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In-Train Positioning System

MAS-06-02.23

SRS

Abstract

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

Keywords

GPS, inertial navigation system, train, C#, .NET

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Small changes and additions	22.10.2008	Marcel Suter
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Small add-ons about IC2000	27.10.2008	Marcel Suter

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1. Introduction

1.1. Purpose

This Software Requirement Specification (SRS) describes requirements to the system that is to be developed in the Master Thesis "In-Train Positioning System", Version 1.0. From this SRS, a time schedule is derived for the thesis.

The intended audience for this SRS, besides the student, are all the supervisor, the expert, and the customer for this thesis plus anyone interested in the topic. A basic knowledge of navigation and computer systems is assumed.

The structure of this SRS is derived from the IEEE Standard 830-1998, described in [IEEE98]

1.2. Scope

The system provides position estimates in moving trains. It will use various technologies for deriving positioning information. The main benefit of this system is to replace an older one, that only produced inertial and gyro data in a raw format, instead of calculating the current position.

The system consists of a portable computer, an executable software component, and the necessary hardware. The system will be portable by a single person and be mountable on a trolley.

1.3. Definitions, acronyms, and abbreviations

1.3.1. Definitions

Term	Description	Hyperlink(s)
Engine executable	An executable, that contains the core functionality of the system. It may run independently from other components.	
Event marker	This denotes a defined landmark, with a known geographical location. In the existing system, event markers are fired by the user when traveling past the landmark and stored in the measurement files. They are used for the positioning in the post-processing step. In the new system they are still used, but directly transformed into a positioning information.	
Event marker database	A local database where all	

	event markers are stored.	
Measurement system	This is used to denote any attached device to the system, that uses the position estimates provided by this system. The attached device may be of any kind. However, in the currently targeted environment of this system, this will be most likely any form of radio frequency measurement system.	
Position provider	A sensor, probably with additional preprocessing, or some other input that provides positioning information to the system.	
Railway segment	English term for the "Fahrplanfeld" in german. This denotes a logical connection between two nodes. In Switzerland all railway tracks are part of such a "Fahrplanfeld".	
Railway segment number	For public transportation trains in Switzerland, railway segments are usually numbered using three digits. For example the connection Bern-Olten has the number 450.	http://de.wikipedia.org/wiki/Liste_von_Eisenbahnstrecken_in_der_Schweiz, in German.

1.3.2. Acronyms and Abbreviations

Acronym / Abbreviation	Description	Hyperlink(s)
AHRS	Attitude Heading Reference System	http://en.wikipedia.org/wiki/Attitude_and_Heading_Reference_Systems
API	Application Programming Interface	
CEP	Circular error probable	http://en.wikipedia.org/wiki/Circular_error_probable
DOF	Degrees of freedom. In this thesis this is often used as	http://en.wikipedia.org/wiki/Degrees_of_freedom_(mechani

	6DOF. This usually means, that the referred component uses 3 gyros and 3 accelerometers.	cs)
GGA	"Global Positioning System Fix Data", a part of the NMEA protocol	http://www.gpsinformation.org/dale/nmea.htm#GGA
GPS	Global Positioning System. The Global Positioning System (GPS) is the only fully functional Global Navigation Satellite System (GNSS) in the world. It was developed by the United States Department of Defense.	http://en.wikipedia.org/wiki/GPS
INS	Inertial Navigation System	http://en.wikipedia.org/wiki/Inertial_navigation_system
ITAR	International Traffic in Arms Regulations (ITAR) is a set of United States government regulations that control the export and import of defense-related articles and services on the United States Munitions List.	http://en.wikipedia.org/wiki/ITAR
MAC	Media Access Control, a quasi-unique identifier	http://en.wikipedia.org/wiki/MAC_Address
MEMS	Microelectromechanical systems	http://en.wikipedia.org/wiki/MEMS
NMEA	National Marine Electronics Association. The term NMEA most often refers the protocol called "NMEA 0183", issued by the organization, a defacto standard for providing GPS-related positioning information.	http://www.nmea.org/ http://en.wikipedia.org/wiki/NMEA
NMEA Sentence	A part of information described by the NMEA Protocol.	http://en.wikipedia.org/wiki/NMEA
RAM	Random Access Memory	http://en.wikipedia.org/wiki/Random_access_memory
RMC	"Recommended Minimum sentence C", a part of the NMEA protocol	http://www.gpsinformation.org/dale/nmea.htm#RMC

