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In-Train Positioning System

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Feasibility Study (public version)

Abstract

Design and implement a multi-input positioning system for use in trains.

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1. Management Summary

On the base of the subject proposal, for the master thesis “In-Train Positioning System” [SUM08TE], a feasibility study was carried out. This document describes the study and it's conclusions.

The goal of the feasibility study was to determine, which intended technologies were usable for incorporating into the positioning system, and to order the corresponding hardware.

2. Introduction

Pursuant the subject proposal in [SUM08TE] this feasibility study evaluated four technologies:

- inertial navigation
- GPS
- WiFi
- Use of a track database

For the WiFi part, also suitable code for acquiring the the required data was evaluated.

3. On inertial navigation

3.1. Preface

The currently used inertial navigation solution is imprecise and should be replaced. The goal is to find a suitable hardware that provides reliable positioning in the 3D space. On inertial navigation systems, a variety of articles are available.

On Wikipedia: http://en.wikipedia.org/wiki/Inertial_navigation

General Description of inertial navigation, its accuracy and used technologies: http://www.media.mit.edu/resenv/classes/MAS836/Inertialnotes/DraperOverview.pdf

Students at the ETH Zurich did build a "Low Cost Inertial Navigation System" as a project. Description is here http://www.trash.net/~luethi/study/ins/ins.html. The project concludes, that accurate positioning data though low cost sensors deteriorates very fast.

Kevin J. Walchko of the University of Florida has carried out a project called "Embedded Low Cost Inertial Navigation System". http://www.mil.ufl.edu/publications/fcrar03/Walchko-2.pdf. It shows how inertial navigation can be combined with a GPS receiver and how Kalman Filtering is applied therefore.

A. D. KING, B.Sc., F.R.I.N., of Marconi Electronic Systems Ltd. Provides an overview of Inertial Navigation here: http://www.imar-navigation.de/download/inertial_navigation_introduction.pdf

On Evaluating the properties of an inertial navigation system, this article by imar may help: http://www.imar-navigation.de/beispiele/decision_assistant.pdf

3.2. Requirements for a suitable inertial navigation device

The ideal inertial navigation device for use in this thesis should have the following features:

- USB-port for fast data transfer and power supply
- software library for easy access in .NET
- Ability to indicate a start position and regular updates via the NMEA protocol.
- Built-In Kalman filter
- probably an internal GPS
- accurate also on high speeds
- full 3D positioning using 3 accelerometers and 3 gyros
- Not depend on an odometer, since we do not have access to odometric data in the train cars.

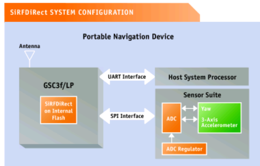
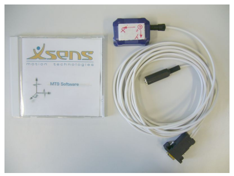
3.3. Commercially available devices (prices removed)

There are several devices on the market, as follows:

Company/Product	Link	Sample Picture		features	Comment
Honeywell, DRM™4000 Dead Reckoning Module	http://www.magneticsensors.com/datasheets/DRM4000.pdf Ordering No: DRM 4000 Overview of similar products: http://www.magneticsensors.com/products.html Contact Customer Service at 1-800-323-8295 for more information.			Blends GPS and dead reckoning data (via internal sensors) to an NMEA output. Suited for personnel on foot.	This just a pedometer, as clarified by a technician from Honeywell and it will not work in trains. DRM 5 and GyroDRM suffer from the same issue, I was told.
Honeywell DRM® - 5 Dead Reckoning Module, Evaluation Kit Available	http://www.ssec.honeywell.com/magnetic/datasheets/drm5.pdf			Similar to DRM 4000, with built-in GPS receiver. Evaluation Kit available. No USB, powered by an internal rechargeable Battery. By specification, this is not to be used on vehicles. Export-Controlled by ITAR.	Since no external GPS is attachable, initializing the device seems impossible. Not usable in trains.

