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Mapping, Path Following, and Perception with Long Range Passive UHF RFID for Mobile Robots

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Berichte aus der Robotik

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For my family

Abstract

Service robots have shown an impressive potential in providing assistance and guidance in various environments, such as supermarkets, shopping malls, homes, airports, and libraries. Due to the low-cost and contactless way of communication, radio-frequency identification (RFID) technology provides a solution to overcome the difficulties (e.g. occlusions) that the traditional line of sight sensors (e.g. cameras and laser range finders) face. In this thesis, we address the applications of using passive ultra high frequency (UHF) RFID as a sensing technology for mobile robots in three fundamental tasks, namely mapping, path following, and tracking.

An important task in the field of RFID is mapping, which aims at inferring the positions of RFID tags based on the measurements (i.e. the detections as well as the received signal strength) received by the RFID reader. The robot, which serves as an intelligent mobile carrier, is able to localize itself in a known environment based on the existing positioning techniques, such as laser-based Monte Carlo localization. The mapping process requires a probabilistic sensor model, which characterizes the likelihood of receiving a measurement, given the relative pose of the antenna and the tag.

In this thesis, we address the problem of recovering from mapping failures of static RFID tags and localizing non-static RFID tags which do not move frequently using a particle filter. The usefulness of negative information (e.g. non-detections) is also examined in the context of mapping RFID tags. Moreover, we present a novel three dimensional (3D) sensor model to improve the mapping accuracy of RFID tags. In particular, using this new sensor model, we are able to localize the 3D position of an RFID tag by mounting two antennas at different heights on the robot. We additionally utilize negative information to improve the mapping accuracy, especially for the height estimation in our stereo antenna configuration.

The model-based localization approach, which works as a dual to the mapping process, estimates the pose of the robot based on the sensor model as well as the given positions of RFID tags. The fingerprinting-based approach was shown to be superior to the model-based approach, since it is able to better capture the unpredictable radio frequency characteristics in the existing infrastructure. Here, we present a novel approach that combines RFID fingerprints and odometry information as an input of the motion control of a mobile robot for the purpose of path following in unknown environments. More precisely, we apply the teaching and playback scheme to perform this task. During the teaching stage, the robot is manually steered to move along a desired path. RFID measurements and the associated motion information are recorded in an online-fashion as reference data. In the second stage (i.e. playback stage), the robot follows this path

autonomously by adjusting its pose according to the difference between the current RFID measurements and the previously recorded reference measurements. Particularly, our approach needs no prior information about the distribution and positions of the tags, nor does it require a map of the environment. The proposed approach features a cost-effective alternative for mobile robot navigation if the robot is equipped with an RFID reader for inventory in RFID-tagged environments.

The capability of a mobile robot to track dynamic objects is vital for efficiently interacting with its environment. Although a large number of researchers focus on the mapping of RFID tags, most of them only assume a static configuration of RFID tags and too little attention has been paid to dynamic ones. Therefore, we address the problem of tracking dynamic objects for mobile robots using RFID tags. In contrast to mapping of RFID tags, which aims at achieving a minimum mapping error, tracking does not only need a robust tracking performance, but also requires a fast reaction to the movement of the objects. To achieve this, we combine a two stage dynamic motion model with the dual particle filter, to capture the dynamic motion of the object and to quickly recover from failures in tracking. The state estimation from the particle filter is used in a combination with the VFH+ (Vector Field Histogram), which serves as a local path planner for obstacle avoidance, to guide the robot towards the target. This is then integrated into a framework, which allows the robot to search for both static and dynamic tags, follow it, and maintain the distance between them.

Kurzfassung

Service-Roboter bergen ein großes Potential bei der Unterstützung, Beratung und Führung von Kunden oder Personal in verschiedenen Umgebungen wie zum Beispiel Supermärkten, Einkaufszentren, Wohnungen, Flughäfen und Bibliotheken. Durch die geringen Kosten und die kontaktlose Kommunikation ist die RFID Technologie in der Lage vorhandene Herausforderungen traditioneller sichtlinienbasierter Sensoren (z.B. Verdeckung beim Einsatz von Kameras oder Laser-Entfernungsmessern) zu lösen. In dieser Arbeit beschäftigen wir uns mit dem Einsatz von passivem Ultrahochfrequenz (UHF) RFID als Sensortechnologie für mobile Roboter hinsichtlich drei grundlegender Aufgabenstellungen Kartierung, Pfadverfolgung und Tracking.

