An Exploration into Control Engineering

By Jinseong Lee

Background

❖ Education

- M.S., Aerospace engineering, University of Maryland, U.S., 2019
- M.S., Robotics Program, Korea Advanced Institute of Science and Technology (KAIST), S. Korea, 2009
- B.S. Electrical & Electronic engineering, Hanyang Univ., South K

❖ Employment

- NASA Jet Propulsion Laboratory, FPGA engineer, Pasadena, CA, 2023 ~
- KLA, Senior FPGA engineer, San Jose, 2022 ~ 2023
- Merlin Test Technologies, Senior Control engineer, Austin, TX, 2020 ~ 2022
- Hypergiant, Senior Satellite Systems engineer, Austin, TX, 2019 ~ 2020
- Satellite Research Institute, Attitude Control engineer, S. Korea, 2013 ~ 2015
- Samsung Techwin, Robotics engineer, S. Korea, 2009 ~ 2012
- Intern: KARI (S. Korea), JAXA (Japan), 2008~2009

Outline

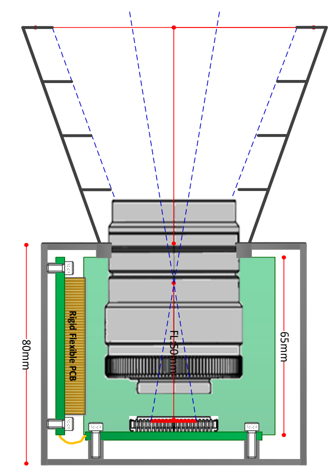
- ❖ Background : A little bit about me
- ❖ Projects
  1. **Star Tracker** : Satellite attitude control system
  2. **Underwater Robot** : Heading guidance using feedback control
  3. **FPGA Automation**: High speed optical inspection metrology
  4. **Algae photobioreactor**: Spectrophotometer and automation
  5. **Military Robot** : Agile and stable motion
- ❖ Patents and Publications
- ❖ Summary

Project 1: Star Tracker Camera (Satellite Attitude control)

Problem statement

- Attitude sensor
  - » NEXTSat–1 project: Jan 2013. ~ Jun 2019
  - » Aim to design the most accurate sensor
  - » Replace a high-cost to purchase (> $150K)

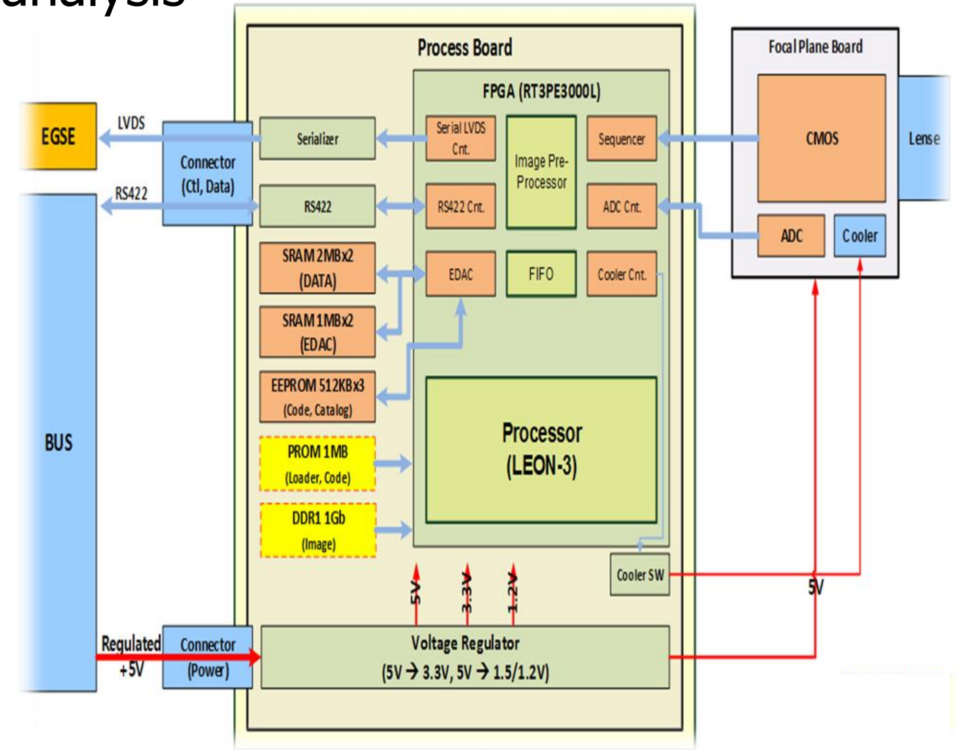
- Goal
  - » Design electronics with small, light, low power/ cost, high accuracy
    - – SWaP: 11L x 11W x 23cm / 1.1kg / 6W
    - – FOV: 18°
    - – Accuracy: <10 arcsec



Design

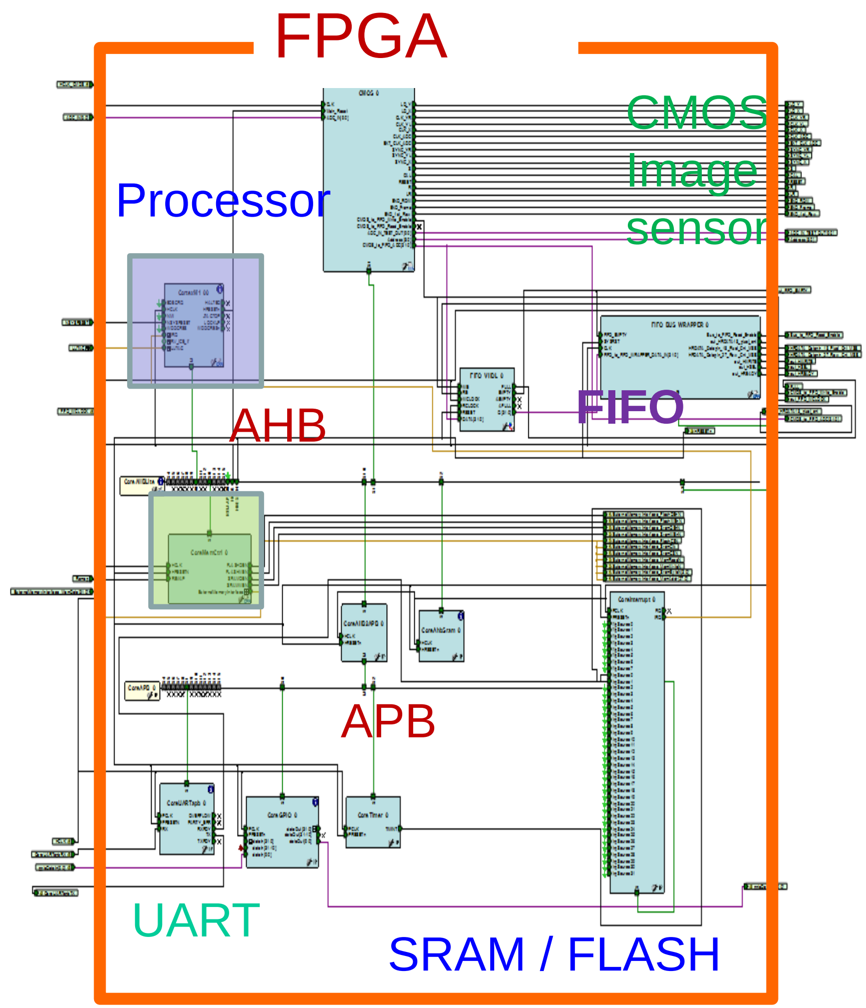
❖ Electronic system

- Designed system architecture
- Parts selection, power budget analysis
- High speed processing
- Board
  - » Power, processor, focal plane
  - » Heat dissipation, cooling
- **FPGA**:
  - » Microsemi ProASIC3
  - » RT3PE3000L
- **CMOS image sensor** :
  - » On semi,
  - » HAS2 1000 (1024 pix)



FPGA Architecture

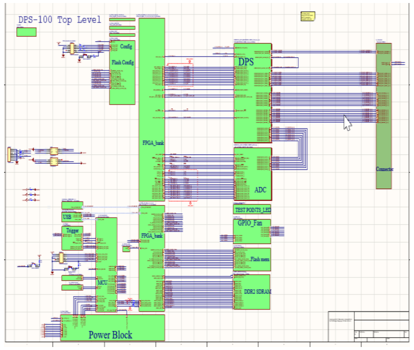
- **Firmware**
  - VHDL
    - » Leon3-FT processor
    - » AMBA (AHB, APB)
    - » FIFO
    - » Memory, GPIO
    - » LVDS, RS-422

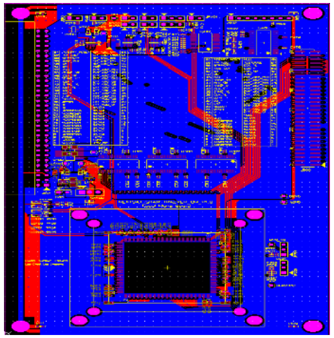


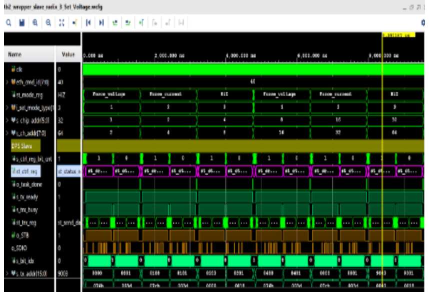
Development

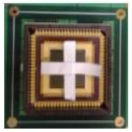
❖ Board design

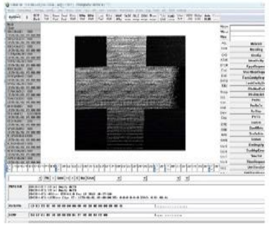
- Schematic, PCB layout
  - » Power : LDO, filtering
  - » Processor : FPGA, memory, peripheral
  - » Focal Plane : CMOS sensor, cooler
- Simulation: Modelsim





