Experiences with the DGPS-based Tramway Location System in Mannheim

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Because of increasing traffic in urban areas, public transport has to become more attractive and efficient by introducing computer-aided dynamic passenger information and on-line vehicle location. The tram location pilot system described makes vehicle scheduling and control systems independent of expensive location infrastructure (e.g. beacons). It uses on-board autonomous DGPS positioning with dead reckoning and a radio link to the control centre. The evaluation of the measured vehicle positions clearly demonstrates that operational accuracy requirements for public transport applications are met. The whole Tramway Location System (TLS) is structured into the 3 segments: on-board equipment, components of the operation centre and roadside equipment. The trial set-up for dynamic real-time measurements of the positioning accuracy is described, and the results of the evaluation of more than 7300 position fixes at 15 geodetically measured reference points along the tramway are presented. The conclusions indicate that, during runs in city environments, DGPS combined with dead reckoning achieves vehicle positioning precise enough to enable a reliable, improved and up-to-date passenger information service at the stops.

1. INTRODUCTION. The tramway location system (TLS) at the public transport company in Mannheim (MVV) aimed to prove that on-board autonomous positioning with GPS, differential corrections (DGPS) and dead reckoning (DR) provides sufficient accuracy, to meet operational requirements.

The measured positions are transferred to the operation centre using an independent radio data link, and displayed on a digital vector map on the screen of the dispatcher's workstation. Using the company's own optical fibre network, the positions of all trams are also distributed to 3 tram stop terminals located on a new tramway line (line 7) with a total number of 8 stops over a length of 2·5 km. Fifteen modern trams equipped with the TLS are running on this line. Passengers obtain dynamic information about the location of all trams, by interacting with the touch screen at the tram stop terminals (Fig. 1).

In conventional public transport applications, vehicle supervision is performed by logical localisation supported by infra-red beacons at a number of waypoints. The route is stored in the vehicle as a one-dimensional stop sequence comprising reference link distances between the stops (Fig. 2a). Detection of a stop is performed by comparing the measured distance of the wheel sensor (odometer) with the known length to the next stop and by interrogating the passenger door contact. Accumulated errors of the distance measurement are corrected when the vehicle passes the next infra-red beacon or the door contact indicates a stop. The drawbacks are cost and inflexibility; beacon infrastructure has to be installed

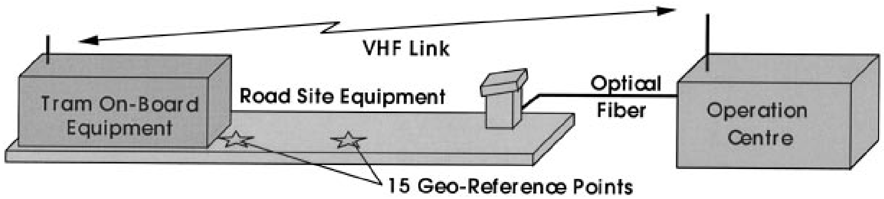

Fig. 1. Tramway location system overview

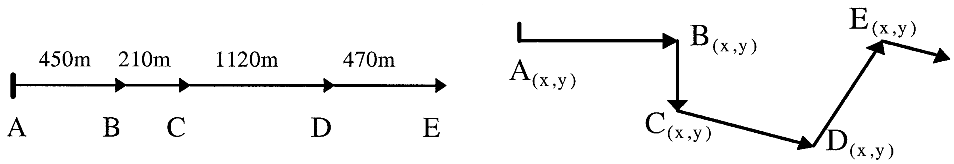

Fig. 2. (a) One-dimensional trace of route A–E. (b) Two-dimensional trace of the route.

