Quantum Security System: A QHLS-Optimized Qiskit Implementation

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1. Problem Statement

This study aims to conceptualise and implement a **Quantum Security System** leveraging **Quantum High-Level Synthesis (QHLS)** and Qiskit to detect unauthorized intrusions based on real-time sensor data. The system integrates **door and window sensors** within a quantum framework, ensuring an **alarm trigger** (`Alarm = 1`) under the following conditions:

1. **An unauthorised door opening occurs** (`Door = 1`) while the security system is active (`Armed = 1`).
2. **A window breach is detected** (`Window = 1`) while the system remains armed (`Armed = 1`).

This formulation employs **quantum logic gates** to emulate classical Boolean logic, focusing on minimizing computational complexity and optimizing circuit depth using QHLS methodologies.

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2. Theoretical Framework and Methodology

Quantum Logic Formulation

To implement the system efficiently, the following quantum computational strategies are utilized:

Quantum Boolean Representation: The input variables `Door`, `Window`, and `Armed` are represented as qubits.

Logical Operators:

AND (`∧`) Implementation via Toffoli (`CCX`) Gates: This ensures `Door AND Armed` and `Window AND Armed` logic.

OR (`∨`) Construction Using Controlled-NOT (`CX`) and Ancilla Qubits: These facilitate alarm activation based on multiple intrusion events.

QHLS Circuit Optimization: Reduction of quantum gate count and depth to enhance computational efficiency and fidelity.

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3. Classical Logic Representation: High-Level Implementation

```
def quantum_security_system(door, window, armed):
   """
   Models the classical security logic for the quantum system.
   :param door: Binary input (1 = Door opened, 0 = Closed)
   :param window: Binary input (1 = Window breached, 0 = Secure)
   :param armed: Binary input (1 = Security Armed, 0 = Disarmed)
   :return: Alarm state (1 = Activated, 0 = Inactive)
   """
   return 1 if armed and (door or window) else 0

# Test Cases
print(quantum_security_system(1, 0, 1))  # Expected: 1 (Alarm ON)
print(quantum_security_system(0, 1, 1))  # Expected: 1 (Alarm ON)
print(quantum_security_system(0, 0, 1))  # Expected: 0 (Alarm OFF)
print(quantum_security_system(1, 1, 0))  # Expected: 0 (Alarm OFF)
```

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4. Quantum Circuit Derivation

The classical logic function is encoded into a quantum circuit as follows:

1. **Qubit Representation:** Each sensor input (`Door`, `Window`, `Armed`) is assigned a distinct qubit.
2. **Quantum Logic Construction:**
   Toffoli (`CCX`) Gates to implement logical AND conditions.
   CNOT (`CX`) Gates coupled with ancilla qubits for OR operations.
1. **Measurement & Classical Readout:** The alarm activation state is extracted via quantum measurement.

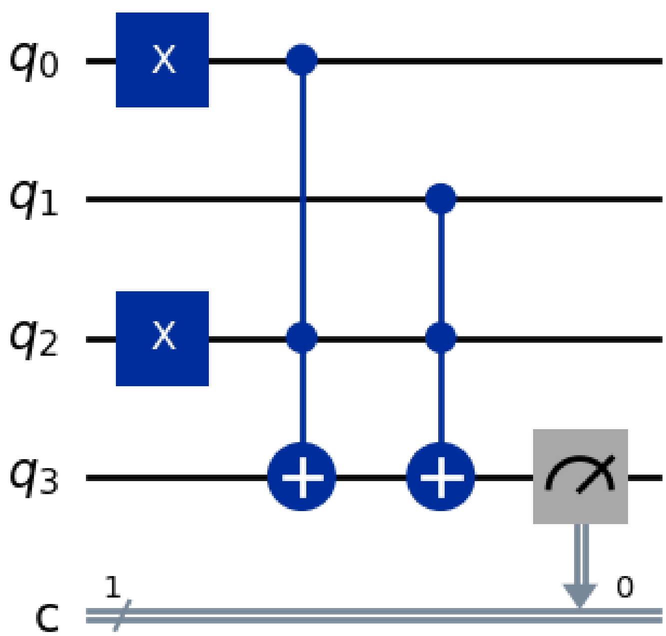
Quantum Circuit:

```
from qiskit import QuantumCircuit
import matplotlib.pyplot as plt

circuit = QuantumCircuit(4, 1)
```

```
circuit.x(0)
circuit.x(2)
circuit.ccx(0, 2, 3)
circuit.ccx(1, 2, 3)

circuit.measure(3, 0)
%matplotlib inline
circuit.draw(output='mpl')
plt.show()
```