RS-232	Widely used protocol and interface specification for binary data transfer	http://en.wikipedia.org/wiki/RS-232
SSID	Service set identifier, a parameter of Wirless LAN's.	http://en.wikipedia.org/wiki/SSID
Wardriving	Wardriving is the act of searching for WiFi wireless networks by a person in a moving vehicle, using a portable computer or PDA.	http://en.wikipedia.org/wiki/Wardriving
WiFi	WiFi is the trade name for a popular wireless technology.	http://en.wikipedia.org/wiki/Wifi
WLAN	Wireless local area network	http://en.wikipedia.org/wiki/Wireless_LAN
ICN2000		

1.4. References (Bibliography)

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[SUM08FS]	In-Train Positioning System MAS-06-02.23 Feasibility Study, 10.10.2008, Marcel Suter. Obtainable from the author.
[IEEE98]	IEEE Recommended Practice for Software Requirements Specification, 1998, The Institute of Electrical and Electronics Engineers, Inc. 345 East 47th Street, New York, NY 10017-2394, USA, ISBN 0-7381-0448-5, SS94654 (PDF)
[GPSI08]	Dale DePriest, NMEA data, 2008, http://www.gpsinformation.org/dale/nmea.htm

1.5. Overview

For the current system in use, this SRS contains a description in Appendix A. However, this is not a considered part of the SRS.

For the new system, an overall description with a possible flow of information plus all the requirements are provided.

2. Overall description

2.1. Product perspective

The system will be used, when positioning information in trains is needed . It is intended to replace an older, existing system in a measurement application. The existing system is mostly used in the IC2000 cars of the SBB.

Illustration 1: IC2000 cars of the SBB

In the new system, to input position estimates into the the measurement application, a different input interface will be used than currently is. Additionally, also completely different measurement applications should be attachable, via the newly supported interface.

All system inputs, except the GUI, of the system are self-contained. Some technologies for providing the position estimates are required to be used and thus specified as to use.

However, no further specification takes place on the system inputs.

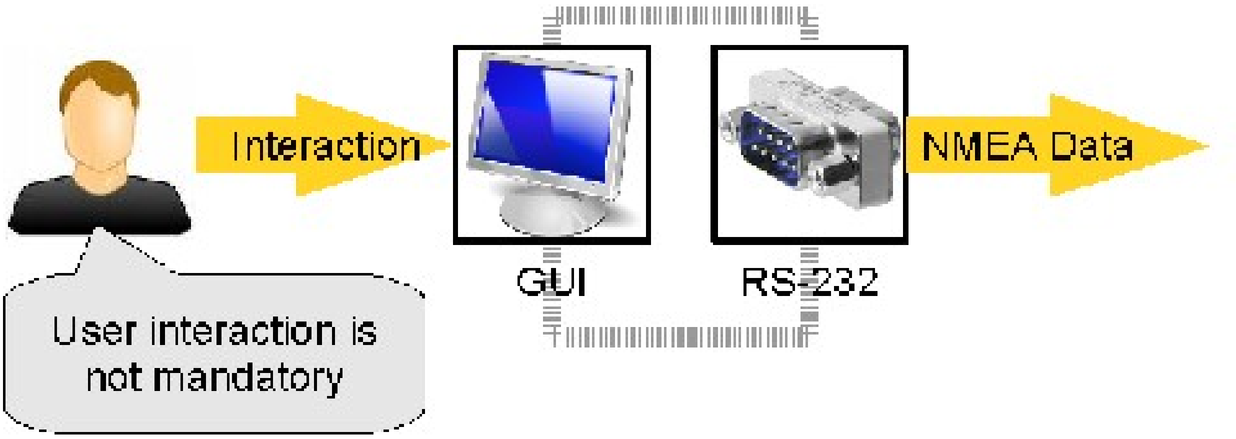

Illustration 2: Overview of interfaces

2.1.1. System interfaces

The system provides data through the NMEA protocol. This is the only system interface specified.

2.1.2. User interfaces

Via the GUI, the user is able to

- Select the current railway segment
- Fire an event marker and indicate a complete stop of movement
- See status indicators

2.1.3. Hardware interfaces

The system runs on a standard laptop, with some sort of RS-232 interface.

2.1.4. Software interfaces

The system runs on top of the Windows XP operating system, Service Pack 3.

2.1.5. Memory

The system runs with 1 GB of RAM and 100 GB hard disk space. Effective hard disk space usage is dependent on the amount of data provided for the various input technologies and may vary over time.

2.1.6. Operations

Starting and stopping the system equals to starting and stopping a process with an executable in it. It is automatable via batch. The GUI is started separately.