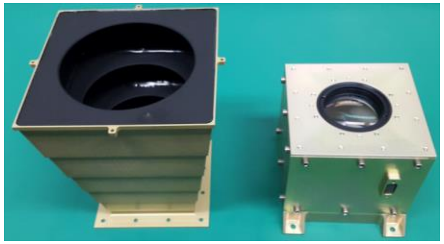


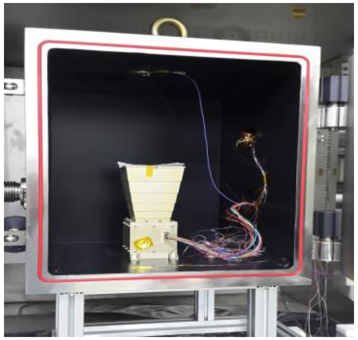




❖ Assembly & Integration, and Test

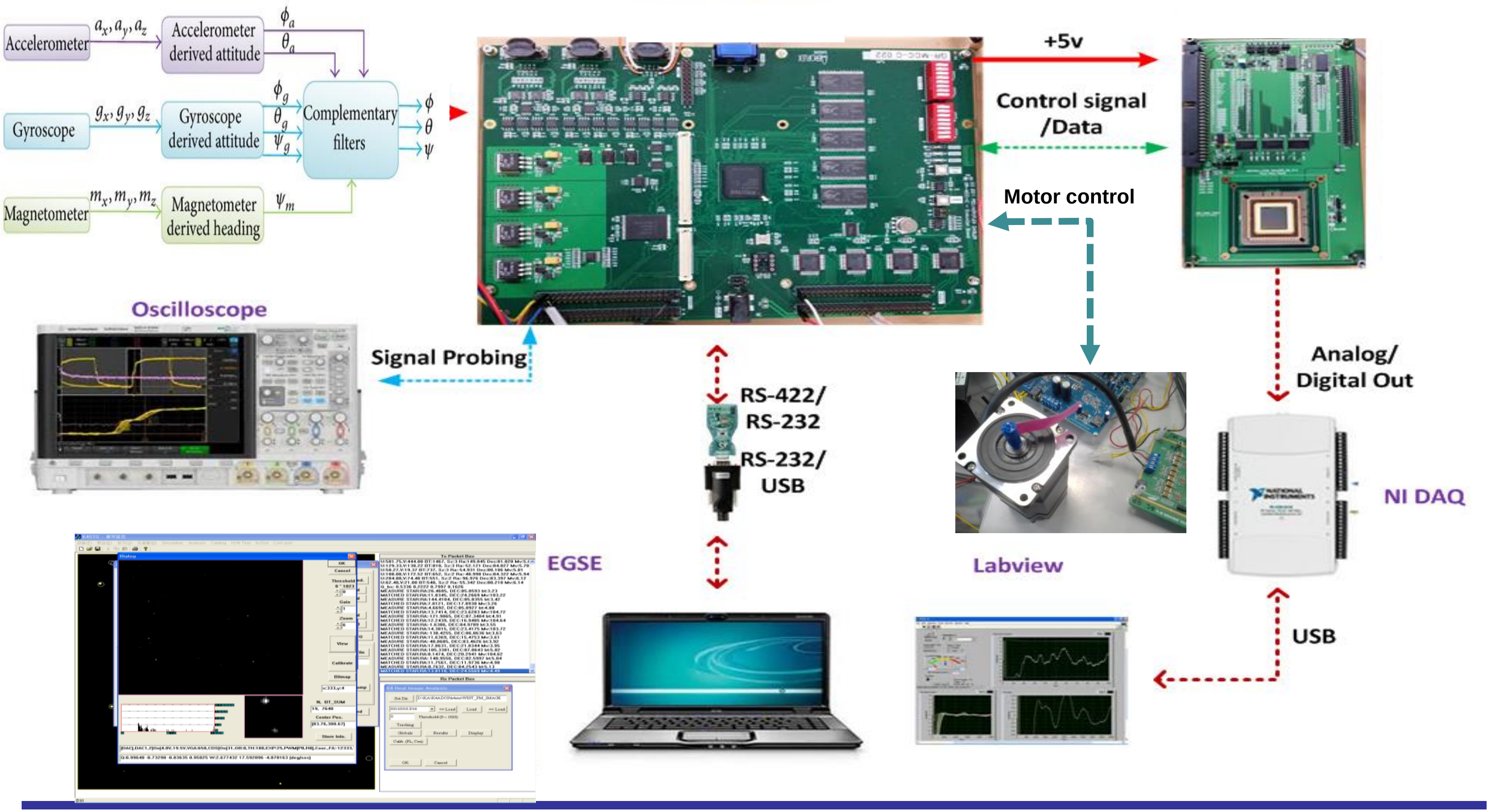
- » Mech/optical alignment
- » Conformal coating
- » Environment test
  - – Thermal / Vibration / Vacuum / Radiation (TID)





Test environment

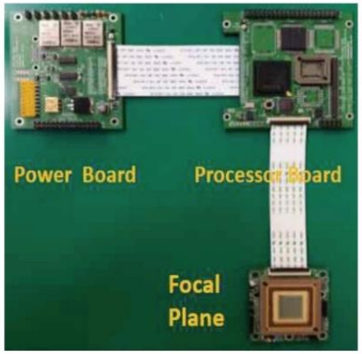
- Feedback control, Automation, embedded system for HILS test
  - FPGA (VHDL, Verilog), C/C++, circuit / PCB, debugging

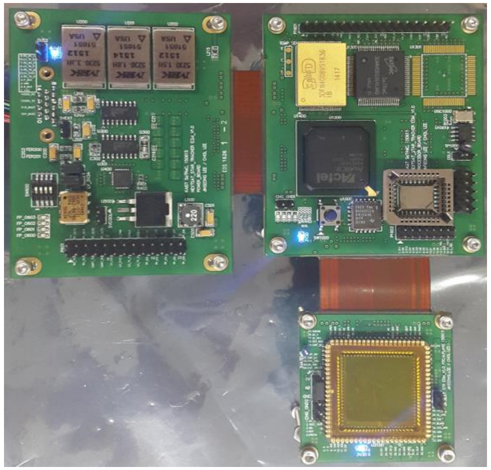


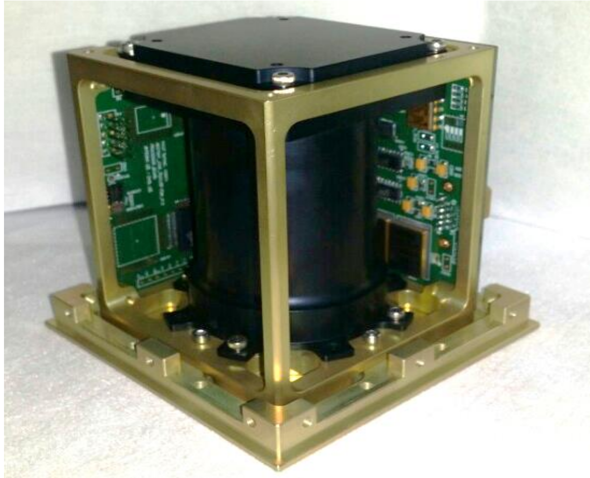
Results

❖ Outcome

- Developed - Engineering / Qualification / Flight model
- Life cycle: SDR / PDR / CDR
- Test and verification
  - » Star tracker
  - » ACS actuators / sensors
    - – torque rod, reaction wheel, magnetometer, sun sensor

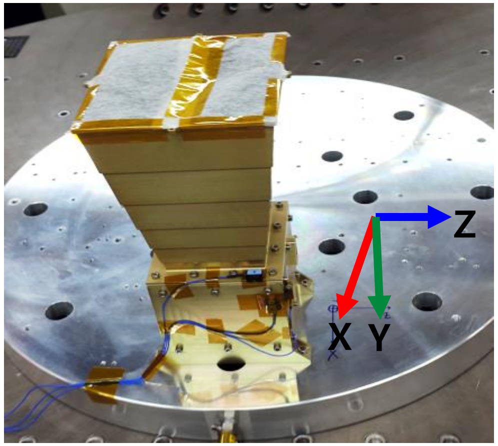




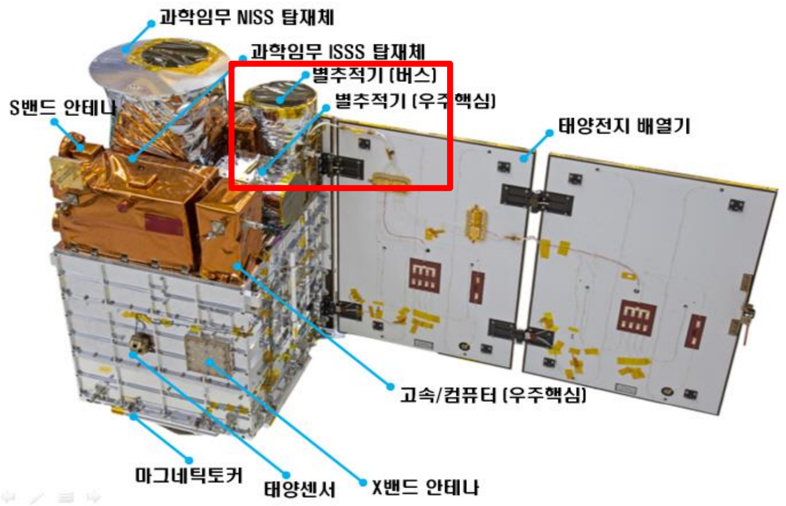


Flight model

- Satellite ACS payload
  - Developed 1st CMOS sensor star tracker
  - Launched by SpaceX Falcon-9 in Dec 2018



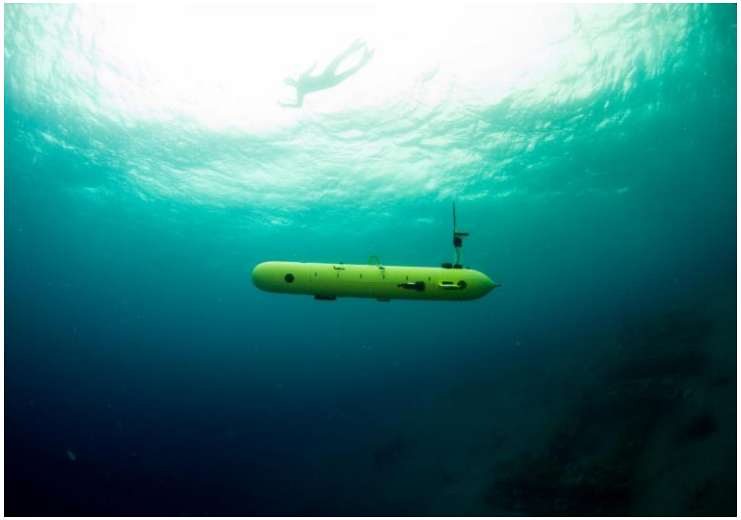
- Lessons learned
  - Completed lifecycle test of satellite project
  - Multi-disciplinary engineering

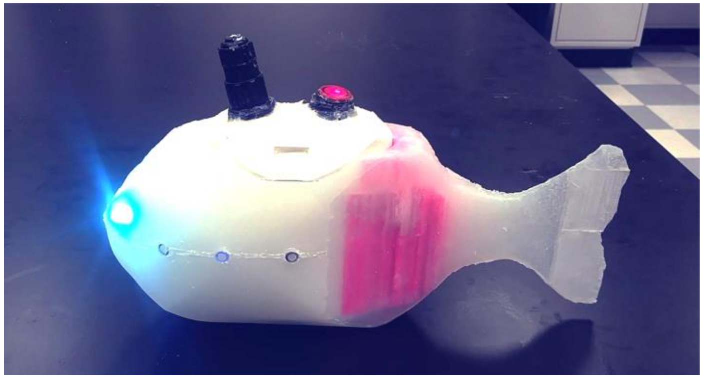


Project 2: Underwater Robot
(Feedback control for steering)

