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Energy Efficiency of ROS Nodes in Different Languages: Publisher-Subscriber Case Studies

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Agenda

- Energy-efficient/Green Software
- ROS 2 Programming
- Research Design
- Results
- RQ Answers
- Limitations and Future Directions

Energy-efficient/Green Software

Battery, Budget and Environmental Sustainability

- Software (ROS) is a key-element in robotic systems [1];
- ICT is estimated to be responsible for 20% of global energy usage by 2025 [4];
- Software energy efficiency has been a recurrent research topic [2,3];
- Greener/More energy-efficient software have been researched with different goals:
  - Saving battery (smartphone apps) [5];
  - Affordable budgets/better resource allocation (infrastructure) [6];
  - Reducing the environmental impact [7].
    - Less greenhouse emissions.
- ROS community discussion on energy efficiency is an open file/no ground truth [8].

[1] Stan Swanborn and Ivano Malavolta. Energy efficiency in robotics software: a systematic literature review. ASE, 2020.

[2] E. Capra, C. Francalanci and S. A. Slaughter. Measuring Application Software Energy Efficiency. IT Professional, 2012.

[3] Gustavo Pinto, Fernando Castor, and Yu David Liu. Mining questions about software energy consumption. MSR, 2014.

[4] A. Fonseca, R. Kazman and P. Lago. A Manifesto for Energy-Aware Software. IEEE Software, 2019.

[5] W. Oliveira, R. Oliveira and F. Castor. A Study on the Energy Consumption of Android App Development Approaches. MSR, 2017.

[6] R. Verdecchia, P. Lago, C. Ebert and C. de Vries. Green IT and Green Software. IEEE Software, 2021.

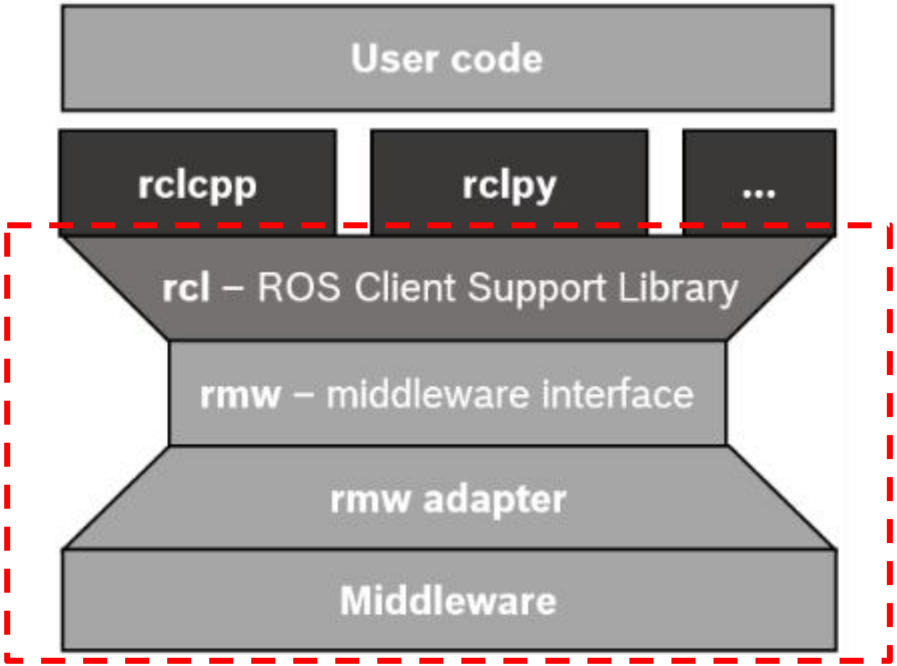
[7] Verdecchia, Roberto, June Sallou, and Luís Cruz. A systematic review of Green AI. Data Mining and Knowledge Discovery, 2023.

[8] M. Albonico, I. Malavolta, G. Pinto, E. Guzman, K. Chinnappan and P. Lago. Mining Energy-Related Practices in Robotics Software. MSR, 2021.