Honeywell GyroDRM	http://www.ssec.honeywell.com/magnetic/datasheets/gyrodrm.pdf			Gyro stabilized inertial navigation for personnel on foot. Has a built-in GPS receiver. A Evaluation Kit is available.	Seems to be an older version of DRM 5. Not usable in trains.
IMAR iDRPOS:	http://www.imar-navigation.de/datenbl/drpos_2pages_e.pdf			2D Navigation module using an external GPS receiver, attachable via RS-232/NMEA. An option for 3D is available.	Is not 3D. According to a sales person, this solution is not eligible for use in trains without odometer, because it would deteriorate fast.
Applanix POS TG	http://www.applanix.com/products/postg_index.php			Inertial, optical and GPS sensors provide millimeter-accuracy on tracks.	Large, and much too precise (probably also too costly)
Gladiator Technologies, Inc. LANDMARK20 AHRS DEMO KIT	http://www.gladiatortechnologies.com/DATASHEET/LandMark20_AHRS_DEMO_KIT_datasheet_051508.pdf			Inertial sensors in one housing, with USB connection. These sensors are mainly developed for sailing and flight application. A Evaluation Kit is available. Integrating and combination of the inertial data and external GPS fixes would have to be done in external software.	This is not a turn-key solution for this thesis, since integration of the inertial data is not done yet. Because integrating is not provided, the precision is probably questionable.

OXTS Inertial+	http://www.oxts.co.uk/default.asp?pageRef=102			Augments the NMEA data of an external GPS receiver with inertial measurements. There are also other models available. Drift without odometer is about 50m/minute	This product would be quite fine, but I don't have the budget for it.
VibTel RT3000	http://www.vibtel.com/EN/Products/InertialNavigationSystems/StrapdownInertialNavigationSystems/OXTS.MODEL.RT-3000.html			Supports an external GPS and povides data via CAN, RS-232, Ethernet. VibTel seems to be a reseller of OXTS.	Way beyond budget.

Sirf SiRFDiRect	http://www.sirf.com/products/SiRFDiRect_Product_Insert.pdf			Enhanced GPS + Dead Reckoning Software for Portable Devices. It sports 3 accelerometers and 1 gyro. There is an evaluation Kit available, that provides USB and RS-232 connection. Supply voltage is 9-24 Volts. NMEA protocol is supported. Dead Reckoning precision after 1 Minute is 225 meters. No direct access to the sensor data is possible.	Good option, smilar to the MIT-G, apart that we will not have access to sensor data for our own processing.
NovaTel SPAN-CPT	http://www.novatel.com/products/span_cpt.htm			Combines GPS and inertial navigation. GPS is built in the device.	No possibility to feed our own GPS signal into the unit. Too costly.
Xsens MT9				This seems to be a earlier version of the Mtx. This product is discontinued.	No possibility for attaching a GPS directly. Mathematical blending of GPS and inertial data would have to be done pro grammatically.

Xsens Mtx	http://www.xsens.com/en/products/human_motion/mtx.php	 		The MTx is a small and accurate 3DOF Orientation Tracker. It provides drift-free 3D orientation as well as kinematic data: 3D acceleration, 3D rate of turn and 3D earth-magnetic field. No external GPS. Evaluation Kit available. Noise of the accelerometers: 0.001m/s^2/sqrt(Hz)	No GPS, therefore no absolute referencing possible.

Xsens MTi-G	http://www.xsens.com/en/products/machine_motion/mtig.php	 		The MTi-G is a MEMS based Inertial Measurement Unit (IMU) and has an onboard Attitude and Heading Reference System (AHRS) combined with GPS and a static pressure sensor. There is a Sensor Development Kit available which contains the sensor and some accessories plus the SDK. The SDK has various possibilities to access the data, namely a WIN32 DLL. Deterioration according to a technical seller is 350m in a minute. The GPS has a tracking sensitivity of -158dBm according to specification. Does work without GPS for only 10 seconds. After that, only orientation information is provided. Noise of the accelerometers: 0.002m/s^2/sqrt(Hz)	No possibility for an external GPS. We can not update the reference position.

Xsens MTI	http://www.xsens.com/en/products/machine_motion/mti.php	 		The MTi is a miniature, gyro-enhanced Attitude and Heading Reference System (AHRS). Its internal low-power signal processor provides drift-free 3D orientation as well as calibrated 3D acceleration, 3D rate of turn and 3D earth-magnetic field data. No GPS attachable. Noise of the accelerometers: 0.002m/s^2/sqrt(Hz)	Just data available. No position data is calculated. This is thus similar to our available sensor, the MT9.

