CPS: Synergy: Integrated Modeling, Analysis and Synthesis of Miniature Medical Devices

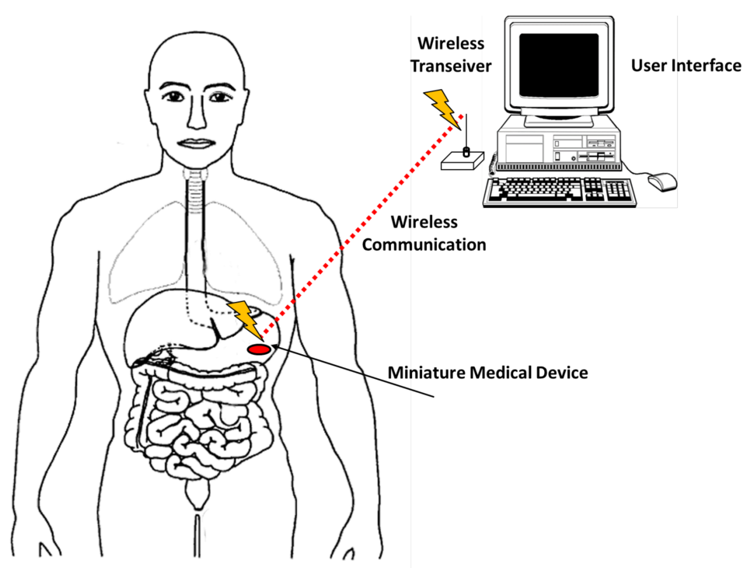
Hakan Tunc[2], Addisu Taddese[1,2], Marco Beccani[1] , Péter Völgyesi[2], Ákos Lédeczi[2], Pietro Valdastri[1]

[1]The STORM Lab
Vanderbilt University
Nashville, TN

[2]INSTITUTE FOR SOFTWARE INTEGRATED SYSTEMS
Vanderbilt University
Nashville, TN

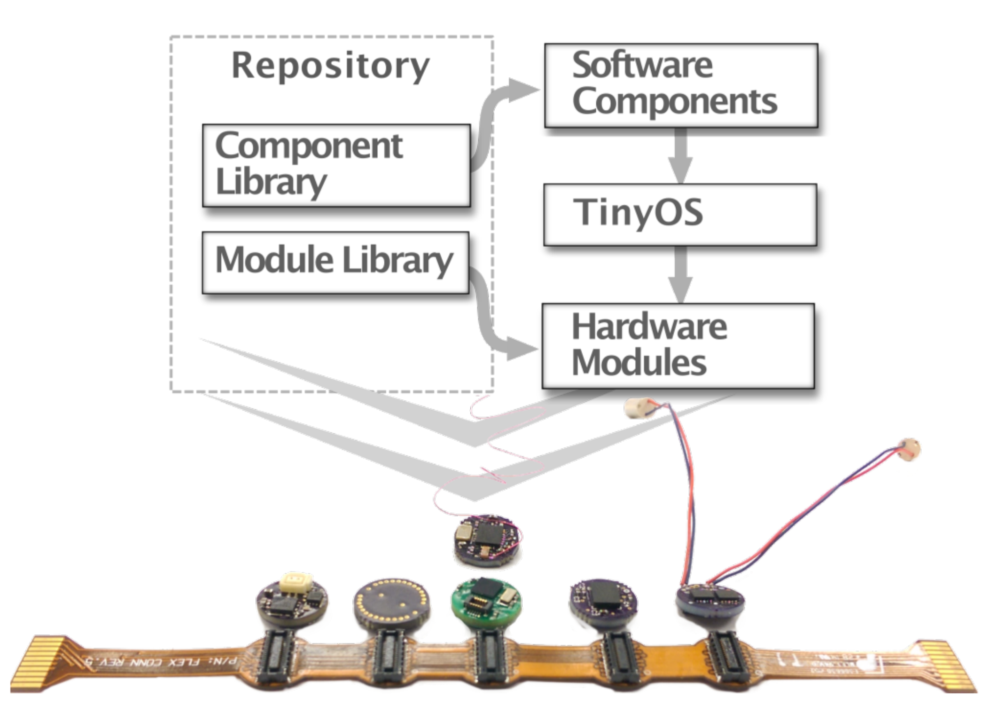
BACKGROUND

Miniature medical devices are classical cyber physical systems(CPS) that can operate autonomously within the human body to augment surgeons' ability to diagnose, prevent, monitor, and cure diseases.