ROS 2 Programming
Shared Underlying Layers

Rui Pereira, Marco Couto, Francisco Ribeiro, Rui Rua, Jácome Cunha, João Paulo Fernandes, and João Saraiva. 2017. Energy efficiency across programming languages: how do energy, time, and memory relate? In Proceedings of the 10th ACM SIGPLAN International Conference on Software Language Engineering (SLE 2017). Association for Computing Machinery, New York, NY, USA, 256–267. https://doi.org/10.1145/3136014.3136031

- ROS Client Support Library



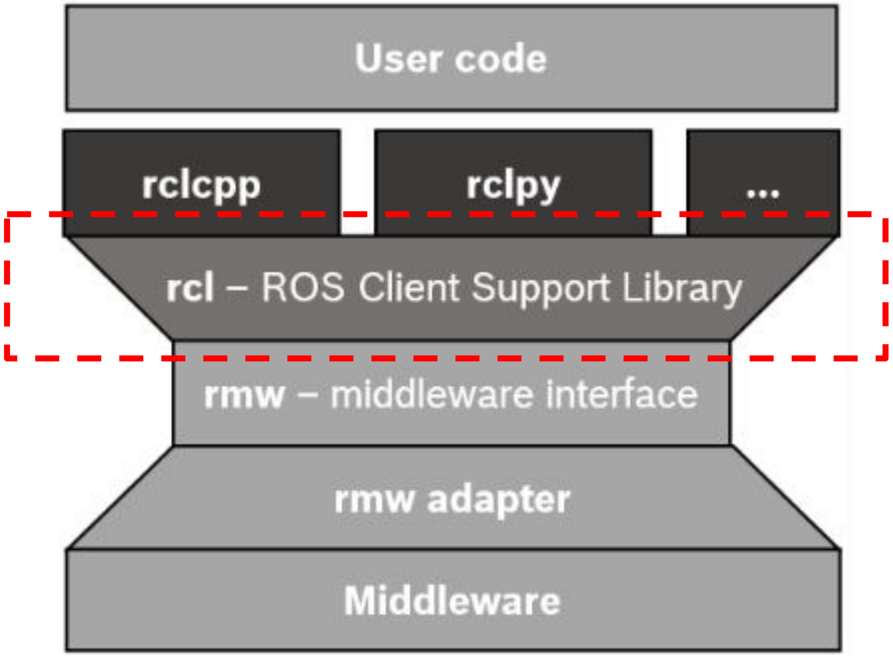
Client libraries

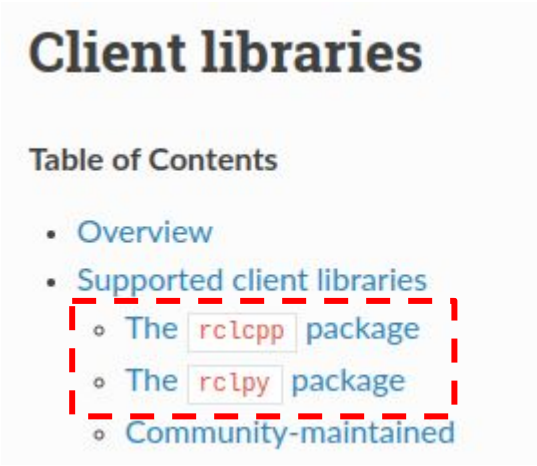
Table of Contents

ROS 2 Programming

rcl API

- ROS Client Support Library





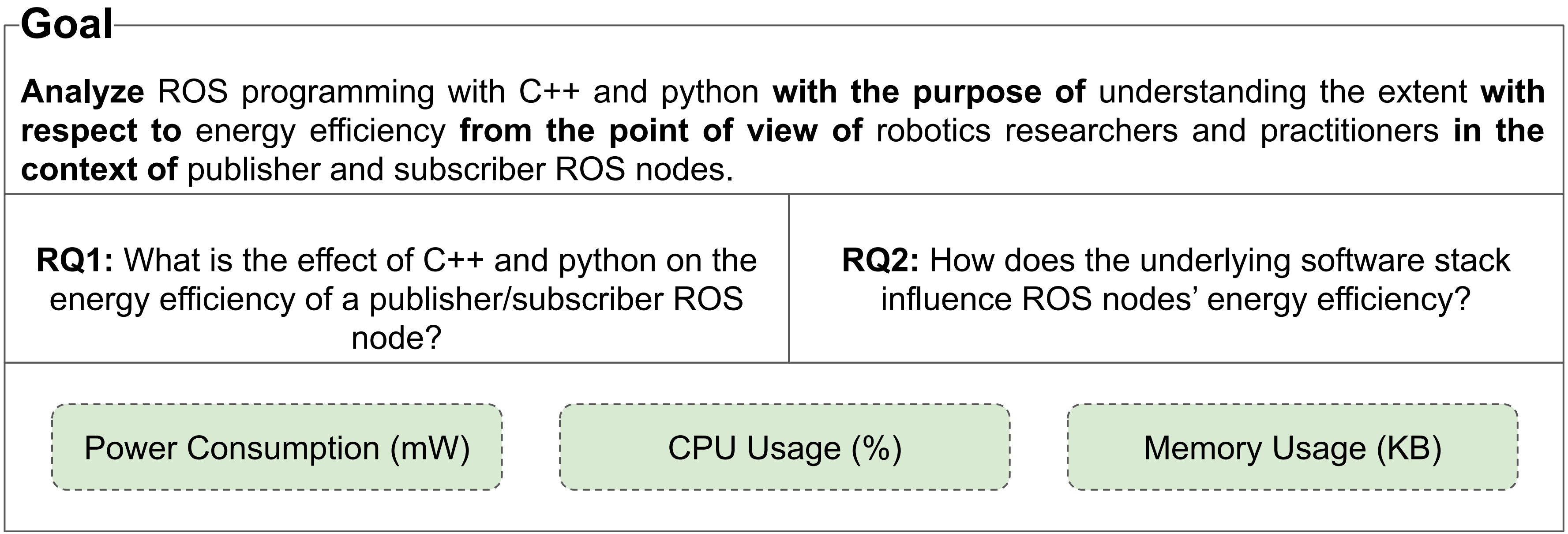
Client libraries

