Toward a Reasoning Service to Improve Routable Road Maps by Deriving Road Attributes from Telematics Data

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Abstract
Detailed road maps are essential for efficient routing of vehicles. However, available data on roads is not always sufficient to support efficient routing, especially in the domain of agricultural vehicles, where route networks are not maintained by official mapping agencies. Efficient route planning can help reducing the cost of agricultural operations such as harvesting. We propose an approach for inferring road attributes from telematics data. The approach is based on semantic web technologies: a SWRL rule-based reasoning service infers road attributes from sensor data gathered by vehicles. This approach is meant to be used to develop a service for efficient routing of agricultural vehicles.

1. Introduction

Routable road maps are essential for navigation and route planning. However, there are several obstacles in their development; notably, knowledge about the route types and attributes is needed to support efficient routing.

Companies like NavTeq generate road data by driving roads with mapping cars. This approach is efficient for public road network since money savings associated with the costs of maintaining road data up-to-date are significant. However, in fields such as agriculture, routable networks are not maintained by public bodies. Also, agricultural route networks are composed of more heterogeneous types of roads, which conditions change more frequently. Consequently, new approaches are needed to generate routable road maps for agricultural vehicles.

We propose an approach to derive enriched information on road networks for agricultural vehicles. The information is derived from an agricultural telematics system that gathers sensor observations collected by vehicles themselves. Our contribution is to introduce the use of semantic web technologies to support inference of information from sensor data. The approach aims at supporting a service for routing agricultural vehicles in an optimal fashion.

Related work is presented in the next section. Agricultural data is presented in Section 3. Section 4 presents the approach and Section 5 provides an example. Conclusions are given in Section 6.

2. Related Work

There are several approaches to generate routable road networks from GPS trajectories. Some approaches focus on the generation of spatiotemporal trajectories but without deriving additional attributes that would enrich the trajectory with knowledge necessary for routing (Morris et al. 2004, Cao and Krumm 2009).

A few approaches for generating routable road networks from GPS trajectories also exploit sensor data to extract additional knowledge about the trajectories. For example, Eriksson et al. (2008) use sensor data on acceleration in combination with GPS data gathered by taxis to show that potholes can be detected from the measured acceleration data. Chen and Krumm (2010) used a Gaussian Mixture Model to detect lanes.

The approach we propose also uses sensor data to enrich routes with attributes. Our contribution is to investigate semantic web technologies to support the inference of road attributes. Few approaches also address the need to enrich trajectories with semantic information (Alvares 2007, Baglioni et al. 2008). However, most existing work focuses on analyzing the behaviour of the moving entities (e.g., animals) (e.g., Spaccapietra et al. 2008). We rather focus on how semantic trajectories could help to improve routing of agricultural vehicles.

3. Data Description

We use telematics data gathered by agricultural vehicles. Telematics systems transfer data captured by sensors placed on vehicles as well as vehicles' trajectories to a central controller (e.g., Figure 1). Sensor observations are associated with timestamp and location.

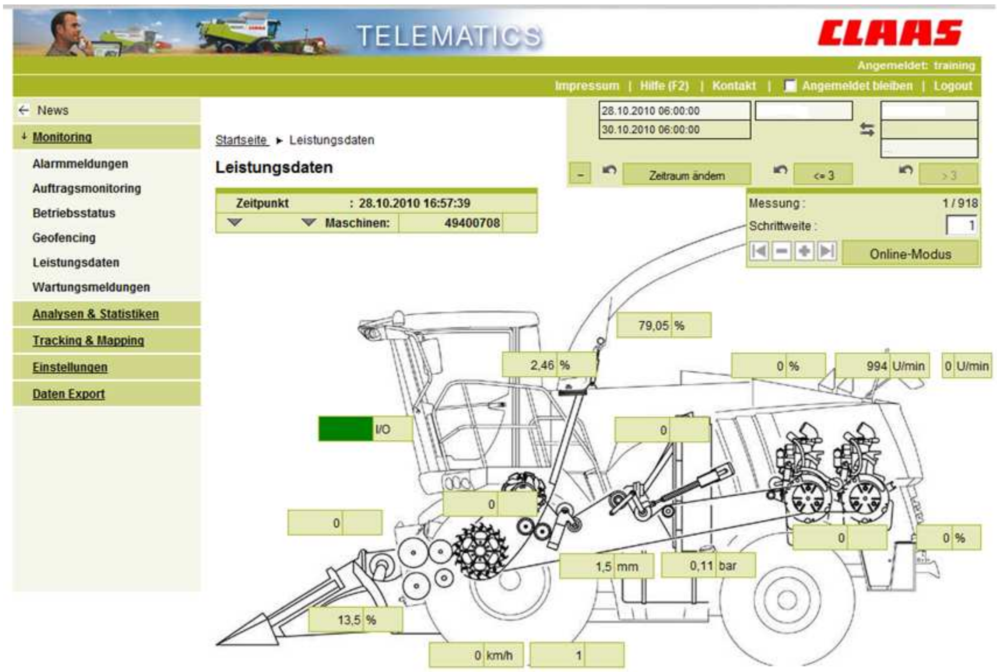

Figure 1. CLAAS Telematics Web GUI

Examples of sensor observations are provided in Table **1**.