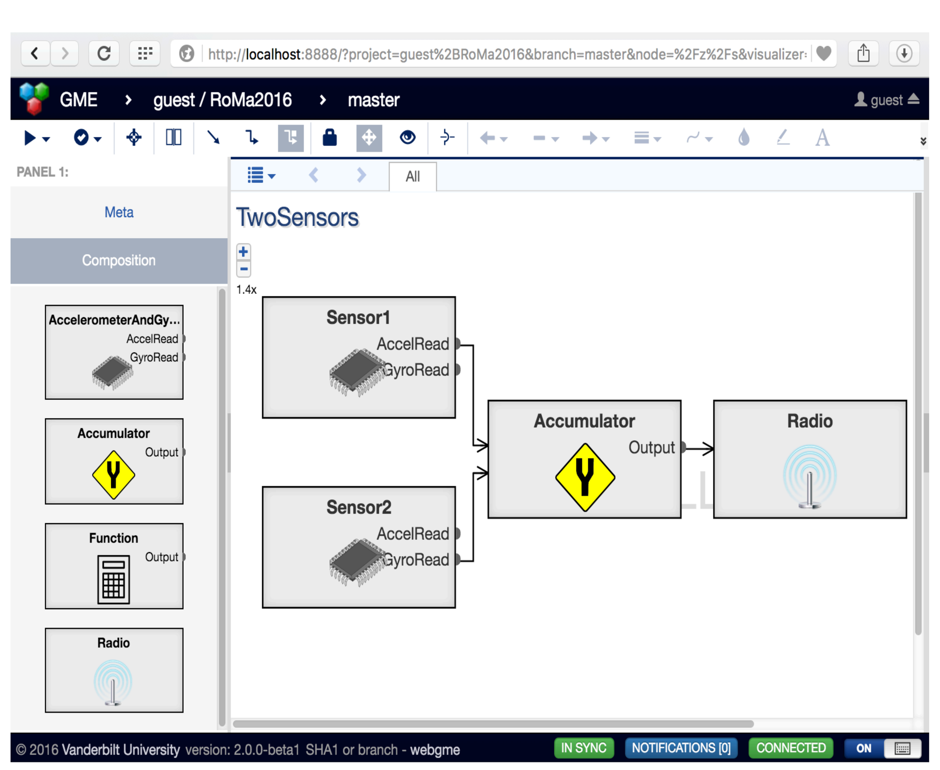
Colorectal cancer strikes more than 170,000 in the USA each year and kills approximately 50,000 [1] with a projected 62% increase by 2030 [32]. If we are successful in promoting the implementation of a painless alternative to traditional colonoscopy, this could have a transformative impact on medicine.

SOFTWARE PLATFORM



The applications designed with the modeling environment generate TinyOS code. This code is compiled on the server. The user downloads the executables through their browser to install on the hardware.

To the right, is the callgraph for a sample application.