Motivation

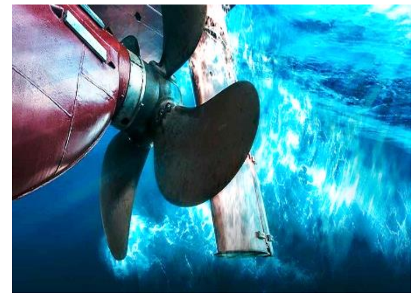
❖ Control and estimation
- Underwater robot: data collection in oceanography, space exploration
- Improving maneuverability is one of the main challenges
- **Bioinspired soft robot** provides advantages
  » Adaptable to environment,
  » Get less damage from shock



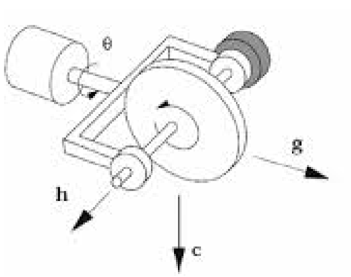


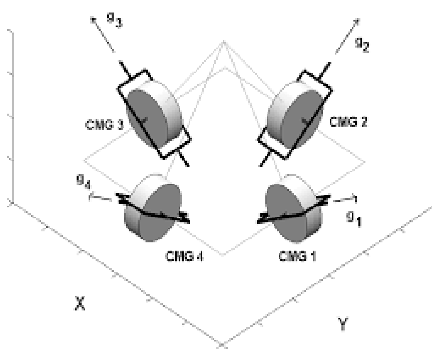
Problem Statement

- Conventional propulsion
  - Screw is not an ideal propulsion
  - Noise harmful to ecosystem



- Goal
  - Use different mechanism using internal momentum (reaction wheel)
  - Design feedback control law for underwater locomotion





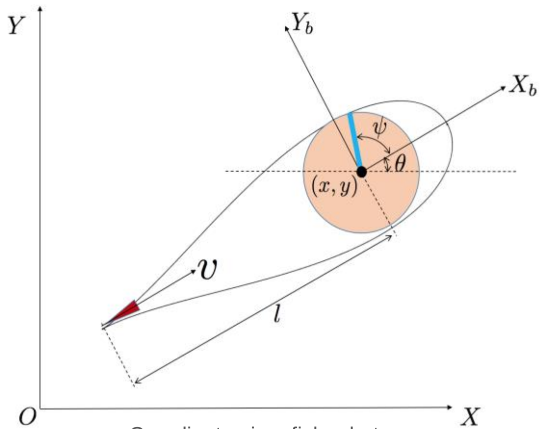
Background Theory

❖ Dynamics

- Angular momentum conservation
- Nonholonomic constraint
  - knife edge motion at tail
- Vehicle dynamics with underwater drag
- Equations of motion

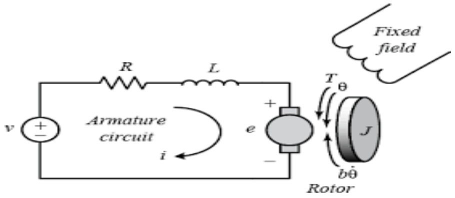
$$\dot{x} = v\cos\theta$$
$$\dot{y} = v\sin\theta$$
$$\dot{v} = -dv + l\omega^2$$
$$\dot{\theta} = \omega$$
$$\dot{\omega} = -\left(\frac{lm}{b}\right)v\omega + \frac{\boxed{u}}{b}$$

$b = ml^2 + J$, $\omega = \dot{\theta}$, and $d = k/m$



Coordinates in a fish robot

- Motor equation
  - Control PWM to generate torque under vehicle dynamics



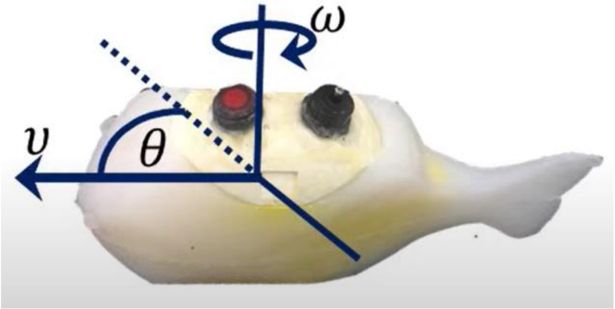
$$\boxed{\mathrm{PWM}} = \frac{255R}{K_\tau K_g V_{\max}}\left(\boxed{u} + \frac{K_\tau K_e K_g^2 \dot{\psi}}{R}\right)$$

Control Law

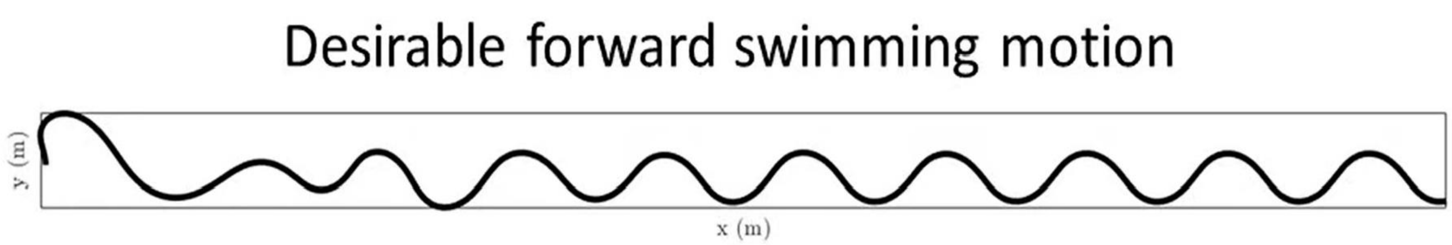
❖ Feedback Control

- Control torque *u*, using state feedback using (θ, ω)

$$u = b\left(-K_1\boxed{\omega} - K_2\sin(\theta_d - \boxed{\theta})\right)$$



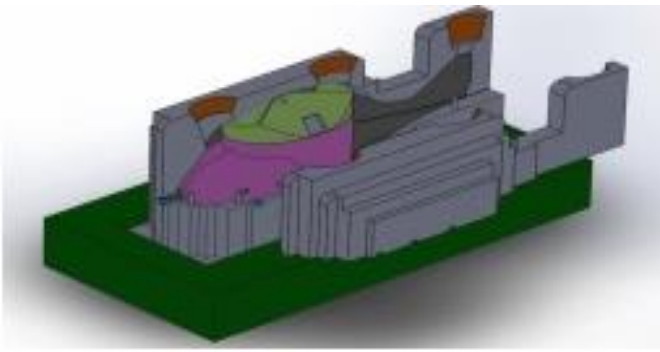
- Find suitable K_1, K_2 gains yields swimming motion



Development

❖ Reaction wheel-driven underwater robot

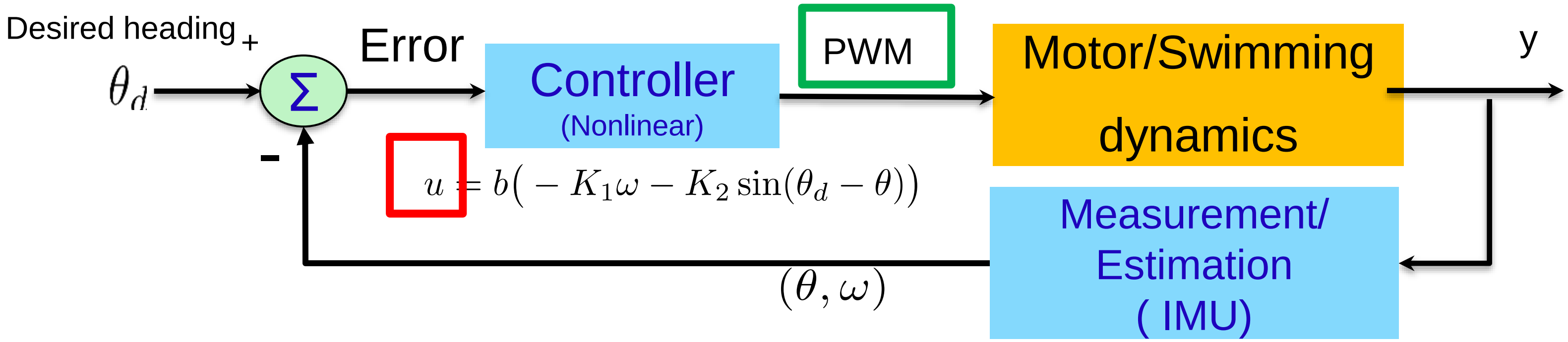
- Soft robot: 3D printing and flexible material
- Designed fish robot using COTS



