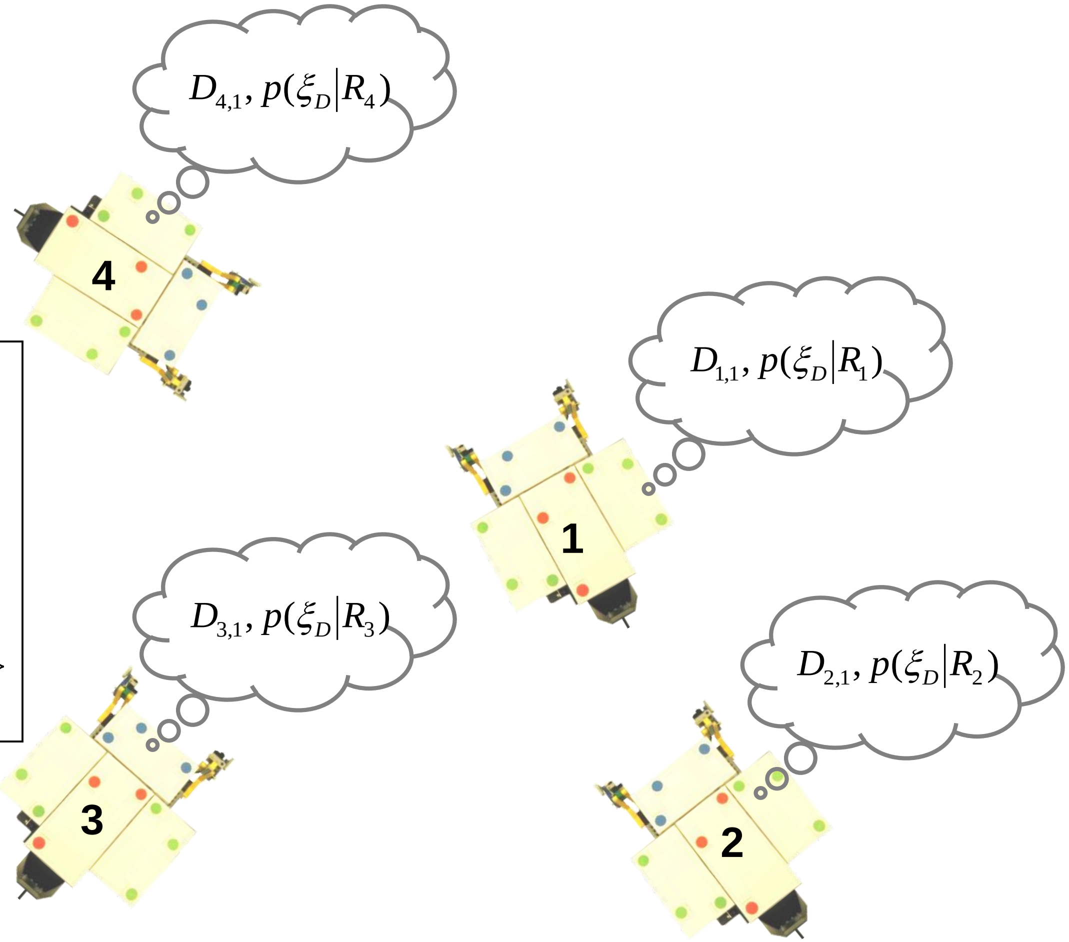
Self-Diagnosis and Repair in Autonomous Field Robots

Group Diagnosis

$$p(\xi_D | R_i) << 1 \quad \forall i \neq 1$$

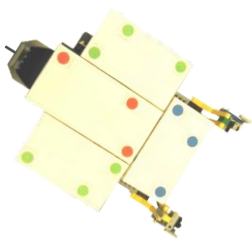
$$p(\xi_D | R_1) < 1$$

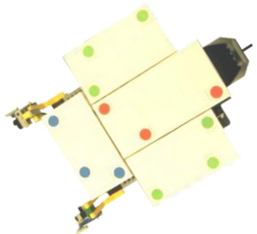
$$p(\xi_D | R_1 \,\&\, R_2 \,\&\, \ldots) = \prod_{i=1}^{4} p(\xi_D | R_i) < p(\xi_D | R_j) \quad \forall j \in \{1, 2, \ldots\}$$

