

**An experimental three-dimensional
indoor localization system using Ultra-
Wideband and inertial sensors**

Von der Fakultät für Elektrotechnik und Informatik der
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Preface

This dissertation has been created during my stay at the Institute of Communications Engineering (IKT) of the Leibniz Universität Hannover. I would like to thank the whole institute for the nice and helpful atmosphere.

Especially, I am grateful for the initiative of Prof. Dr.-Ing. Kyandoghere Kyamakya and Prof. Dr.-Ing. Klaus Jobmann for giving me the possibility to work at the IKT and for the financial support of the Minna-James-Heinemann Stiftung. In addition, I appreciate the cooperation of the Institute of Radiofrequency and Microwave Engineering (HFT) for providing generous access to the digital sampling oscilloscope.

Hannover, October 2007

Jens Schroeder

Kurzfassung

Indoor-Ortungssysteme für Personen und Objekte gewinnen in zunehmendem Maße an Bedeutung für Industrie- und Privatanwendungen. Insbesondere die Kombination von Position und Information auf Basis drahtloser Technologien und geographischer Daten führt zur Generierung von intelligentem Kontext, welcher eine Vielzahl von wertsteigernden und neuen Diensten ermöglicht. Anwendungen wie z.B. Produktionsautomatisierung, Lagerlogistik oder Notfallnavigation verlangen zuverlässige und sehr genaue dreidimensionale Ortungssysteme, wobei die spezifizierte Genauigkeit (nahezu) immer garantiert sein muss. Des Weiteren sind energiesparende und preiswerte Lösungen erwünscht, um eine hohe Marktdurchdringung zu erreichen.

Da die Ultra-Wideband (UWB) Technologie großes Potential für die Erfüllung solcher Anforderungen hat, wird ein experimentelles UWB-Ortungssystem entwickelt, und es wird demonstriert, dass der dreidimensionale Positionsfehler bei direkter Sichtverbindung (Line of Sight) in der Größenordnung von einem Dezimeter liegt. Das System wird schrittweise erweitert, um neue Ortungskonzepte praktisch zu bewerten. In diesem Zusammenhang werden die geometrische Anordnung von Basisstationen und Mobilteilen unter realistischen Bedingungen optimiert und Empfehlungen für die Installation solcher Systeme gegeben. Des Weiteren wird gezeigt, dass Non Line of Sight (NLOS) Kanäle die Qualität auf ein inakzeptables Niveau senken. Daher werden zwei aufeinander folgende Strategien untersucht, um solche Situationen zu bewältigen. Die Aufgabe, einen NLOS-Kanal zu erkennen, wird simulativ und messtechnisch anhand von vier teils neuen Methoden durchgeführt, und es wird bestätigt, dass der Kanalzustand annähernd genau geschätzt werden kann. Anschließend wird dieses Wissen in einem neuen und einem abgewandelten Algorithmus genutzt, um die Genauigkeit und Zuverlässigkeit zu erhöhen. Realistische Messungen zeigen, dass eine deutliche Verbesserung erreicht werden kann. Um eine weitere Steigerung der Ortungsqualität zu bewirken, wird das System durch Trägheitssensoren erweitert. Es wird demonstriert, dass die entworfene Koppelnavigation (Dead Reckoning) zusammen mit der NLOS-Erkennung den Ortungsfehler im NLOS soweit reduzieren kann, dass die Anforderungen des zugrundeliegenden Szenarios annähernd erreicht werden.

Diese Dissertation leistet einen Beitrag auf dem Gebiet der hybriden Lokalisierung mit UWB und Trägheitssensoren unter besonderer Beachtung von Genauigkeit und Robustheit in schwierigen Indoor-Umgebungen. Das Potential solcher Systeme wird bestätigt, und Erkenntnisse bezüglich der Umsetzung in ein mögliches Produkt werden gewonnen. Da die Entwicklung von UWB-Schaltungen und die Leistungssteigerung von Trägheitssensoren in naher Zukunft weiter voranschreiten wird, werden die gewünschten Anwendungen realisierbar sein.