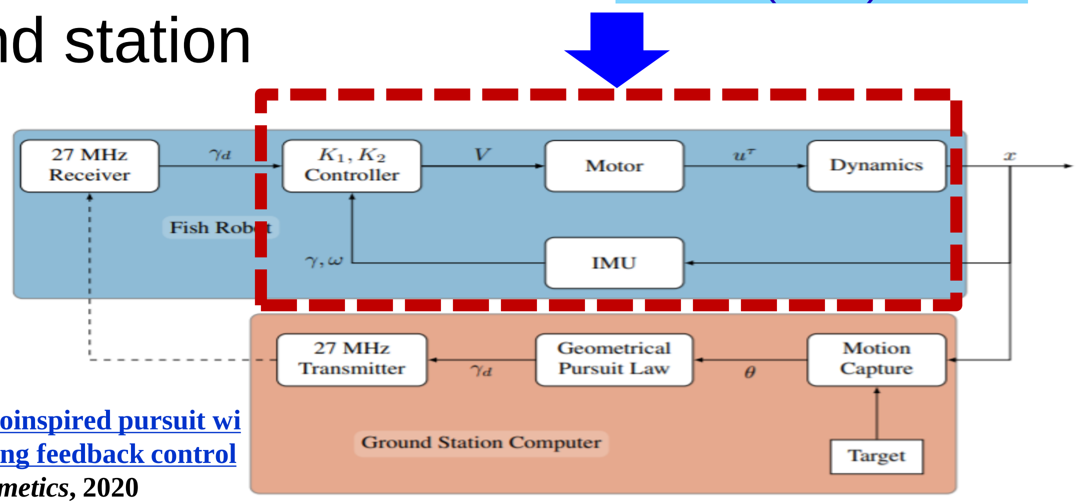
Closed-loop control

Date: 12th January 2017

❖ Feedback loop of a robot



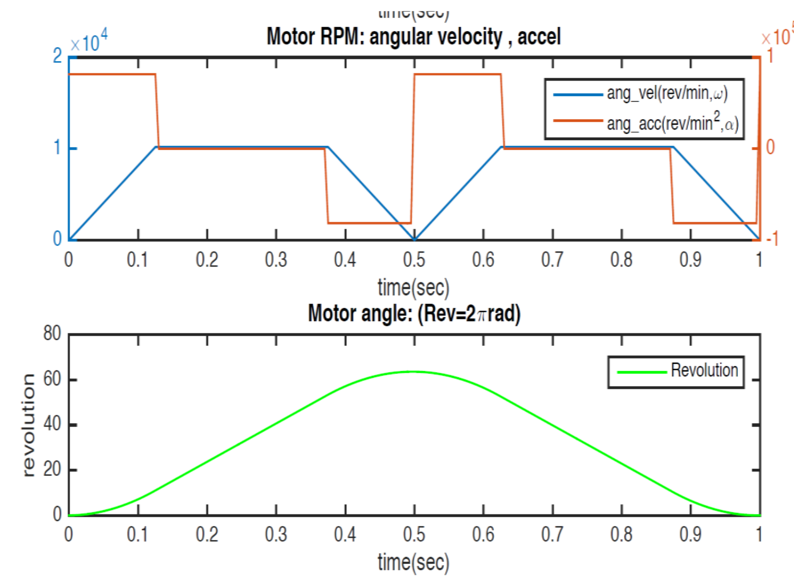
❖ Robot + Ground station

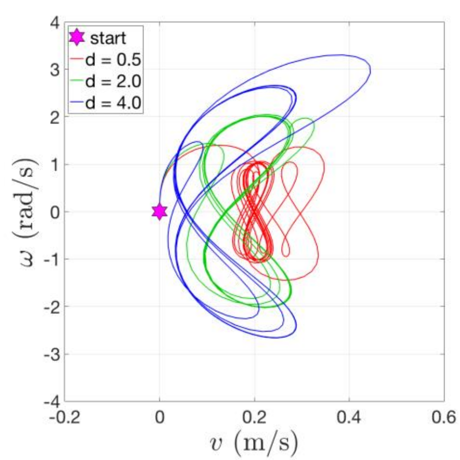


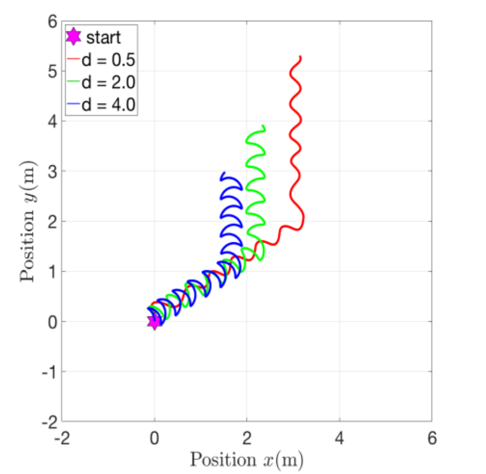
B. Free, J. Lee, et. el . [Bioinspired pursuit with a swimming robot using feedback control](#) . *Bioinspiration & Biomimetics*, 2020

Simulation

- Motor profile
  - acceleration, speed, angle
- Nonlinear dynamics
  - Phase portrait forms a limit cycle
  - Drag coefficient affects
    - amplitude
    - swimming distance

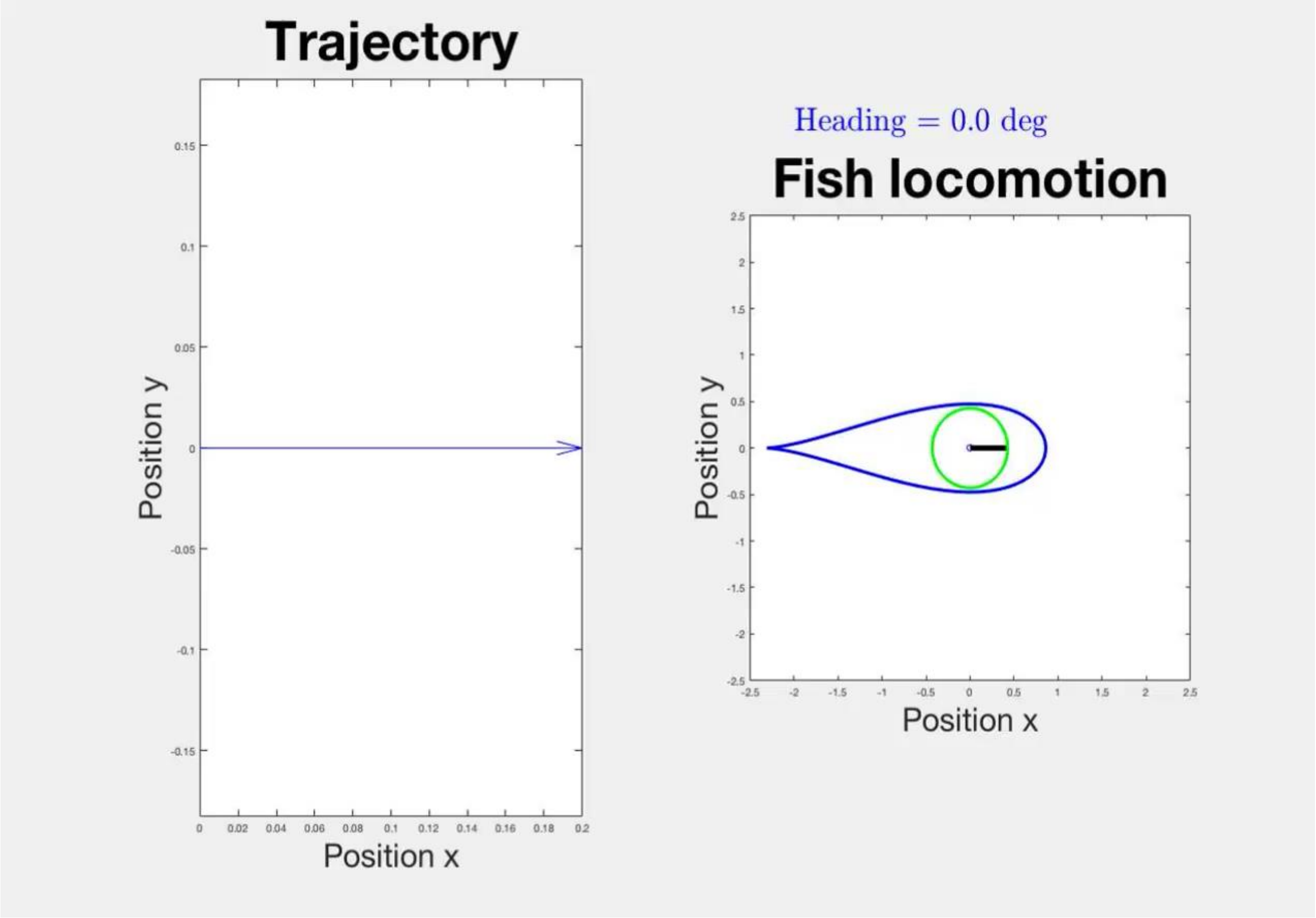






Simulation

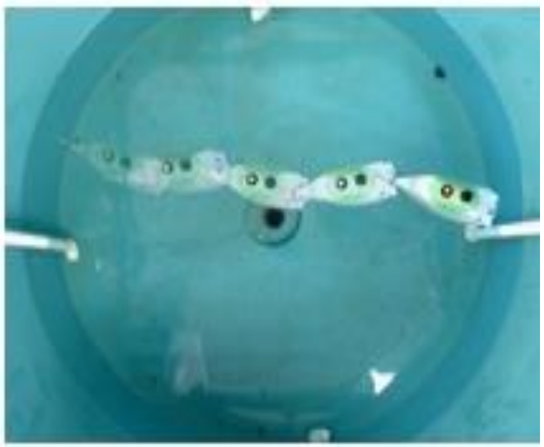
❖ Swimming motion



Test environment

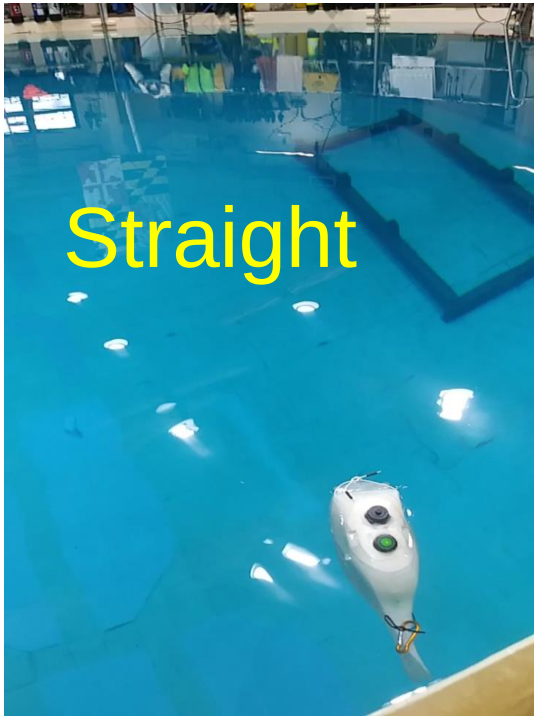
❖ Neutral Buoyancy Facility

- 15 m diameter x 7.5 m depth
- Provides underwater or micro-gravity environment
- 16 Qualisys underwater motion capture cameras



Underwater Test

- Heading guidance



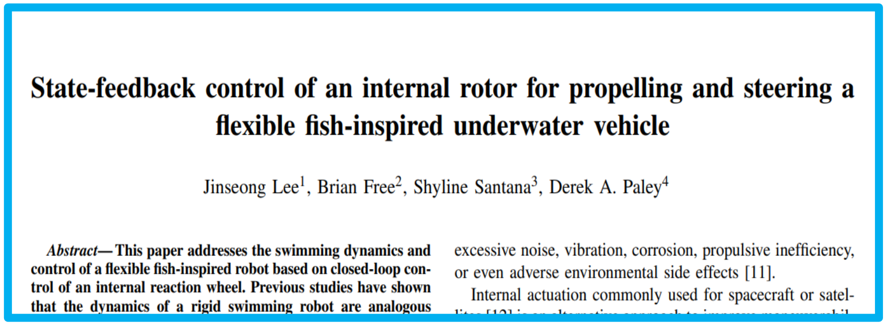
Univ. Maryland’s Clarke School of Engineering featured

https://www.youtube.com/watch?v=TTxS19EofQ0

- Outcome
  - Motor control, control law, interface (ARM, SPI/ I2C, ZigBee)
  - PCB design, 3D CAD, sensing, modeling

Publications

- ❖ Heading guidance
  - ▪ State feedback control
- ❖ Steering control
  - ▪ Bioinspired pursuit using feedback control



State-feedback control of an internal rotor for propelling and steering a flexible fish-inspired underwater vehicle

Jinseong Lee[1], Brian Free[2], Shyline Santana[3], Derek A. Paley[4]

***Abstract*— This paper addresses the swimming dynamics and control of a flexible fish-inspired robot based on closed-loop control of an internal reaction wheel. Previous studies have shown that the dynamics of a rigid swimming robot are analogous**

excessive noise, vibration, corrosion, propulsive inefficiency, or even adverse environmental side effects [11].