Data provision

Data for the various positioning providers must be available in the formats described below.

2.1.7. Site adaptation requirements

Data Input

The system relies on locally available data. The step of loading the data into the system is only required once for a given set of data. Afterwards, the data gets loaded automatically at system start.

2.2. Product functions

The system replaces an existing one. An overview over that system is given in Appendix A.

Illustration 8 shows a possible high-level diagram of the positioning data flow in the new system. This is not necessarily exactly the diagram that will get designed and implemented.

The data of the input devices, called position providers, gets directly processed in the system itself. The system outputs the resulting position estimates via an RS-232 serial connection in the well known NMEA format. Any attached device may use the position estimates as input.

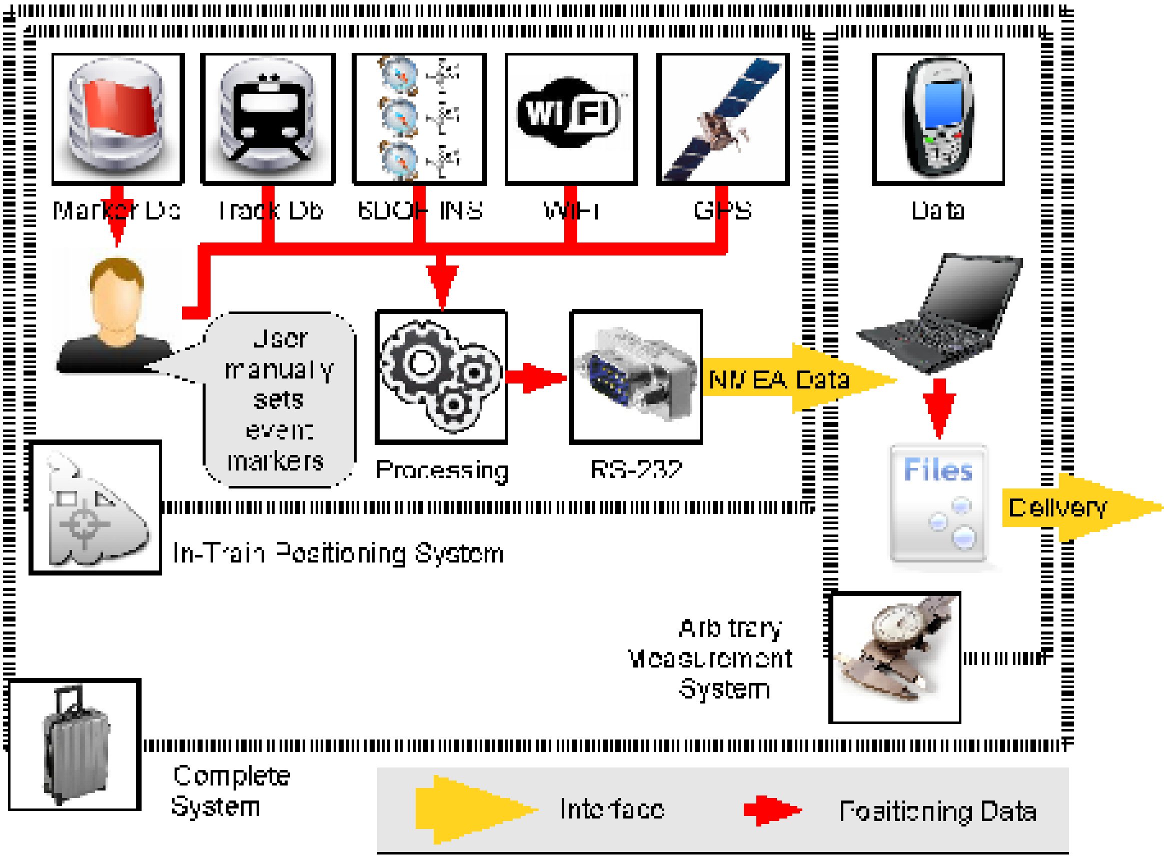

Illustration 3: Positioning data flow in the new system

The positioning system and the attached device (here, a measurement system) are entirely separated, making them completely replaceable, as long as the data interface is maintained.

The files of the measurement system are now ready for delivery without additional post processing step, unlike in the older system.

2.3. User characteristics

The average user of the system is a measurement technician that has general computing skills. The user may be occupied with other tasks when using the system.

It can not be assumed, that the user thoroughly understands navigation and positioning methodologies.