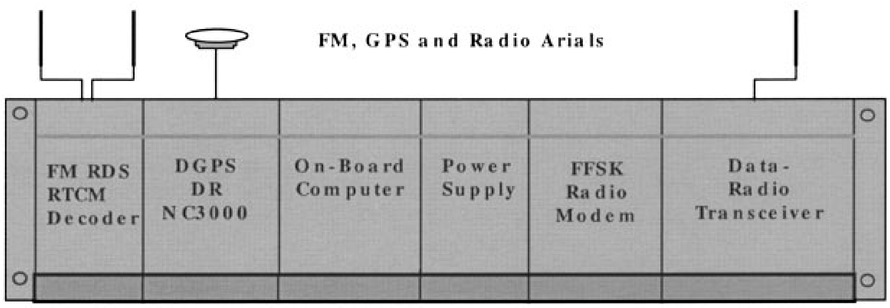

Fig. 3. TLS on-board components

along the line, cleaned and maintained. If the vehicle passes a stop without detecting it, or is re-routed, the passenger information announcement loses synchronisation with the stops. Another solution is to use DGPS and DR to perform two-dimensional localisation of the vehicles (Fig. 2b). A more accurate distance measurement using GPS, which is also used for alignment of the odometer, does not require beacons placed along the line. Such a modern autonomous vehicle location system was evaluated in Mannheim during 1996.

2. SYSTEM OVERVIEW. The first segment of the TLS in Mannheim, the operation centre, communicates with the trams *via* professional mobile data radio (Fig. 1) and displays vehicle locations on a monitor. Due to a clearly arranged visualisation of the vehicles on the screen, positions are displayed on a vectored digital map instead of an often-overloaded scanned map. The geographical representation of the current vehicle positions is not only available in the centre, but also at the roadside on passenger information terminals located at the tram stops. For evaluation of the localisation accuracy of the trams during their run, 16 geodetically measured points along the rail tracks were equipped with reflectors. Light barriers mounted on the trams released an electrical pulse, when passing one of these reflectors.

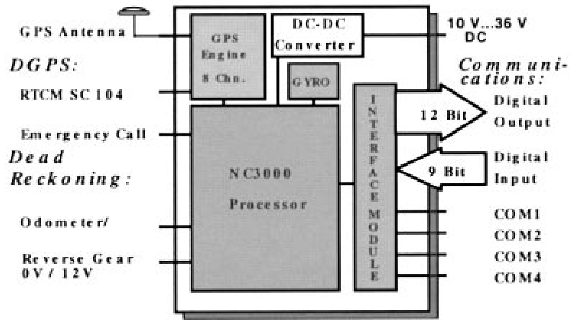

Fig. 4. DGPS/DR unit NC3000

3. ON-BOARD EQUIPMENT. The main TLS on-board components are mounted in a 19″ rack (Fig. 3). DGPS corrections are received by a two-channel FM RDS decoder module and transferred to the GPS receiver. The calculated position, combined DGPS and DR measurements, is embedded in a VDV protocol frame and forwarded to the VHF data radio transceiver *via* an FFSK radio modem. The tram driver gets information about the next stop and the system status by a remote control and display unit in his cabin. He is able to choose line and route, and to skip stops. Further controlling of peripheral equipment is provided.

3.1 *DGPS/DR unit*. An 8-channel GPS engine, a gyro and the communication processor are integrated in one case named NAVCOM NC3000 (Fig. 4). The NC3000 was especially designed for fleet management applications controlling communication *via* different paths. In this application, positioning is the main task. A serial interface transfers the positions to the on-board computer, a second serial interface is used for diagnosis purposes.

In an adverse city environment for GPS reception (e.g. narrow streets and tall buildings), GPS positioning is degraded due to shading and reflections. A significant enhancement is achieved, coupling the GPS results with DR sensors like an odometer and gyroscope, measuring the covered distance and the turn rate respectively. This yields continuous availability of a position result.

3.2 *FM RDS DGPS corrections receiver*. The Radio Data System (RDS) for FM broadcast radio transfers digital data in parallel with the 2 audio channels. In Germany, the data stream comprises DGPS corrections coded according to the RASANT method. RASANT is standardised in Germany and achieves a better DGPS availability within the FM transmitter coverage area than a transparent broadcast of the corrections. Due to the high signal strength required for RDS data, and the multipath effects not avoidable in urban areas, more common FM RDS receivers have difficulties in tracking the data continuously.