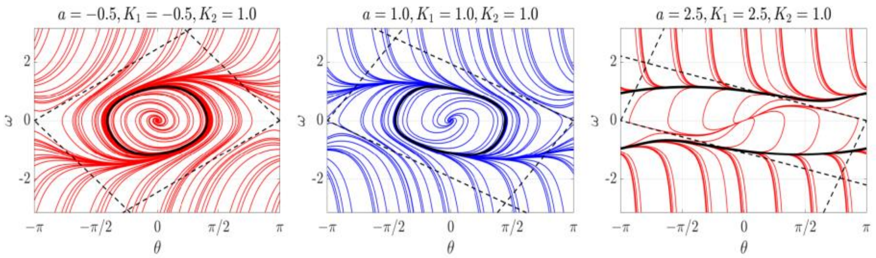
Internal actuation commonly used for spacecraft or satel-

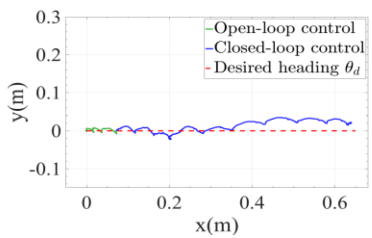
Bioinspired pursuit with a swimming robot using feedback control of an internal rotor

Brian A Free [1], Jinseong Lee, Derek A Paley

Affiliations + expand

PMID: 32040943 DOI: 10.1088/1748-3190/ab745e

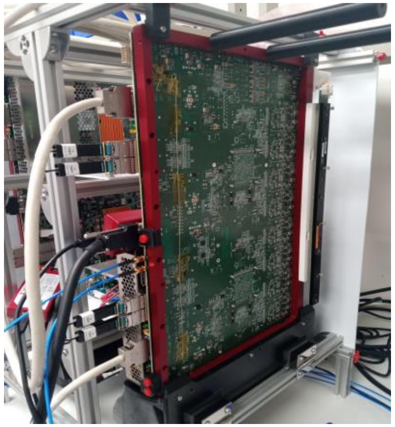


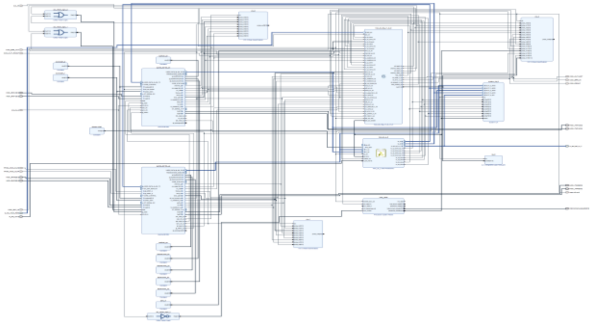


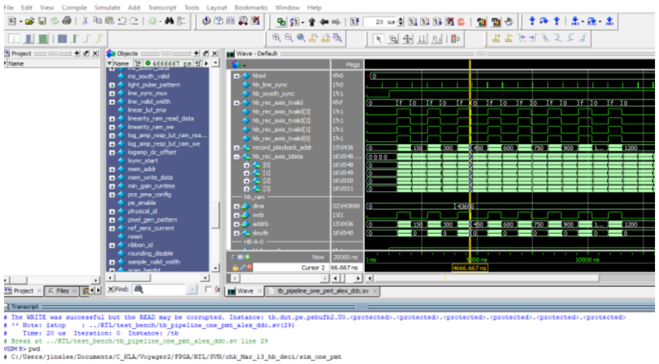
Project 3: FPGA-based automation (Optical Metrology for Semiconductor Inspection)

Optical Metrology System

- Senior FPGA Engineer, KLA
  - High speed image acquisition
    - Xilinx Kintex UltraScale FPGA with AXI bus
    - Created Verilog RTL for fault detection, ADC/ DAC, LVDS
      - I/O constraint, timing closure, simulation
    - DSP48 pipeline processing
      - Buffer, filter, interpolation
    - Test and verification using Python script
      - Debugging, fault management
      - Chipscope



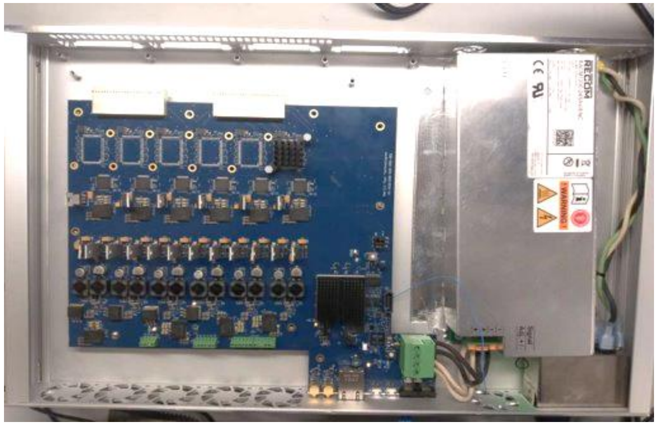


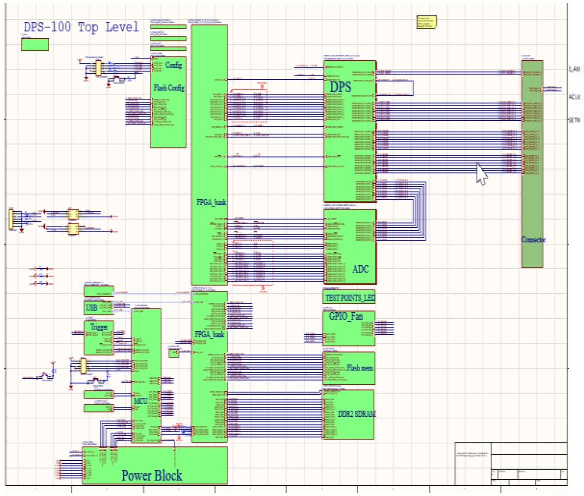


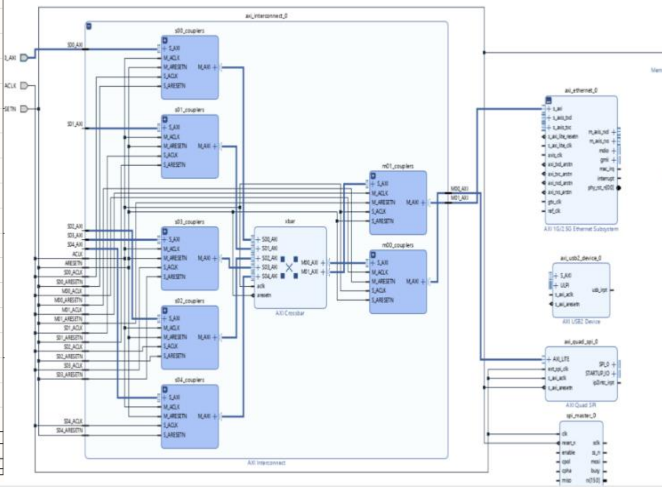
- Skills learned
  - FPGA system architecture, configuration
  - Interface, RTL for communication
  - Tight collaboration between HW and SW

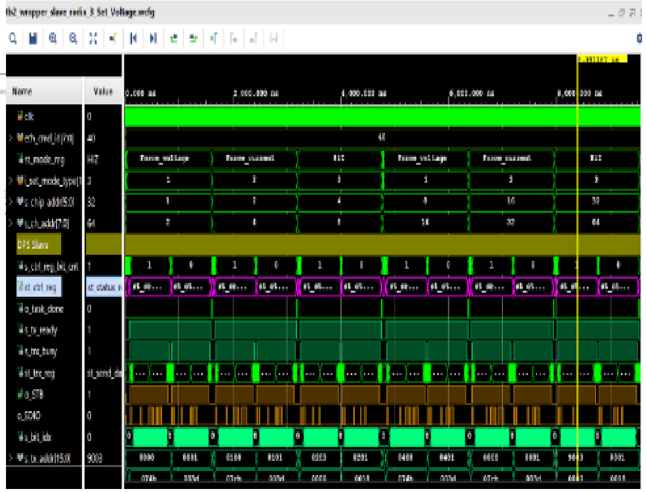
Semiconductor Inspection System

- Senior Control engineer, Merlin Test
  - Automated test equipment for 48 DUTs
    - System architecture/ Power budget
    - Analog/Digital mixed signal design
    - Schematic / PCB layout
    - Xilinx Artix-7 FPGA with AXI bus interface
      - DDR, Flash, USB, Giga Eth, SPI, GPIO
  - Feedback by voltage/current, calibration









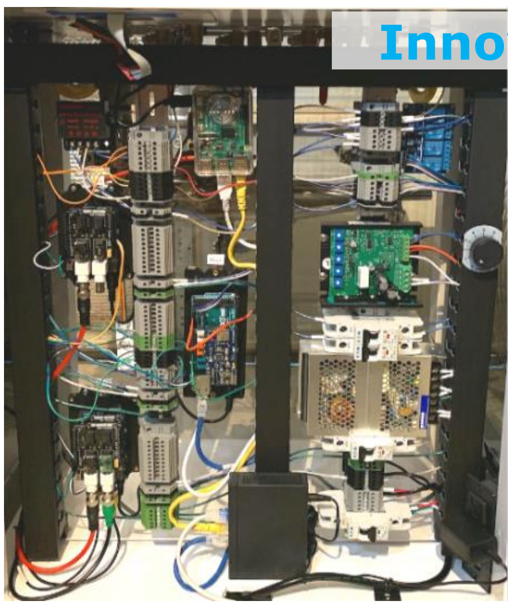
Project 4:
Space Life Support and Climate Change Solution

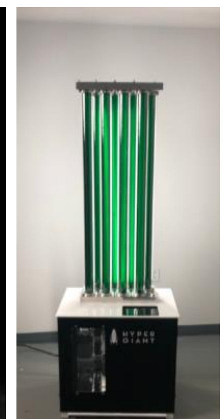
(algae photobioreactor and Spectrophotometer)