No further user characteristic is intended. Especially there is no user identification. Anyone with physical access can use the system.

2.4. Constraints

Technologies used for positioning

The system uses multiple technologies from which it derives it's current position. These are:

- a GPS receiver with external antenna
- a database of georeferenced WiFi Access Points
- an inertial positioning system
- a track database. The system uses prerecorded data about train tracks to correct the currently determined position from the other position providers.
- An event marker database. The system uses prerecorded event markers and their geographical position to present the user with event markers, he or she can fire.

2.5. Assumptions and dependencies

Power Supply and mechanics

The power supply for the system will not be developed within this thesis. It is assumed, that enough power will be available for operation and there is no power interruption during it's uptime. The hardware will only be assembled as prototype.

Look-And-Feel of the GUI

The GUI may be all contained within a single dialog or they may get integrated into several independent visual elements. The exact implementation may be chosen as part of the designed system architecture.

3rd party library usage is unrestricted

The system depends on the .NET Runtime package, version 3.5, Service Pack 1. It is also assumed, any available libraries for .NET may be used in the development

The system may depend on 3rd party software and libraries. For the sake of development speed, it is even encouraged to use such 3rd part components.

As database system, the Microsoft SQL server 2005 or any newer version may get used.

Only basic math is used

Only basic mathematical algorithms are used for the processing of the positioning data. With this assumption, the position estimate is calculated on a best-effort basis.

Availability of data for the input technologies

All data used for the event marker database, the track database and the WiFi Access Point database is already available in an easily parseable file format. Acquiring this data is not part of this thesis.

Where necessary or useful, small amounts of sample data may get acquired during the development of the system.

Installation and Distribution

Only one system is needed and therefore no installer package is compiled. Also, any device drivers are required to get installed manually, according to the instructions from the respective manufacturer.

It is assumed, that, besides the components of this system, no other software runs on the same computer.

Position estimate quality

There is no probability check of the outputted position estimates. The position estimates do not emulate the real movement of the train along the track.

For estimating the position, the effect delay caused by the traveling speed of the system is neglected.

Hardware

The used laptop features an internals WiFi card that is accessible using the native Windows API.

2.6. Apportioning of requirements

In later versions, the following requirements could be additionally met:

- The processing of position estimates uses advanced mathematical algorithms, as for example the Kalman filter and the Bayes estimator.
- Additional inputs interfaces may be supported, as for example NMEA.

3. Specific requirements

ID	Name	Description	Prio.	
3.1. External interface requirements				
3.1.1. System Interfaces				
1	NMEA Protocol	The well-known NMEA 0813 protocol is used for outputting data from the system.	1	
2	NMEA Update	Each Sentence is issued every second.	1	
3	NMEA serial configuration	The standard NMEA serial configuration is supported, which is 4800 b/s (bit per second rate) with 8 bits of data, no parity, and one stop bit.	1	
4	NMEA speed	Higher baud rates are supported: 9800 b/s and 115200 b/s	2	
5	RMC Sentence	The RMC Sentence with all parameters is provided. The data is compiled as follows, where the units are according to the NMEA specs: ● Time of fix is the current UTC ● Navigation receiver warning is A (valid) when the currently estimated CEP is less than the specified CEP, V (Warning) otherwise. ● Latitude and direction is according to the current position estimate ● Longitude and direction is according to the current position estimate ● Speed over Ground (in Knots!), is current speed estimate ● Track angle in degrees is the current track estimate ● Date is the current date ● Magnetic variation is set to zero ● The checksum is calculated according to the data.	1	

6	GGA Sentence	The GGA Sentence with all parameters is provided. The data is compiled as follows, where the units are according to the NMEA specs: ● Time of fix is the current UTC ● Latitude and direction is according to the current position estimate ● Longitude and direction is according to the current position estimate ● Fix Quality indicator. It is set to: 0 (invalid) when no positioning information was yet obtained since system start. 1 (GPS fix) if a fix from the GPS input was available within the last 3 seconds. 6 (estimated) otherwise ● Number of satellites is set to: to the number of satellites from the last GPS fix, if it is not older than 3 seconds, 0 otherwise. ● Horizontal dilution of position is set to an estimation of the CEP of the current position estimate. ● Altitude, Meters, above mean sea level is set to the value of the last GPS input ● Height of geoid (mean sea level) above WGS84 ellipsoid is set to the corresponding value of the last GPS input ● time in seconds since last DGPS update is left empty ● DGPS station ID number is left empty ● The checksum is calculated according to the data.	3	
3.1.2. User Interfaces				
7	GUI not mandatory	The system must also work (with accordingly limited precision) with no user input at all.	1	
56	GUI English	The language of the GUI of the system is US English.	1	
	GUI translatable	The language of the GUI can be changed without recompilation, e.g. by replacing one or more files.	1	
Selecting the current railway segment				

