Final Presentation

Noordwijk, December 2004
Introduction
Michel ROUSSEAU
Introduction

The LOCOLOC project

Project data:
- ESA funded project.
- Project has started 03/02
- Project duration is 26 months

Partnership:
- Industrial companies: ALSTOM, Septentrio, TRASYS
- Railway: SN CB/N MBS

Synergy:
- Locoloc = complementary counterpart of Locoprol project
Introduction

The LOCOPROL project

Project data:

- EU DG INFSO (ex DG XIII) funded project.
- Project has started 08/01
- Project duration is 42 months
- Result of the project will be in public domain

Partnership:

- Industrial companies: ALSTOM, Honeywell, Septentrio, TRASYS
- Research centres: IN RETS, NJTU (China)
- Railways: SN CB/NMBS, RFF/SN CF, CFTA (CONNEX)
- Others: ERTICO, BPV
Introduction

The LOCOLOC/LOCOPROL synergy

- Locoloc consortium partners have been involved in the Locoprol project
- Frequent coordination meeting including project officer and projects coordinator have been organised
- Common public demonstration (Gembloux - March 2004)
- Test campaign have been performed on same test track (Belgian TT)
Introduction

The global objective

Locoprol/Locoloc main objectives = to develop and test:

- An innovative low life cycle cost fail safe satellite based train positioning solution;
- A low life cycle cost signalling system for low density traffic lines.

Locoprol:
- Satellite based Safe train location system
- Its application to ERTMS/ETCS
- Its application on LDTL

Lococol:
- Satellite based speed & acceleration calculation algo
- Satellite based Train completeness
- Interface to end users

ALSTOM

B

TRASY

Septentrio satellite navigation
System overview

Interface to end user’s

Nice station
ATS

CSVC  RBC

GSM infrastructure

Train

Trackside

Speed & acceleration

3RG A4L
**Introduction**

**Project organisation**

**Phase I: Setting the requirements for LDTL and Secondary lines.**
- Definition of needs (system functionnality, train completeness, performances, interfaces, safety, and specific constraints)
- Requirements on rail user navigation equipments have been derived.
- Assessment of the technical solution.

**Phase II: Building the prototypes.**
- Design & Development of the equipments
- Detailed demonstration plan

**Phase III: Field demonstration**
- On site test & public demonstration
- Preliminary safety case
Field demonstration

Test Track

Belgian test track (finished):
- Testing focused on satellite based train positioning validation.
- Testing focused on satellite based train speed and acceleration validation + EGNOS
- Common Public live demonstration

RFF test track (finished):
- Testing focused on application of LO CO PRO L satellite based train positioning to ERTMS trainborne sub-system.

CFTA test track (under testing):
- Testing focused on application of the innovative LO CO PRO L signalling system on an existing infrastructure.
Next presentations:

- Description of the algorithm developed in the frame of the 2 project (Locoprol/Locoloc)
- Special attention to safety aspect
- Interface to the end user’s
- Projects results and conclusions
Thank you for your attention

Visit also
WWW.LOCOLOC.ORG
WWW.LOCOPROL.ORG
Safe Train Location by Satellite Positioning

Frank WILMS
Basic principles

- Train Location + Confidence interval
- Train Speed + Confidence interval
- Train Direction

Vital process
- Pseudo ranges
- Doppler meas.

GNSS RECEIVER

DIGITAL MAP

1D POSITION

Signalling system (e.g. IXL)

Route information
GNSS receiver: PolarRx2

- dual-frequency GNSS receiver
- 48 HW channels
- GPS/GLONASS/SBAS
- C/A + P code tracking
- L2C models available
- attitude determination
- 1PPS in/out
- 10 MHz reference in/out
- Eurocard sized
- compatible connectors
Digital map: example

- Sections (e.g. S113)
  - Straight lines (e.g. L3)
  - Point objects (e.g. O19)
  - Extended objects (e.g. O17)

- Nodes (e.g. N237)
  - Coordinates in WGS84
**Satellite positioning**

3D positioning:
4 satellites (3 + 1 for Rx clock shift)

1D positioning:
2 satellites (1 + 1 for Rx clock shift) => 3 times

~10^{-4}/Hr

~10^{-11}/Hr

2 satellites (1 + 1) = 3 times
Satellite positioning

6 different satellites
Availability of 6 satellites at ground level in mixed area (urban and non-urban area) is below 80%