Table 1. Selection of machine sensors (from CLAAS Lexion Harvester)

Name	**unit**
GPS (lat/lon)	°
Velocity	km/h
Engine rpm	rpm
Diesel fill level	l
Yield	t/ha
Auto pilot	on/off
Grain moisture	%
Lateral inclination	°
Longitudinal inclination	°
…	…

4. SWRL Rule-based Reasoning for Analysis of Trajectory Data

Figure 2 illustrates the framework for analyzing trajectory data and the annotation of agricultural vehicle trajectories with enriched attributes. The sensor observations are collected by the telematics web server. Sensor observations are used to identify sub-trajectories that are associated with similar observations (e.g., same velocity). This results in a set of road segments.

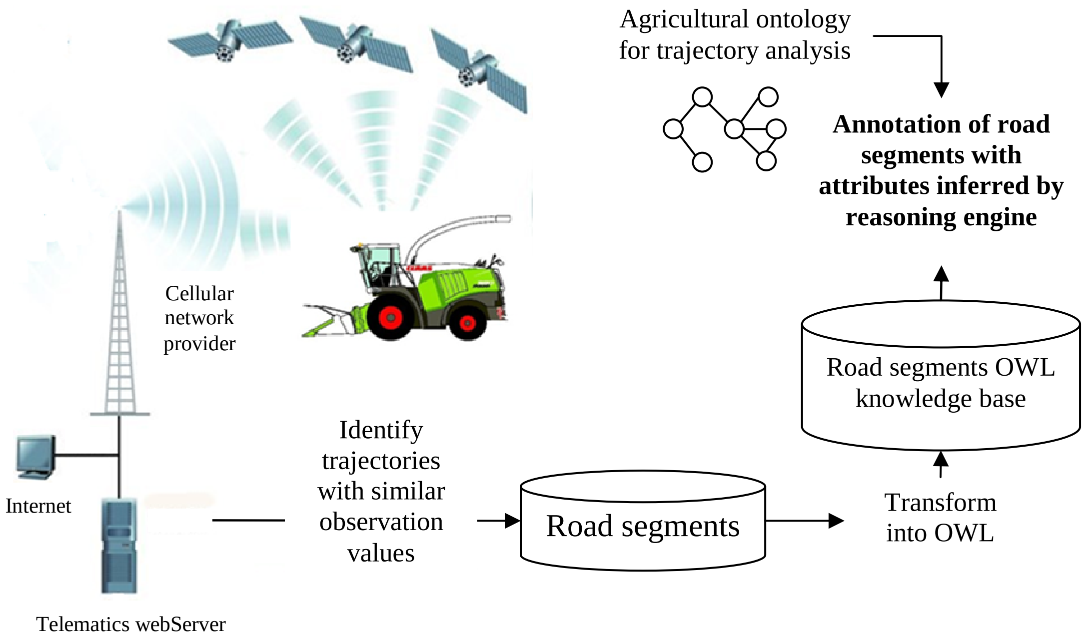

Figure 2. Framework for the analysis of trajectory data

To infer the road segments' attributes, we use a rule-based reasoning service that uses the Semantic Web Rule Language (SWRL) (Horrocks et al. 2004). The reasoning service uses Jess, a SWRL rule-based reasoning engine that takes as input Ontology Web Language (OWL) statements and SWRL rules to infer facts (Eriksson 2004), which can be used to combine data from heterogeneous sensors (Bakillah et al. 2012).

To make information about road segments computable by the reasoning engine, sensor observations associated to segments are transformed into OWL statements. The reasoning engine infers the segments' attributes based on their associated observations. The inference is supported by SWRL rules that express dependencies between sensor observations and attributes. Terminology for expressing rules and attributes is formalized in an ontology. Inferred attributes are used to annotate road segments.

5. Application to Analysis of Agricultural Vehicle Trajectory

Sensor observations and road attributes are formalized in an ontology, an excerpt of which is provided in Figure 3.