8	GUI railway segment number	At any time, the user may input the railway segment number he or she is currently traveling on. This narrows down the possible positions to a set of lines between the way points for this segment.	1	
9	GUI segment as text	The input is possible via a text field.	1	
10	Track db input matching	If the input does not match to an entry in the track database, an error message is shown to the user.	1	
11	Track db input plausibilit y	A plausibility check against the current position is done for this user input.	3	
12	Track db input success	A successful input of a segment number (re)populates the event marker list. As long as the user has not entered a valid segment number, the event marker list remains empty, thus disallowing firing of event markers.	1	
Event marker firing by the user				
13	Event firing	The user must be able to fire an event when traveling past a landmark in the event marker database.	1	
14	Stop event	The user has the possibility to fire an event, when the train is completely stopped.	1	
15	Event list scrollable	The event markers are presented in a scrollable list. Each list entry equals to one event marker.	1	
16	Event list population	After the list gets populated (see above), the first event marker is selected.	2	
17	Event reselectio n	When the user fires an event marker, the next one in the list is automatically selected.	2	
53	Event shortcut	Firing the selected event marker is possible using a single shortcut key on the computer keyboard.	2	
54	Event double-click	Firing an event marker is possible by a double-click of the mouse pointer on an event marker in the list.	1	
18	Event re-firing	The system allows a given event marker to be fired more than once. This allows a user to somewhat “correct” a previously executed firing which was too early.	2	
19	Last event	If the last event marker in the list was fired, no entry is selected.	2	

Status output				
20	Status at any time	At any time, the user can see status information of all attached position providers.	2	
21	Position Provider Status informatio n	Each position provider provides the following status information: a free textual description (e.g. “3 Satellites in view”), a standard deviation for the last known position, the timestamp of the last known position, and a status indication from one of the following states. ● Working:The provider has issued a new position in the last 3 seconds. ● Ready:The provider is ready to provide positioning information. ● Faulty:The provider is not able to provide positions, because of an error.	2	
22	Output status informatio n	At any time, the user can see status information of the currently outputted, estimated position. The status information is the same as for a position provider, respectively.	1	
3.1.3. Hardware Interfaces				
23	Comport Adapter	For the serial RS-232 interface output, a USB-To-RS-232 Adapter shall get used, if the computer does not have a built-in interface.	1	
57	Virtual Comport	The NMEA data is additionally outputted via a virtual com port.	3	
3.1.4. Operations				
System start and shutdown				
24	Engine start	The user starts the system by starting an engine executable file. No other user action is necessarily needed. This step must be automatable at startup of the underlying operating system by a batch file or similar means.	1	
25	GUI start	The user starts the graphical user interface via another executable file, as he or she sees necessity for.	2	
26	GUI stop	Terminating the user interface does not stop the system's engine executable.	2	
27	Engine stop	The user stops the system by terminating the engine executable's process.	1	

3.2. Functions

3.2.1. Using WiFi as a position provider

28	WiFi scan	The system shall scan for surrounding WiFi access points.	2	
29	WiFi lookup	The system shall look up the found access points in a local database with positions of known Access points. If matches are found, the current position of the system shall be estimated by using simple mathematical algorithms.	2	

3.2.2. Using GPS as a position provider

30	GPS usage	The system shall use a GPS device.	1	

3.2.3. Using an IMS as position provider

31	IMU usage	The system shall use an inertial measurement unit to continue providing position estimate when all other technologies provide no position estimate.	1	

3.2.4. Using a track database for correction

32	Track db usage	Before outputting, the system shall tie all estimated positions to the nearest point on a given set of tracks.	1	
33	Track as waypoints	The tracks are defined by waypoints.	1	
34	Unique segment number	Each track has a unique segment number for identification.	1	
35	Segment narrowing	The set of tracks is narrowed down according to user input of the current track segment number	1	

3.2.5. Using event markers as position provider

36	Using event markers	The system shall use the event markers fired by the user as positioning data.	1	

3.2.6. Logging

37	Log output	The system produces a log of all outputted data.	1	
38	Log disabling	Disabling this function must be possible by configuration.	1	
39	Log file	The log is written to a file. The filename contains a timestamp of the current UTC time when the log was started.	1	
40	XML log	The log file is in a variety of an XML format.	2	