~\(10^{-11}/\text{Hr}\)

4 different satellites
Availability of 4 satellites at ground level in mixed area equals 98%

~\(10^{-11}/\text{Hr}\)

1D positioning:
2 satellites (1+1) => 3 times

~\(10^{-11}/\text{Hr}\)
Railway is a guided transport:

3D → 1D

+ Position of points
+ Track equation
Satellite positioning

Using satellites by pair

\[ \varepsilon_1 + \varepsilon_2 \]

\[ S_1(S_{x1}, S_{y1}, S_{z1}) \]

\[ S_2(S_{x2}, S_{y2}, S_{z2}) \]

Basic Confidence Interval

\[ \sim 10^{-4} / \text{hour} \]

Using several pairs of satellites

\[ \sim 10^{-11} / \text{hour} \]

Sections of the track not occupied by the train

Union of BCI

ALSTOM

B

TRASYS

Septentrio satellite navigation
Test results: position

Graph of the position

Intervals - File: TPC_20040322_201923.TPC

Red: Safe rear end of confidence interval
Blue: Safe front end of confidence interval
Green: Reference position
Test results: speed

Graph of the velocity

Blue: Upper boundary of confidence interval
Green: Ref. speed
Red: Lower boundary of confidence interval
**Length of Position confidence interval:**
- Integrity: $\sim 10^{-11}/\text{Hr}$
- Availability: 98%
- Accuracy (L1 only): 200m to 400m
- Accuracy (L1+L2): 150m to 250m

**Length of Speed confidence interval:**
- Integrity: $\sim 10^{-11}/\text{Hr}$
- Availability: 98%
- Accuracy: 3m/s
Thank you for your attention
Visit also
WWW.LOCOLOC.ORG
WWW.LOCOPROL.ORG
Safety aspects

Stéphane Besure
Can we use GNSS for a safe railway application?
Main features of a signalling application

- The basic logic of a signalling system is to provide a movement authority to a train when track ahead of the train is safe.
- The basic logic of an ATP is to keep the train within this movement authority.
- The signalling system presents numerous states characterised by the position of the different trains on the railway network and the status of the points associated to this network.
Advantages of a railway application

- Train movement is constrained by track and point positions
- Train dynamics permit to define a worst case confidence interval for position and speed at any time
- Fail-safe state: train can be stopped
- Advanced ATP offer a braking curve supervision in real time (curve is re-calculated every cycle with the current error margin)
Constraints of a railway application

- Norm Cenelec 50129 requires a SIL4 for a signalling system (Tolerable Hazard Rate between $10^{-8}$/h and $10^{-9}$/h for the complete system)

- With the SIL4 objective, performances are limited to low density railway applications: what precision can be offered by the solution?

- Railway environment limits the visibility of satellites
Additional constraints

- Absolute and safe position of the trains is required at initialisation (the train will use the movement authority relative distance to reach a new safe position)

- In the case of positive train detection, the transition from a safe position to another safe position requires the check of train integrity
Safety principles

- Pseudorange and integrity (1)
  - Standard GPS pseudorange measurement provides an accuracy of 100m with a probability of 95% (variations of physical phenomena or abnormal events resulting from failures of the GNSS system)
  - A failure rate of 10^-4/h is considered for the GNSS system integrity
  - A Gaussian approach extrapolated at 99.99% is considered for the physical phenomena...
Safety principles

- Pseudorange and integrity (2)
  - adequate modelling is required to offer an acceptable accuracy in a $[3.89\sigma; 3.89\sigma]$ interval
  - correlation time is necessary to convert probabilities in failure rates
  - Gaussian assumption not always correct

Detailed study of the physical phenomenon is required
Safety principles

- Pseudorange and integrity (3)
- ...99.99% is not sufficient to reach a SIL4
- ...increasing accuracy is limited by the adverse effect introduced by the correction factor

Use of 3 independent measurements
Safety principles

- Algorithm 1D and safety (1)
  - Basic Confidence Interval has a length of $(\varepsilon_1 + \varepsilon_2) \times \text{DOP}$
  - Union Interval has the length obtained by the fusion of the 6 BCIs (no rejection!)
  - Train interval integrates UI, train length and worst case train dynamics (to bound impact of GNSS failures or to give a solution when GNSS availability is degraded)
Safety principles

