INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES TOULOUSE

Designing a Low-Tech, Open-Source Motor Controller for Electric Cargo Bikes

Hugo ABESCAT – Karima ATTAR – Brage JOHNSEN – Oskar ORVIK – Julien PAVILLON – Nolan REYNIER NOMER – Aleksander TABAN

4th year AE-SE, Department of Computer and Electrical Engineering

Tutors: Pascal ACCO – Mathieu PRADIN

Commercial controllers limit local repair

Typical commercial e-bike controller

Battery — Proprietary IC Controller — MOSFET Bridge — BLDC Motor

⚠ **Not locally repairable**

LaMAD's answer: VESC open-source project

The VESC project

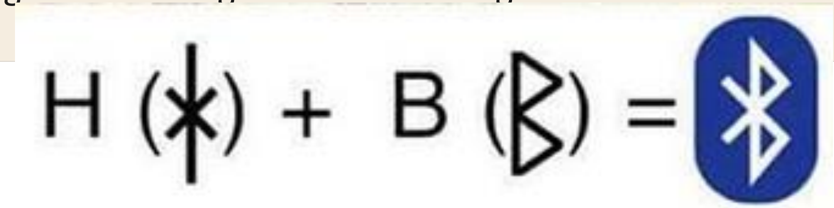
Open-source firmware & hardware for BLDC motor control
Widely adopted, but **not designed** for local fabrication or repairability

- Reliability
- Reparability
- Accessible for everybody

Open-source controllers lack low-tech and repairability design

What exists

- ✓ FOC vs Trapezoidal comparative studies (torque ripple, efficiency, cost)
- ✓ High-performing VESC controllers, well documented
- ✓ Torque ripple: 18.38% (FOC) vs 35.67% (Six-Step) at 500 RPM [1]
- ✓ BLE integration for diagnostics and tuning



What is missing

- ✗ Low-tech adaptation of open-source controllers
- ✗ Local fabrication with standard, off-the-shelf components
- ✗ Repairability documented for non-specialist communities
- ✗ Bluetooth security for decentralized, community-run fleets

Research gap: no controller combines open-source firmware, local manufacturability, repairability, and BLE security

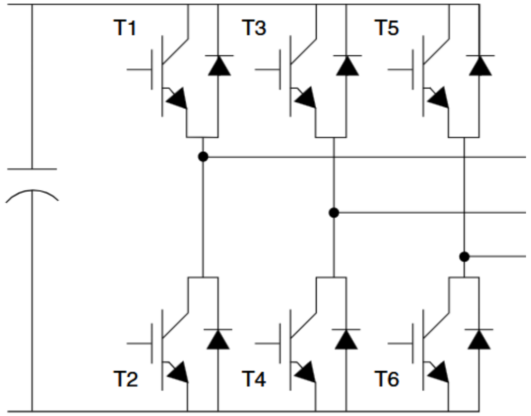
[1] Jomsa-Nga et al., IEEE ISC2, 2024

Design a low-tech, repairable, open-source BLDC controller

01

Low-tech PCB

Six-step BLDC control
discrete MOSFETs



[1]

02

VESC : FOC PCB

Field Oriented Control on STM32
VESC firmware adaptation

[2]

03

Software Security

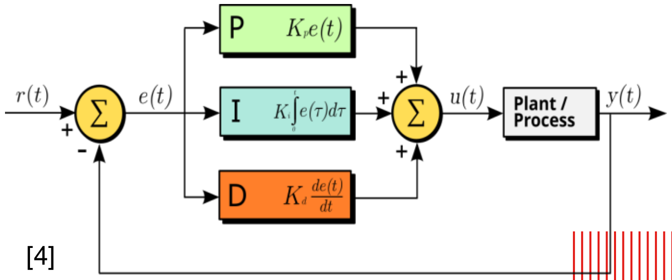
BLE vulnerability analysis

[3]

04

Control System

Dynamic model
PID controller



[4]