In order to reduce these problems, Alcatel applied a 2-channel decoder. This FM RDS receiver is able to switch over to the second channel during decoding, if the first one detects bad reception quality. It contains 2 independent new generation front ends each using its own antenna (Fig. 5). A micro controller chooses the best channel for data decoding. The RASANT format is converted to

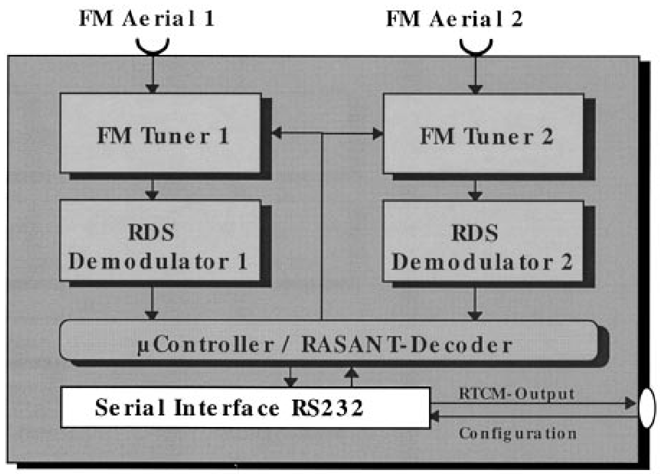

Fig. 5. Two-channel RDS/RTCM decoder

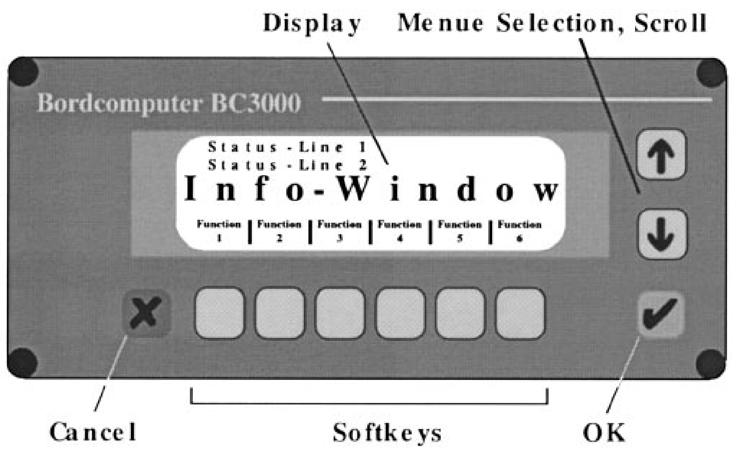

Fig. 6. Control and display unit

the common standardised international RTCM messages which most GPS receivers accept.

3.3 *On-board computer with control and display unit*. The computer is the core of the on-board equipment, developed for public transport systems (Fig. 6). It is able automatically to control VDV-compatible vehicle peripheral equipment *via* a recommended data bus (up to 32 components). The tram driver is supported by the menu-driven control and display unit (CDU) linked to the on-board computer with a high-speed Bit bus (375 kbit/s), which relieves him from routine activities. The CDU is equipped with softkeys and comprises a full graphical LCD showing up to 8 lines with 40 characters each. The key functions are indicated in the display and can vary depending on the selected menu. This yields an easy-to-handle man/machine interface with acceptable user guidance.

3.4 *Data radio facilities*. To transfer the data via the analogue radio, a modem is connected to the on-board computer *via* an RS485 Interface. Data

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transmission is organised in a half duplex mode; the centre transmits messages on a permanent RF carrier, while the vehicles respond at a different frequency with short transmissions. Response messages to the centre are generated by the on-board computer, transferred to the modem and stored there. When the centre requests a response, the modem immediately activates the PTT and sends the message. Afterwards the buffer in the modem is cleared, to avoid re-transmission of the same message. The VHF transceiver is extended by a system board with DC-DC converter and also mounted in the 19″ rack.

4. ROADSIDE EQUIPMENT. One part of the pilot project was the trial of dynamic passenger information, never applied anywhere else before. Not just the current waiting time for the next tram, but the whole situation of the line 7 trams is indicated. At 3 central tram stops, interactive passenger information terminals with touch screens have been installed. Each terminal consists of a PC using the same Geographical Information System (GIS) software as the centre. Every 5 seconds, the centre provides information for the remote terminals about all the current vehicles' positions. Communication is performed *via* fibre optical lines with a length of 2 km. A waiting passenger can select a sector of the city map, and look at the trams with their identification number symbolised as arrows indicating their current position and driving direction.

