Demo: Monitoring Movement Dynamics of Robot Cars and Drones Using Smartphone's Built-in Sensors

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***Abstract*—In this demo, we present a smart system that can monitor the movement dynamics of any carrying platform (e.g., robot car and drone) leveraging the inertial sensors of the attached smartphone. Through the measured inertial sensor readings, we can monitor the movement dynamics of the carrying platform in real-time, such as the platform's moving speed, displacement, and position. Unlike Global Positioning System (GPS), which shows severe accuracy degradation when GPS signals are weak (e.g., in indoor or urban environments), our system tracks the platform's movements and performs positioning without receiving external signals. Thus, our system can be an effective alternative approach to monitor the movement dynamics of those indoor objects (e.g., sweeping robot, indoor drone). Specifically, we exploit the motion-sensing capabilities of smartphone's inertial sensors to measure the carrying platform's movement dynamics. The inertial magnetometer of the smartphone allows us to reorient sensors with the cardinal directions; the gyroscope and accelerometer enable measuring the velocity and displacement of the platform. Our experimental results demonstrate that our system can accurately measure the movement dynamics of carrying platform with the easy-to-access smartphone sensors, as a substitution of GPS-based positioning in indoor environments.**

***Index Terms*—Movement dynamics, smartphone, velocity, displacement**

I. Introduction

With the flourishing development of smart carrying platforms (e.g., robot cars and drones), there exists an increasing demand for monitoring movement dynamics of the carrying platforms under various environments. Especially existing methods based on GPS [1] are less accurate in dense urban or indoor areas due to the GPS signal attenuation and distortion when traveling through buildings. To tackle this constraint, we present a smart system that can monitor the movement dynamics of any carrying platform (e.g., robot cars and drones) leveraging the inertial sensors of the attached smartphone, which can be an alternative approach to monitor the movement dynamics of indoor moving objects (e.g., sweeping robot, indoor drone).

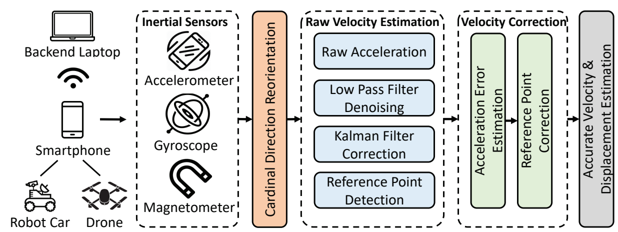

Fig. 1. The system overview of smart monitoring prototype.

Various inertial sensors in the smartphone are easy-to-access and have the capability of sensing the smartphone's acceleration and direction without relying on external signals. Attaching the smartphone to the carrying platform has high potential to monitor the carrying platform's movement dynamics. In our work, we attach the smartphone on the carrying platform (e.g., a robot car or drone) to monitor movement dynamics such as velocity and displacement leveraging smartphone's various inertial motion sensors (i.e., accelerometer, gyroscope, and magnetometer). When the carrying platform moves, the attached smartphone captures acceleration via the accelerometer to discriminate the velocity and displacement of the carrying platform. Moreover, we exploit the gyroscope and magnetometer in the attached smartphone to measure the angular velocity of the carrying platform and reorient the platform's coordinate plane with that of the earth. Through integrating multiple inertial sensors of the smartphone attached to the carrying platform, our work accurately derives the movement dynamics of the carrying platform such as the velocity and displacement.

We implement the carrying platform prototype using a robot car and drone respectively as shown in Figure 2. The movement dynamics are monitored through the smartphone attached

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to the prototype, and the real-time movement dynamics are shared with the backend server through WiFi connection.

II. System Design

A. Prototype Design

The overview of our system is illustrated in Figure 1. We implement our systems on a robot car and drone to monitor the 2D and 3D movement dynamics, respectively.

The robot car is prototyped based on Arduino and programmed in C++ to possess various capabilities such as remote control and obstacle avoidance. A phone holder is mounted on the robot car to tightly grip the smartphone and reduce the noises of the sensor readings caused by vibration when the robot car moves.