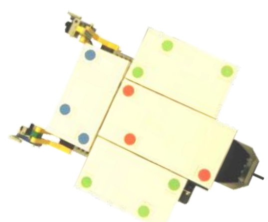


Testbed Diagnosis Routine

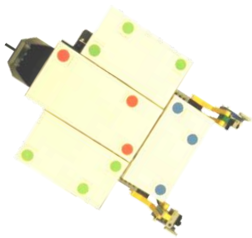
$$y_1 = \begin{pmatrix} e_1 \\ e_2 \\ \theta \end{pmatrix}$$



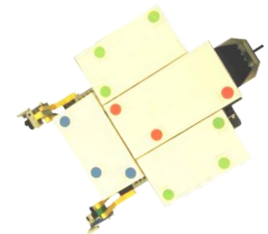


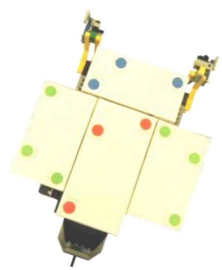


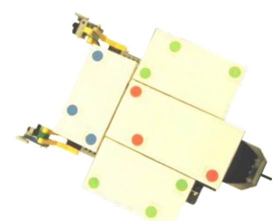
Testbed Diagnosis Routine



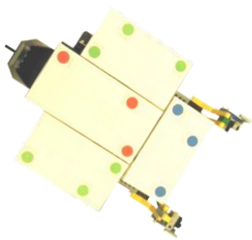
$$y_2 = \begin{pmatrix} e_1 \\ e_2 \\ \theta \end{pmatrix}$$