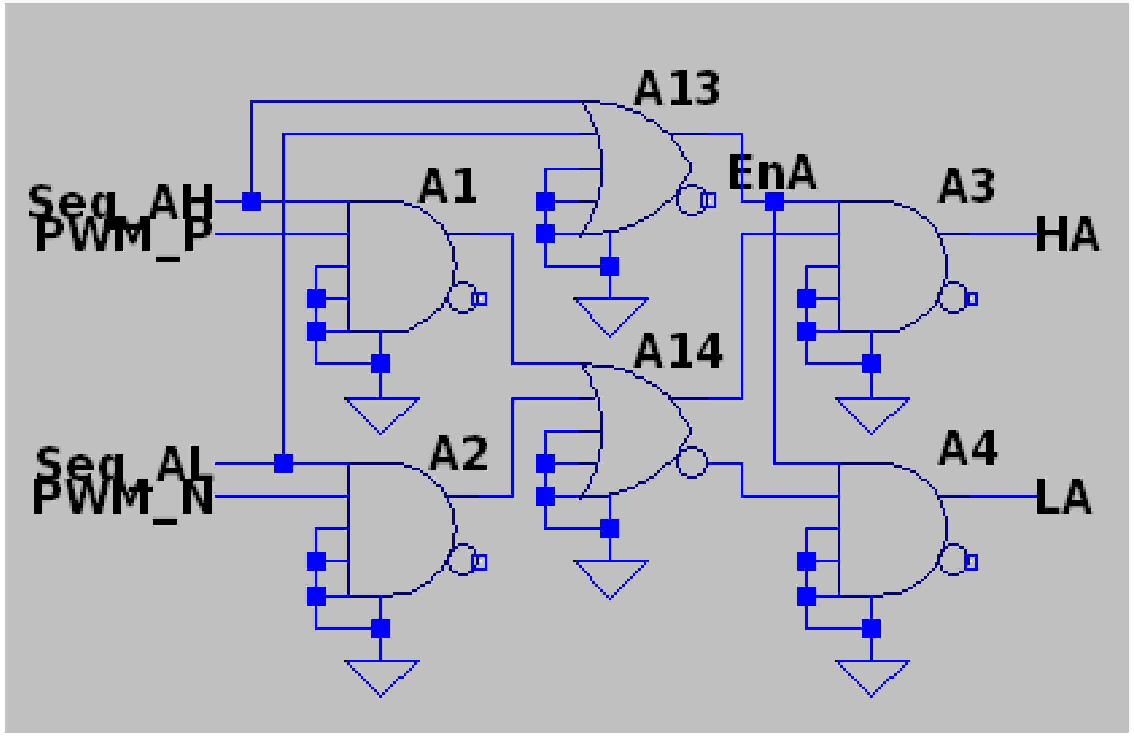
Four complementary approaches to one controller

01	**Low-tech PCB (Six-Step)** *Aleksander*	MOSFET/BJT/Diodes, discrete PWM logic, no microcontroller
02	**VESC PCB (FOC)** *Hugo, Karima*	STM32F405, M. Rocacher tile, KiCad schematics
03	**Software Security** *Brage, Oskar*	Flipper Zero, BLE frame analysis, BLE interference
04	**Control System** *Julien, Nolan*	Matlab/Simulink model, PID, distance sensor

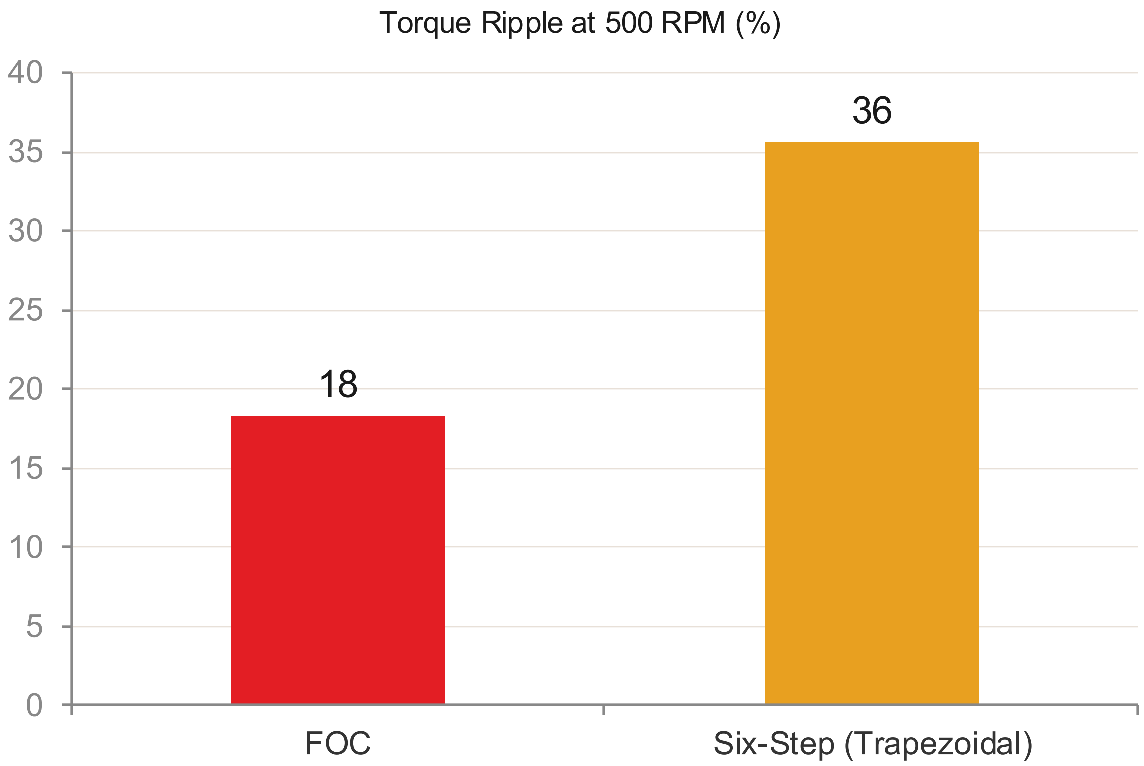
Low-cost, repairable six-step control without a microcontroller