The robot car moves on the ground plane, thus can be monitored using 2D movement dynamics. To extend the capability of our work, we also implement a 3D aerial prototype based on a commercial off-the-shelf (COTS) quadcopter with a smartphone fixed to its frame.

To sense the movements through smartphone sensors, we use the open-source Android-based smartphone and develop an Android application. Our application integrates hardware-level APIs to read the raw data from various inertial sensors. The raw sensor readings are processed through multi-threading techniques to reduce the response latency of the application and transmitted to a backend server through TCP protocol-based wireless connection for the server-side demonstration.

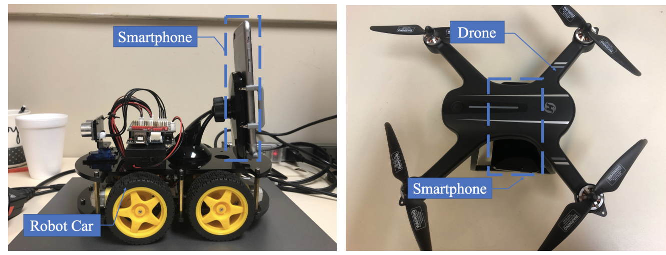
B. Displacement & Velocity Measurement

The inertial sensors of the smartphone demonstrate the device's position in the phone's coordinate system, which changes with the phone's orientation. Hence, we first align the coordinate plane of the smartphone with that of the earth by leveraging the magnetometer and the gyroscope. Particularly, we calculate the rotation matrix that maps the orientation information of the phone with the geomagnetism and monitors the movements based on the cardinal directions. Then we acquire the real-time acceleration from the accelerometer to calculate movement velocity. To mitigate the noise of raw accelerometer readings, we apply a low pass filter to denoise the acceleration. Then we use Kalman filter [2] to recursively estimate the velocity. However, the velocity estimation through accelerometer suffers from accumulated error over time. To address this, we develop a velocity correction algorithm based on Senspeed [3], which corrects the velocity at a series of reference points. Specifically, we derive the acceleration error as:

$$\widetilde{A}_i = a \cdot \widetilde{A}_{i-1} + (1-a) \times \frac{\Delta V(T_i) - \Delta V(T_{i-1})}{\Delta T_{i-1}^{i}}, \qquad (1)$$

where the $\widetilde{A}_i$ is the current acceleration error at the i^{th} reference point, a is the weight coefficient set as 0.5, $V(T_i)$ is the accelerometer's readings from zero to time T_i, and ΔT_{i-1}^{i} is the time interval between reference points a and b. Then we correct the velocity using the below method:

$$V'(t) = V(t) - \Delta V(T_i) - \widetilde{A}_{i+1} \times (t - T_i). \qquad (2)$$



(a) (b)

Fig. 2. The robot car-based and drone-based smart monitoring platforms.

The above velocity correction algorithm achieves accurate speed measurement. Based on the moving speed and time, we derive the displacement to demonstrate the movement and position of the carrying platform.

III. Hardware Implementation

We design and implement a carrying platform using a robot car to monitor 2D movement dynamics. As shown in Figure 2(a), the robot car grips the smartphone using a phone holder. The robot car is implemented based on Arduino UNO Rev3 and programmed in C++. We develop various functions for the robot car including Bluetooth-based remote control (e.g., move forward/backward, turn left/right, control moving speed), line tracking, and obstacle avoidance.

Besides, we devise a carrying platform with a drone, which can move in three dimensions to monitor 3D movement dynamics. This platform is implemented using a COTS quadcopter with a smartphone bound to the drone's frame, as shown in Figure 2(b). When the quadcopter moves, the attached smartphone captures 3D inertial sensor readings to monitor the movement dynamics aerially.

IV. Demonstration Setup

We need a table (a normal office table) to hold the laptop, robot car, drone, and a monitor. Moreover, black tapes need to be attached on the ground as the tracking path for the robot car. Plastic-made obstacles are also needed to be placed on the ground.

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