3.2.7. Estimating the position

41	Blending inputs	The positioning data gathered from the positioning providers, the IMU, and from the track database is blended together.	1	
42	Position estimation	The blending is done in a way that, at any time, the most probable position is outputted, using basic mathematical algorithms.	1	
43	Estimatio n CEP	The CEP after blending is 25 meters or below when the train is stopped, at any time.	3	

3.3. Performance Requirements

44	Waypoint count	The system is capable of working with as much as 100000 track waypoints.	1	
45	AP count	The system is capable of working with as much as 100000 stored access points.	2	
46	Maximum speed with GPS	The system works at traveling speeds up to 200 km per hour, when the GPS sensor is providing position estimates.	1	
64	Maximum speed with any sensor	The system works at traveling speeds up to 200 km per hour, when any of the sensors is solely providing position estimates.	3	

3.4. Database requirements

47	Db update	When the system is not running, all data for the track waypoints, the WiFi Access points, and the event markers is replaceable.	2	

3.5. Design constraints

48	Using laptop	The system runs on a standard, mid-class, laptop computer of a recent date.	1	
49	Using 3rd party libs	Used 3rd party components and its interfaces must be noted. In case they do not allow commercial usage through their licensing model, they must be later replaceable and the interfaces used must be described.	1	
55	Engine separated	The system has the positioning engine (without any GUI) and the GUI in separate executables.	2	
63	Emulation mode	One or more position provider can get emulated to the system with some form of prepared position estimates. This serves for the test of parts of the system without using the actual hardware or boarding a train. An interface for implementation is provided for this.	1	

3.5.1. Standards compliance

50	NMEA output	The output conforms to the NMEA 0813 protocol	1	

3.6. Software system attributes

3.6.1. Source Code

51	Coding Guidelines	The coding guidelines of the customer are applied.	1	

3.6.2. Availability

52	Availability	The system must be able to run 10 hours continuously.	2	

3.7. Other requirements

58	Quick Start Guide	A “Quick Start Guide” of 2 pages A4, laminated is provided in English and German. No further user manual is required.	1	
59	Documentation	A documentation according to the needs of the Master Thesis is provided.	1	

3.8. Accuracy determination

60	GPS Accuracy	The accuracy when using GPS and the track database alone, in open sky conditions, in an ICN2000 car, while the train is stopped, is determined.	2	

61	WiFi Accuracy	The accuracy when using WiFi and the track database alone, when at least 3 Access Points are visible, in an ICN2000 car, while the train is stopped, is determined.	2	
62	Inertial Accuracy	The accuracy when using inertial measurements and the track database alone, when the train is stopped, is determined, one minute after one of the position providers provided an estimate. This may get simulated in the office without actually boarding a train.	2	
65				

Appendix A: Overview of the existing system

Positioning data flow overview

Illustration 7 shows the positioning data flow in the existing system. Various input devices provide absolute and relative information about the current position. This information, together with the measurement data, is stored in one or more measurement files, depending on the current measurement task. The files are transferred manually to a backoffice computer. In the backoffice, an operator re-references the relative positoning information by using the stored event markers. The relative informations gets adjusted according to stored information about the event markers and the tracks. This process requires much user interaction from the operator.

