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Ontological Modeling of African Road Environments

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Abstract

Sensors (camera, radar, lidar...) help Autonomous Vehicles to perceive the environment in which they move. These environments are for most of the cases, unpredictable, having a large dynamic execution context, with strong interactions. To guarantee the safety of the autonomous vehicle, its occupants and other road users, it is necessary to validate the decisions of the algorithms for all situations that will be encountered [31]. These situations depend essentially on the scenes in which the autonomous vehicles evolve. In this work, we propose an Ontological modeling of African road environments. In this context, we have defined three Ontologies: highway, weather and vehicle. The Highway Ontology and the Weather Ontology conceptualize the environment in which the autonomous vehicle evolves, and the Vehicle Ontology includes the vehicle devices. These different Ontologies were defined using the METHONTOLOGY method and the $ALCreg$ logical description family, and previous designed Ontologies.
Keywords: Autonomous vehicles, Ontology, Road environment, algorithm.

INTRODUCTION

Since the 1970s, autonomous vehicle research has become a trend in the industry. Many Companies and researchers are lunching many researches and prototype of autonomous vehicle [1]. The autonomous vehicles currently under development are equipped with several highly sensitive sensors such as camera, stereo camera, Lidar, and Radar. Although objects and traffic lanes can be detected using these sensors, the vehicles cannot understand the meaning of the driving environment without data representation [31]. Therefore, a machine-understandable knowledge representation method is needed to bridge the gap between perceived driving environments and knowledge processing. Ontologies are structural frameworks for the representation of knowledge about the world or a part of it that mainly consists of concepts (classes) and the relationships (properties) between them. Ontologies have been built to enable intelligent vehicles to understand driving environments. Ontologies can represent knowledge of sophisticated maps, paths, and driving control concepts that are required for autonomous driving [16]. Works in the field of Ontologies applied to autonomous vehicles are developed by some countries in Asia, Europe, and America, and their studies are based on their scenes, so the vehicles that are developed will take into account just the existing data on the scene. This problem is a handicap to the integration of Autonomous Vehicles in African environments. Hence the need to design knowledge bases of African road environments. This article is organized as follows: Firstly, the method, based on ontologies and descriptive logic $ALCreg$ [4] is presented in section 2, secondly, we will present in section 3 the results and discussions. At the end we will try to situate our work in relation to some work done in this area.

METHOD

The growth of Ontology has permitted the development of many Ontology design Method. E can site: Uschold and King [5], Grüninger and Fox [6], METHONTOLOGY [7] and Ontology development 101 [8]. We decided to use METHONTOLOGY because it matches our requirements in terms of building an ontology from scratch while using some existing ontologies. METHONTOLOGY clarifies the different steps of building an ontology through its seven phases: specification, knowledge acquisition, conceptualization, integration, formalization, implementation and maintenance. However, the construction of such an ontology must be conducted according to the specificities of this particular domain [7].

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SPECIFICATION

Our work is based on the Cameroonian road environment in particular. We base our work on everything that can exist in the environment of an autonomous vehicle placed in a Highway. The introduction of an ontology for African Highways aims at making autonomous vehicle guidance software efficient in the African environment. A set of terminologies are used to move towards a common and shared understanding to improve communication, information sharing and exchange, interoperability and reuse. The ontology will take into account the deep semantics of all represented concepts, including those that refer to certain metaphors [32]. The requirements specification document for the African Roads Environment (ARE) ontology is summarized as follows:

Table 1: Specification of ontology requirements in the ARE domain

ARE Ontologie Requirements Spécification document	
Domain	African Road Environment
Objectives	Ontologie on concepts to be used when informations are needed for the guidance of AV in ARE. This ontologie could be used in area where the road is bad.
Formalization level	Formal
Field of Application	List of concepts in weather, Highway, and Vehicles
Main sources of knowledge	Toyota Technologgies Institut, Institut of research SystemX, Road survey (National Road N°3)

CONCEPTUALIZATION

In order to conceptualize the ontology, we need to deepen it, involving concepts specific to Cameroonian environments. The African road environment has certain specificities that are unique to Africa, which we will not see in European, Asian, or North American environments. We will develop 3 ontologies:
a vehicle ontology, an environment ontology, a weather ontology.