Table of Contents

- Overview
- Supported client libraries
    - The `rclcpp` package
    - The `rclpy` package
    - Community-maintained

Research Design

Experiment Definitions (GQM)



Goal

Analyze ROS programming with C++ and python **with the purpose of** understanding the extent **with respect to** energy efficiency **from the point of view of** robotics researchers and practitioners **in the context of** publisher and subscriber ROS nodes.

RQ1: What is the effect of C++ and python on the energy efficiency of a publisher/subscriber ROS node?

RQ2: How does the underlying software stack influence ROS nodes' energy efficiency?

Power Consumption (mW)

CPU Usage (%)

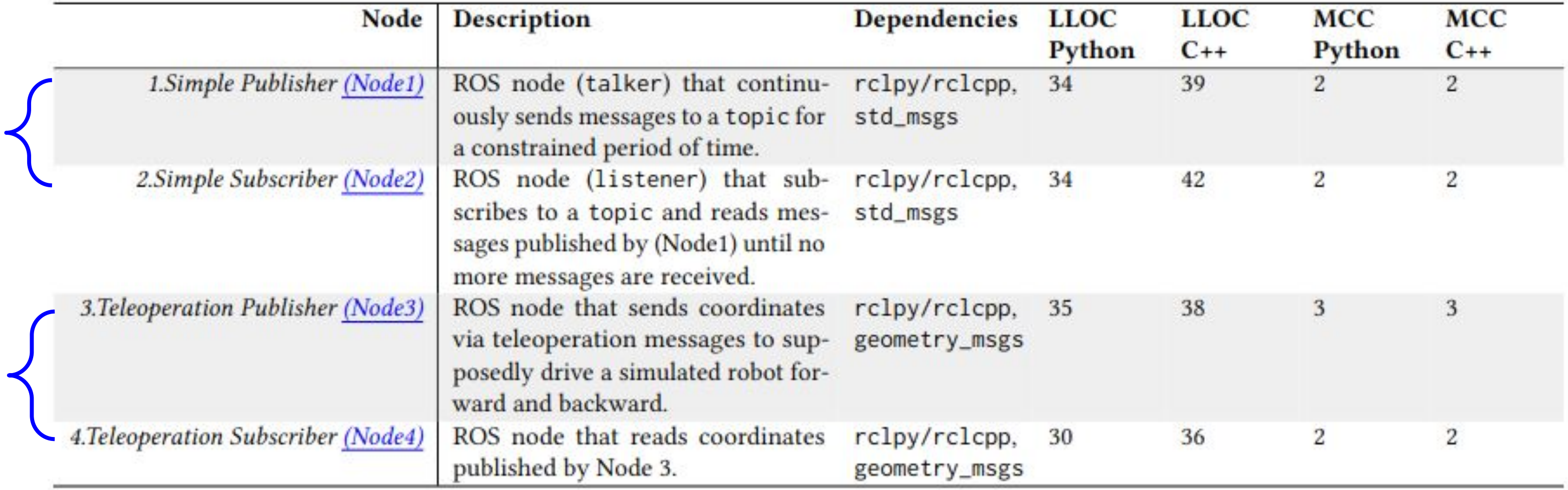
Memory Usage (KB)

