PROJECT TITLE: **Fabrication and Design Tools for Printing Origami Robots**
APPLICANT: PAIK, Jamie (*Reconfigurable Robotics Lab, EPFL-STI-IGM-RRL)*
REQUEST: 1 PhD Student for 36months

PROBLEM

Recent advances across engineering disciplines have widened the scope of applications for autonomous robots and consequently placed more demands on robot design and manufacturing processes. New custom robots, such as biomedical, custom part assembly and loading robots are conceived with personalized tasks and functional parameters. As every level of robot component customization is financially and timely expensive, this necessitates novel fabrication methods to minimize costs for task-tailored robots. Moreover, the broad space of new designs causes off-the-self components to be too limiting. Therefore, novel fabrication techniques for embedding functionality in the robot's body (e.g. integrated sensors, actuators, and embodied intelligence) while minimizing the limitations for the designer are a new challenge for robotic engineers.

GOAL

To facilitate the design and the manufacture of customized robots, we aim to develop a novel process based on a combination of additive manufacturing and folding. We will standardize and automate the design process with a set of mechanical and functional parameters including desired geometry, degrees of freedom (DoF), structural properties and task orientations. Ultimately, in combination with our proposed advances on composite materials, actuation and sensor solutions, this research will serve as a foundation for an additive processing station (similar to the concurrent 3D printing techniques where multiple thin slices of material is fused to create the final shape) capable of depositing not just materials but functional components: a "**4D printer**"!

OBJECTIVES

The proposed research will leverage the robotic origami (*robogami*) platform developed in the EPFL Reconfigurable Robotics Lab. Robogami consists of multiple functional layers laminated to form a quasi-2D composite. Following lamination, robogami is folded into its 3D configuration to create the desired structure or mechanism. Given its planar shape and multi-layer manufacturing methods, the proposed additive manufacturing techniques for robot fabrication are directly applicable. The objectives of this research are to expand the robogami concept in the following ways:

1. Development of quasi-2D robotic components: development of functional constituent layers (e.g. sensors, actuators, circuits and adaptive stiffness elements).
2. Integration process and strategies for both mechanical and control design.
3. Design automation tools to standardize selection of the components and functional layers prior to 2D lamination and 3D assemblies.

STATE OF ART

Creating the complex geometric features of a robot's body (directly or via molding) is the most common application of additive manufacturing to robot development. In recent years, researchers have also used filaments and inks with different electrical and mechanical properties for printing structures with diverse functionalities embedded in them: a 3D printed bionic ear (McAlpine 2013), a loudspeaker (Hsu 2013), and a miniature Li-ion battery (Lewis 2013). However, techniques for additive manufacturing have yet to be combined into a universal printing machine capable of creating complex, monolithic electromechanical devices from different functional materials. Regarding design software development, there are examples in each of the fields mentioned above. As an example, researchers have developed a program that designs 3D printed structures to have a certain level of mechanical stiffness by altering stacking patterns of constituent cubes (Lipson 2010); however, for all of them, each developed software is solely unique to the given geometries and processes.

RESEARCH PLAN

Robogami is a multi-DoF robot platform based on lamination of 2D functional layers and folding to transform into different 3D shapes using the embedded actuators (Paik 2013). Based on feedback from the sensor layers, the embedded control circuits govern the shape of the robot and performs different tasks. Figure 1 shows an example concept of robogami.

Currently, the design, fabrication, and actuation are executed in a serial fashion where all the components are individually customized and assembled for the unique final structure. Within the scope of the proposed project, we plan to:

1. Develop an expanded library of quasi-2D robotic components (sensors, actuators, circuit and adaptive stiffness body): we already have potential solutions for some components but here, the focus will be on developing fabrication methods for each functional layer by introducing modular components that could be reused for robots with different design parameters (robot geometry, DoF/reconfigurability, and sensor choices). This will allow functional layers to be repeated across multiple robot designs while minimizing the dimensional and physical limitations of prototyping during the additive manufacturing processes. The primary challenge for this stage is to identify appropriate functional materials and develop design and process recipes that are compatible with each layer so that we can maintain the monolithic construction method for the 3D printing process.

2. Develop integration methods for layers and discrete components: complex tasks call for more elements (e.g. sensors, microcontrollers, and communications) to be integrated into the system. Often, errors are detected at the end of the manufacturing cycle and misplaced components will result in reduced functionality (e.g. a mismatch between the electrodes and vias). Construction methods for physical assembly (monolithically – based on lamination and folding) and unification of embedded controllers will be the main task.

3. Develop algorithms for a design tool that modularizes robot functions and standardizes component selection process. This requires us to characterize robogami tasks and finding the corresponding mechanical components. Building such algorithm will eventually be used for the *4D printer* running software.

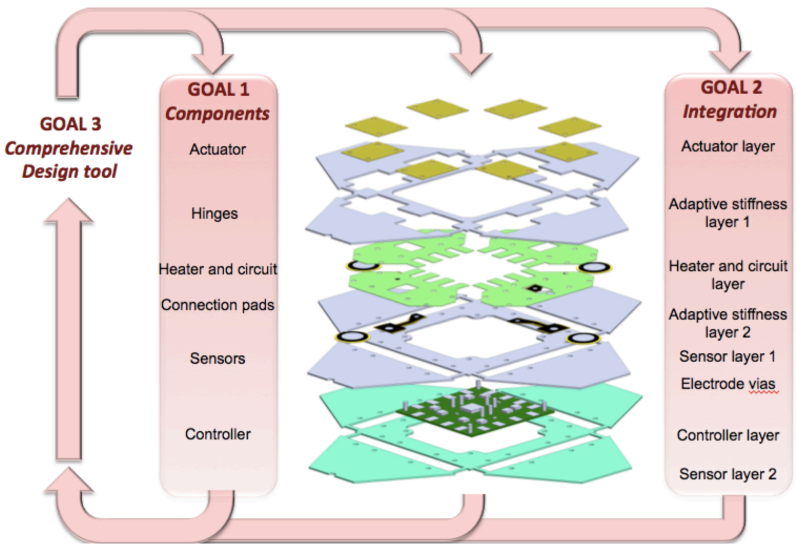

Fig. 1: Exploded view of multiple functional layers of an example origami robot and the involvement of three main objectives of the proposed project. This platform is consistent with additive manufacturing process for its modularity and applicability to planar fabrication / assemblies where we can introduce multiple layers of sensors, circuits and body composition materials including adaptive stiffness layers.

IMPACT AND SIGNIFICANCE

The proposed study focuses on the practical yet ambitious utilization of additive fabrication techniques for decreasing the production time while facilitating the design iterations for highly customized robots, in which the robot design is dictated by the specific applications.

The first part of the project tackles the technical issues we will face when a single machine needs to process multiple components of a working robot. We base our study on the components necessary in a robogami, such as actuators, sensors, adaptive stiffness elements, control circuits, and electrical connections. The second topic of integration is necessary given the engineering challenges in the assembly and comprehensive physical and signal integration of all the parts. The third stage of the project, which is the algorithm definition for design software, targets tools to automatize the design process.

The ultimate goal for robogami-based additive manufacturing process is to have a **4D printer**, unlike conventional 3D printer that prints out building blocks for robots, that **prints out an operational robot** that can be actuated simultaneously as it rolls out of the printing tray.