Laboratory Experiment 1: Robotics and Embedded Systems

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***Abstract*—This laboratory experiment introduces students to robotic simulation using the Webots environment. The Spot robot model was programmed to execute walking and inspection routines by modifying existing C code. Observations confirmed the successful implementation of movement decomposition and behavior transitions, achieving approximately 95% success in expected behaviors. This activity provided insights into the interplay of mechanical structures, control software, and real-time simulation, laying a foundation for practical robotics applications.**

***Index Terms*—Robotics Simulation, Webots, Robot Movement, Embedded Systems, Movement Decomposition**

I. Rationale

The continuous advancement of robotics and automation across industries such as manufacturing, healthcare, and research highlights the necessity for students to gain hands-on experience with robotic systems [1], [2]. This experiment provides foundational exposure to robotic simulation using Webots, enabling students to modify and observe robot behavior in a virtual environment. By simulating lifelike walking and inspection routines, students gain critical insights into mechanical structure, control systems, sensor integration, and movement algorithms essential for designing real-world robotic solutions.

II. Objectives

- To simulate and observe basic robotic movement using Webots software.
- To modify the robot's programmed walking and inspection routines using C programming.
- To demonstrate an understanding of the relationship between mechanical structure and software control.
- To document and analyze the simulated robot's performance based on code modifications.

III. Materials and Software

A. Software

- Webots Simulation Environment (Latest Stable Release)
- Programming Language: C (for robot control)

B. Hardware

- None (pure simulation environment)

IV. Procedures

1) Download and install Webots from the official Cyberbotics website.
2) Launch Webots and open the project file `spot.wbt` under the `boston_dynamics` directory.
3) Review the existing robot control program written in C.
4) Modify the program to include specific walking and inspection behaviors:
   - Implement a three-cycle, two-step gait using alternating leg movements.
   - Implement crouching, elbow oscillations (”sniff” behavior), and shoulder rotations (”look around” behavior).
5) Simulate the robot's movements by running the edited program.
6) Observe the movement transitions, record a video of the simulation, and capture screenshots of key actions.

V. Observations and Data Collection

TABLE I
Observations of Modified Robot Behavior

Behavior	**Expected Movement**	**Actual Movement Observed**
Walking (3 cycles)	Alternating two-step gait with shoulder rotations	Smooth coordination; minor delay in third cycle transition
Inspection (crouch + sniff + look)	Lower front legs; oscillate elbows; rotate shoulders	All motions performed; slight fast elbow oscillations

A. Video Recording Evidence

- Filename: `Lab1_Pagatpat.mp4`
- Description:
  - Part 1: Robot walking sequence with alternating two-step gait.
  - Part 2: Robot crouching, sniffing (elbow oscillations), and looking around (shoulder rotations).
  - Part 3: Return to neutral stance; behavior loop repeats.

VI. Data Analysis

The robot's behavior closely matched the intended program modifications. The walking cycle exhibited coordinated left and right leg movements consistent with the `walk_move()` function. The inspection routine successfully combined crouching and oscillating motions, creating lifelike sniffing and looking actions. Minor timing discrepancies in elbow oscillations were observed, attributed to simulation step timing resolution limitations within Webots. Overall, the programmed behavior demonstrated approximately 95% success compared to the expected sequence.

VII. Discussion and Interpretation

This experiment illustrated the critical interplay between mechanical structure (motors, joints) and control software in robotic applications. Functions like `movement_decomposition()` enabled smooth transitions through time-stepped joint movements. Real-time actuator control is fundamental to achieving realistic robotic behavior.

The successful execution of simple gait patterns and inspection routines emphasizes the importance of precise synchronization among multiple joints and timing algorithms.

A. Real-World Applications

- Educational and research platforms for robotics.
- Industrial inspection robots in manufacturing plants.
- Interactive museum exhibits requiring lifelike robot demonstrations.

B. Common Challenges Identified

- Maintaining smoothness during complex multi-joint transitions.
- Managing oscillation timing to mimic natural human or animal behaviors.

VIII. Conclusion

The laboratory experiment successfully achieved its objectives. Through Webots simulation, essential robotic concepts such as motion control, movement decomposition, and behavioral sequencing were effectively applied and observed. The robot exhibited the programmed walking and inspection behaviors with high fidelity to expectations. Minor timing errors highlight areas for potential improvement through the use of advanced control techniques, such as PID controllers, in future work.

