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Design and performance evaluation of wiimote-based two-dimensional indoor localization systems for indoor mobile robot control

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ABSTRACT

Indoor localization of mobile units is critical for subsequent task development of intelligent living technology. In this work, a modified wiimote-based 2D localization scheme is proposed and experimentally validated for indoor mobile robot tracking and control tasks. This scheme uses one wiimote to monitor the position of at least two IR LEDs simultaneously for determining both translation and rotation motions of the wiimote-mounted carrier. An algorithm is then developed for converting the wiimote readouts to the position and orientation of the corresponding mobile unit based on the major axes identification, coordinate transformation, and position updating. The scheme and the algorithm are then validated by tracking the wiimote location on a two-axis linear servomotor. Finally, by integrating this global positioning scheme with feedback control, trajectory tracking of an omni-wheel based mobile robot is performed to demonstrate the importance of the scheme in indoor smart living technology.

1. Introduction

Position sensing plays a critical role in intelligent living and smart building applications. With accurate positioning information, important tasks in navigation, feedback control, coordinated motion, and trajectory planning can be realized. Furthermore, position information of mobile carriers is also essential for executing key deliberative navigation schemes for multiple robot collaboration [1], path planning [2] and collision avoidance [3,4]. As a result, the importance of selecting an appropriate localization sensor and scheme is increasing. However, due to restrictions in positioning resolution, system dynamic responses, and the need to compromise with complicated indoor environments, a flawless positioning technique has not yet been achieved. Various solutions currently exist for indoor positioning, navigation, and communications such as inertial navigation system (INS) [5,6], ultrasonic localization [7], laser range finders [8], and radio signals such as ultra-wide band signal (UWB) [9–12] and received signal strength indication (RSSI) [13,14] methods have been developed. These techniques each have their own strengths and weaknesses. For example, the advantages of using GPS include its larger range of valid satellite coverage and the global localized signals. However, ultrasonic localization generally provides higher localization accuracy with a simpler structure. However, reflection effects and Non-Line-of-Sight (NLOS) propagation have a huge impact on positioning accuracy. Meanwhile, it may require several laser range finders simultaneously mounted on a mobile unit for better location estimation. This brings cost concern. In addition, it can only detect the relative distance between the mobile unit and some obstacles. On the other hand, systems based on radio signals have suffer from multipath fading in indoor environment [15] and it usually results in considerable localization

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uncertainties and it is also prohibited for areas with RF sensitive equipment. Finally, INS suffers from signal drafting and cannot be used without an external position updating scheme.

Another solution is to use multi-sensor fusion approach. For example, Luo and Lai [16] integrated a SwissRanger, a stereo camera, a laser ranger finder, several ultrasonic sensors, and a wheel odometer on a mobile robot for constructing the indoor map for robot control. Although this approach may yield better performance, the cost may not be affordable since these sensors are all mounted on each mobile unit, not on the fixed space.

For reducing the cost for indoor localization, optical-based localization could be a possible solution. Jung et al. [17] proposed a concept by placing several light emitted diodes (LEDs) with different frequencies on the ceiling of an indoor space. The mobile carrier simultaneously receives these light signals and its location can be determined by the time difference of arrivals (TDOA) of these lights. The simulation results indicated that the localization resolution can be in the order of 2 cm. However, it lacks of experimental validation and this scheme may face difficulties in real indoor space due to complicate space arrangement and the cost for performing the TDOA measurement and computations.

IR positioning is another possibility for indoor localization and this technique has been extensively used in smart items [18] or mobile robot localization [19,20]. Furthermore, Nintendo wiimotes recently integrated a CMOS IR-detector (called the *wiimote camera hereafter*), a MEMS accelerometer, and Bluetooth communication for TV games. In addition to home entertainment applications, wiimotes have also gained attention in mechatronics [21] and human–machine interactions [22–24], and its capability in these fields has already been demonstrated. For example, Olufs and Vincze used a wiimote as a control interface to manipulate an indoor mobile robot [25]. One major aspect of wiimotes in this work is that it can simultaneously detect simple light-emitted IR sources with reasonable speed and accuracy, implying that wiimotes could serve as indoor IR-based position sensors. Furthermore, the cost for realizing the localization is relatively affordable. It only requires a wiimote module for each mobile unit, an array of IRLEDs for a living space, and a Bluetooth-compatible computer with LabView environment. This makes the scheme cost comparative in comparison with other localization schemes. Notice that the deployment of IR LEDs must be careful since if there are other IR sources nearby (such as sun, halogen lamps, and even an IR-reflective media such as shining metal surfaces), wiimotes may not be able to capture the image of the desired IR LEDs correctly even an optical filter is already placed in the front of the wiimote camera for filtering possible disturbances.

For advancing subsequent sensor/actuator integration and control development, the capability of wiimote IR detectors must first be characterized. Typical key issues include resolution, measurement ranges, bandwidth, and linearity. In addition, a localization scheme to cover the entire indoor space must also be developed. Furthermore, in our earlier works [26,27], a preliminary wiimote 2D multi-zone indoor localization scheme was developed and successfully demonstrated via experiments. It was able to perform localization for a whole living space with a positioning resolution on the order of 2 cm. However, that scheme did not consider the rigid rotation of the target and the global coordinate can be lost if the target moves in both translation and rotation. As a result, the object must be manipulated in a special way to avoid the violation of the above restrictions. In our subsequent work, a modified localization scheme was proposed to address the above concerns [28–30]. In this paper, the development of the scheme is first introduced and subsequently experimentally validated for tracking both translation and rotation of a moving object. In order to demonstrate the importance and possible application of this wiimote localization scheme in mobile robot control, an omni-directional mobile robot is designed and assembled as the test protocol for robot control. We perform several feedback control demonstrations of trajectory following in which the wiimote system is integrated with feedback control to perform the designated tasks by successfully tracking the coordinates and orientation of the robot.

The remainder of this article presents the development and integration of the wiimote localization in detail. In Section 2, essential background and calibration of wiimote are introduced. The development of the localization scheme and its associate experimental validation, as well as the control in mobile robot localization, is then presented in Sections 2–5, respectively. Essential discussions to elucidate the novelty, contribution, and current limitation, as well as the future directions of this work, are offered in Section 6. Finally, Section 7 concludes this work.

2. Wiimote fundamentals and its calibration

As shown in Fig. 1, the wiimote camera is able to detect up to four IR LEDs. Its visual angle is approximately 45° and 35° in two in-plane axes (i.e., X and Y) directions to form a sensing zone with a resolution of 1024×768 pixels with a sampling rate of 107 Hz. There are two practical concerns for wiimote localizations. First, the detectable horizontal motion range is in the order of 1–2 m, which cannot cover the entire living space. Second, the individual IR LED cannot be distinguished and it cannot detect self-rotation using a single IR LED. Both concerns demand that special effort be made in order to use wiimotes for tracking indoor mobile units. To address the first concern, a multi-zone localization scheme is developed. For the second issue, a scheme based on simultaneously interpreting the positions of two IR LEDs, followed by coordinate transformation, is proposed for extracting the rotating motion of an object and is addressed in this work.

Fig. 2a shows the schematic plot of the experimental system for characterizing the static performance of wiimote. A wiimote is mounted on a Yokogawa linear servomotor (model types = LM110-1N-100AN). An IR LED is positioned on the opposite side with an adjustable sensing distance (66 cm in this experiment). The results are shown in Fig. 2b. The correlation between the wiimote output (LabView, in pixel unit) and the linear motor travel distance is highly linear. The spatial resolution reduces line-