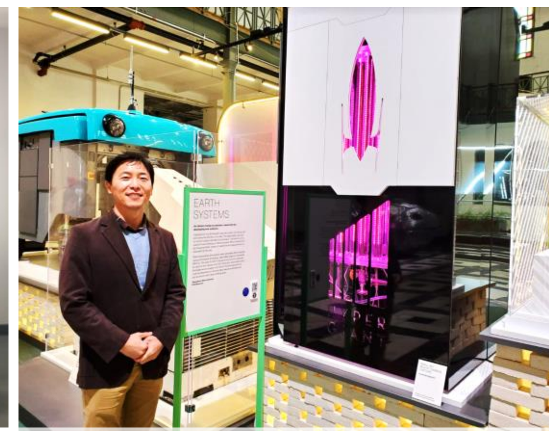
Award project : Algae photobioreactor

- Applied Research Engineer, Hypergiant (Austin, TX)
  - Algae cultivation for climate change and space life support
    - » Photosynthesis: Light + **CO_2** + H_2O => biomass + **O_2**
    - » Designed control sequence, spectrophotometer sensing

Innovation award







Smithsonian Museum, Futures Exhibit 2021-2022, Washington DC

https://dallasinnovates.com/hypergiants-eos-bioreactor-is-on-display-at-the-smithsonians-futures-exhibition/

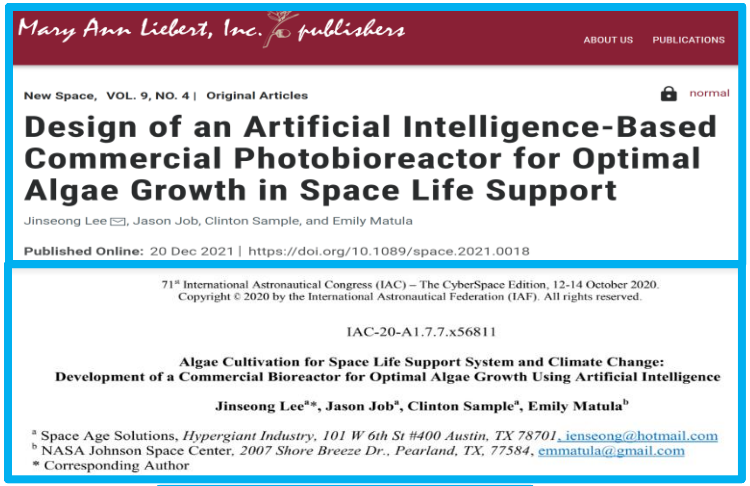
Others: Papers & Patents

1. Journal / Conference:

1. Algae for space life support/climate change
   - » CO_2 absorption modeling by algae cultivation

2. **Patent**: optical photobioreactor

- Automatic algae sampling sequence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New Space, VOL. 9, NO. 4 | Original Articles   normal

Design of an Artificial Intelligence-Based Commercial Photobioreactor for Optimal Algae Growth in Space Life Support

Jinseong Lee, Jason Job, Clinton Sample, and Emily Matula

Published Online: 20 Dec 2021 | https://doi.org/10.1089/space.2021.0018

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IAC-20-A1.7.7.x56811

Algae Cultivation for Space Life Support System and Climate Change: Development of a Commercial Bioreactor for Optimal Algae Growth Using Artificial Intelligence

Jinseong Lee[a]*, Jason Job[a], Clinton Sample[a], Emily Matula[b]

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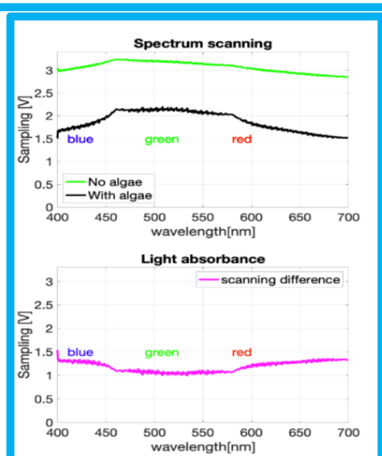
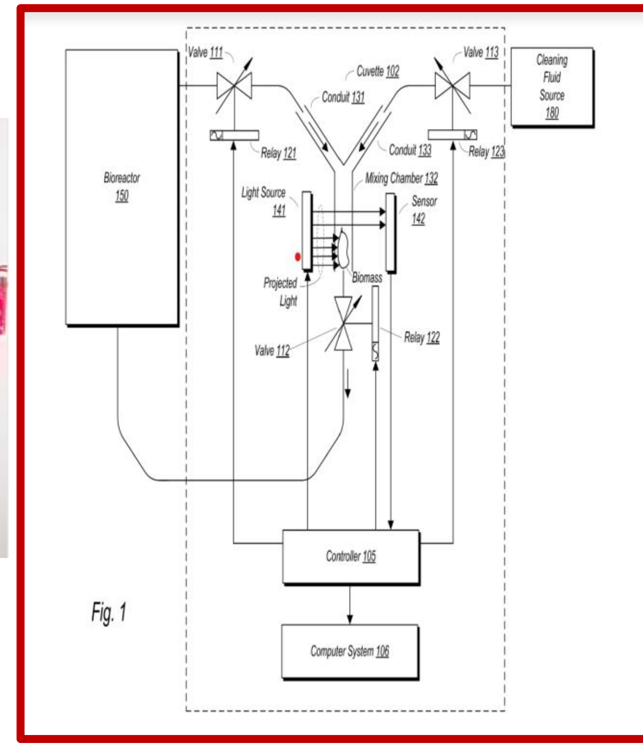
[b] NASA Johnson Space Center, *2007 Shore Breeze Dr., Pearland, TX, 77584*, emmatula@gmail.com
* Corresponding Author





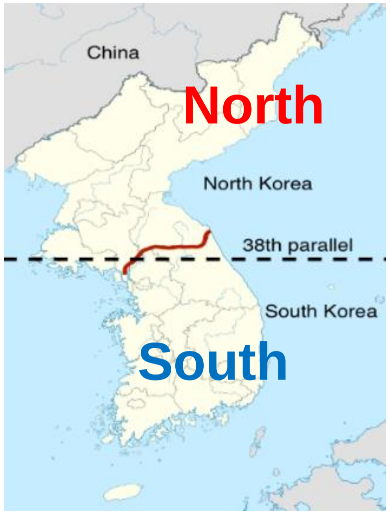
Project 5: Military Robot (Precise Camera motion)

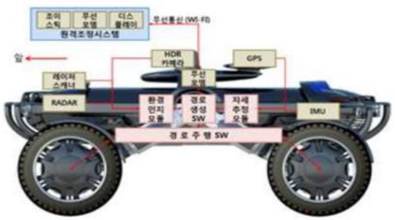
Problem Statement

❖ Motion control

SAMSUNG TECHWIN

- Stationary robot:
  - » Pan/tilt motion control for accuracy and stability of camera/gun payloads
- Mobile Robot:
  - » Augment pitching motion for LIDAR sensor





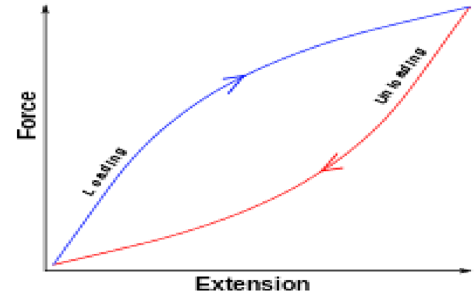
❖ Goal

- » Design motor controller for security robots
- » Implement accurate pan / tilt motion
- » Slew rate: 40 deg/s
- » Position accuracy: < 0.1 deg

Type 1: Stationary robot

❖ Precise motion control

- Homing position varies with direction and speed
  - » Gear backlash, sensor hysteresis



- **Hysteresis** : sensor value changes by direction
- Calibrate hysteresis on a homing sensor
- Position control of PMSM motor with encoder feedback

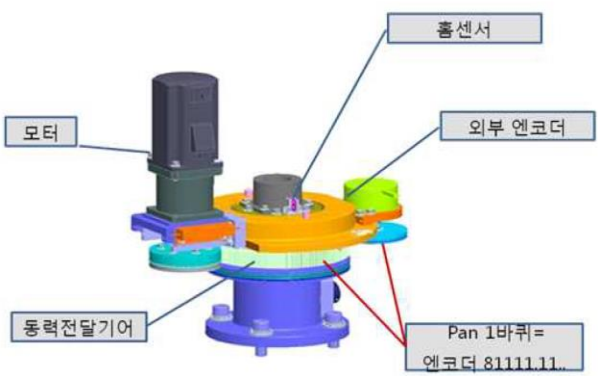
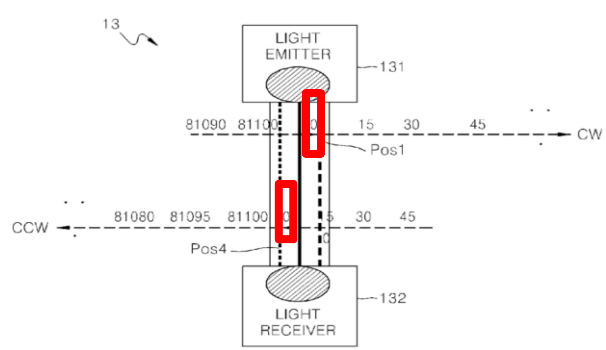
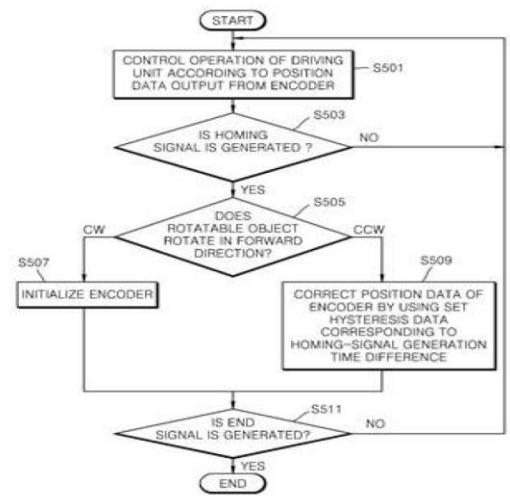