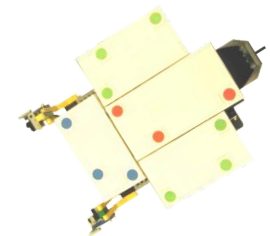




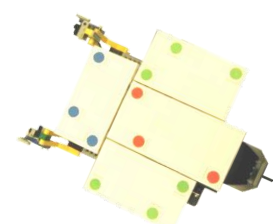
Testbed Diagnosis Routine



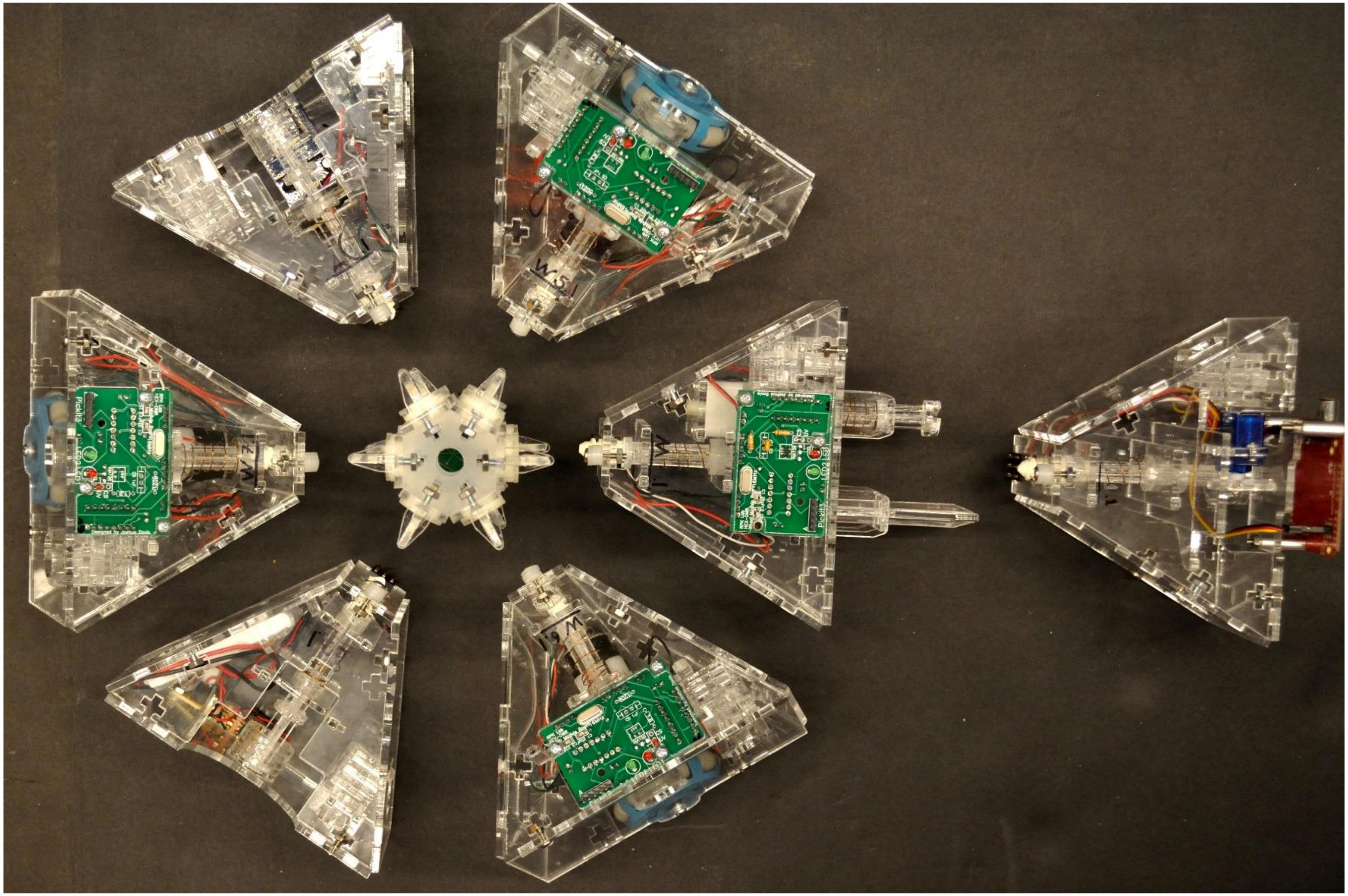