Fundamentally flawed project

- It is "easy" to make the logic on campus (AIME) and replace the IC, but the power components are hard to make
- AIME is really interested in making power components, but this project would need time and investments from the GEI
- Conclusion: Focus on repairability and ease of production with cheap and readily available (but not necessarily locally made) components



FOC reduces torque ripple by half compared to Six-Step control



Source: Jomsa-Nga et al., IEEE ISC2, 2024

	FOC	Six-Step
Torque ripple	~18 %	~36 %
Low-load efficiency	Better	Adequate
Dynamic response	Fast	Standard
Implementation complexity	High	Simple
Hardware cost	Higher	Lower
High-speed switching loss	Higher	Lower

Field Oriented Control on STM32F405 : VESC firmware adaptation

1

Starting point

Open-source project : Cheap FOCer-2
Compatible with VESC
(for STM32F405)

2

Rocacher tile

Tile that runs FOC, for STM32L4,
a different µC family

3

Modular concept

L4 tile easily pluggable
→ repairable

4

Pin compatibility

F4/L4 mapping verified: USB,
PWM, outputs, alternate functions

5

Schematic & routing

ERC passed ✓
Footprint issue on tile connectors

Main challenge : Cheap FOCer-2's routing is dense and optimized for a non-removable F4 chip, adapting it to accept a removable F4 tile proved complex.

Our approach to the security problematic

Software Security

Risks

Unauthorized motor control
Parameter modification - lispBM

Proposed solution

Application in C
Maintain and document code

Bluetooth

BLE scan and frame reading
Unauthenticated connection attempt
Jamming of Bluetooth channel

Repairability

Discrete-component PCB

No proprietary internal components
Each component individually replaceable

Standardised

Fully open-source documentation
Allow for modularity

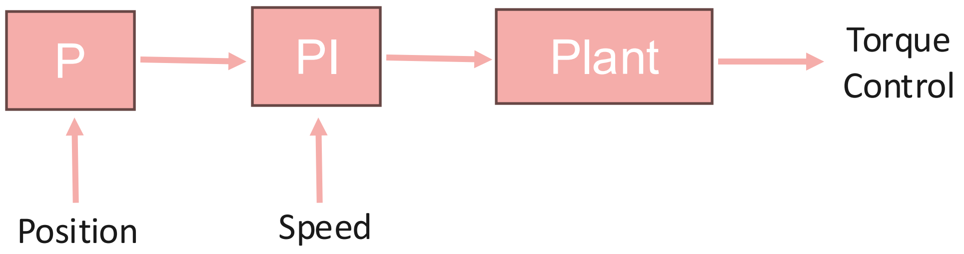
Open schematics & BOM

Gerber files
Bill of materials

Dynamic modelling and control laws to cancel perceived effort

Characterize the system and establish an effective control law with the aim of making the cargo self-propelled
=> Control Strategy: Cascaded Loop Architecture

Avoid the cargo cart pushing or be pulling by the bike in every situation possible