- Algorithm 1D and safety (2)
  - The algorithm tolerates 2 satellite failures i.e.
    the probability that the train is outside UI is
    the sum of probabilities of 3 satellite failures
    and 4 satellite failures in the same direction
  - This probability equals $4 \times 10^{-12}$
  - The precision given by the UI can be
    improved by selective correction: safety
    requires that correction factor is applied on one
    pair only

ALSTOM  B  TRASYS  Septentrio
satellite navigation
Error quantification

- Methodology
  - Identification of error sources (context diagram)
  - Study of a possible common mode for these errors (error affects more than one satellite)
  - Use of a mitigation measure (detection and rejection or use of a safety margin) when a common mode is identified
  - Quantification of the residual risk
Error quantification

- Errors associated to segments ① and ②
- Master Control Station is a common mode to the 24 active satellites
- EGNOS is used to check the health status of the satellites every 7s
- Satellite information is tracked and checked over time to anticipate EGNOS validation
- Residual risk (train outside interval because MCS fails and EGNOS does not detect it) is very low: 10^-4/h*10^-7/h
Error quantification

- Errors associated to interface ③
  - Identification of error sources at information level
    - Satellite identification
    - Satellite health status
    - Ephemeris
    - Clock
Error quantification

- Errors associated to interface ③
  - Identification of error sources at physical level
    - Ionosphere effect
    - Troposphere effect
    - Rotation of the Earth during signal propagation
    - Relativistic effects
    - Multiple path effect
    - Alternate path effect
    - Train oscillation effect
Error quantification

Satellite identification

- Risk: receiver takes satellite A for satellite B and satellite B for satellite A (common mode between two satellites GNSS signals)
- Mitigation measure: none
- Residual risk: $2.3 \times 10^{-12}/h$
Error quantification

- Satellite health status
  - Risk: 4 satellites declared healthy erroneously
  - Mitigation measure: EGNOS
  - Residual risk: 10-11/h
  - Remark: if failure affects one satellite, either it is detected and the satellite is rejected from the algorithm or it affects one BCI and UI is degraded
Error quantification

- Ephemeris
  - Risk: satellite positions different from the estimated positions (model error)
  - Mitigation measure: safety margin of 10m (Gaussian value corrected with a factor 2)
  - Residual risk: 10-12/h (correlation time of 1h)
Error quantification

- Clock
  - Risk: satellite clocks different from the estimated clocks (model error)
  - Mitigation measure: safety margin of 1.5m (Gaussian value acceptable)
  - Residual risk: 10-12/h (correlation time > 1h)
Error quantification

- Ionosphere effect
  - Risk: ionosphere is common to all satellites
  - First mitigation measure: safety margin of 2m (Gaussian value corrected with a factor 2 and margin for different paths between L1 and L2)
  - Second mitigation measure: use of a second dual frequency receiver
  - Residual risk: 2.10^-12/h (correlation time of 30 min)
  - Residual risk 2: 5.10^-16/h
Error quantification

- Troposphere effect
  - Risk: troposphere is common to all satellites
  - Mitigation measure: safety margin of 17.5m (Gaussian value acceptable)
  - Residual risk: $2.10^{-12}/h$ (correlation time of 30 min)
Error quantification

- Multiple path effect
  - Risk: see alternate paths
  - Mitigation measure: use of multiple path detection features of advanced receivers (a basic safety margin of 4m is considered)
  - Residual risk: see alternate paths
Error quantification

Alternate path effect (1)
Error quantification

- Alternate path effect (2)
  - Risk: error potentially unbounded and obstacle is a possible common mode to several satellites
- First mitigation measure: variable satellite elevation criteria (5° suburban -> 10° urban)
- Second mitigation measure: RHCP polarised antenna (LHCP rejection limited to 14 dB)
- Third mitigation measure: threshold on signal/noise ratio fixed to 13 dB
Error quantification

Alternate path effect (3)

Alternate path detection and exclusion
Error quantification

- Alternate path effect (4)
- Residual risk: with a correlation time of 10s, 2.88.10-12/h for dense areas (precision of 100m) and 1.2.10-10/h for suburban areas (precision of 50m)
Error quantification

- Errors associated to segment ④
  - Not examined (black box approach)
  - Train Positioning Computer and 1D algorithm have to be developed in accordance with CENELEC standards
  - Receiver and antenna have to be standard products of the market
  - Block diagram of receiver has to be studied for possible common modes
1,46.10⁻¹⁰/h