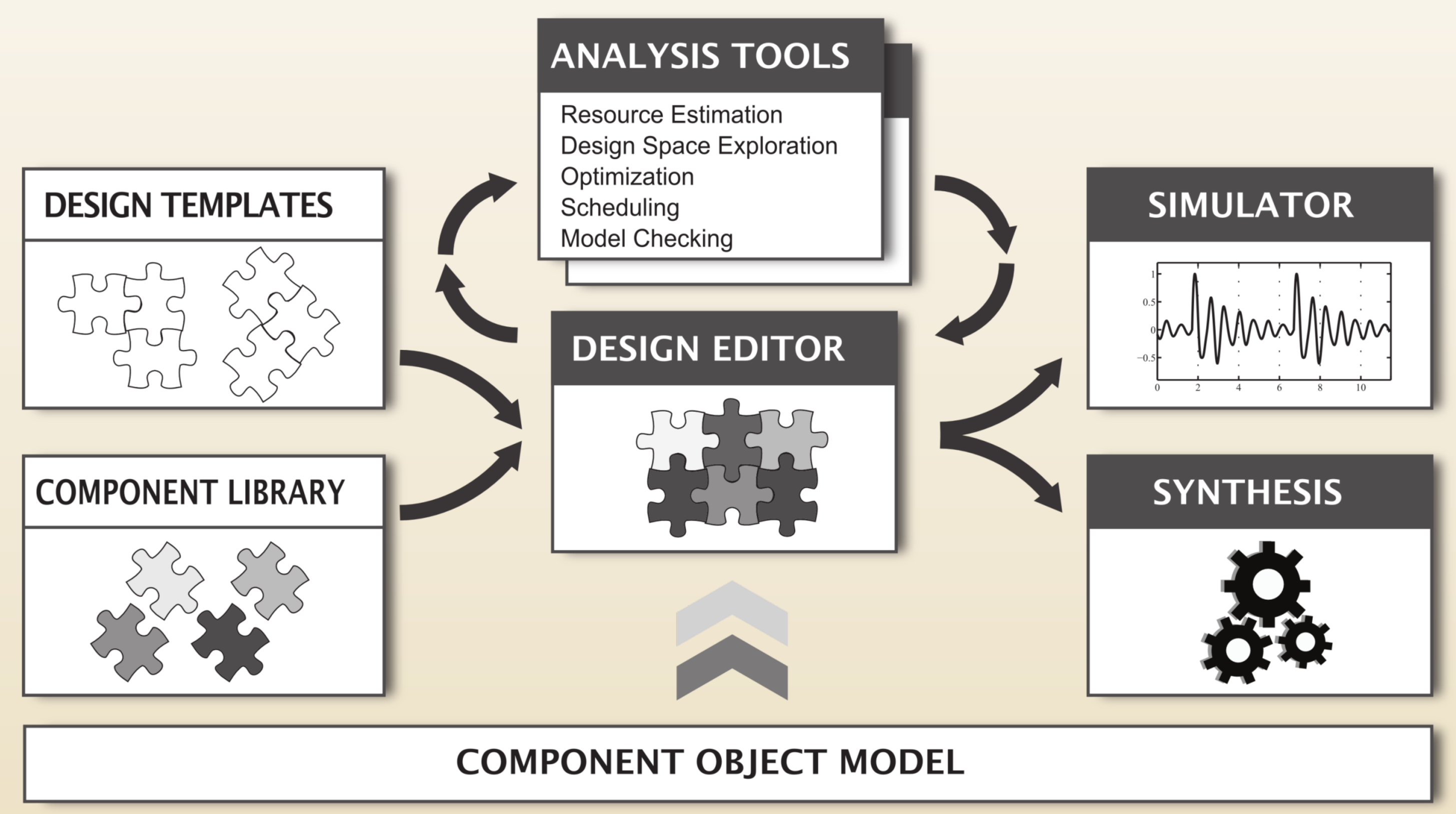


DESIGN ENVIRONMENT

The objective of this project is to create a focused cyber-physical design environment to accelerate the development of miniature medical devices.

A versatile **component model** will provide the structural and semantic foundation for the entire model-based design flow

A pre-built **component library** will provide the building blocks for design construction