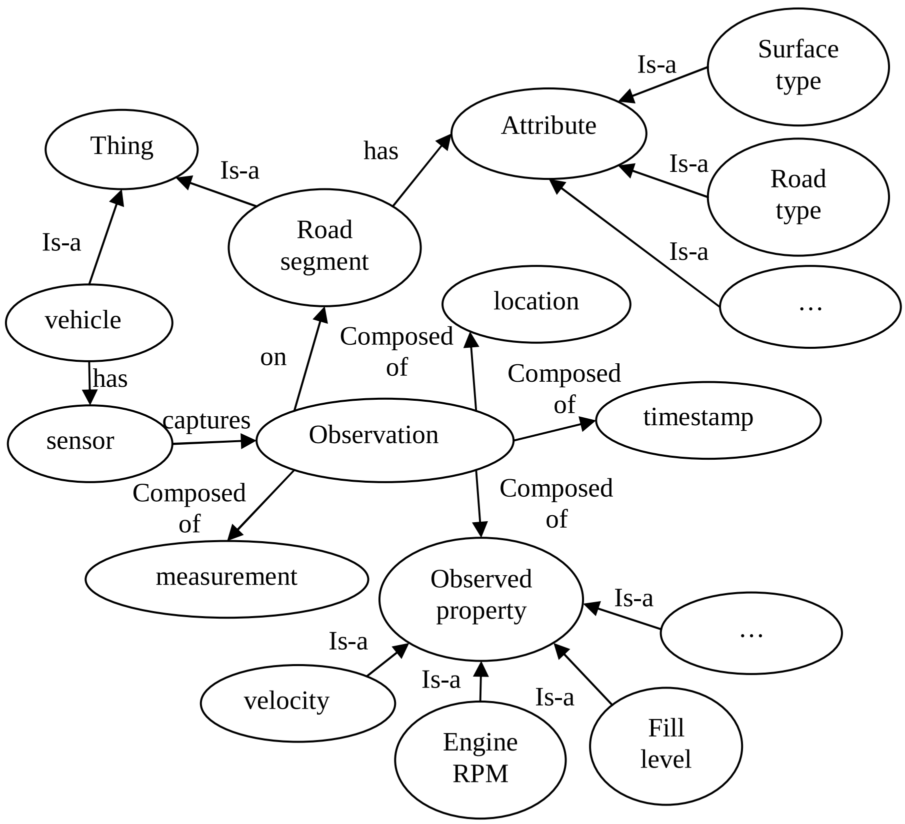

Figure 3. Trajectory analysis ontology excerpt

Dependencies linking observations and road attributes are formalized with SWRL rules. A rule expresses a logical implication between an antecedent and a consequent. The antecedent and consequent are formed with the following main elements (more complex elements exist):

1. **Class axioms:** *c*(?*x*) means that individual *x* is an instance of concept *c* (e.g. Vehicle(?*v*) means that *v* is a vehicle).
2. **Property axioms:** *p*(?*x*, *z*) means that the value of property *p* for individual *x* is *z* (e.g., speed(?*v*, *s*) means that the speed of *v* is *s*).

The following is an example of rule that links the type of road (paved street) to minimal tire pressure (*p_min*) and vehicle velocity (*v_min*):

Vehicle(?*v*) ∧ HasSensor(*?v*, ?*s1*) ∧ Observation(?*o1*) ∧ RoadSegment(?*r1*) ∧ On(?*o1*, ?*r1*) ∧ Captures(?*s1*, ?*o1*) ∧ ComposedOf(?*o1*, velocity) ∧ MoreThan(velocity, *v_min*) ∧ HasSensor(*?v*, ?*s2*) ∧ Observation(?*o2*) ∧ On(?*o2*, ?*r1*) ∧ Captures(?*s2*, ?*o2*) ∧ ComposedOf(?*o2*, tirePressure) ∧ MoreThan(tirePressure, *p_min*) → PavedStreet((?*r1*)

To enrich sensor data, we also compute attributes with filter methods. We identify peak values that are significant for determining attribute classes (e.g., average speed and changes in driving direction). We also extract information from geometric patterns in trajectories, e.g., we can obtain parallel tracks within the field where two vehicles can operate together. Also, driving patterns are used to infer road surface or street type.

6. Conclusion

This work demonstrates possibilities for generating enriched trajectories from telematics datasets with support of inference engines. The rule-based reasoning approach can detect several complex patterns from spatial, temporal and descriptive data to annotate the segments of trajectory with advanced knowledge. This knowledge is currently used to develop a service for efficient routing of agricultural vehicles.

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