- Example of Conceptualization of the Highway Ontology
- Highway is a class
- Roadpart is a subclass of Highway
- Segment is a subclass of Roadpart
- Interchange is a subclass of Roadpart
- Brane's is a subclass of Interchange
- Obstacle is a subclass of HighWay
- Object is a subclass of Obstacle
- Tree is a subclass of Object
- Branches is a subclass of Tree
- Trunk is a subclass of Tree

- Example of Conceptualization of the Vehicle Ontology
- Automobile is a subclass of Vehicle
- Bicycle is a subclass of Vehicle
- Motorcycle is a subclass of Vehicle
- Engine is a subclass of MyCar
- Sensor is a subclass of MyCar

- Example of Conceptualization of the Weather Ontology
- DayLight is a subclass of Weather
- Temperature is a subclass of Weather
- Precipitation is a subclass of Weather

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FORMALIZATION

To higher the level of formalization, we use a logical description language (DL) to represent the ontology as a TBOX in which concepts are formally described using $AL\ Creg$ (a variant of PDL) with any combination of the features: inverted roles, nominals, quantified number restrictions, the universal role, the concept constructor to express the local reflexivity of a role.
We denote the sets of concept names, role names and individual names by C, $R+$ and I respectively [34]. A concept name is an atomic concept, a role name is an atomic role. Let $R = R+ \cup R-$, where $R- = \bar{r} \mid r \in R+$ and $\bar{r}$ is called the inverse of r. We call the elements of R base roles. We distinguish a subset of $R+$ whose elements are called simple roles. If $r \in R+$ is a simple role, then $\bar{r}$ is also a simple role. The set $\sum = C \cup R+ \cup I$ is called the signature. Let Φ⊆{𝔗, 𝔒, 𝔔, 𝔘, Self}, where the symbols stand for inverse roles, nominals, qualified number restrictions, universal role, and local role reflexivity, respectively. The roles and concepts of DLs, ALC, ALC+Φ, $(ALC + \Phi)trans$and $(ALC{+}\Phi)reg$ are defined as follows.
If L = ALC, then:
- if $r \in R+$, then r is a role of L
- if A ∈ C, then A is a concept of L
- and ⊥ are concepts of L
- If C and D are concepts of L and R is a role of L,
then ¬C, C t D, C u D, ∃R.C and ∀R.C are concepts of L.
If L = ALC+Φ, then in addition:
- If I ∈ Φ and R is a role of L, then R is a role of L
- If O ∈ Φ and a ∈ I, then {a} is a concept of L
- If Q ∈ Φ, n ∈ N, C is a concept of L, R is a simple role of L (i.e., a simple role that is a role of L) then ≥n R.C and ≤n R.C are concepts of L,
- If U ∈ Φ, then U is a role of L
- If Self ∈ Φ and r ∈ R+, then ∃r.Self is a concept of L
If L = ALC + Φ) $trans$, then in addition :
- ε is a role of L
- if R and S are roles of L and are different from U then $R \sqcup S$, R ∘ S and R∗ are roles of L [33].

TBOX

A TBox axiom (or terminology axiom) is either a general concept inclusion (GCI: General Inclusion Concept) $C \sqsubseteq D$ or a concept equivalence $C \doteq D. A$. A concept equivalence $A \doteq D$ (where A ∈ C) is called a concept definition. A TBox is a finite set of axioms. It is permissible for a DL L if it uses only concepts from L. A valid interpretation $\mathfrak{I}\ C \sqsubseteq D$ (resp. $C \doteq D$) if $C\mathfrak{I} \sqsubseteq D\mathfrak{I}$ (resp. $C\mathfrak{I} = D\mathfrak{I}$). It is a model of a TBox $\mathcal{T}$ if it validates all axioms of $\mathcal{T}$. A TBox $\mathcal{T}$ is acyclic if there are concept names $A1$ ... . An such that $\mathcal{T}$ consists of n axioms and the i-th axiom of $\mathcal{T}$ is of the form $Ai. \doteq C$, $C \sqsubseteq Ai$ or $Ai \sqsubseteq C$ where C does not use the concept names Ai ... ... An. The $A1$ ... . An are called intentional predicates specified by $\mathcal{T}$. A TBox $\mathcal{T}$is called a simple stratified TBox if there is a partition ($\mathcal{T}$ 1....... $\mathcal{T}n$) of $\mathcal{T}$, called a stratified one of $\mathcal{T}$, such that, for every 1 ≤ i ≤ n, $\mathcal{T}\ i = \{Ci,j{\sqsubseteq}Ai,j|1{\leq}j{\leq}ni\}$, where each $A\ i,j$ is a concept name that does not appear in, $\mathcal{T}$ 1....... $\mathcal{T}i$-1 and may appear in the LHS of ⊑ in $\mathcal{T}\ i$ axioms only under the scope of ⊓,⊔et∃. The concept names, Ai,j for 1 ≤ i ≤ n and 1 ≤ j ≤ ni, are called intensional predicates specified by $\mathcal{T}$. Note that negation (¬) is allowed at the LHS of ⊑ in the GCIs of a simple stratified TBox, but it can only be applied to concepts that do not use the predicates defined in the current or later strata [33].
We will formalize the different ontologies, by presenting a TBox, of the different concepts of the ontology.