Fig. 7. Information terminal at the tram stop

5. OPERATION CENTRE. At the headquarters, a GIS displays the tram locations on a vectored digital map. The information is polled and is received *via* the duplex radio transceiver, a modem and the Radio Communication Server (RCS) (Fig. 8). The RCS polls the vehicles and collects the response messages. A sophisticated algorithm controls the process and avoids conflictions in the radio

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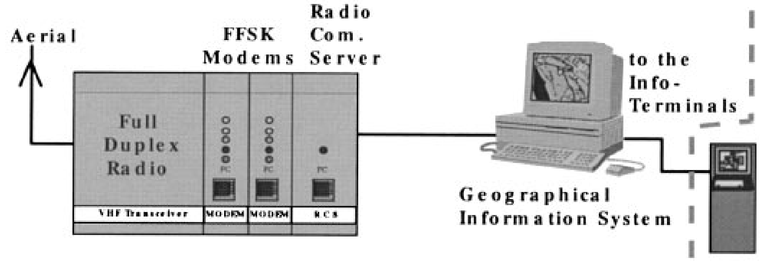

Fig. 8. Components of the operation centre

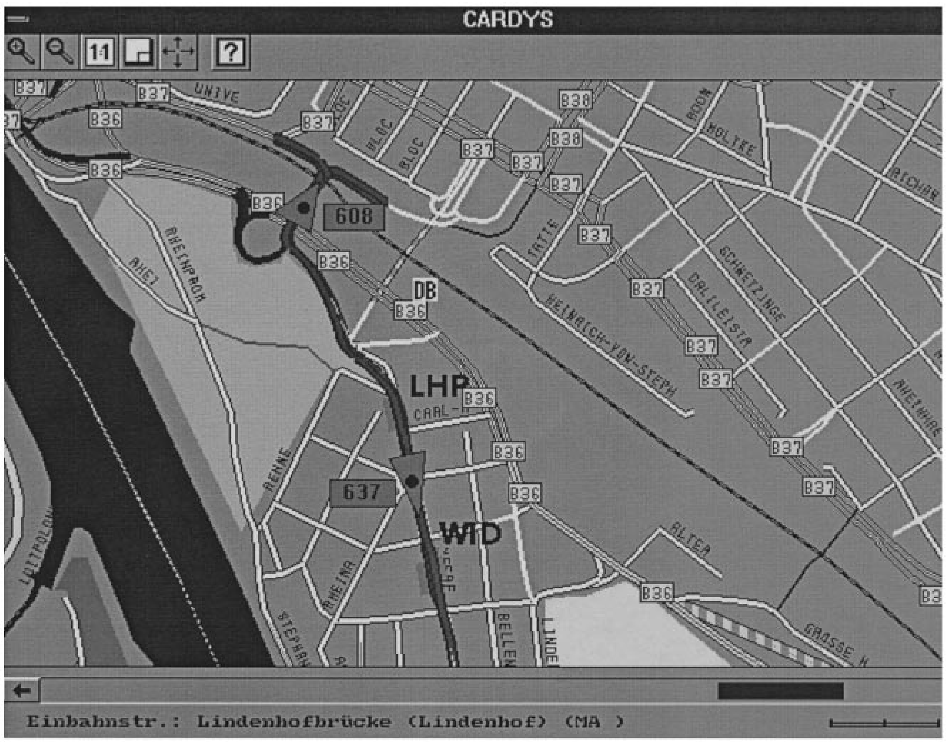

Fig. 9. GIS display of the north part of the tramway line with stops (LHP, WID)

channel due to overlapping vehicle transmissions. The radio modems use an FFSK modulation with 2400 bd.

Polling of the vehicles is initiated by a Graphical Workstation (GWS), communicating with the RCS. The essential part of the GWS is the GIS software. A database stores vectored information about the city of Mannheim (e.g. streets, rivers, parks).