Research Design

Experiment Planning

https://github.com/IntelAgir-Research-Group/energy-ros2-cpp-python

Table 2: Algorithms subject of investigation



Node	Description	Dependencies	LLOC Python	LLOC C++	MCC Python	MCC C++
1.Simple Publisher (Node1)	ROS node (talker) that continuously sends messages to a topic for a constrained period of time.	rclpy/rclcpp, std_msgs	34	39	2	2
2.Simple Subscriber (Node2)	ROS node (listener) that subscribes to a topic and reads messages published by (Node1) until no more messages are received.	rclpy/rclcpp, std_msgs	34	42	2	2
3.Teleoperation Publisher (Node3)	ROS node that sends coordinates via teleoperation messages to supposedly drive a simulated robot forward and backward.	rclpy/rclcpp, geometry_msgs	35	38	3	3
4.Teleoperation Subscriber (Node4)	ROS node that reads coordinates published by Node 3.	rclpy/rclcpp, geometry_msgs	30	36	2	2

Research Design

Experiment Execution

- Instrumentation:
    - Linux Ubuntu 22.04 operating system, kernel version 6.2.0-33-generic, with 8GB of RAM, and a Intel(R) Core(TM) i5-10210U CPU @ 1.60GHz.
    - ROS humble distribution.
    - Algorithms are executed via ROS run command.
    - Power saving mode: performance.
    - Process priority level: -20.
    - 1 minute cool-down period between executions.

Research Design

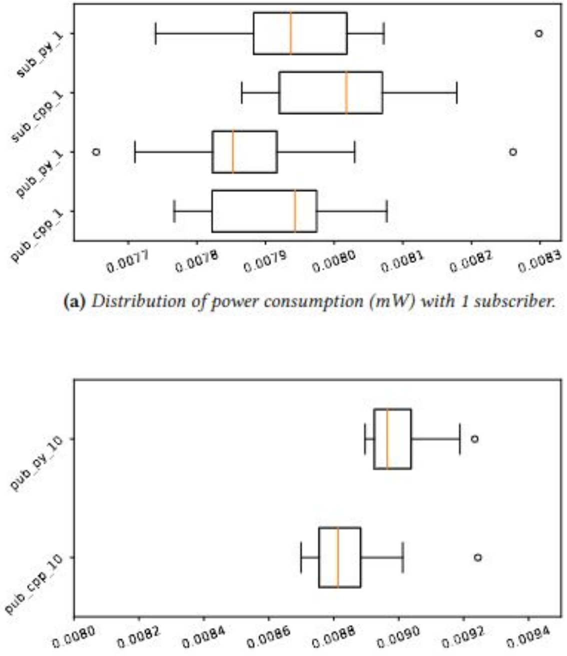
Experiment Execution

- Resource profiling instrumentation:
  - Energy Consumption: Intel Running Average Power Limit Energy Reporting.
    - pyRAPL wrapping up the ROS run command.
    - Validated against partial measurements with existing RAPL-based tool by Pereira et al. *
  - Power Consumption: P = E / t
  - CPU Usage: ps Linux command.
  - Memory Usage: pmap Linux command.

*Rui Pereira, Marco Couto, Francisco Ribeiro, Rui Rua, Jácome Cunha, João Paulo Fernandes, and João Saraiva. 2017. Energy efficiency across programming languages: how do energy, time, and memory relate? In Proceedings of the 10th ACM SIGPLAN International Conference on Software Language Engineering (SLE 2017). Association for Computing Machinery, New York, NY, USA, 256–267. https://doi.org/10.1145/3136014.3136031

Results

Simple Publisher and Subscribers



(a) *Distribution of power consumption (mW) with 1 subscriber.*

(b) *Distribution of power consumption (mW) of* n1 *with 10 subscribers (*n2 *instances).*

Figure 2: Power consumption of Nodes 1 (n1) and 2 (n2).

