Integration of Webots and Qiskit for experimentation with quantum circuits as robotic controllers

1o Taller Latinoamericano de Ingeniería de Software Cuántico (TLISC 2024)

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Agenda

Motivations

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2. As we demonstrate in these experiments, both simulators, Webots and Qiskit, can be integrated for education and research.

Agenda

Webots robotics simulator

Webots is an open source robotics 3D simulator (Apache 2 license). Originally developed by Olivier Michel at the *École Polytechnique Fédérale de Lausanne* (EPFL) in 1996 and used in industry, robotics research, and educational environments [1].

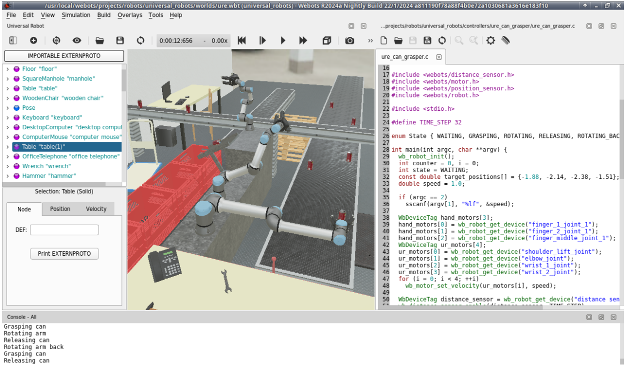


Figure: URE3 and URE5 robots simulated in Webots GUI.

e-puck robot

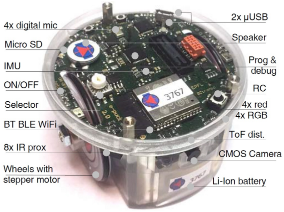


Figure: *e-puck* differential robot.

In these experiments, we utilized the e-puck robot, which was originally conceptualized by EPFL. This robot employs differential displacement via wheels and is equipped with an array of sensors and other devices, including eight proximity sensors, an accelerometer, a gyroscope, a camera, one encoder (position sensor) per wheel, eight light sensors, and others.

Braitenberg vehicles

In his book, *Vehicles - Experiments in Synthetic Psycology* [2], Valentino Braitenberg outlines robotic control systems based on simple controllers that exhibit simple behaviors considered natural, such as fear, aggression, and love. These mechanisms are referred to as *Braitenberg vehicles*.

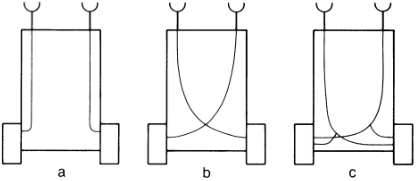


Figure: Three simple types of Braitenberg robots with two sensors and two motors. a) the motors are connected to their respective sensor, considering the orientation; b) cross connection; c) both motors receive data from the two sensors. [2].

Braitenberg vehicles

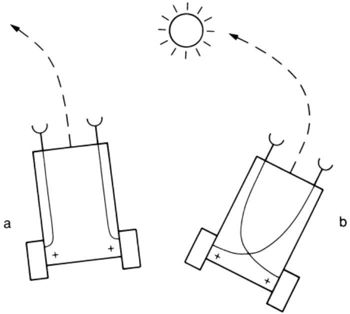


Figure: Two different behaviors corresponding to excitatory (+) or inhibitory (-) signals. a) the robot moves away from the light source, “fear”; b) the robot moves closer to the source, “love” [2].

The significance of these vehicles lies in their ability to exemplify a moderately intricate behavioral system through the use of highly simplified sensing and circuitry.

Agenda

Very brief introduction to QC

A quantum state is defined as a d-dimensional complex vector within a Hilbert space $\mathcal{H}$. The minimal unit of information is referred to as a *qubit*. These states can be in quantum superposition, expressed as a linear combination of the fundamental states. In the case of the computational basis, the aforementioned vectors are represented as follows:

$$|0\rangle = \begin{bmatrix} 1 & 0 \end{bmatrix}^{\mathsf{T}}, \qquad |1\rangle = \begin{bmatrix} 0 & 1 \end{bmatrix}^{\mathsf{T}}, \tag{1}$$

and their overlap is defined as:

$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle\,, \tag{2}$$

where $|\psi\rangle$ is a qubit, $|i\rangle$ with $i = \{0, 1\}$ is called a ket of i basis vectors, the coefficients $\alpha, \beta \in \mathbb{C}$ are called *probability amplitudes* and must be normalized according to Born's rule:

$$|\alpha|^2 + |\beta|^2 = 1. \tag{3}$$

Agenda

Main objective

> *The application of quantum mechanics, algorithms, and quantum computation to the study of robotics [3].*

Quantum robotics. Approaches

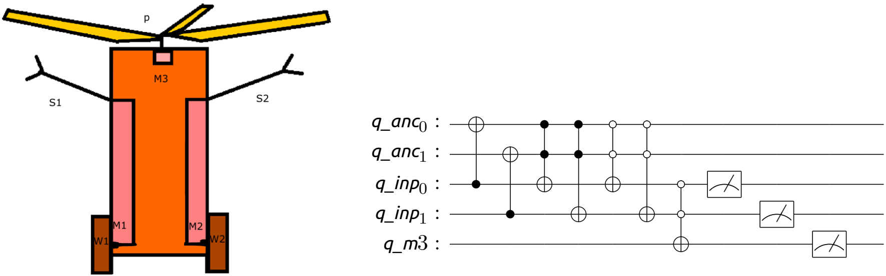
Two approaches to quantum robotics. In the first one, the complete immersion of a robot in a quantum system has been studied by introducing the theoretical concept of quantum robots by Benioff [4, 5, 6]. In this approach, a quantum robot is a mobile quantum system that includes an on-board quantum computer and requires auxiliary systems.

