BioBrick-A-Bot:
Lego Robot for Automated BioBrick DNA Assembly
iGEM 2009 University of Washington Software Team

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Project Website : http://2009.igem.org/Team:Washington-Software

Abstract

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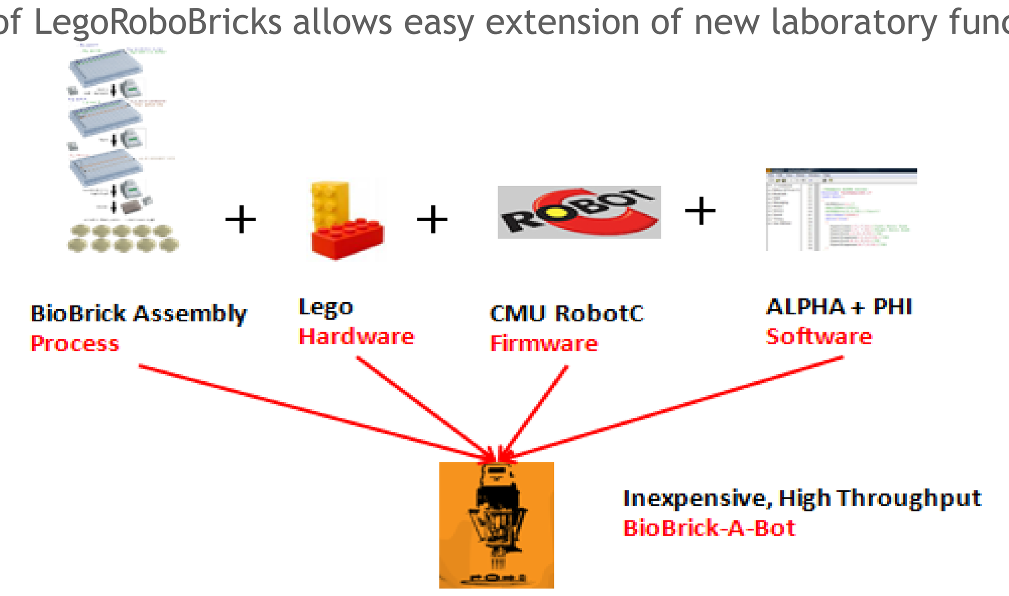
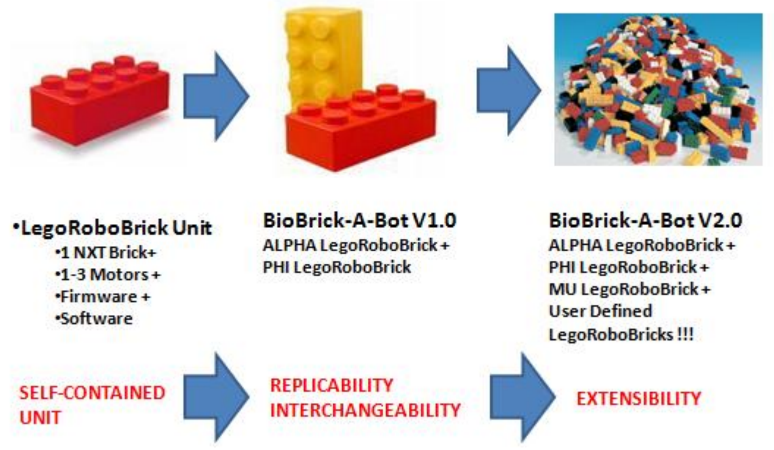
Commercial Liquid Handling Systems are extremely expensive, and are typically beyond the reach of the average molecular biologist interested in performing high throughput methods. To address this problem, we designed and implemented a liquid handling system built from commonly accessible Legos. Our goal is the automation of BioBrick assembly on a platform that can itself be easily replicated and we demonstrate a proof-of-principle for this system by transferring colored dye solutions on a 96-well plate. We introduce a new concept called LegoRoboBrick. The liquid handling system is build from 2 new LegoRoboBrick modular components: ALPHA (Automated Lego Pipette Head Assembly and PHI (Pneumatic Handling Interface), mounted on a chassis BETA (BioBrick Environmental Testing Apparatus). We will demonstrate that the same BioBrick assembly software can run on multiple plug-and-play LegoRoboBrick instances with different physical dimensions and geometric configurations. The modular design of LegoRoboBricks allows easy extension of new laboratory functionalities in the future.