Abstract

Indoor localization systems for persons and objects are lately gaining high interest for consumer and industrial applications. Especially the combination of position and information using wireless technologies in conjunction with geographical data allows the creation of intelligent context, which enables a great variety of value added or even new services. In this context, applications like production automation, warehouse logistics or emergency navigation, require highly reliable and very accurate three-dimensional localization systems, which are robust in a sense that the specified accuracy must (almost) always be guaranteed. In addition, low-power and low-cost implementations are desired to reach an adequate market penetration.

Since Ultra-Wideband (UWB) technology is seen as the enabler for achieving such requirements, an experimental UWB localization system is developed in this dissertation and it is shown that the three-dimensional position error remains in the order of a decimetre in Line of Sight environments. The basic configuration of the system is gradually enhanced for practical evaluation of novel positioning concepts. In this context, the geometrical arrangement of base stations and mobile units is optimized under realistic conditions and “best-practices” to install localization systems are formulated. Furthermore, the impact of Non Line of Sight (NLOS) channels is shown to degrade the performance to an unacceptable level. Therefore, two consecutive strategies are investigated to cope with such situations. First, the task of detecting an NLOS condition is conducted by means of simulative and real-world comparisons of four, partly newly proposed methods. It is confirmed that the channel state can be estimated quite accurately. Second, the knowledge of the NLOS state is exploited by designing a novel NLOS mitigation method and a derivation of an existing algorithm. Real-world measurements show that the three-dimensional accuracy and robustness can greatly be improved. To further increase the localization performance, the experimental system is enhanced with complementary inertial sensors. It is demonstrated that the designed dead reckoning algorithm combined with the novel NLOS mitigation method can decrease the localization error in NLOS condition close to the requirements of the underlying scenario.

This dissertation contributes to the field of hybrid localization using UWB and inertial sensors especially under the aspect of accuracy and robustness in difficult indoor environments. The potential of such a system is confirmed and insights into the feasibility towards a possible product are gained. As the developments of UWB circuitry and the performance increase of inertial sensors will proliferate further in the near future, it will be possible to realize the desired applications.

Schlagwörter / Keywords

Schlagwörter: Ultra-Wideband (UWB), Ortung, Inertialsensoren

Keywords: Ultra-Wideband (UWB), localization, inertial sensors

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Index of abbreviations

3D	Three-dimensional
ANSI	American National Standards Institute
AOA	Angle of Arrival
CDMA	Code Division Multiple Access
CRLB	Cramer-Rao Lower Bound
CSS	Chirp Spread Spectrum
DDP	Dominant Direct Path
DR	Dead Reckoning
DSP	Digital Signal Processor
DS-UWB	Direct Sequence Ultra-Wideband
DTDOA	Differential Time Difference of Arrival
EGNOS	European Geostationary Navigation Overlay Service
EIRP	Equivalent Isotropic Radiated Powers
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FPGA	Field Programmable Gate Arrays
GLONASS	GLObales NAVigations-Satelliten-System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
IC2	InertiaCube 2
IEEE	Institute of Electrical and Electronics Engineers
IHP	Innovations for High Performance Microelectronics
IKT	Institute of Communications Engineering
IMU	Inertial Measurement Unit
IR-UWB	Impulse Radio Ultra-Wideband
LEP	Linear Error Probable
LOS	Line of Sight
MA(n)	n-Moving Average
MB-OFDM	Multiband Orthogonal Frequency Division Multiplex

MEMS	Micro-Electrical Mechanical Systems
NDDP	Non-Dominant Direct Path
NLOS	Non Line of Sight
PDOP	Position Dilution Of Precision
PDR	Pedestrian Dead Reckoning
PRF	Pulse Repetition Frequency
PULSERS	Pervasive Ultra-Wideband Low Spectral Energy Radio Systems
RFID	Radio Frequency Identification
RMS	Root Mean Square
RSS	Received Signal Strength
SEP	Spherical Error Probable
SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TWR	Two-Way Ranging
UCAN	Ultra-Wideband Concepts for Ad-hoc Networks
UDP	Undetected Direct Path
UWB	Ultra-Wideband
VDOP	Vertical Dilution of Precision
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System 1984
WLAN	Wireless LAN
WPAN	Wireless Personal Area Networks