Quantum robotics. Approaches

Two approaches to quantum robotics. In the first one, the complete immersion of a robot in a quantum system has been studied by introducing the theoretical concept of quantum robots by Benioff [4, 5, 6]. In this approach, a quantum robot is a mobile quantum system that includes an on-board quantum computer and requires auxiliary systems.

In the second approach, all physical elements of a regular robot, such as sensors and effectors, are considered as part of a classical system, i.e. they are regarded as a macro system that obeys Newtonian laws and which does not require the application of quantum theory in order to be subjected to analysis or operation. In this instance, the control elements are implemented through the use of quantum circuits [7][8][3]. Raghuvanshi [7] has proposed the term *quantum controlled robot*.

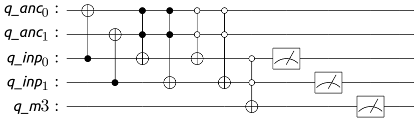
Quantum robots can fly [3]



(a) (b)

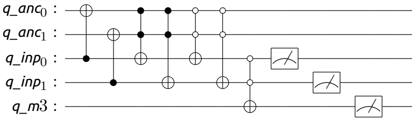
Figure: A three-motor quantum robot control circuit has been developed. (a) Schematic representation; (b) circuit diagram. The upper two qubits serve as auxiliary qubits (ancillae), the next two are input qubits, and the final one is connected to the third motor, which controls the propeller *M3* [3].

Code




```
q_anc = QuantumRegister(2, 'q_anc')
q_inp = QuantumRegister(2, 'q_inp')
q_m3 = QuantumRegister(1, 'q_m3')

c_m1m2 = ClassicalRegister(3, 'c_m1m2')

qc = QuantumCircuit(q_anc, q_inp, q_m3, c_m1m2)

qc.cx(q_inp[0], q_anc[0])
qc.cx(q_inp[1], q_anc[1])

qc.ccx(q_anc[0], q_anc[1], q_inp[0])
qc.ccx(q_anc[0], q_anc[1], q_inp[1])
```

Code




```
# (ctrl_state=0) == active in 0
qc.ccx(q_anc[0], q_anc[1], q_inp[0], ctrl_state=0)
qc.ccx(q_anc[0], q_anc[1], q_inp[1], ctrl_state=0)

qc.ccx(q_inp[0], q_inp[1], q_m3, ctrl_state=0)

qc.measure(q_inp, c_m1m2[0:2])
qc.measure(q_m3, c_m1m2[2])

sim = AerSimulator()
qc_trans = transpile(qc, sim)
job = sim.run(qc_trans)
counts = job.result().get_counts(qc_trans)
```

Webots + Qiskit

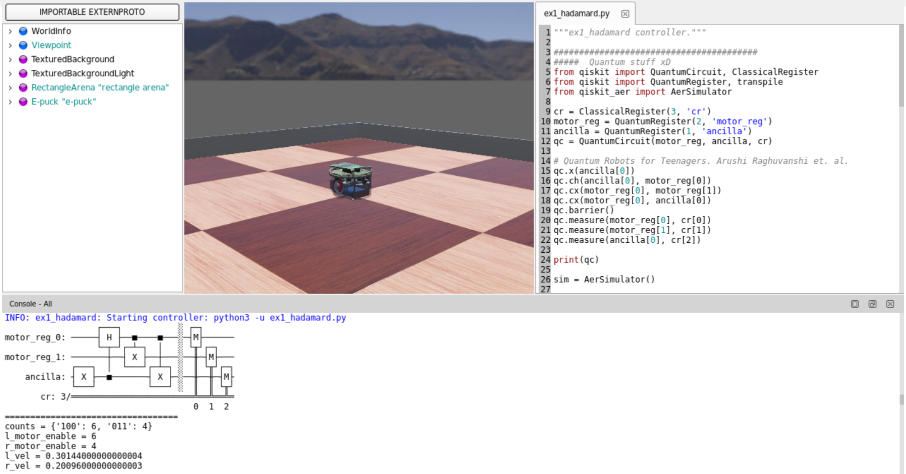


Figure: Webots simulation environment, running a GHZ quantum circuit which serves as the controller for the *e-puck* robot.

Future work

- Research and integration of quantum reinforcement learning tasks and algorithms are planned for experimentation with the Webots simulator.

Agenda

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> We plan to study quantum algorithms, which are **interesting** whether quantum computers are built soon, in the next ten years, in the next fifty years, or never. The area of quantum algorithms contains some **beautiful ideas** that **everyone** interested in computation **should know**.
>
> – *Quantum Algorithms via Linear Algebra. A Primer*
> Richard J. Lipton, Kenneth W. Regan.

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