Goals, Vision and Achievements

Low Cost –
HW+FW US $700, SW free (open-source)
Hardware Platform easily accessible
Lego Mindstorm Set
Hardware Design easily replicable
Step by Step Instructions
Plug & Play Design
Demo with ALPHA 120 & ALPHA 90
Extensible Design
Open source, modular (ALPHA & PHI)



Project Overview

BioBrick-A-Bot Model C is built using Lego bricks, and it can be easily replicated. The design is modular plug-and-play, so that we can easily collaborate with future iGEMers to modify or improve on its design and to add new functionalities.

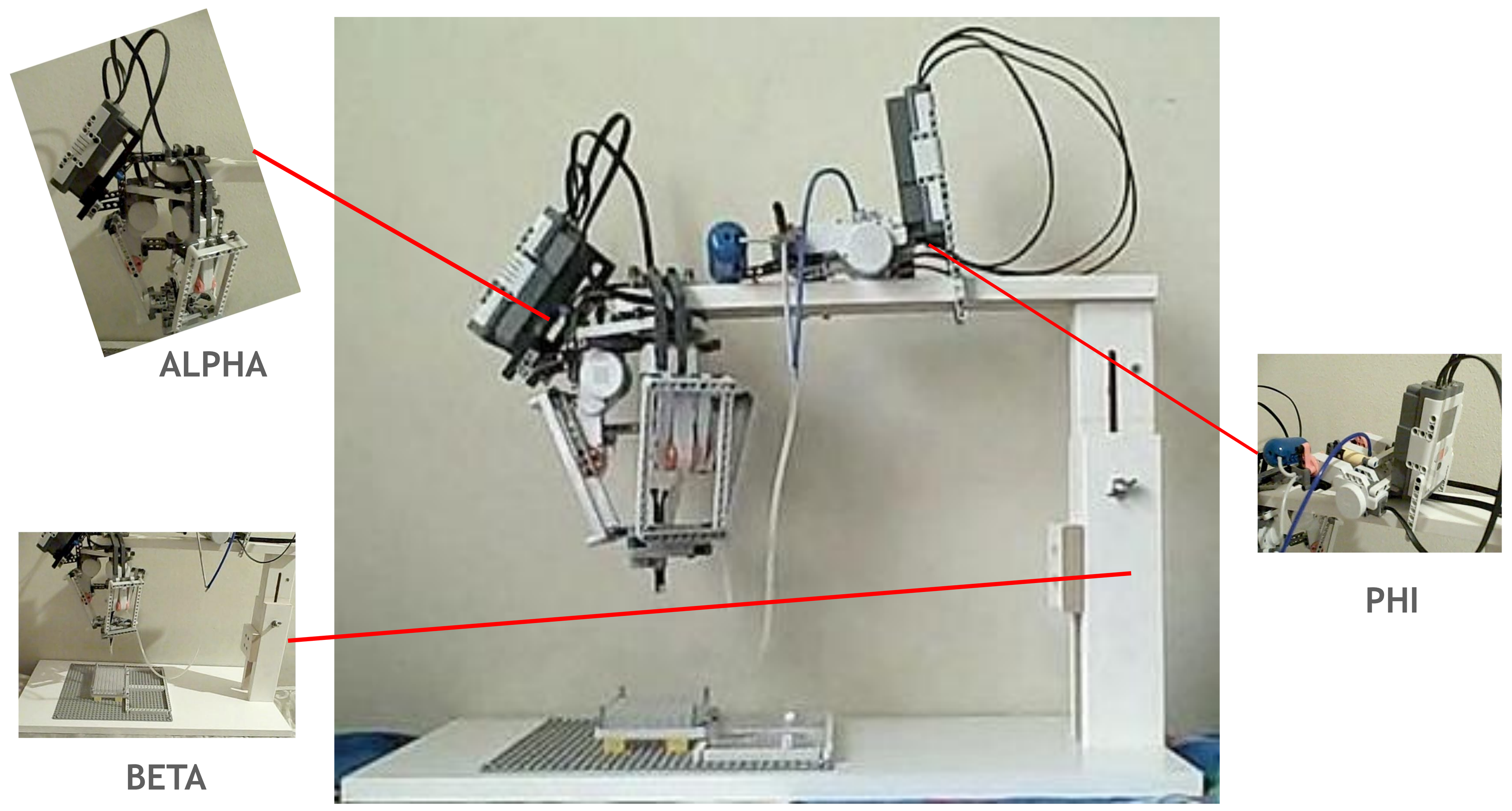
The minimum specifications for replicating BioBrick-A-Bot are:

•Hardware: Lego Mindstorm NXT 2.0 (2 sets)
•Firmware: RobotC Version 1.40 fromCMU Robotics Academy
•Software : ALPHA & PHI Modules V1.0 (open source, download from our project website)

Evolution of BioBrick-A-Bot

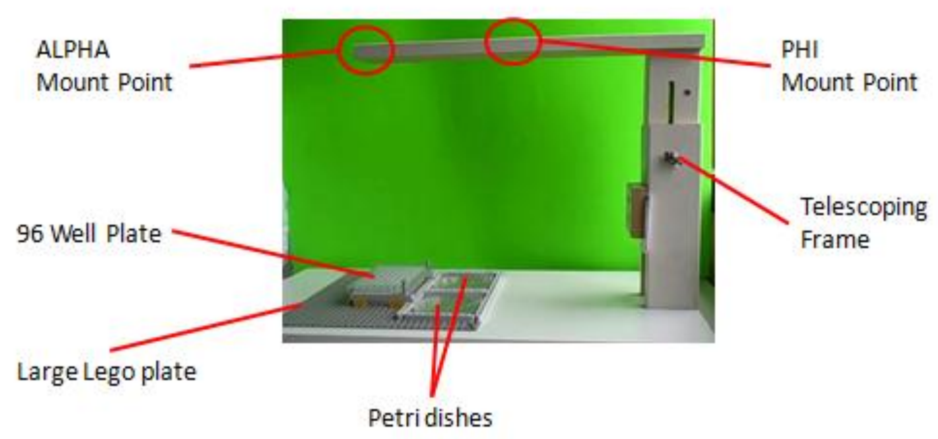
	Coordinate System	Pipette Head	96-Well Plate	Major Components (Motors)
Model A	2D Polar	Stationary	Movable	Mobile Platform(2) Pipette Holder (3)
Model B	3D Cartesian	Movable	Stationary	Movement Assembly (3) Pipette Assembly (2)
Model C	3D Polar	Movable	Stationary	BETA (0) ALPHA (3) PHI (3)

BioBrick-A-Bot



BETA Chassis

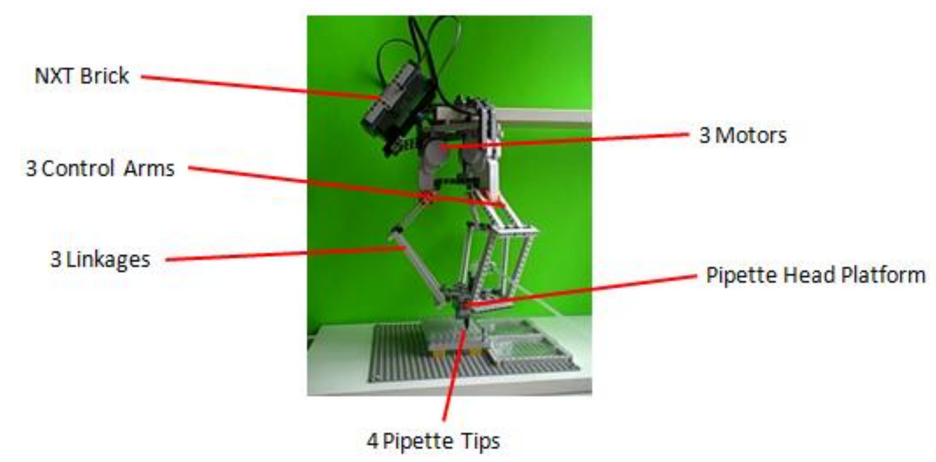
BioBrick Environmental Testing Apparatus



BETA provides the environment where the robot can move and conduct its task. It consists of a telescoping frame and a big Lego plate under the stand. The telescoping frame is used for holding ALPHAs and PHIs, and the lego plate is where the 96-well plates and petri dishes for sterilization and cleaning are placed.