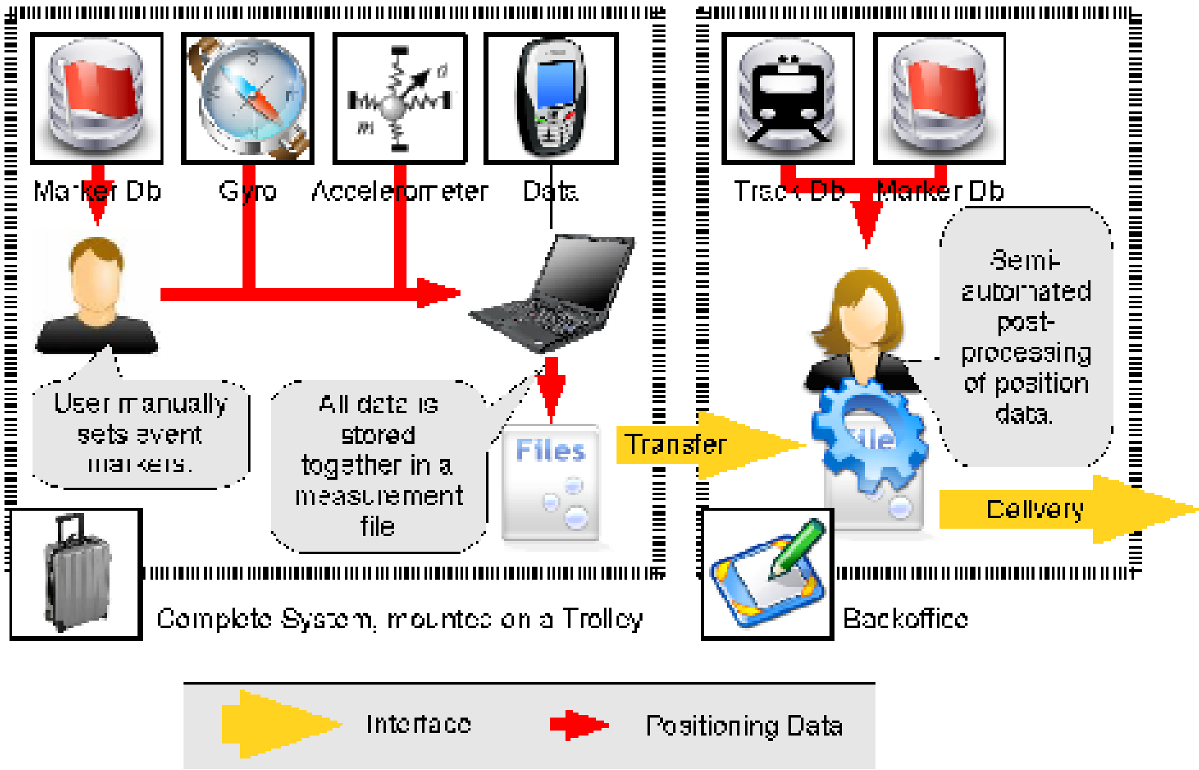

Illustration 4: Positioning information data flow in the existing system

The Hardware

The current solution is built in a trolley. It consists of a single box containing an accelerometer and a gyro.

Illustration 5: The current measurement solution is built on a trolley

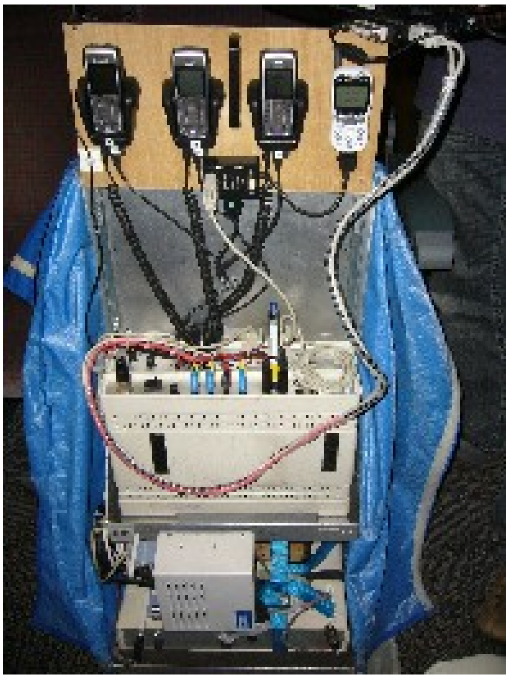

Illustration 6: A look inside the existing measurement trolley, laptop removed. The inertial system is on the bottom.

A laptop is used to measure the radio parameters and to read out the data of the gyro and the accelerometer via an RS-232 serial connection. All Positioning and measurement data is then saved into the measurement files. However, no real positioning data is saved; just the accelerometer and gyro data are saved in a customized format for later post-processing.

Illustration 7: The measurement technician at work

The currently used laptop is an IBM Thinkpad R52. It has 8GB and a 18GB Hard disk in it. The processor runs at 1.5GHz and there is 512MB RAM.

The software

The GUI of the current positioning solution is built into the GUI of the measurement software.