3.4. Conclusion

From a technical an implementation's point of view, the Inertial+ device is the most suitable, because is is the most accurate one, and provides custom input of pre-calculated position estimates with advanced kalman filtering already solved.

From a product point of view, one of the Xsens products without GPS makes most sense, because they are cheaper and smaller. However, in the thesis, there will be not enough time to solve the advanced mathematics involved with this.

SirfDiRect would also be a solution for the thesis. However, for a later product, this does not provide the needed flexibility, since no access to the sensor data is possible.

As a compromise, I recommend the Xsens MTI-G. It provides both the ease-of-use that is required for easy integration in the project, and the flexibility to later add customized advanced mathematical algorithms.

4. On using WiFi

4.1. Preface

The goal is to find out, how good the reception of WLAN Access Points in trains is. Therefore I used two systems trying to scan for surrounding Access points. On was a standard laptop, and one a mobile phone.

4.2. War driving with a laptop in the train

A Thinkpad X60 with a built-in WiFi Antenna plus an external GPS (for reference only) was used. The actual scanning was done using the Netstumbler software.

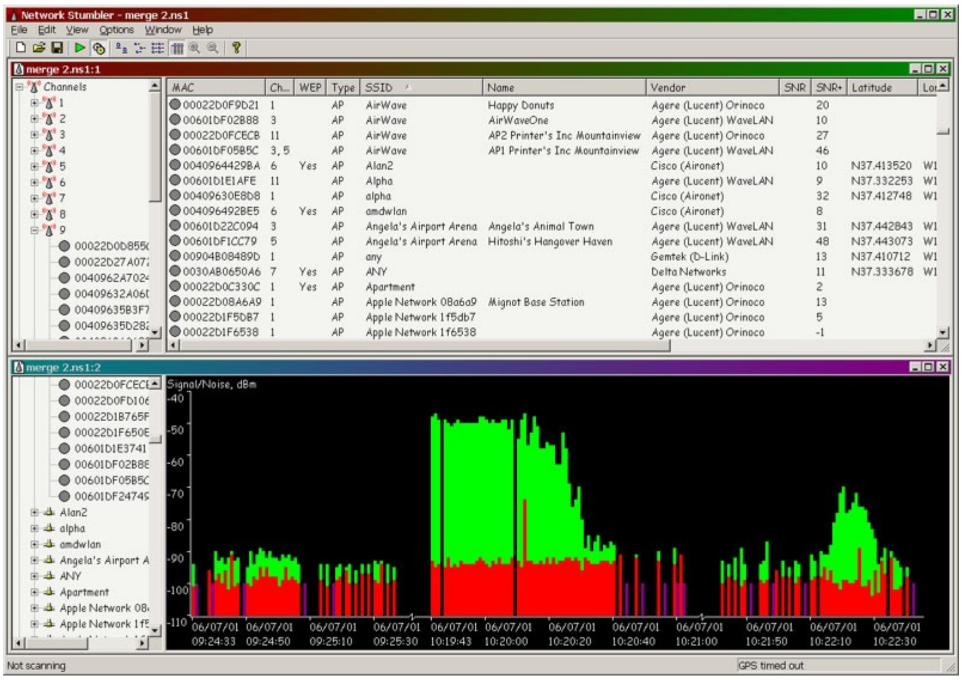


Illustration 1: Netstumbler in Action

4.2.1. Bern S-Bahn

Measurements on these (older) trains showed many access points not only in stations but also while moving.

4.2.2. Zurich S-Bahn

In the cars of the Zurich S-Bahn, the WLAN reception was good, continuously some Access Points were showing up, usually between 2 and 20.

4.2.3. Intercity Zurich-Bern

Near stations and when driving through populated areas there were always more than one Access Point available. In open areas, only rarely an Access Point is visible.

Swisscom operates public non-free Access Points in many larger stations, including Bern, Aarau and Zurich. they are receivable from within the train, even when driving trough a station at high speed, eg. in Aarau.

The cars have their own Access Points to provide the passengers with payable Internet access. These Access Points must get marked and stored as non-usable for positioning purposes. There should also be a general plausibility check for positions when doing positioning with Access Points as they may change position at will. Examples may be if a person owning a private Access Point moves or when the Access Point is in another train car.