- Weather Ontology TBox

$DayLight \sqsubseteq Weather$ (1)

$Temperatur \sqsubseteq Weather$ (2)

$Pressure \sqsubseteq Weather$ (3)

$Humidity{\sqsubseteq}Weather$ *(4)*

- Car Ontology TBox

WindScreenWiper ≡ MyCar ⊓ ∃$part.\ WindScreen$ (5)

WindScreenWasher ≡ MyCar ⊓ ∃$part.\ WindScreen$ (6)

ParkingLight ≡ MyCar ⊓ ∃$part.\ Light$ (7)

HeadLight ≡ MyCar ⊓ ∃$part.\ Light$ (8)
ReversingLight ≡ MyCar ⊓ (∃$part.\ Light$ ⊓ ∀Serves.To_Reversing) (9)

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LeftDirectionLight ≡ MyCar ⊓ (∃$part.DirectionLight$ ⊓ ∀Serves.To_Left) (10)
RightDirectionLight ≡MyCar⊓(∃$part.DirectionLight$⊓∀Serves.To_Right) (11)
Sonar ≡ Sensor ⊓ (∃$Serves.Distance$) (12)
Camera ≡ Sensor ⊓ (∃$Serves.Image$) (13)
Acceleration ⊔ $Deceleration$ ⊔ $Constant$ ≡ $Sensor$ ⊓ (∃$Serves.Distance$) ⊔ $Sensor$ ⊓ (∃$Serves.Distance$) (14)
$SuddenAcceleration \equiv \exists isIrregular.Acceleration$ (15)

- Highway Ontology TBox
$Roadpart \cup Roadway \cup Zone \cup Equipement \cup Obstacle \sqsubseteq Highway$ (16)
$Divergence \equiv Brane's \sqcap (\exists Serves.Diverge)$ (17)
$EntranceRamp \equiv Ramp \sqcap (\exists Serves.Enter)$ (18)
$CarriageWay \cup Median \cup Shoulder \sqsubseteq Roadway$ (19)
$EntranceLane \cup WeaveLane \cup ExitLane \sqsubseteq AuxiliaryLane$ (20)
$Symbol \cup Barrier \cup Fence \cup Lighting \cup EmergencyTelephone \sqsubseteq Equipement$ (21)
$Obstacle \sqsubseteq Highway$ (22)
$Animals \cup Tree \sqsubseteq Objects$ (23)
$Potholes \cup Objects \sqsubseteq Obstacle$ (24)
$Branches \cup Stem \sqsubseteq Tree$ (25)

RESULTS AND DISCUSSION

The analyses of the Cameroonian driving environments, allowed us to acquire a number of useful information for the construction of our Ontologies. We have 3 Ontologies: Car Ontology, Weather Ontology, Highway Ontology. We will present these different Ontologies in the following paragraphs.

RESULTS

We explored several works on Ontologies applied to autonomous driving, we found that the majority of these works did not take into account certain realities specific to Africa. We synthesized several Ontologies from relevant works, and introduced new concepts specific to the Cameroonian environment. This resulted in the modeling of 3 Ontologies.