Benefits of using it

✓ Provide both precision in positioning and smoothness in speed transitions

✓ Using two physic parameters : position and speed

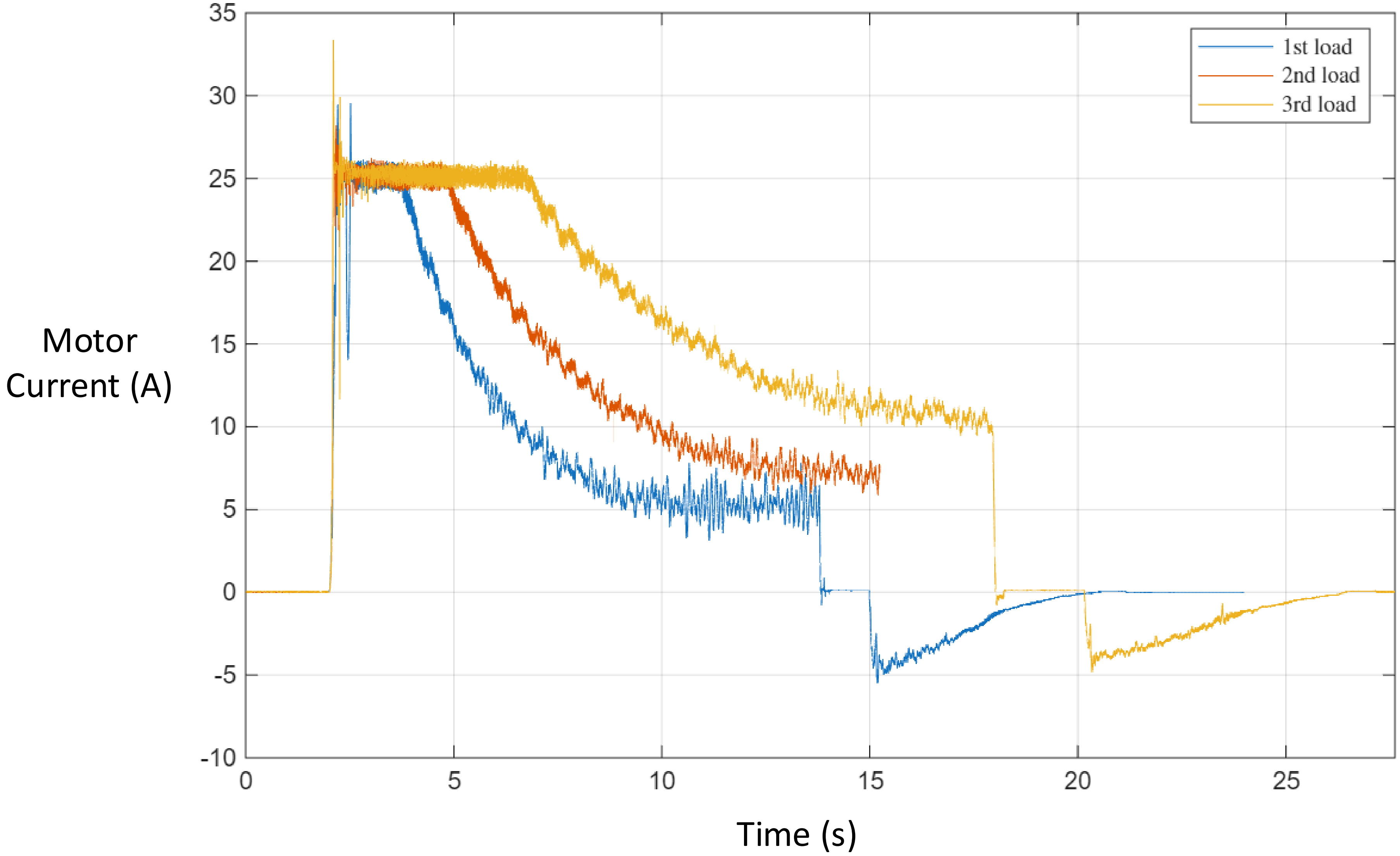
✓ Highly robust to mass/inertia changes

Simulation by Simulink

✓ Robustness against Mass Variation (unload to 200kg)

✓ In simulation, the force exerted by the cargo is almost zero

Dynamic modelling and control laws to cancel perceived effort



What we have already achieved

Task	Status
VESC compilation	Done
Matlab model + PID	Done
F4/L4 pin compatibility	Done
VESC KiCad schematic	Done
Software vulnerability identified	Done
PCB routing (VESC)	In progress
Motor bench test	In progress
BLE patch validation	In progress
Low-tech PCB design	In progress

A low-tech, repairable, open-source controller is achievable

Preliminary results

- ✓ VESC firmware compiled and adapted for target BLDC motor
- ✓ FOC and Trapezoidal commutation both operational
- ✓ Positional control validated (settling < 50 ms)
- ✓ BLE unauthenticated access and software security explored
- ✓ Matlab PID model: distance sensor + control loop validated

Future work

- → Finalize PCB routing and fabrication
- → Bench and real-world tests on LaMAD trailer
- → Implement Bluetooth authentication scheme
- → Publish PCB design and firmware open-source
- → Train LaMAD teams in repair procedures

Open-source, low-tech, locally repairable motor control is feasible and community-ready.

References

- [1] https://www.st.com/resource/en/application_note/an4220-sensorless-sixstep-bldc-commutation-stmicroelectronics.pdf
- [2] https://vesc-project.com/
- [3] https://flipper.net/
- [4] https://commons.wikimedia.org/wiki/File:PID_en.svg

Contacts

Hugo ABESCAT abescat@insa-toulouse.fr

Karima ATTAR kattar@insa-toulouse.fr

Brage JOHNSEN johnse@insa-toulouse.fr

Oskar ORVIK orvik@insa-toulouse.fr

Julien PAVILLON pavillon@insa-toulouse.fr

Nolan REYNIER NOMER reynier-nome@insa-toulouse.fr

Aleksander TABAN taban@insa-toulouse.fr

Department of Computer and Electrical Engineering
INSA Toulouse, France

Questions?

Thank you for your attention