

Haifeng Song

Development and analysis of a
Train-centric Distance Measurement
System by means of Colored Petri
Nets



Development and analysis of a Train-centric Distance Measurement System by means of Colored Petri Nets

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Braunschweig, June 2018

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Kurzfassung

Basierend auf technologischen Trends sollte das Zugbeeinflussungssystem den Anteil der Bodenanlagen reduzieren und den Zügen mehr Eigeninitiative geben als in der Vergangenheit, da so die funktionale Sicherheit und die Flexibilität des Zugbeeinflussungssystems erhöht werden können. In dieser Arbeit wird ein verbessertes System vorgeschlagen, das die Vorteile der zugbezogenen Kommunikation mit den aktuellen Fahrbefehlsmechanismen kombiniert. Um die notwendigen Daten des Zugabstandsintervalls zu erhalten, werden die Bordausrüstung und ein neues Zug-zu-Zug-Entfernungsmesssystem (TTDMS) als normale bzw. Backup-Strategien angewendet.

Während verschiedene Ortungstechnologien zur Zugdatenerfassung genutzt wurden, bleibt die Entwicklung und Validierung neuer Systeme eine Herausforderung. In dieser Arbeit werden formale Ansätze zur Entwicklung und Verifikation von TTDMS vorgestellt. Zur Unterstützung der Systementwicklung werden CPNs zur Formalisierung und Bewertung der Systemstruktur und ihres Verhaltens eingesetzt. Basierend auf dem CPN-Modell wird die Systemstruktur validiert. Zusätzlich wird eine Methode vorgeschlagen, mit der eine Code-Architektur aus dem formalen Modell generiert werden kann. Die Systemleistung wird im Erfassungsbereich und in der Genauigkeit beurteilt. Daher werden sowohl eine mathematische Simulation als auch eine praktische Validierung der Messungen implementiert. Die Ergebnisse zeigen, dass das System in der Lage ist, Entfernungsmessungen in Metro- und Eisenbahnlinien durchzuführen. Zudem sind die formalen Ansätze bei der Entwicklung und Verifikation anderer Systeme wiederverwendbar.

Die Abstandsmessung mit TTDMS basiert auf einem Frequenzspreizungsverfahren. Die Messung wird durchgeführt, indem die Ankunftszeit angewendet wird, um den Abstand zwischen zwei Zügen zu berechnen. Dieses Verfahren erfordert keine Synchronisierung der Zeitquellen der Übertragung. Der Zeitunterschied kann damit berechnet werden, indem die Autokorrelation des Pseudo-Random-Noise-Codes verwendet wird. Im Unterschied zu Systemen im Luft- und Seeverkehr benötigt dieses System keine andere Lokalisierungseinheit als die Kommunikationsarchitektur.

Um zu gewährleisten, dass ein System wie vorgesehen funktioniert, muss es validiert werden. Nur wenn das Systemverhalten validiert wurde, sind Bewertungen anderer relativer Leistungen sinnvoll. Aufgrund ihrer eindeutigen Definition kann das TTDMS mit formalen Methoden viel klarer beschrieben werden als mit ausführbaren Codes.

Abstract

Based on the technology trends, the train control system should weaken the proportion of ground facilities, and give trains more individual initiative than in the past. As a result, the safety and flexibility of the train control system can be further improved. In this thesis, an enhanced movement authority system is proposed, which combines advantages of the train-centric communication with current movement authority mechanisms. To obtain the necessary train distance interval data, the onboard equipment and a new train-to-train distance measurement system (TTDMS) are applied as normal and backup strategies, respectively.

While different location technologies have been used to collect data for trains, the development and validation of new systems remain challenges. In this thesis, formal approaches are presented for developing and verifying TTDMS. To assist the system development, the Colored Petri nets (CPNs) are used to formalize and evaluate the system structure and its behavior. Based on the CPN model, the system structure is validated. Additionally, a procedure is proposed to generate a Code Architecture from the formal model. The system performance is assessed in detection range and accuracy. Therefore both mathematical simulation and practical measurements validation are implemented. The results indicate that the system is feasible to carry out distance measurements both in metropolitan and railway lines, and the formal approaches are reusable to develop and verify other systems.

As the target object, TTDMS is based on a spread-spectrum technology to accomplish distance measurement. The measurement is carried out by applying Time of Arrival (TOA) to calculate the distance between two trains, and requires no synchronized time source of transmission. It can calculate the time difference by using the autocorrelation of Pseudo Random Noise (PRN) code. Different from existing systems in air and maritime transport, this system does not require any other localization unit, except for communication architecture.

To guarantee a system can operate as designed, it needs to be validated before its application. Only when system behaviors have been validated other relative performances' evaluations make sense. Based on the unambiguous definition of formal methods, TTDMS can be described much clearer by using formal methods instead of executable codes.