The train is outside UI because:

- 3 satellites fail independently: 4.10⁻¹²/h
- MCS and EGNOS fail: 10⁻¹¹/h
- 2 satellite PRNs are permuted by receiver and 1 other satellite fail: 2,3.10⁻¹²/h
- 3 satellite exceed the 99.99% ephemeris margin: 10⁻¹²/h
- 3 satellite exceed the 99.99% clock margin: 10⁻¹²/h
The train is outside UI because:
- 2 dual frequency receivers provide the same erroneous ionosphere correction: $5 \times 10^{-16}/h$
- 3 satellite exceed the 99.99% ionosphere margin: $2 \times 10^{-12}/h$
- 3 satellite exceed the 99.99% troposphere margin: $2 \times 10^{-12}/h$
- Alternate path error is greater than 50m on 3 satellite signals in suburban areas: $1,2 \times 10^{-10}/h$
- Alternate path error is greater than 100m on 3 satellite signals in urban areas: $2,88 \times 10^{-12}/h$
Global figures: Precision

- 120m (1 BCI, DOP=1, suburban area)
- 170m (1 BCI, DOP=1, urban area)

The train is outside UI because:
- Residual error after ephem correction: 10m
- Residual error after clock correction: 1.5m
- Residual error after iono correction: 2m
- Residual error on troposphere: 17.5m
- Residual error on multiple path: 4m
Global figures: Availability

- Measured (test tracks)
- Based on 4 satellites availability
- 98% outside the tunnels
Thank you for your attention

Visit also
WWW.LOCOLOC.ORG
WWW.LOCOPROL.ORG
Interface to end user

Jacques WILLEKENS
Introduction

Objective
- To make real-time information available to end users

Target: long lines with little traffic.

Prototype
- Re-usable as the basis of a commercial implementation
Introduction (2)

- Services for passengers
  - Web site
  - Alert services
- Services for other users
  - Database query
Passengers

- Web Site
  - Services for travellers (trip planning)
  - Real-time information
  - Registration
    - Profile (preferences)
    - Alerts
Trip planning

Search by:
- Line / origin / destination
- Time range, date
- Train number
- (Use profile if defined)

Information returned depends on railway company
Real-time information

- Display current position of trains on a line or route
- Display estimated delay
  - Computed
  - Entered by traffic manager
Real-time display

These positions are refreshed every 20 seconds

Last refresh: 31/10/2003 19:18:22

Trains located on your selected train route.

<table>
<thead>
<tr>
<th>Train</th>
<th>Departure Station</th>
<th>Arrival Station</th>
<th>Departure Time</th>
<th>Arrival Time</th>
<th>Delay</th>
<th>Canceled</th>
</tr>
</thead>
<tbody>
<tr>
<td>555</td>
<td>Jemeppe</td>
<td>Namur</td>
<td>15:56</td>
<td>14:16</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

To obtain more detailed information about a journey, click on the number of the train.
Alert service

- Each registered user has a list of alerts
- Events
  - Delays (with thresholds)
  - Cancellation
  - Strikes, disturbances...
Alert service (2)

- Other criteria
  - Train route
  - Time frame
  - Days of week
- Notification by e-mail or SMS
Other users

- **Types of users**
  - **Freight actors**
    - Rolling stock maintenance and follow-up
    - Tracking of consignments
  - **Public transport operators**
    - Same information as passengers
  - **Courier, e-commerce, mail order...**
    - Tracking of parcels
Other users (2)

- Direct query into database
  - Additional criteria: parcel ID, carriage ID, ...
  - Query using HTTP(S)
  - Returns XML file
Thank you for your attention

Visit also
WWW.LOCOLOC.ORG
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Main results & Conclusions

Michel ROUSSEAU
Main results

- Belgian test track (1st Test Track)
- RFF test track (2nd Test Track)
- CFTA Test track (3rd Test Track)
- Conclusion
Main results

- Belgian test track (1st Test Track)
- RFF test track (2nd Test Track)
- CFTA Test track (3rd Test Track)
- Conclusion
Main results

• Tests description:

Large amount of runs performed on the line 144 (14km of TT).
All data have been recorded (output of 1D algorithm and rough GNSS data)
-> to make off time statistical analysis of performance and availability
-> to replay scenario off-line with upgraded algorithm