- Weather Ontology

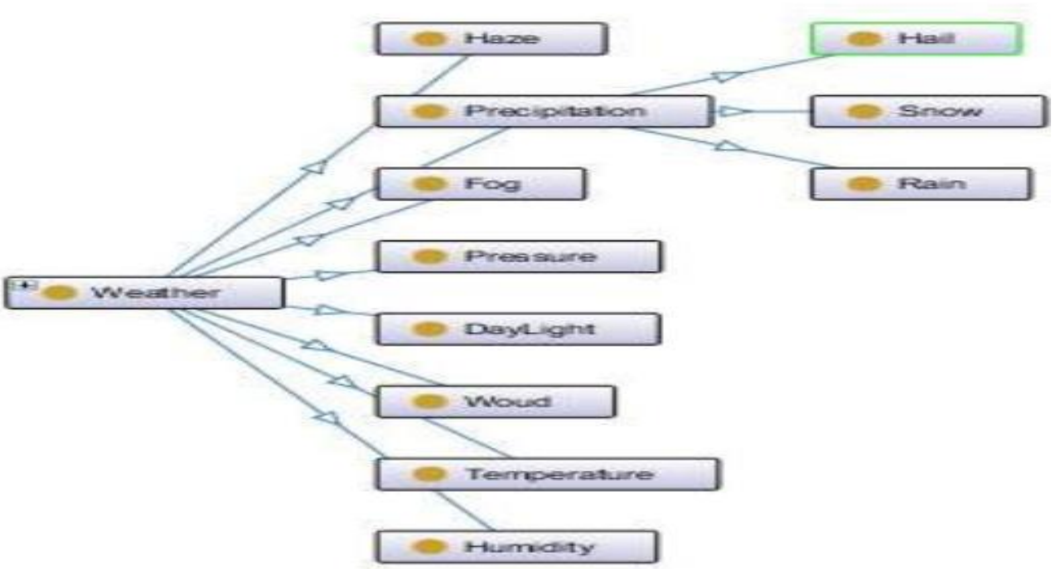

Figure1: OntoGraf Weather

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Figure 1 presents the ontology of Weather; it is composed of 12 concepts. These concepts are the different elements that can be found in the weather, we can mention: Fog, Precipitation, fog mist, pressure, daylight, temperature, humidity, hail, rain, snow. These parameters, most often neglected, are very important because the guidance software of the autonomous vehicle can generate errors in its operation if the weather parameter is not considered.

- Car Ontology

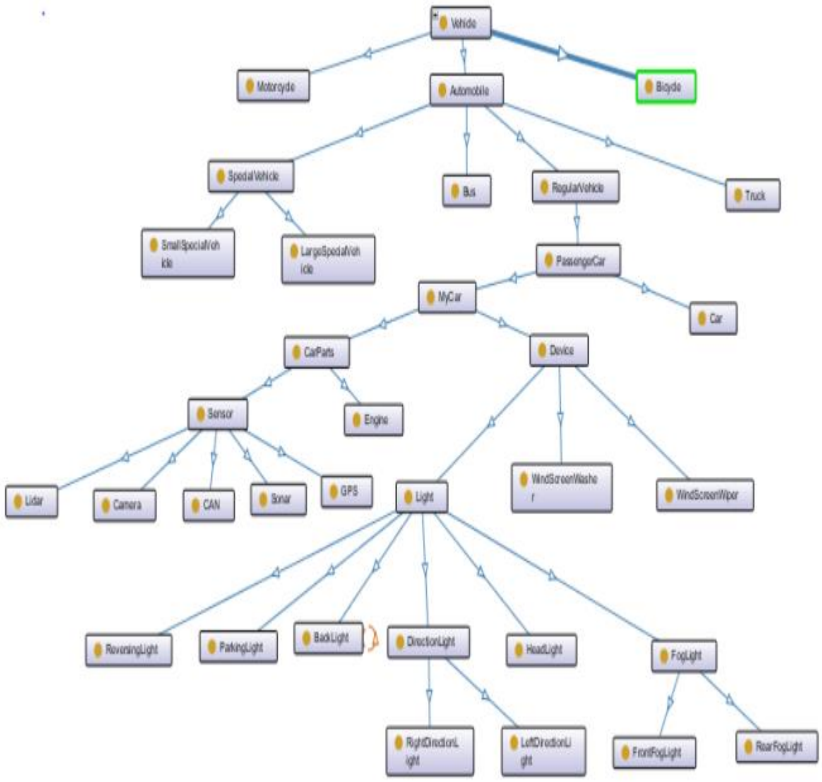

Figure 2 : OntoGraf Car

The Car Ontology is the ontology of vehicles that are present on the road environment. We present the Car Ontology, which provides a large knowledge base for autonomous driving. Taking into account the elements such as sensors and lights, make this Ontology powerful because it allows the autonomous vehicle to have information about the different vehicles sharing the road with it.