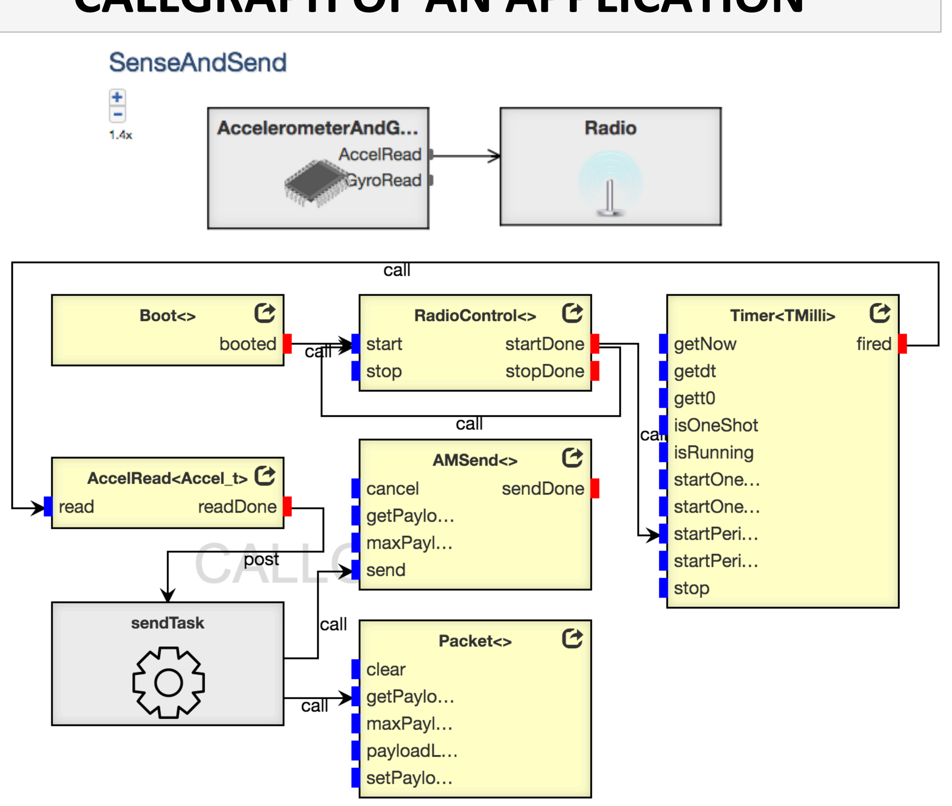


An integrated **simulation framework** will provide insight into the dynamic behavior of the design before manufacturing

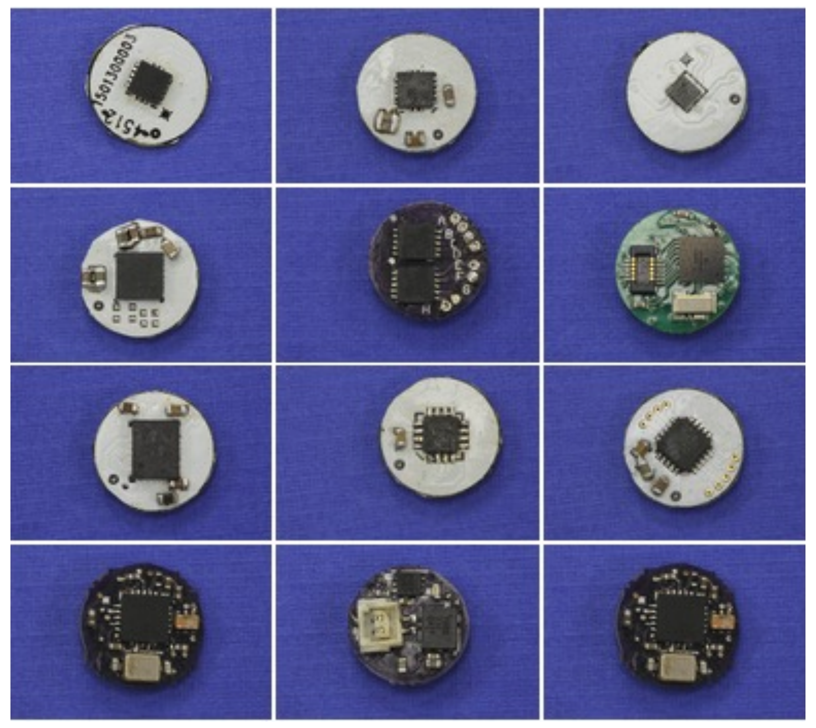
Static analysis tools will provide performance and cost estimates before system **synthesis**

The goal is to **synthesize** application software, printed circuit board (PCB), computer aided design (CAD) models, and bill of materials with cost estimates with minimal manual guidance