The GIS software shows this information as a digital map on the screen (see Fig. 9). The displayed section can be chosen in steps. Depending on the scale, the GIS selects the information to be displayed. Zooming in increases the amount of detail presented, until names of all streets can be read. So, with all zoom factors a clear

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presentation of the information is ensured. This is a big advantage compared to scanned maps.

6. EVALUATION OF THE TRIAL. For the evaluation of the achieved dynamic accuracy, a real-time comparison of the actual tram positions with the 16 geo-reference locations along the tramway was performed. The goal was to obtain position error results and determine their repeatability as a 2 DRMS, 95 percent figure of the measurements. A statistical method implemented in the DGPS/DR unit software creates a collecting bucket for each reference point to calculate mean and deviation of the position measurements. When the tram passes a reflector mounted at a post near the tramway (Fig. 10), a single

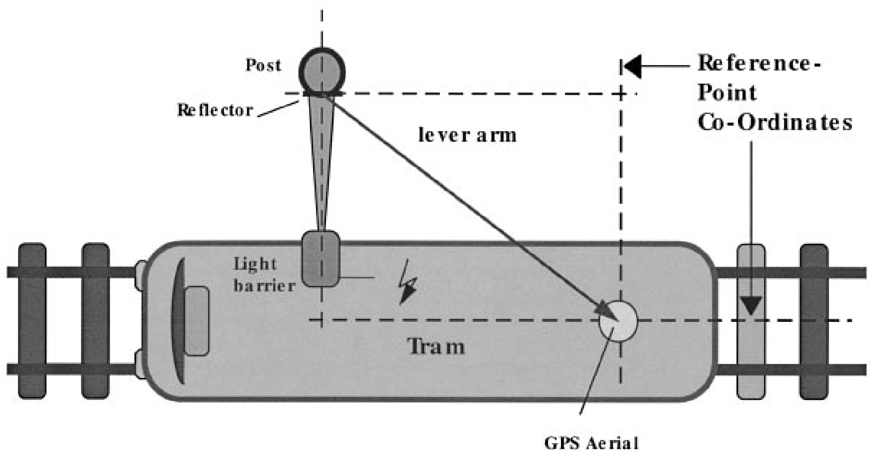

Fig. 10. Arrangement of measurement at the reference location

measurement is initiated by the light barrier installed on the trams. Due to a fixed installation arrangement of post, light barrier and GPS antenna, the reference point on the rails can be marked, above which the GPS antenna is located, when the light barrier sends a pulse.

During 4 weeks of operation, 4 trams equipped with sensitive light barriers collected 7382 measurements which could be clearly referred to one of the reference sites.

7. RESULTS. 99·2 percent of the measurements occurred under DGPS conditions (Fig. 11). This proved that RDS with RASANT was a reliable link for the DGPS correction broadcast even in the city environment.

At locations 6, 9 and 14, less events than usual occurred; location 8 did not trigger any measurement and is therefore omitted from the evaluation. This was caused by the tolerance of the reflector installation leading to weak light reflections below the detection level of the light barriers.

The mean value of the passing velocity varied between 14·2 km/h at reference location 1 near a stop and 48 km/h on a straight link at location 4. There was no correlation between mean velocity and position error at each location. This proved that the real-time relationship was implemented correctly.

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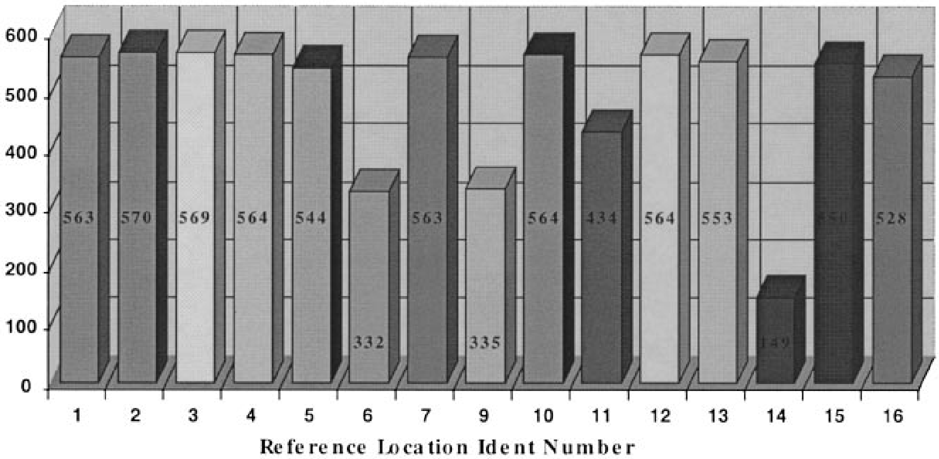