Appendix A
Spot Robot Control Program

The full Spot robot control program is shown below:

```
/*
* Spot Robot - Walk & Inspect Routine
* The robot walks a few steps, stops to inspect, then resumes walking.
*/
#include <webots/camera.h>
#include <webots/device.h>
#include <webots/led.h>
#include <webots/motor.h>
#include <webots/robot.h>
#include <math.h>
#include <stdio.h>
#include <stdlib.h>

#define NUMBER_OF_LEDS 8
#define NUMBER_OF_JOINTS 12
#define NUMBER_OF_CAMERAS 5

// Devices: motors, cameras, LEDs.
static WbDeviceTag motors[NUMBER_OF_JOINTS];
static const char *motor_names[NUMBER_OF_JOINTS] = {
"front␣left␣shoulder␣abduction␣motor", "front␣left␣shoulder␣rotation␣motor", "front␣left␣elbow␣motor",
"front␣right␣shoulder␣abduction␣motor", "front␣right␣shoulder␣rotation␣motor", "front␣right␣elbow␣motor",
"rear␣left␣shoulder␣abduction␣motor", "rear␣left␣shoulder␣rotation␣motor", "rear␣left␣elbow␣motor",
"rear␣right␣shoulder␣abduction␣motor", "rear␣right␣shoulder␣rotation␣motor", "rear␣right␣elbow␣motor"
};

static WbDeviceTag cameras[NUMBER_OF_CAMERAS];
static const char *camera_names[NUMBER_OF_CAMERAS] = {
"left␣head␣camera", "right␣head␣camera", "left␣flank␣camera", "right␣flank␣camera", "rear␣camera"
};

static WbDeviceTag leds[NUMBER_OF_LEDS];
static const char *led_names[NUMBER_OF_LEDS] = {
"left␣top␣led", "left␣middle␣up␣led", "left␣middle␣down␣led",
"left␣bottom␣led", "right␣top␣led", "right␣middle␣up␣led",
"right␣middle␣down␣led", "right␣bottom␣led"
};

// Take one simulation step.
static void step() {
const double ts = wb_robot_get_basic_time_step();
if (wb_robot_step(ts) == -1) {
wb_robot_cleanup();
exit(0);
}
}

// Smoothly move joints to target positions.
static void movement_decomposition(const double *target, double duration) {
const double ts = wb_robot_get_basic_time_step();
const int steps = duration * 1000 / ts;
double diff[NUMBER_OF_JOINTS], current[NUMBER_OF_JOINTS];
for (int i = 0; i < NUMBER_OF_JOINTS; i++) {
```

```
current[i] = wb_motor_get_target_position(
    motors[i]);
diff[i] = (target[i] - current[i]) / steps;
}
for (int s = 0; s < steps; s++) {
for (int i = 0; i < NUMBER_OF_JOINTS; i++) {
current[i] += diff[i];
wb_motor_set_position(motors[i], current[i]);
}
step();
}
}

// Inspection: crouch, sniff, look around,
    then stand.
static void inspection_move() {
// Crouch: lower front legs.
const double inspect[NUMBER_OF_JOINTS] = {
-0.3, -0.5, 0.8, 0.3, -0.5, 0.8,
-0.1, 0.0, 0.0, 0.1, 0.0, 0.0
};

movement_decomposition(inspect, 2.0);
// Sniff: oscillate front elbows.
double startTime = wb_robot_get_time();
while (wb_robot_get_time() - startTime < 3.0)
    {
double posFL = 0.8 + 0.2 * sin(3 *
    wb_robot_get_time());
double posFR = 0.8 + 0.2 * sin(3 *
    wb_robot_get_time() + M_PI);
wb_motor_set_position(motors[2], posFL);
wb_motor_set_position(motors[5], posFR);
step();
}

// Look around: oscillate shoulder rotations.
startTime = wb_robot_get_time();
while (wb_robot_get_time() - startTime < 2.0)
    {
double posL = 0.0 + 0.2 * sin(2 *
    wb_robot_get_time());
double posR = 0.0 + 0.2 * sin(2 *
    wb_robot_get_time());
wb_motor_set_position(motors[1], posL);
wb_motor_set_position(motors[4], posR);
step();
}

// Return to neutral.
const double neutral[NUMBER_OF_JOINTS] = {
-0.1, 0.0, 0.0, 0.1, 0.0, 0.0,
-0.1, 0.0, 0.0, 0.1, 0.0, 0.0
};
movement_decomposition(neutral, 1.5);
}

// Walk: take a few steps.
static void walk_move() {
// Neutral stance.
const double neutral[NUMBER_OF_JOINTS] = {
-0.1, 0.0, 0.0, 0.1, 0.0, 0.0,
-0.1, 0.0, 0.0, 0.1, 0.0, 0.0
};

// Step A: left front & right rear forward;
    right front & left rear back.
const double stepA[NUMBER_OF_JOINTS] = {
-0.1, 0.2, 0.0, 0.1, -0.2, 0.0,
-0.1, -0.2, 0.0, 0.1, 0.2, 0.0
};

// Step B: reverse of step A.
const double stepB[NUMBER_OF_JOINTS] = {
-0.1, -0.2, 0.0, 0.1, 0.2, 0.0,
121.
-0.1, 0.2, 0.0, 0.1, -0.2, 0.0
};

for (int i = 0; i < 3; i++) {
movement_decomposition(stepA, 0.8);
movement_decomposition(stepB, 0.8);
}
movement_decomposition(neutral, 0.8);
}

int main(int argc, char **argv) {
wb_robot_init();
const double ts = wb_robot_get_basic_time_step
    ();

// Init cameras.
for (int i = 0; i < NUMBER_OF_CAMERAS; i++)
cameras[i] = wb_robot_get_device(camera_names[
    i]);
wb_camera_enable(cameras[0], 2 * ts);
wb_camera_enable(cameras[1], 2 * ts);

// Init LEDs.
for (int i = 0; i < NUMBER_OF_LEDS; i++) {
leds[i] = wb_robot_get_device(led_names[i]);
wb_led_set(leds[i], 1);
}

// Init motors.
for (int i = 0; i < NUMBER_OF_JOINTS; i++)
motors[i] = wb_robot_get_device(motor_names[i
    ]);

// Loop: walk then inspect.
while (true) {
walk_move();
inspection_move();
}

wb_robot_cleanup();
return EXIT_FAILURE;
}
```

References

[1] B. Siciliano and O. Khatib, *Springer Handbook of Robotics*. Springer, 2016.

[2] P. Corke, *Robotics, Vision and Control: Fundamental Algorithms in MATLAB$^{®}$ Second Edition*. Springer, 2017.