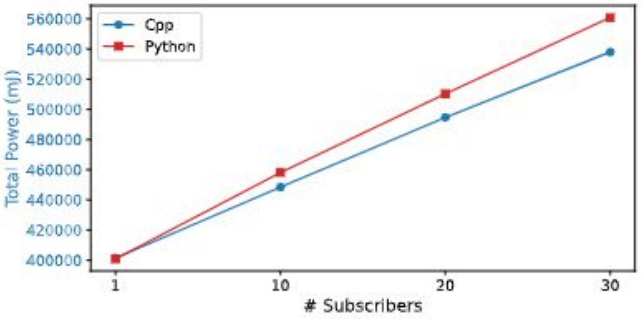


Figure 3: Power consumption scalability for Node 1.

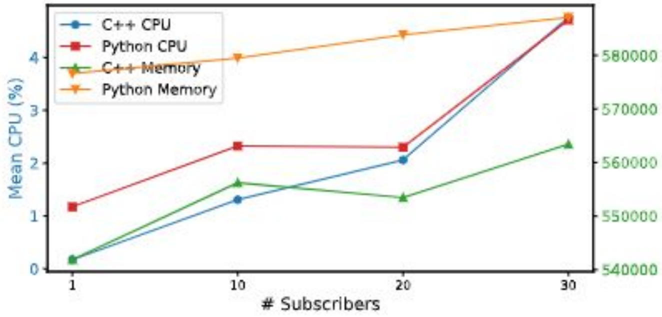


Figure 4: CPU and memory scalability of Node 1.

Results

Teleoperation Publisher and Subscribers

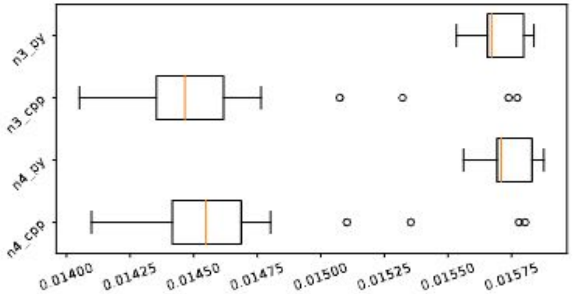


Figure 5: Power consumption (mW) of Nodes 3 (n3) and 4 (n4) with one instance each.

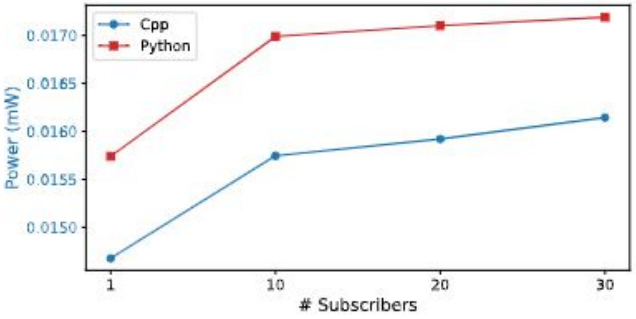


Figure 6: Power consumption scalability of Node 3.

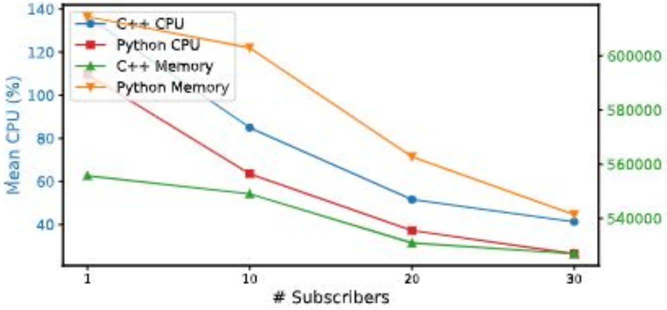


Figure 7: CPU and memory scalability of Node 3.

RQ Answers

- **RQ1:** What is the effect of C++ and python on the energy efficiency of a publisher/subscriber ROS node?
    - The choice of programming language, has an impact, with C++ being more energy-efficient.
- **RQ2:** How does the underlying software stack influence ROS nodes’ energy efficiency?
    - Memory tends to be the more determinant factor, despite not being exactly proportional.
    - There may be other architectural aspects of rcl client library implementations may influence the energy efficiency.
        - e.g., multithreading, memory allocation, garbage collection…

Limitations and Future Directions

- The study is reveals that carefully deciding about the programming language can help in having a greener/energy-efficient ROS code;
- The experiments focus on very specific nodes, which may not be completely representative:
  - Different communication layers;
  - Different message type formats;
  - Composed nodes.
- Part of the second experiment is inconclusive (overload), which requires further investigation.
- It is important to have a more detailed understanding of the implementation of each of the rcl client libraries.

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