Fig. 11. Number of measurements at each reference location

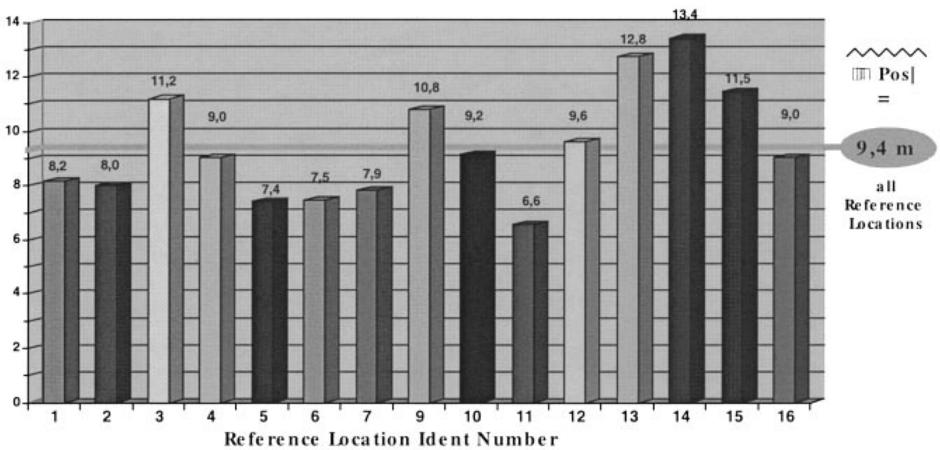

Fig. 12. Mean deviation from associated geo-reference points/metre

Due to the different GPS receiving conditions at the chosen measurement sites, each site also generated different results in accuracy. The absolute position error for each measurement location is shown in Fig. 12.

The best result, with 6·6 metres, was found at location 11. Location 14 generated the worst result with 13·4 metres. At this location however, the lowest number of measurements occurred (149 instead of usually about 560). The weighted average position error of all the 15 evaluated locations is 9·4 metres.

A common value used to describe GPS position accuracy is 2 DRMS. This is the radius of a circle comprising 95 percent of all results. You can interpret it as a figure for the repeatability of a measurement. The 2 DRMS for the worst (6·2 metres) and the best location (4·9 metres) are very close. A weighted average 2 DRMS over all 15 locations results in 5·7 metres.

8. CONCLUSIONS.

(i) During runs in a city environment, positioning using DGPS combined with DR achieved an average accuracy of 9·4 metres. The repeatability of position fixes results in 95 percent of the measurements falling within a circle of 5·7 metres.
(ii) The evaluation of more than 7300 dynamic fixes proved that vehicle position was precise enough, to enable reliable, enhanced and up-to-date passenger information at the stops.
(iii) Accurate next-stop information in the public transport vehicle network can be achieved without expensive beacon infrastructure to support localisation.
(iv) Traffic light priority systems require high real-time positioning accuracy. This was achieved by enhancing conventional localisation with DGPS calibrating the wheel sensors continuously.
(v) DGPS-based public transport operating systems enhance the attractiveness of public transport.
(vi) Better vehicle utilisation, and the avoidance of expensive beacon infrastructure, means that operational and maintenance costs can be reduced.
(vii) Equipped with DGPS-based vehicle scheduling and control systems, public transport in cities can be more efficient than the competing individual vehicle traffic.

KEY WORDS

1. DGPS 2. Vehicle location. 3. Fleet management.