$$y_6 = \begin{pmatrix} e_1 \\ e_2 \\ \theta \end{pmatrix}$$



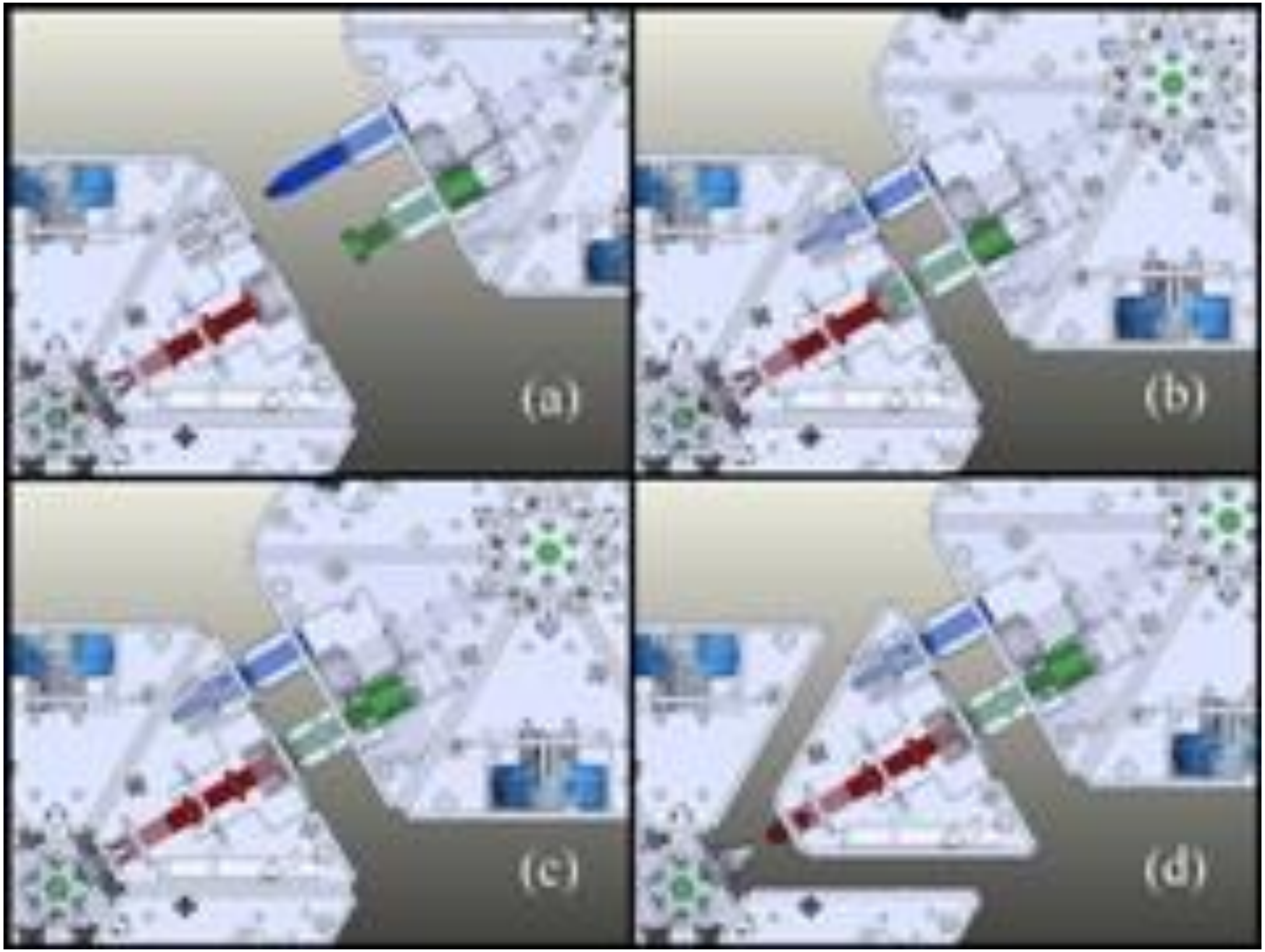
$$Y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_6 \end{pmatrix}$$