Highway Ontology

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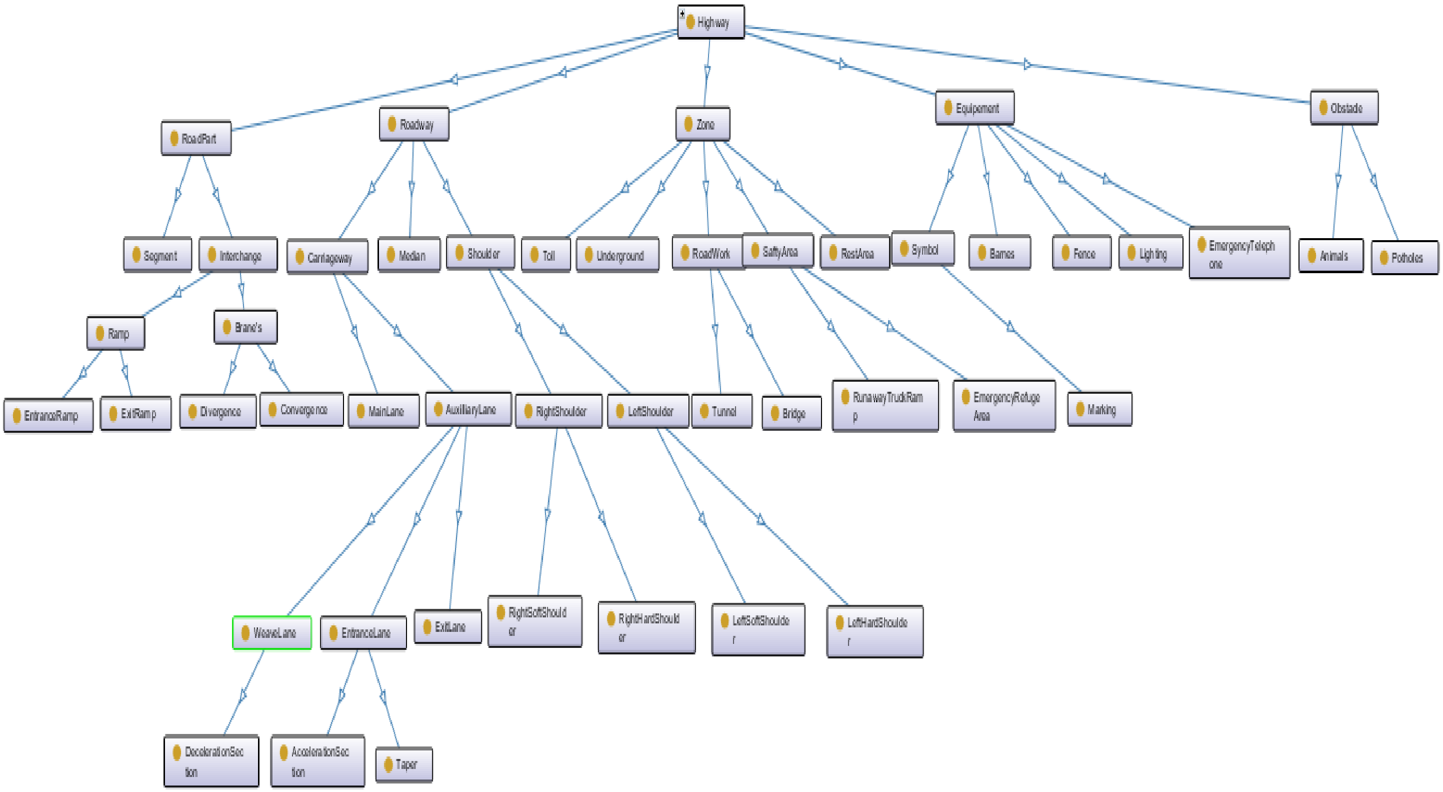

Figure 3: OntoGraf Highway Ontology

The road infrastructure consists of the physical components of the road network that provide the essential facilities for the vehicle to travel on the road. We have constructed the ontology of highways from official French and Cameroonian documents (Ministry of Ecology, 1988) [12], (Ministry of Transport). This ontology includes five main concepts: RoadPart, Roadway, Zone and Equipment Obstacle. The RoadPart concept refers to the longitudinal profile of the Highway. We consider that the Highway is composed of connected segments and interchanges. There are two types of interchanges on the highway: the spur and the ramps. The spur connects to another highway and the ramp connects to other types of roads. The pavement concept refers to the longitudinal profile of the Highway. Special areas on the highway (toll, safety area, rest area, etc.) are classified in the area concept. The Equipment concept refers to the facilities that guarantee the normal operation of the freeways. This may include barriers, fences, etc. The Obstacle refers to the concepts in this ontology that are defined in terms of potholes; trees, animals... A sophisticated machine understandable map is needed for autonomous cars to perceive driving environments. Therefore, we build an ontology of Road to describe road networks such as road, intersection, lane, and traffic information, etc [31]. The Highway ontology contains 67 classes.