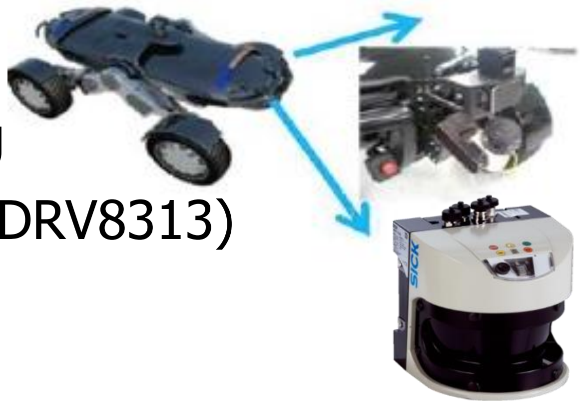
FIG. 4



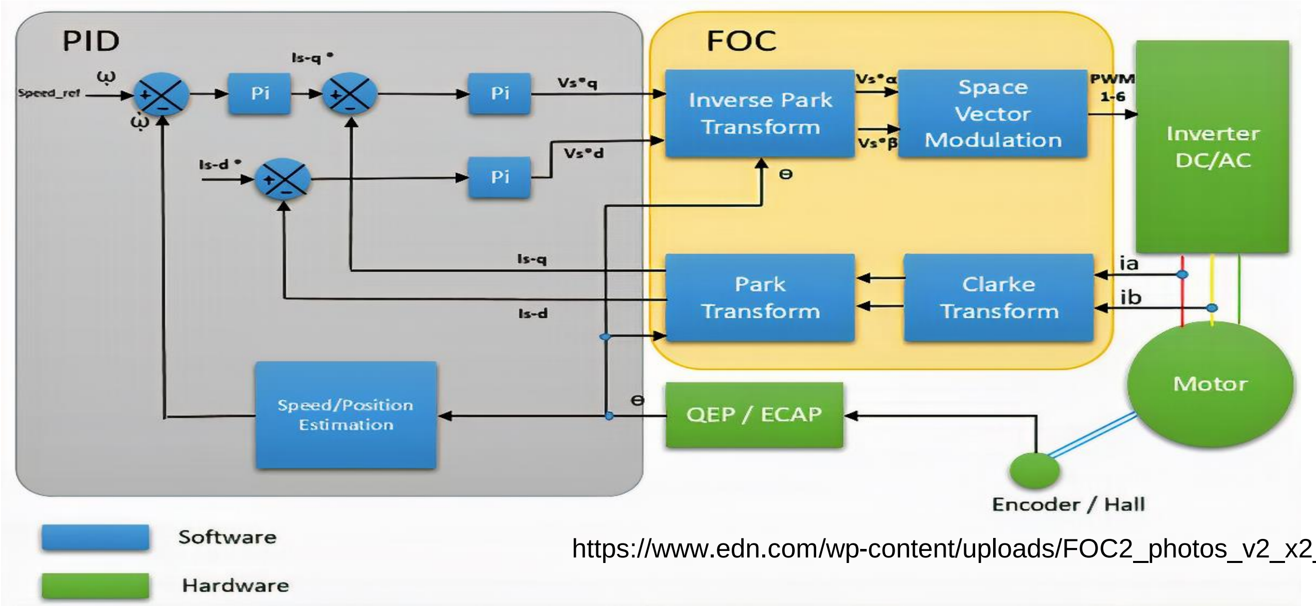


Type 2: Mobile robot

- ❖ Motor controller
  - Pitching motion with 2D LIDAR scanning
    - » DSP board (TI DSP TMS320F28335, DRV8313)
    - » BLDC motor with PI control loop



  - Field Oriented Control (FOC) block diagram

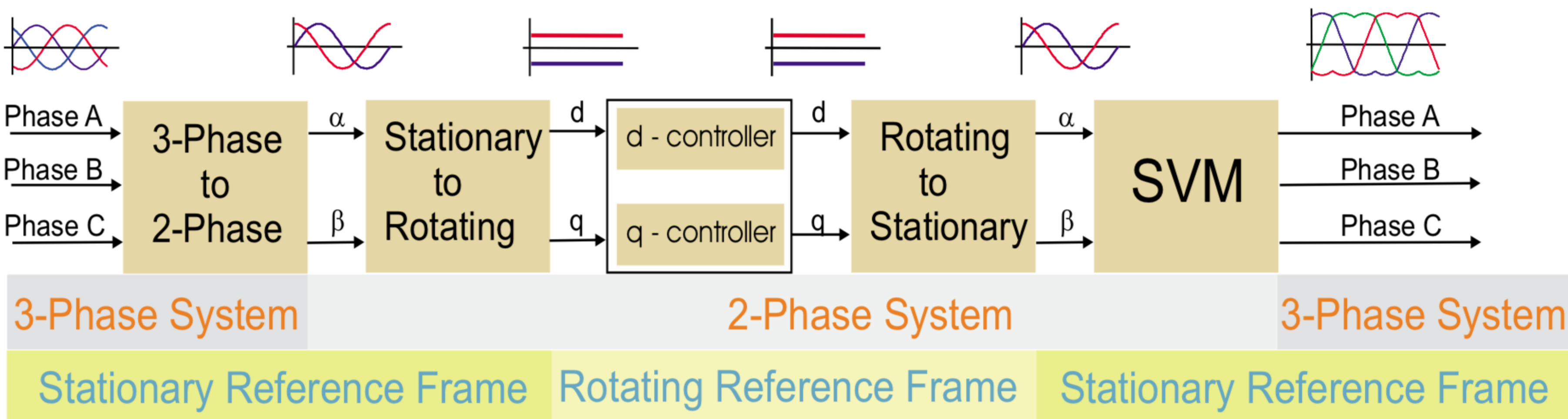


https://www.edn.com/wp-content/uploads/FOC2_photos_v2_x2_colored.png

Motor control

❖ Field Oriented Control (FOC)

- Generate 3 phases for BLDC / PMSM motor
  - » BLDC, PMSM motor



https://3l4sbp4ao2771ln0f54chhvm-wpengine.netdna-ssl.com/wp-content/uploads/2019/03/Vector-Control-Transformations.png

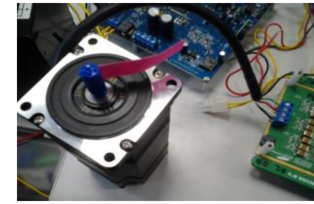
Developments

❖ Motion driver / controller

Stationary robot

- Precise PMSM motor control using sensor calibration
- Satisfied requirement
  accuracy/ repeatability : 0.04° < 0.1 °

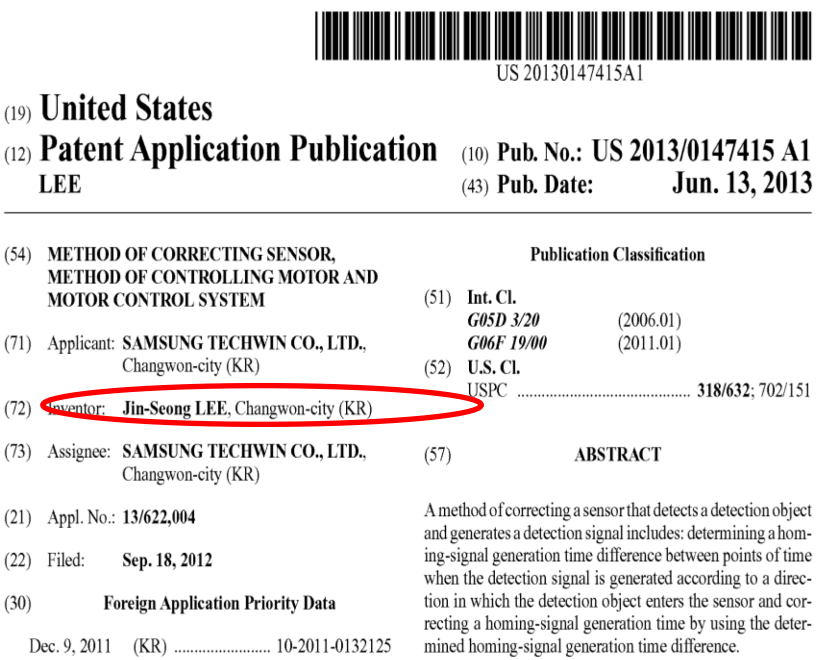
Mobile robot



- Implemented motor controller for LIDAR sensor
- FOC with BLDC and PI control

Patent

- Precise motor control
  - Calibrated hysteresis on a homing sensor
  - Automatically measure hysteresis
  - Implemented long-run test algorithm



US 20130147415A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2013/0147415 A1**
LEE (43) **Pub. Date: Jun. 13, 2013**

(54) **METHOD OF CORRECTING SENSOR, METHOD OF CONTROLLING MOTOR AND MOTOR CONTROL SYSTEM**

(71) Applicant: **SAMSUNG TECHWIN CO., LTD.**, Changwon-city (KR)

(72) Inventor: **Jin-Seong LEE**, Changwon-city (KR)

(73) Assignee: **SAMSUNG TECHWIN CO., LTD.**, Changwon-city (KR)

(21) Appl. No.: **13/622,004**

(22) Filed: **Sep. 18, 2012**

(30) **Foreign Application Priority Data**

Dec. 9, 2011 (KR) 10-2011-0132125

Publication Classification

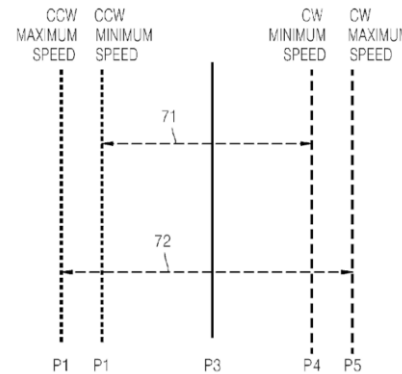
(51) **Int. Cl.**
G05D 3/20 (2006.01)
G06F 19/00 (2011.01)

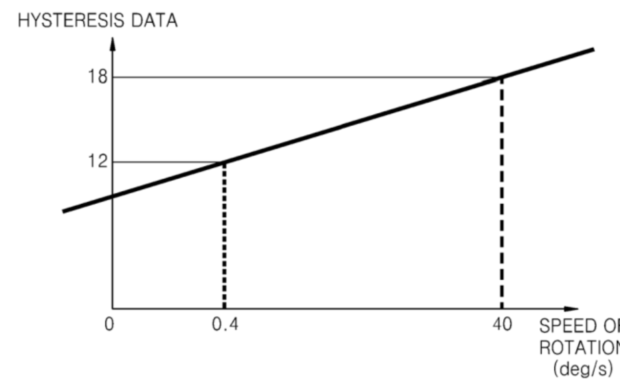
(52) **U.S. Cl.**
USPC **318/632**; 702/151

(57) **ABSTRACT**

A method of correcting a sensor that detects a detection object and generates a detection signal includes: determining a homing-signal generation time difference between points of time when the detection signal is generated according to a direction in which the detection object enters the sensor and correcting a homing-signal generation time by using the determined homing-signal generation time difference.