In tunnels, no Access Points were detected, except the ones from the car itself.

4.3. War driving with a mobile device in the train

A commercially available mobile phone, the Trinity 100 from HTC was used. It has a built-in WiFi and also built-in GPS. The WiFiFoFum software was used for sniffing.

In urban areas, many Access points were picked up, sometimes up to 16 at the same time. When traveling faster, especially in the Intercity, few, but still some, Access points were picked up.

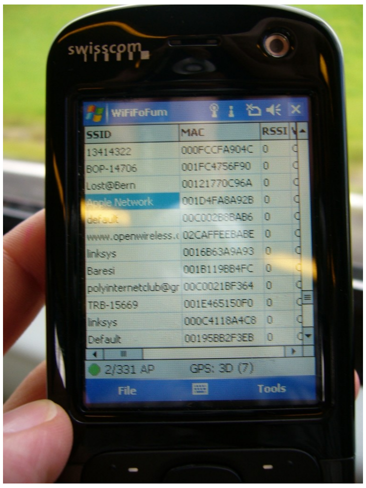


Illustration 2: Seeing 7 Satellites and two active Access points

4.4. Conclusion

Using WiFi access points for positioning purposes in trains is very feasible. The results are expected to get even better if an external antenna would be used, instead of built-in ones.

Especially WiFi is suitable to replace the manual markers of the current solution, because at or near train stations there are generally many Access Points receivable.

5. On code for WiFi scanning

5.1. Preface

To get information about a laptop's surrounding WiFi networks, software is necessary. This software could either be written in the master thesis, or an existing library could be bought. A Linksys Wireless-G Adapter „WUSB54GC" was used for evaluating. The important part of the information is the SSID and the MAC Address of a network.

I have studied several methods to reliably get data from surrounding networks.

Illustration 3: Wireless USB Adapter from Linksys

5.2. Existing Projects

There are already several projects and solutions in this field, including:

Placelab

http://www.deviceforge.com/articles/AT8606455669.html

It consist of Open Source software and multiple databases, including self-created ones, could be used. There is a complete paper explaining the concept and the architecture of the software in [PLLB01].

SkyHook

http://www.skyhookwireless.com/howitworks/

Navizon

http://www.navizon.com/

Ekahau

http://ekahau.com/?id=4200

5.3. Own Code in C#

A first try with writing own code was unsuccessful. (See the Solution "WifiDetector" in the code directory).

5.4. Managed WiFi API

I have found an open source project, Managed WiFi API, which works with Windows XP SP2, but is not capable to retrieve the MAC address of surrounding networks [CPLX01].

5.5. Advanced WiFi Manager

Advanced WiFi-Manager [NICO01], is capable of getting both the SSID and the MAC, including the signal strength of course. It provides a sample program in C#, showing it's capabilities.

This library would suit our needs.

5.6. Existing Code from Enkom Inventis (removed)

5.7. Conclusion

Multiple solutions are possible. I will evaluate again and decide on one after the SRS is written, because the using of the WiFi technology might be optional.

6. On using GPS

6.1. Preface

I have tested the GPS reception in trains using a NaviLock GPS receiver with a high sensitivity of -160dB.

Illustration 4: Test drive for GPS usability in trains

6.2. Measurements

The measurements were done using the same Hardware as for the WiFi test drive.

Zurich S-Bahn

In the car of the Zurich S-Bahn I experienced very good GPS reception, with 7 to 8 satellites used. The speed of the train was around 70 km/h max.

Intercity Zurch-Bern

In the car of the Intercity from Zurich to Bern the reception of the GPS was varying. In the Zurich Main Station there were 5 to 6 satellites used. While moving slowly and the sky was open, up to 8 satellites were used. At traveling with about 100 km/h and open sky, 3 to 5 Satellites were used. When the train moves slower, reception is generally better.

In tunnels, of course, no fix was available. When exiting a tunnel, it lasts about 30 seconds before the first fix again.

After a forced cold start in the moving train,(at around 100 km/h in the open field) the receiver did not recover for the rest of the drive (at least 30 minutes).

6.3. Evaluation of Hardware

Several GPS receivers are available on the market. I have evaluated some.