• Architecture:

![Diagram of the architecture](image_url)
Main results

• Test Schedule:

• Phase I:
  • Data capture on line 144
    - Track data capture (for track database generation)
    - Images recorded for horizon mask generation

• Phase II:
  • Satellite positioning subsystem tests on line 144

Number of run: more than 100
Number or recorded points: more than 100k
Number of recorded bytes: more than 300M
Main results

2 types of environment

«Blue sky»
type: 1/4

«Canyon»
type: 3/4

Main results

14 km
Main results

Number of runs: 83
Number of samples: 76737
>= 6 sats: 83%
>= 4 sats: 96%

Blue sky environment
>= 6 sats: 95%
>= 4 sats: 98%

Canyon environment
>= 6 sats: 80%
>= 4 sats: 96%
Main results

Position Confidence interval

[Graph showing position confidence interval over time]

ALSTOM

TRASYS

Septentrio satellite navigation
Main results

Speed Confidence interval
Main results

Results without any augmentation

Positioning:
< 350 m for 95%

Speed:
< 17% for 95%

Positioning:
< 550 m for 95%

Speed:
< 23% for 95%
Main results

For more information regarding this event and the Locoloc Belgian Test Track:
Visit the web site Locoloc.org or Locoprol.org
You will find:

• Technical Presentation
• video dedicated to these tests
Main results

• Belgian test track (1st Test Track)
• RFF test track (2nd Test Track)
• CFTA Test track (3rd Test Track)
• Conclusion
Objectives: integration of the satellite positioning into ETCS trainborne equipment

- Fusion between GPS and Wheel sensor odometry in order to cover tunnel and masked area
- Eurobalise: ETCS interoperability
  - Local augmentation
Main results

EVC
- CORE
- TIU
- CAN1
- CAN2
- CETI
- BTM
- RTM
- SDMU
- TDMI

TCP/IP

TPC
- CPU Board
- GNSS Receiver
- TPC Server
- CETI Server
- CAN1/CAN2

RS422
- HoneyWell reference
- TCP/IP/SERIAL Converter
- CAN1
- CAN2

PC DATA LOGGER
- CANIBAL
- CANAPE

Radio

Eurobalise or Simulation (master simu)
Odometric sensor or Simulation (master simu)

ALSTOM

Septentrio satellite navigation

Trasys
Main results

**GNSS antenna**

**Eurobalise**

**Trainborne equipment:**

- Wheel sensor
- Eurobalise antenna

**Logos:**

- ALSTOM
- Septentrio
- TRASYS
Main results

Distance (m)

Train location fusion (m)

-2000 0 2000 4000 6000 8000 10000 12000 14000 16000

Front_Nominal
Front_Upper
Front_Lower
Rear
TPC_Rear
TPC_Front
Train_Loc_Fusion_Front_Nominal
Train_Loc_Fusion_Front_Upper
Train_Loc_Fusion_Front_Lower
Train_Loc_Fusion_Rear
Main results

- Belgian test track (1st Test Track)
- RFF test track (2nd Test Track)
- CFTA Test track (3rd Test Track)
- Conclusion
Main results

• Belgian test track (1st Test Track)
• RFF test track (2nd Test Track)
• CFTA Test track (3rd Test Track)
• Conclusion
Regarding satellite positioning…..

- It has been demonstrated that the technology is available and can be exploited to produce results compliant with low density user requirements (in terms of safety, availability and performance)

- A prototype system, using the 1D-algorithm has been developed, installed on a train and successfully tested on a real railway environment.

- EGNOS integrity messages constitutes a possible mitigation method to reduce risks associated to possible common mode.

- It has been demonstrated that a failsafe speed determination through the use of the GNSS doppler signal constitute a very interesting and promising way for the speed computation function of a vital trainborne signalling equipment:
  - The control of the maximum speed of the line
  - The control of the braking curve (in an ATC supervision system)
  - The use of the speed for odometric purposes (integration of the speed from a trackside balise).
Regarding the system….

- The satellite positioning has been integrated into a ETCS trainborne equipment: a prototype system has been developed, installed on a train and successfully tested on a real railway environment.

- The complete Locoprol system is currently under test in France and will be demonstrated live in a next public event in Nice on January 2005

…See you there!!
Thank you for your attention
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