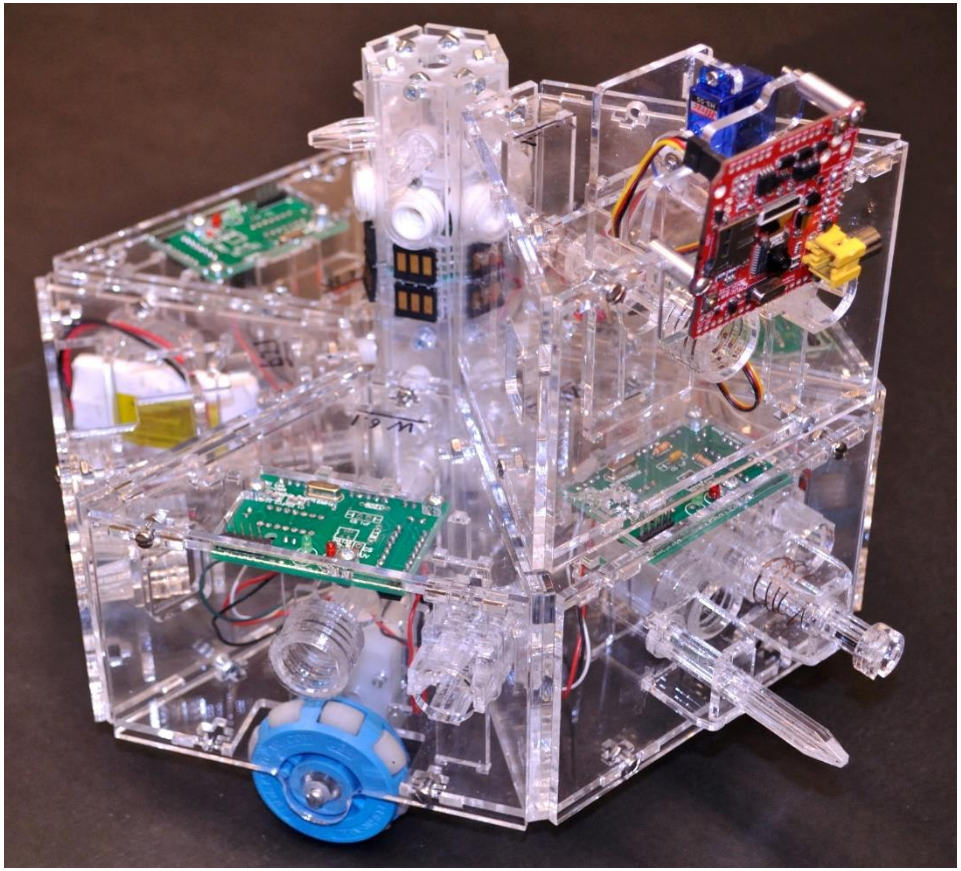
Hex DMR II

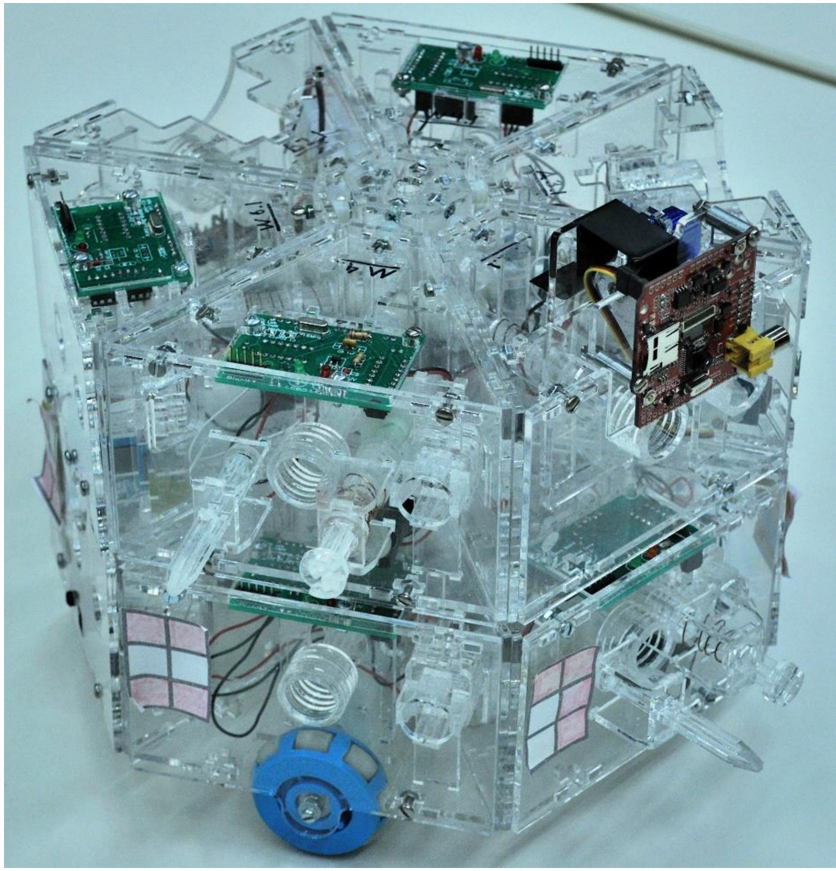


Hex DMR II



The Hex DMR II





References

1) Moses, M.S., Ma, H., Wolfe, K.C., Chirikjian, G.S., ``An Architecture for Universal Construction via Modular Robotic Components,'' Robotics and Autonomous Systems, 62(7):945-965, July 2014.

2) Davis, J.D., Sevimli, Y., Eldridge, B.R., Chirikjian, G.S., ``Module Design and Functionally Nonisomorphic Configurations of the Hex-DMR II System,'' ASME Journal of Mechanisms and Robotics, in press, to appear in 2016.

3) Kutzer, M.,Brown, C., Scheidt, D., Armand, M., Wolfe, K.,Moses, M., Chirikjian, G., ``Reconfigurable Robotic System with Independently Mobile Modules,'' Johns Hopkins APL Technical Digest, 28(3):270-1 (2010)

Summary

Minimalist mechanical design concepts include:

binary-actuated manipulators

spherical motors

self-manufacturing robots

robots that are easy to repair by other robots

Relevant Literature