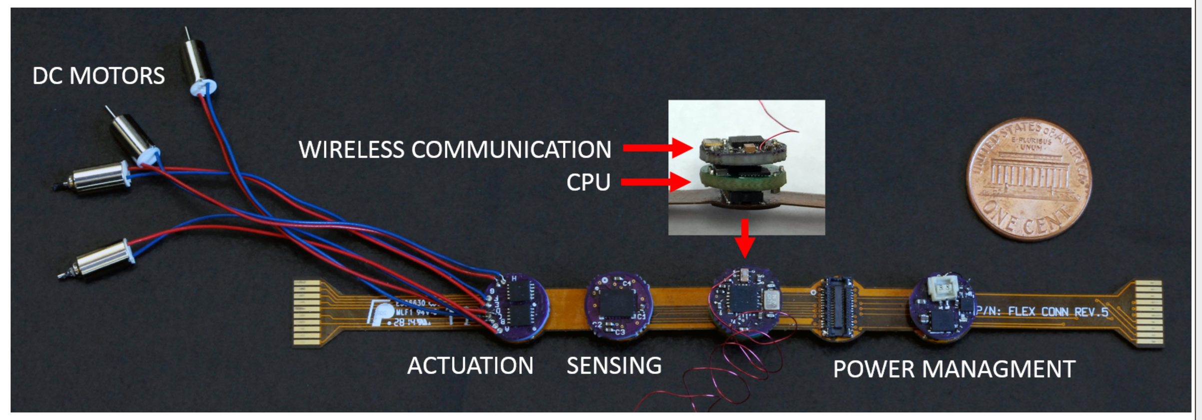
CALLGRAPH OF AN APPLICATION



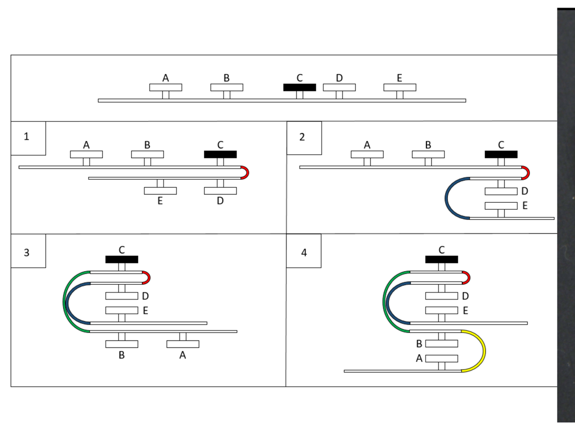
HARDWARE OVERVIEW

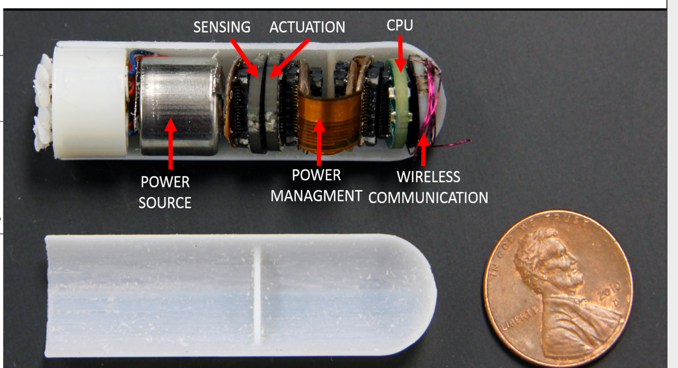


MODULE NAME	FUNCTIONALITY	INTEGRATED CIRCUIT (IC)	DIAMETER (mm)	Thickness (mm)	Max Consumption (mA)
MCU	Microcontroller	MSP430F5528	10.5	3.84	2.32
433 MHz Radio	Wireless Communication	CC1101	10.5		29.2
3DA	3D Accelerometer	LIS331DLH	9	2.92	0.25
3DG	3D Gyroscope	L3GD20	9	2.96	6.1
3DM	3D Magnetometer	LIS3MDL	9	2.85	0.27
3DAG	3D Accel. – Gyro	LIS330DLC	10	3.00	6.11
3DAM	3D Accel – Magn.	LIS303D	9.8		0.3
3DAMG	3D Accel. - Gyro.– Mag.	LSM9DS0	9.8	2.96	6.15
PT	Pression & Temperature	MPL115A1	9.8	2.98	0.005
2AF&ADC	2 Ch. Front End ADC	AD623 – ADS8320	9.8		2.57
8CHADC	8 Ch. ADC	AD7689	10	2.84	3.78
BSDCC	Brushed Motor	A3901	10		800 (Max)
PMM	Power – Battery Monitor	LTC2942	9.8		200 (Max)