FIG. 7



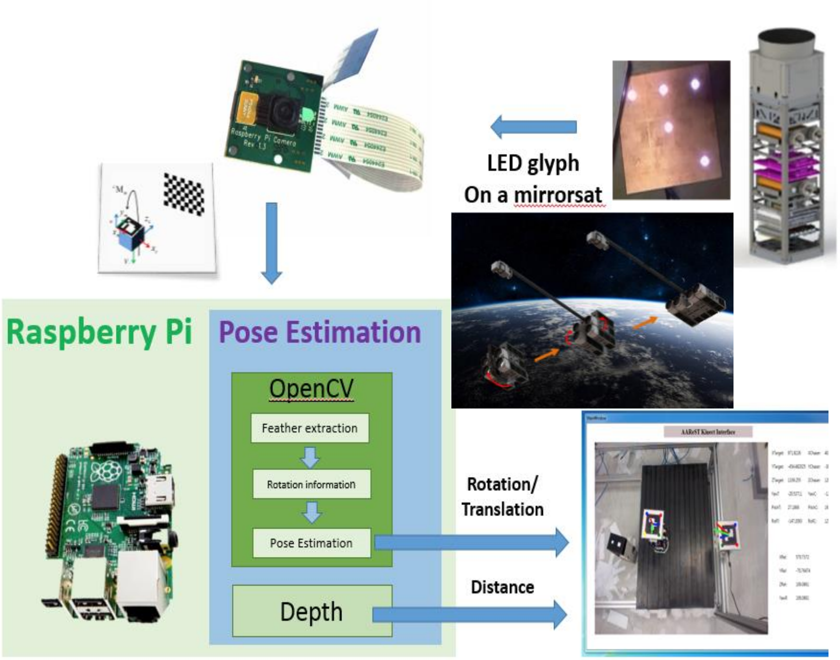


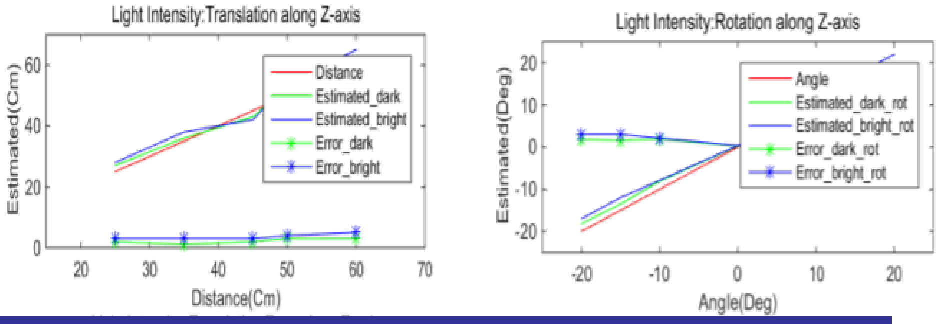
Other Projects

Camera Pose estimation

❖ Surrey Space Centre, UK

- **A**utonomous **A**ssembly of **RE**configurable **S**pace **T**elescope
  - » **AAREST** in collaboration with Caltech
  - » Vision-based pose estimation using infrared LED glyph
    - – Camera calibration, object detection based on OpenCV
    - – Determine Translation/Rotation under different geometry and ambient light
  - » Outcome : Translation error < 1.5 %, Rotation error: < 2.2 deg

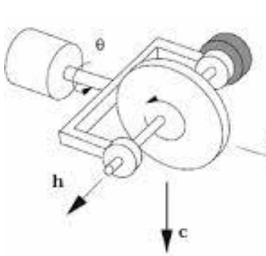




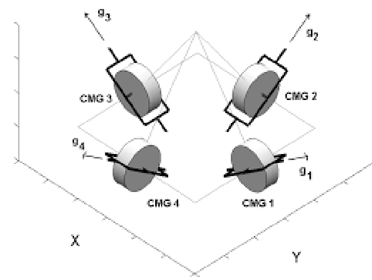
Underwater attitude control

❖ KAIST, S. Korea

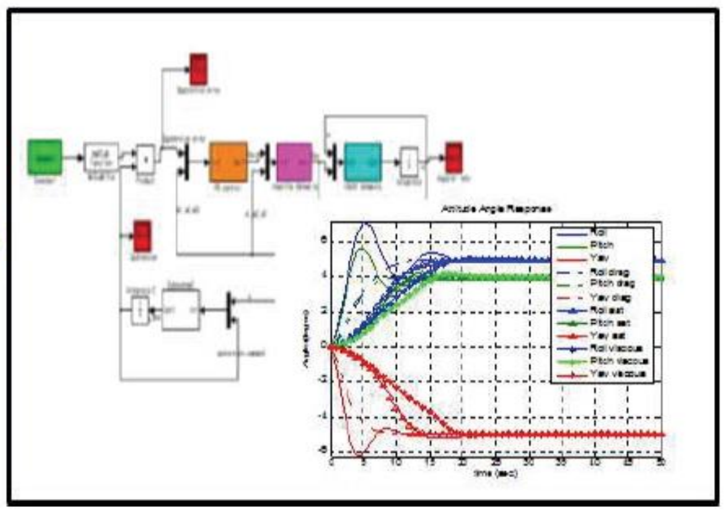
- Attitude control using Control Moment Gyro (CMG)
- Designed underwater robot system architecture
- Dynamics modeling wt. MATLAB@SIMULINK

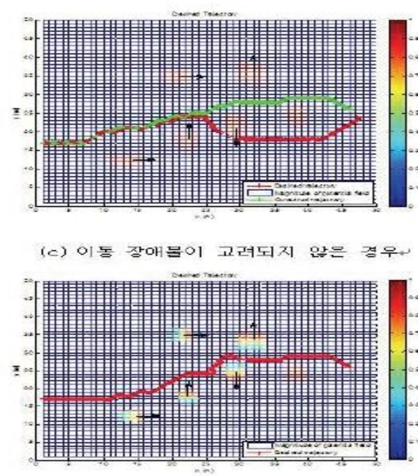


(a) Schematic Overview[6]



- **Outcome** : Analyzed nonlinear dynamics under drag, stabilized motion





Internship- Space Agency

❖ Korea Aerospace Research Institute (KARI)

- Processed satellite downlink data, technical reports for the 2nd Multi-Purpose Satellite (Arirang- 2)
- Assessed modeling for satellite attitude control, analyzed telemetry data and diagnosed RTOS

❖ Japan Aerospace eXploration Agency (JAXA)

- Simulated Control Moment Gyro (CMG) actuator for attitude control dynamics
- Embedded programming with H8-3048F for data processing
- Tested IMU sensing algorithm

Patents & Publications

❖ Patents

1. **U.S.**, "Optical density sensor instrument in the bioreactor", No.63/042965, 2020
2. **U.S.**, "Precise Motor Control using Sensor Calibration", NO.20110902003, 2011
3. **Korea**, "T-typed Unmanned Security Robot with Gimbal structure", NO.20110017298, 2011

❖ Papers

1. **J. Lee**, J. Job, E. Matula, "Space Life Support System and Climate Change : Development of a Commercial Bioreactor for Optimal Algae Growth Using Artificial Intelligence", International Astronautical Congress, 2020
2. B. Free, **J. Lee**, D. Paley, "Bioinspired pursuit with a swimming robot using feedback control of an internal rotor", J. Bioinspiration and Biomimetics,15(3):035005,2020
3. **J. Lee**, B. Free, D. Paley "State-feedback control of an internal rotor for propelling and steeri ng a flexible fish inspired underwater vehicle", American Control Conference, 2019
4. **J. Lee** and D. Lee, "Attitude Control of Aqua Farm Patrol Robots Based on a Gyro Momentum Approach", Ubiquitous Robots Ambient Intelligence, 2008
5. C. Lee, **J. Lee**, "Clonal Selection Algorithms for 6-DOF PID Control of Autonomous Underwate r Vehicles", Journal of Artificial Immune System, page 182-190, Volume 4628, 2007
6. J. Lee, **J. Lee**, "Intelligent Navigation of Autonomous Underwater Vehicles for Cage Aqua Far m Surveillance", Frontiers in the Convergence of Bioscience and Information, 2007

Skills

- Tasks
  - FPGA architecture, RTL implementation, Verification and Validation
  - Schematic, PCB design, power budget
  - Precise motor control, interface (I2C, SPI, CAN, UART, LVDS, SerDes, Ethernet)
  - State estimation, attitude control, feedback control, automation
  - Image processing, data analysis and modeling

- Tools
  - **FPGA**: Xilinx Vivado, Microsemi Libero, Altera Quartus II, ModelSim/QuestaSim
  - **Programming** : VHDL/Verilog, C/C++/Basic, Python, OpenCV, OpenGL
  - **Circuit / PCB / CAD** : Altium, OrCAD, PSPICE, PowerPCB, SolidWorks, Fusion360, AutoCAD
  - **ARM / DSP/ AVR** : Raspberry Pi, NXP LPC Xpresso, TI Code Composer Studio, AVR Studio, IAR, WinAVR
  - **Simulation** : MATLAB@Simulink, LABVIEW, AGI STK
  - **Robotics** : ROS, Gazebo, Rviz, MoveIt
  - **Processor**: European Space Agency (ESA) Fault Tolerant Leon3, Linux
  - **Foreign Languages**: English (Proficient), Japanese (SJPT L5), Chinese (TSC L3)

Personal activities

- The Republic of the Korea Marine Corps
  - » Military training in the air / sea / everywhere

- Membership:
  - » Astronomy instructor
  - » Planetary Society
  - » Scuba diver

제3-10510호

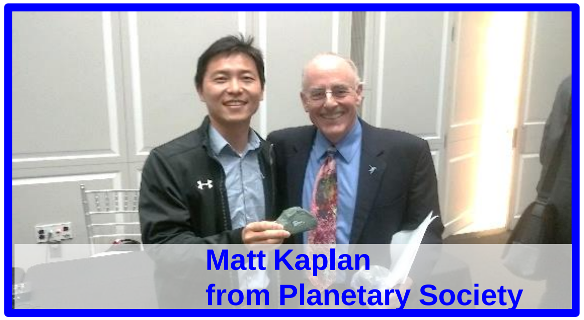
자 격 증

자 격 번 호 : 08-3-10510
종목 및 등급 : 천문지도사 3급
성 명 : 이 진 성
주민등록번호 : 810210-1655111

위의 사람은 사단법인 한국아마추어천문학회의 천문지도자 과정을 이수하고, 소정의 시험에 합격하여 천문지도사 자격을 얻었으므로 이를 인정함.

2008년 9월 27일

사단법인 한국아마추어천문학회장 장세일



- 1st Korean Astronaut Selection
  - » 245 candidates out of 36500 applicants

THE KOREAN ASTRONAUT PROGRAM

제 214 호

합 격 증

성 명 : 이 진 성
주민등록번호 : 810210-1655111

위 사람은 한국 최초 우주인 1차 선발과정에 합격하였기에 본 증서를 수여합니다.

2006년 10월 21일

한국항공우주연구원장

Summary

1. Attitude control system

- Developed an CMOS image sensor-based star tracker payload
- Developed small, low power, low cost with high-speed

2. Underwater Robot

- Developed a reaction wheel-driven robot
- Implemented state feedback control law for swimming

3. High speed semiconductor inspection and optical metrology

- Designed schematic for Analog/Digital mixed PCB and analyzed power budget
- Implemented RTL for FPGA-based image data processing

4. Algae photobioreactor

- Modelled space life support automation system modeling
- Designed spectrophotometer optical sensing instrument

5. Military Robot

- Developed motor driver, motor control for surveillance camera system
- Obtained accuracy and repeatability using sensor calibration

Thank you for your reading