DISCUSSION

The work of Wei Chen et al, presents us with three ontologies for conceptualization and characterization of use case components: a highway ontology and a weather ontology to specify the environment in which the autonomous vehicle operates, and a vehicle ontology that includes vehicle devices and control actions.[31]

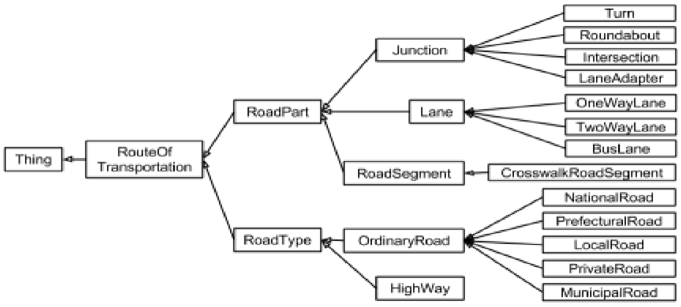

Figure 4: Highway Ontology of Wei Chen and al

When we compare it to our Highway Ontology, we notice that in our Ontology there is a component that has been added, that of Obstacles. Such as potholes, trees… We thought that in order for our Ontology to perform better in the Cameroonian environment, it is important to take these parameters into account because our road network in most cases is strewn with obstacles.

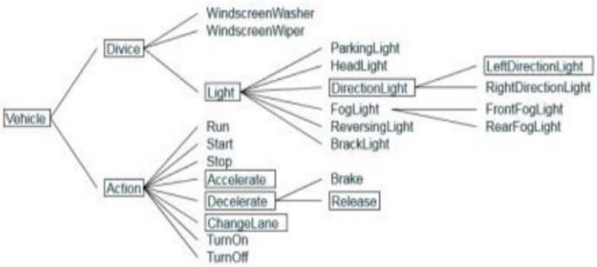

Figure 5: Car Ontology of Wei Chen and al

Our Car Ontology, unlike Wei Chen and al, takes into account parameters as Sensors; because, if the guidance system does not contain a knowledge base on sensors, it cannot be trained on the use cases of telemetry, pattern recognition, or spatial guidance. Lihua Zhao and al, present in their paper, the ontology-based dataset for safe autonomous driving that can be used to develop systems for advanced driver assistance systems (ADAS). The dataset is based on three main ontologies: the map ontology, the control ontology and the car ontology. [16]

Figure 6: Highway Ontology de Lihua Zhao et al

We note that they have opted for a Top-level Ontology, which can cause problems for a vehicle moving in the driving environment, as the lack of data in the knowledge base will not allow the vehicle to move in all environments. This gives our Ontology an advantage because it has many more parameters in its knowledge base on $ALCreg$, it allows the design of more complex Ontologies. Most Ontologies for Autonomous Vehicles are developed in Europe, and America, and these Ontologies are based on the environments where they are developed, so if an Autonomous Vehicle were to be driven in Africa, its guidance software would not adapt to this environment. This observation makes our work as one of the pioneering works in the development of Autonomous Vehicles adapted to adapted to African environments.

CONCLUSION

In this paper, we present an Ontological modeling of the road environment, based on the METHONTOLOGY method and on the logical description family, $ALCreg$. We describe the African interurban driving environment, i.e., the existing elements in the autonomous vehicle driving scene. We studied the environment and found that African environments have specificities due to poor road conditions, and probable obstacles that can block the passage. The results of this paper are the conceptualization of a knowledge base for the African driving environment, through 3 Ontologies, one of the vehicles, highlighting the relevant components of the vehicles, a Weather Ontology presenting the different weather a vehicle may face in the driving environment, and a Road Ontology that presents in detail the components of a Highway, with the relevant innovation of obstacles on the road. In the future, we plan to extend this work in the design of guidance software for autonomous vehicles, this will be done by integrating our Ontology as a knowledge base, using Artificial Intelligence algorithms for recognition, and finally the use of advanced image processing and remote sensing methods for the integration of information from the driving scene.

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