Kartierung nimmt eine wesentliche Rolle im Bereich der Robotik als auch beim Einsatz von RFID Sensoren ein. Hierbei ist das Ziel die Positionen von RFID-Tags anhand von Messungen (die Erfassung der Tags als solche und die Signalstärke) zu schätzen. Der Roboter, der als intelligenter mobiler Träger dient, ist in der Lage, sich selbst in einer bekannten Umgebung auf Grundlage der bestehenden Positionierungsverfahren, wie Laser-basierter Monte-Carlo Lokalisierung zurechtzufinden. Der Kartierungsprozess erfordert ein probabilistisches Sensormodell, das die Wahrscheinlichkeit beschreibt, ein Tag an einer gegebenen Position relativ zur RFID-Antenne (ggf. mit einer bestimmten Signalstärke) zu erkennen.

Zentrale Aspekte dieser Arbeit sind die Regeneration bei fehlerhafter Kartierung statischer RFID-Tags und die Lokalisierung von nicht-statischen RFID-Tags. Auch wird die Verwendbarkeit negativer Informationen, wie z.B. das Nichterkennen von Transpondern, im Rahmen der RFID Kartierung untersucht. Darüber hinaus schlagen wir ein neues 3D-Sensormodell vor, welches die Genauigkeit der Kartierung von RFID-Tags verbessert. Durch die Montage von zwei Antennen auf verschiedenen Höhen des eingesetzten Roboters, erlaubt es dieses Modell im Besonderen, die 3D Positionen von Tags zu bestimmen. Dabei nutzen wir zusätzlich negative Informationen um die Genauigkeit der Kartierung zu erhöhen.

Dank der Eindeutigkeit von RFID-Tags, ist es möglich die Lokalisierung eines mobilen Roboters ohne Mehrdeutigkeit zu bestimmen. Der modellbasierte Ansatz zur Lokalisierung schätzt die Pose des Roboters auf Basis des Sensormodells und den angegebenen Positionen der RFID-Tags. Es wurde gezeigt, dass der Fingerprinting-Ansatz dem modellbasierten Ansatz überlegen ist, da ersterer in der Lage ist, die unvorhersehbaren Funkfrequenzeigenschaften in der vorhandenen Infrastruktur zu erfassen. Hierfür präsentieren wir einen neuen Ansatz, der RFID Fingerprints und Odometrieinformationen für die Zwecke der Pfadverfolgung in unbekannten Umgebungen kombiniert. Dieser basiert

auf dem Teaching-and-Playback-Schema. Während der Teaching-Phase wird der Roboter manuell gelenkt, um ihn entlang eines gewünschten Pfades zu bewegen. RFID-Messungen und die damit verbundenen Bewegungsinformationen werden als Referenzdaten aufgezeichnet. In der zweiten Phase, der Playback-Phase, folgt der Roboter diesem Pfad autonom. Der vorgeschlagene Ansatz bietet eine kostengünstige Alternative für die mobile Roboternavigation bei der Bestandsaufnahme in RFID-gekennzeichneten Umgebungen, wenn der Roboter mit einem RFID-Lesegerät ausgestattet ist.

Die Fähigkeit eines mobilen Roboters dynamische Objekte zu verfolgen ist entscheidend für eine effiziente Interaktion mit der Umgebung. Obwohl sich viele Forscher mit der Kartierung von RFID-Tags befassen, nehmen die meisten eine statische Konfiguration der RFID-Tags an, nur wenige berücksichtigen dabei dynamische RFID-Tags. Wir wenden uns daher dem Problem der RFID basierten Verfolgung dynamischer Objekte mit mobilen Robotern zu. Im Gegensatz zur Kartierung von RFID-Tags, ist für die Verfolgung nicht nur eine stabile Erkennung notwendig, es ist zudem erforderlich schnell auf die Bewegung der Objekte reagieren zu können. Um dies zu erreichen, kombinieren wir ein zweistufiges dynamisches Bewegungsmodell mit einem Dual-Partikelfilter. Die Zustandsschätzung des Partikelfilters wird in Kombination mit dem VFH+ (Vektorfeld Histogramm) verwendet, um den Roboter in Richtung des Ziels zu leiten. Hierdurch ist es dem Roboter möglich nach statischen und dynamischen Tags zu suchen, ihnen zu folgen und dabei einen gewissen Abstand zu halten.

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