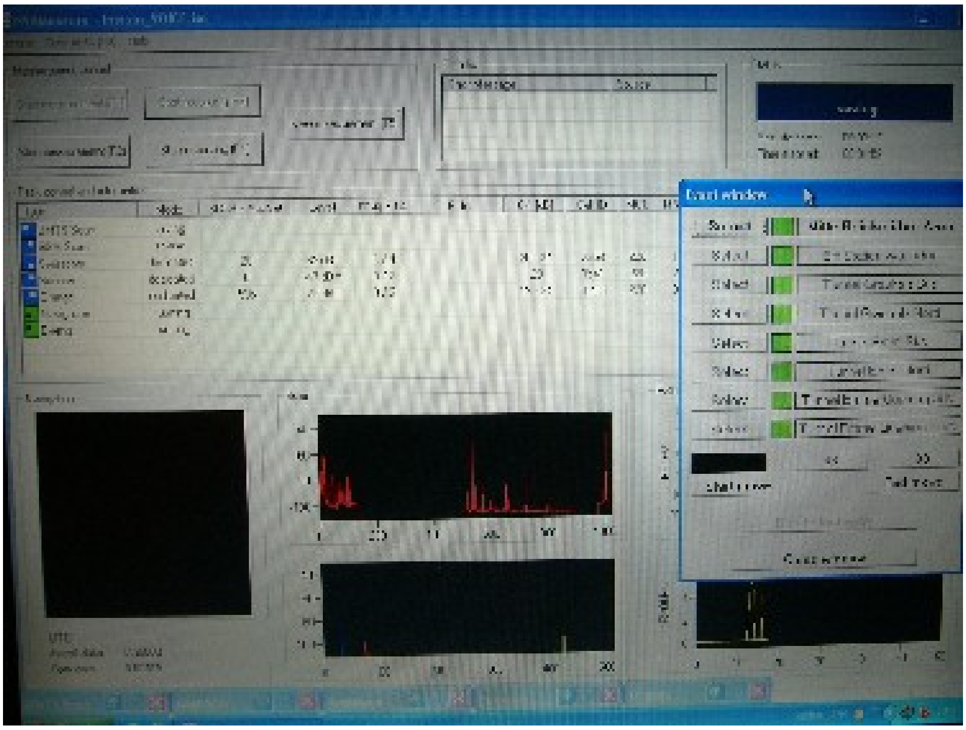

Illustration 8: GUI of the current GSM measurement solution, measurement is running

When starting the measurement, the user inputs the railway segment number of the current segment he or she is traveling on into the system. The system looks up the number in local database and presents a set of predefined event markers denoting landmarks along the track.

During the course, the user clicks on each of this marker when it passes. Additionally two buttons can be pressed to indicate either that the train stopped moving or that it just has started moving. This and the event markers are later used in the post processing step, to correct the stored inertial data.

The user has the possibility to revoke a marker up to 5 seconds after it has been fired. This is useful in case of errors when a landmark was misinterpreted.

Additionally the user can make comments during and after the course to indicate specific events or circumstances experienced during the measurements, be it of positioning matter or else. (Applies only to the GSM version of the measurement software, in the UMTS version, comments are only allowed at the start of the measurement).

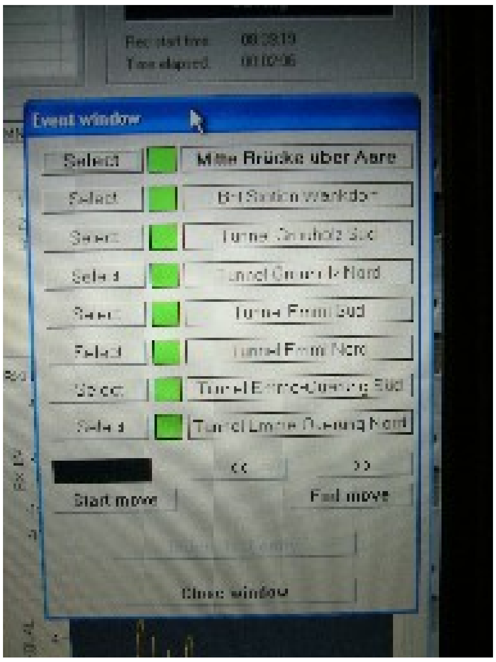

Illustration 9: (Detail) Available event markes during the course

Measurement modes

There are 4 possible measurement modes:

- GSM Voice
- GSM Data
- UMTS Voice
- UMTS Data

The laptop is set up as dual boot system with two Windows XP operating systems. Each system is set up for either measuring with the UMTS or the GSM Hardware. Also the software used, is different.

The pictures shown here are all with the GSM Hard- and Software. In terms of positioning, the requirements will be the same for GSM and UMTS measurements. Both systems take the data from a serial comport using the RS-232 protocol.

Quantities, Uptime and power

During a normal day, up to 8 files, each representing a measurement along one railway segment are created. During a year, measurement is done on 50 days.

The system runs on a 12 Volt Accumulator of 60Ah capacity. It may be continuously up for 10 hours, including the laptop. The laptop is usually not shut down during the day, not even when changing the train.