6.3.1. UBLOX ANTARIS GPS Positioning Engine

This is a stand-alone GPS receiver, build as an evaluation Kit with external Antenna and an RS 232-Output. Power comes from an external 9VDC Adaptor.

This device is a little outdated but is already available in the company. It's disadvantage however is that it does not feature an USP port.

6.3.2. NaviLock

The company has a GPS receiver from Navilock which has a specified input sensitivity of -160dBm. It was used to make the feasibility test drive in the train.

6.3.3. ublox EVK-5H Evaluation Kit with KickStart

The EVK-5H is an evaluation kit of a GPS chip with the so-called “KickStart” and “SuperSense” technology. This provides fast TFF and accurate results with low reception levels. Information is provided here: http://www.u-blox.de/products/evk_5h.html

Tracking sensitivity is -160 dBm.

Price is EUR 150.00 (Exclusive V.A.T.)

Illustration 5: EVK-5H   Evaluation Kit

6.4. Conclusion

The usage of GPS is feasible. To have good results, the GPS receiver should have already a fix when boarding the train.

I ordered the EVK-5H Evaluation Kit from uBlox.

7. On using the track database

7.1. Preface

The information of all relevant tracks of the swiss federal railways is available as raw, comma separated coordinate values in the swiss coordinate system, in plain text files. They are each named after the logical track number according to the numbering scheme of the swiss federal railways.

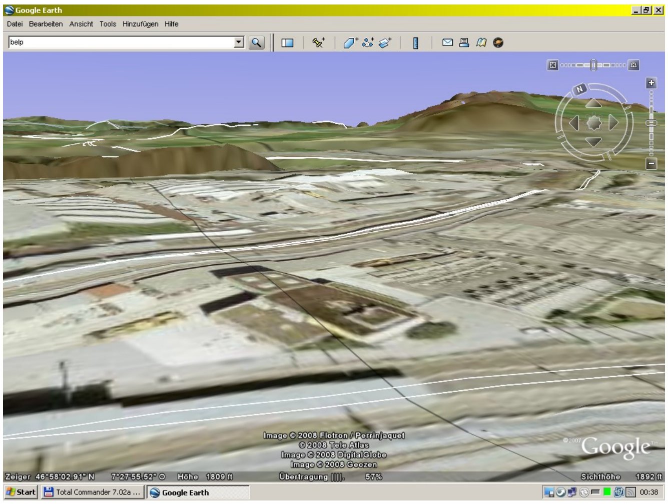


Illustration 6: Available track data of swiss railways, detail of the Wankdorf station, near Bern

7.2. Analysation

The accuracy of these coordinate is quite good, often around several meters. An analyzation of the data in Google Earth shows this, see below. Tracks are shown as white lines.

7.3. Conclusion

The usage of this data is feasible. I will have to build a custom database to hold that data, and import it manually. To keep the database design and administration simple, there will be most likely no automatic update of tracks with either new text files or on-the-fly from acquired position fixes during drives.

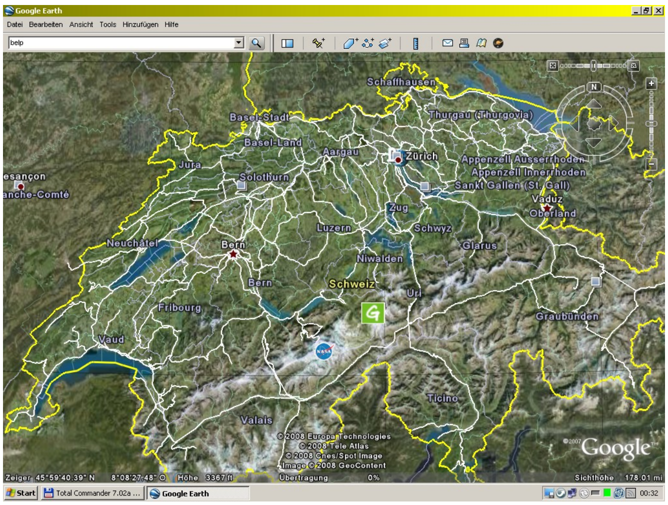


Illustration 7: Available Track data of swiss railways, overview

8. Bibliography

[SUM08TE]	Themeneingabe Master Thesis Thema In-Train-Navigation, 21.8.2008, Marcel Suter. Obtainable from the author.