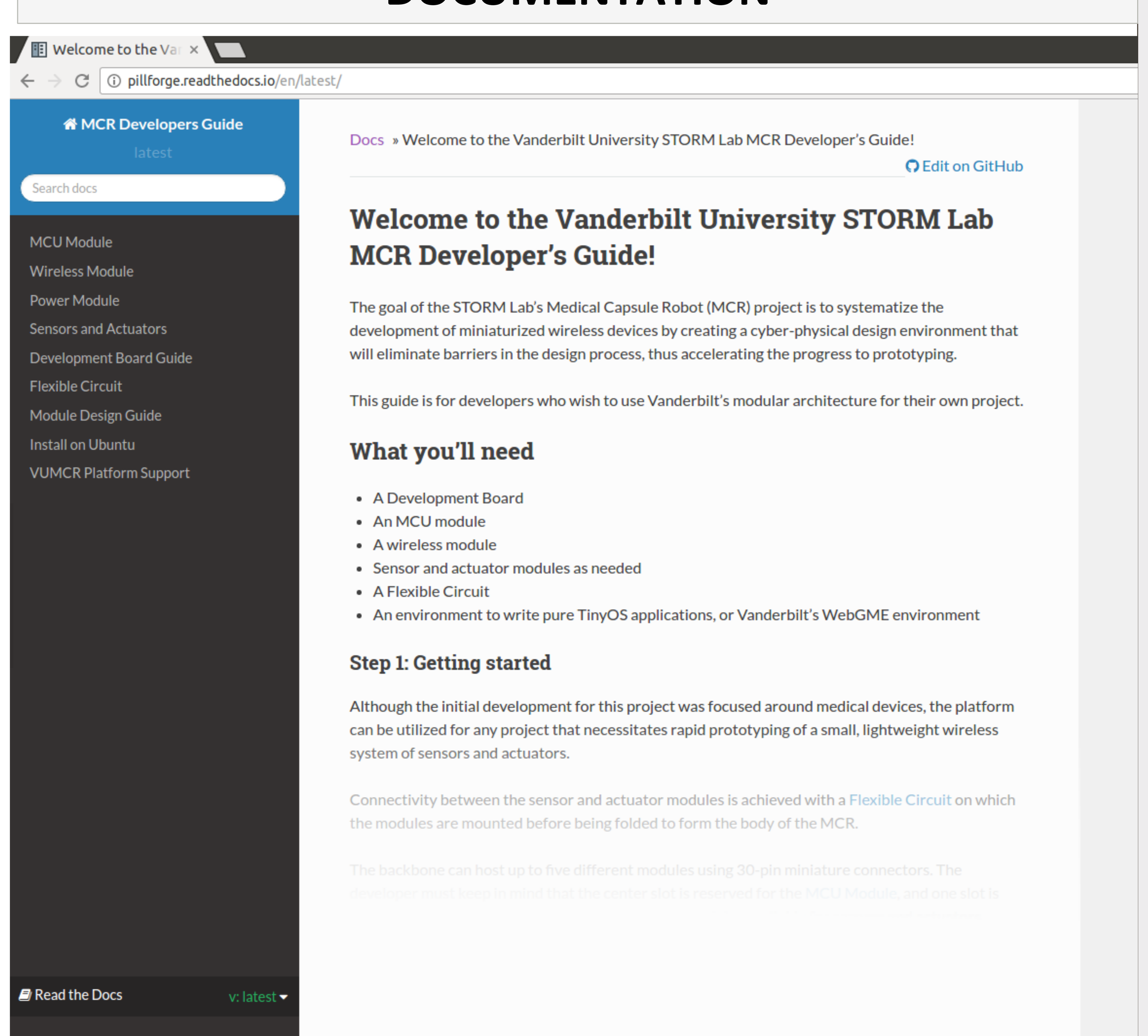
The flexible circuit with hardware modules before folding in a shape that can be integrated inside an MCR. The flexible circuit can host up to five different modules. In this case the wireless communication module is plugged on the CPU module in the central slot. The other slots are respectively hosting an actuation module, a sensing module and the power managing module.





Propeller based swimming capsule robot

DOCUMENTATION



REFERENCES

- Marco Beccani, Hakan Tunc, Addisu Taddese, Ekawahyu Susilo, Péter Völgyesi, Ákos Lédeczi, Pietro Valdastri, "Systematic design of medical capsule robots," IEEE Design Test, vol. 32, pp. 98–108, Oct. 2015.
- Marco Beccani, Ekawahyu Susilo, Pietro Di Natali, Christian, Pietro Valdastri, "SMAC-A Modular Open Source Architecture for Medical Capsule Robots," Int J Adv Robot Syst, vol. 11, pp. 1–16, 2014.
- Hakan Tunc, Addisu Taddese, Péter Völgyesi, Janos Sallai, Pietro Valdastri, Ákos Lédeczi, "Web-based integrated development environment for event-driven applications," in Proceedings of IEEE Southeastcon 2016.
- Marco Beccani, Gregorio Aiello, Nikolaos Gkotsis, Hakan Tunc, Addisu Taddese, Ekawahyu Susilo, Péter Völgyesi, Ákos Lédeczi, Elena De Momi, Pietro Valdastri, "Component Based Design of a Drug Delivery Capsule Robot," Sensors and Actuators A: Physical, 2016.

Open source @ http://pillforge.github.io

VANDERBILT UNIVERSITY

Sponsor: The National Science Foundation (Award: IIS 1239355)