Module ALPHA

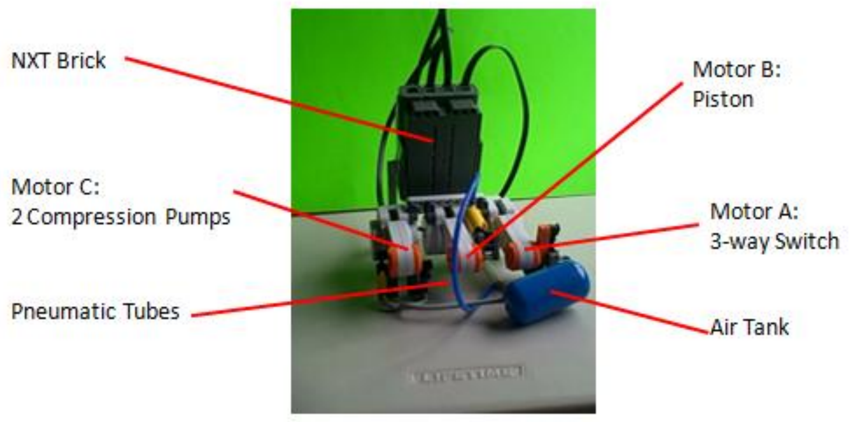
Automated Lego Pipette Head Assembly



ALPHA consists of three robot arms, and each arm consists of two arm segments. The top segment is called the Control Arm and is connected to a motor. The bottom segment is called the Linkage and is attached to the platform that holds the four pipette tips.

Module PHI

Pneumatic Handling Interface



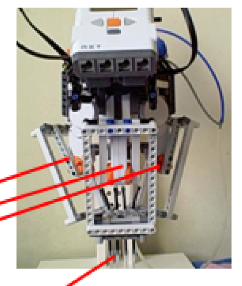
PHI is basically the pipette.
PHI controls 3 pipette actions, Aspirate, Dispense and Clean.

Technical Challenges / Solutions

Overcoming Lego's limitations
Replacing Lego NXT firmware with CMU RobotC firmware for Floating Point Precision & Programmability
Computing Reverse Triangulation
This is non trivial and involve the application of 3D Rotational Matrices.
Master Slave Synchronization
Synchronize wireless messages between ALPHA & PHI.
Plug and Play Design
Software work seamlessly, replacing ALPHAs with different geometric configuration (ALPHA120 with ALPHA90)

Mathematical Modeling

- Solving Reverse Triangulation
  - in 3D space
  - with Polar Coordinate Constraints
- Problem
  - For any location p = (x, y, z),
  - solve for 3 angles θ_1, θ_2, θ_3
  - of the robot motors
  - using 5 given physical constants
  - so that the pipette tips are at p.
- Details at
  - http://2009.igem.org/Team:Washington-Software/Modeling



- Found a neat solution
- After computing θ_1
  – apply 3D rotational matrix to get θ_2 and θ_3

$$\begin{bmatrix} \cos(\phi_1) & -\sin(\phi_1) & 0 \\ \sin(\phi_1) & \cos(\phi_1) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} \cos(\phi_1+\phi_2) & -\sin(\phi_1+\phi_2) & 0 \\ \sin(\phi_1+\phi_2) & \cos(\phi_1+\phi_2) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Limitations (BioBrick-A-Bot 1.0)

•It is not user-friendly enough to be used by a standard molecular biologist directly yet because it still needs a programmer to write the driver program.

•Version 1.0 provides the following primitive functions:
• ASPIRATING, DISPENSING and CLEANING for PHI and
•ALPHAMOVE for ALPHA.

Future Goals (BioBrick-A-Bot 2.0)

•Fully automated calibration using color sensors
•Automatic Interpolation of Physical Location of each well
•GUI (Graphical User Interface) to generate DNA Assembly Programs
•Batch Scheduling Option with Timing
•Addition of a third LegoRoboBrick, called MU (Movement Utility)
•Single-Master-Multiple-Slaves synchronization
•Support User Defined LegoRoboBricks
•Support pipetting between individual tubes and 96-well plates
•Support pipetting of 12 tips simultaneously

Acknowledgements

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