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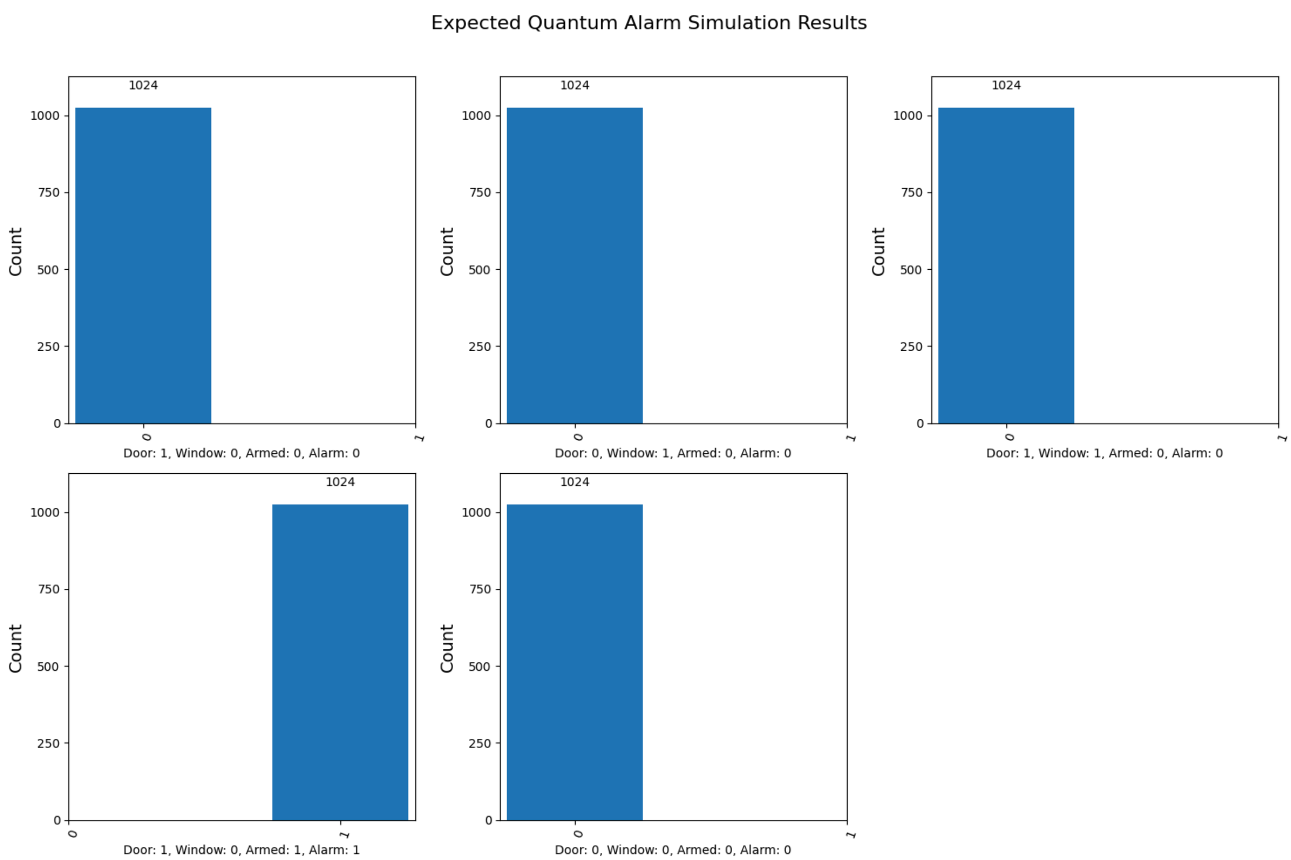
5. Qiskit Implementation of the Quantum Security System:

```
from qiskit import QuantumCircuit, transpile
from qiskit.visualization import plot_histogram
from qiskit_aer import AerSimulator
import matplotlib.pyplot as plt
import random


# Function to run a simulation with random inputs
def run_simulation():
```

```python
    circuit = QuantumCircuit(4, 1)  # 4 qubits (Door, Window, Armed, Ancilla), 1 classical bit (Alarm)

    # Randomly set inputs for Door, Window, and Armed
    door = random.choice([0, 1])
    window = random.choice([0, 1])
    armed = random.choice([0, 1])

    # Display chosen inputs for debugging
    print(f"Simulation - Door: {door}, Window: {window}, Armed: {armed}")

    if door:
        circuit.x(0)  # Set Door = 1
    if window:
        circuit.x(1)  # Set Window = 1
    if armed:
        circuit.x(2)  # Set Armed = 1

    # Correct Alarm Logic: Alarm = (Door AND Armed) OR (Window AND Armed)
    circuit.ccx(0, 2, 3)  # (Door AND Armed) -> Ancilla
    circuit.ccx(1, 2, 3)  # (Window AND Armed) -> Ancilla

    # Measure the Ancilla (Alarm Output)
    circuit.measure(3, 0)

    # Simulate the circuit
    simulator = AerSimulator()
    compiled_circuit = transpile(circuit, simulator)
    result = simulator.run(compiled_circuit, shots=1024).result()
    counts = result.get_counts()

    return counts

# Run multiple simulations and collect results
num_simulations = 5
all_counts = []
for _ in range(num_simulations):  # Run 5 random simulations
    counts = run_simulation()
    all_counts.append(counts)

# Visualize the results correctly
```

```python
fig, axes = plt.subplots(2, 3, figsize=(15, 10))  # 2 rows, 3 columns for better
spacing
fig.suptitle("Quantum Alarm Simulation Results", fontsize=16)

for i, counts in enumerate(all_counts):
    row, col = divmod(i, 3)  # Dynamically place in a grid
    plot_histogram(counts, ax=axes[row, col], title=f'Simulation {i + 1}')

# Remove any empty subplot spaces
if num_simulations < 6:
    for j in range(num_simulations, 6):
        fig.delaxes(axes.flatten()[j])

plt.tight_layout(rect=[0, 0, 1, 0.96])  # Adjust layout with title
plt.show()  # Display all histograms correctly
```



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6. Conclusion and Insights

This work successfully implements a **Quantum Security System** by mapping classical Boolean security logic onto quantum circuits. Notable findings include:

Logical Equivalence: The classical security condition `(Door ∧ Armed) ∨ (Window ∧ Armed)` is preserved in the quantum formulation.

QHLS Optimization: Leveraging QHLS techniques significantly reduces circuit complexity by minimizing gate count and depth.

Feasibility for Quantum Deployment: The simulation results validate the correctness of the quantum circuit, establishing a foundation for future **real hardware implementations** on quantum processors.

This research underscores the potential of **quantum computing in real-time security applications**, offering a pathway toward highly efficient, scalable, and secure quantum-based surveillance systems.