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DISCLAIMER

This Use Cases and Functional Requirements document is work in progress.

It defines the scope of the future Connected Autonomous Vehicle (CAV) standard identifying 4 subsystems and, for each subsystem, the workflow – AI Workflow (AIW) – whose function, interfaces and I/O data formats will eventually be standardised and the basic components – AI Modules (AIM) – whose function, interfaces and I/O data formats will eventually be standardised.

The process envisages issuing a Call for Technologies open to all interested parties based on which the standard will be developed.

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**MPAI Use Cases and Functional Requirements**

**Connected Autonomous Vehicles**

**MPAI-CAV**

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| **WD0.10** |

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**Connected Autonomous Vehicles**

**V1**

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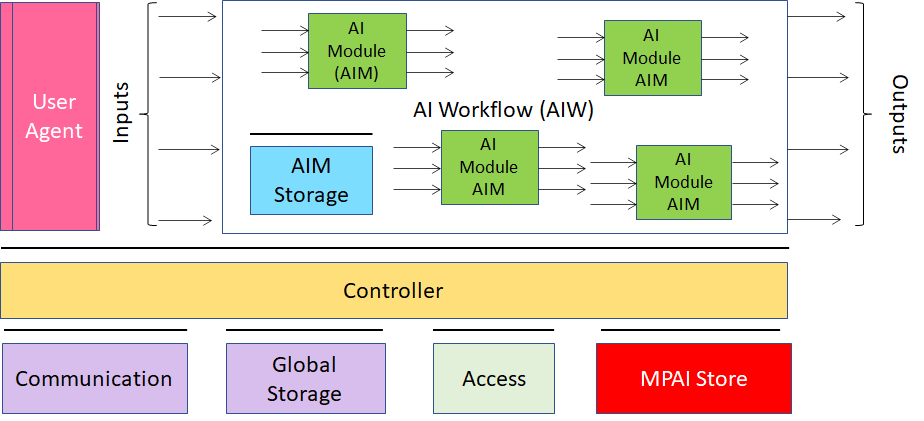
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# Introduction

Moving Picture, Audio and Data Coding by Artificial Intelligence (MPAI) is an [international Standards Developing Organisation](http://mpai.community/) with the mission to develop *AI-enabled data coding standards*. Research has shown that data coding with AI-based technologies is generally *more efficient* than with existing technologies. Compression and feature-based description are notable examples of coding. MPAI Application Standards enable the development of AI-based products, applications and services.

In the following, Terms beginning with a capital letter are defined in *Table 4* if they are specific to this Standard and in *Table 16* if they are common to all MPAI Standards.

MPAI Application Stan­dards Implementations operate in the AI Framework (AIF) specified by the MPAI-AIF Standard (MPAI-AIF). *Figure 1* depicts the MPAI-AIF Reference Model. This Introduction only describes the basic processing elements called AI Modules (AIM) which make up an AI Workflow (AIW) executed in an AI Framework (AIF).



*Figure 1 – The AI Framework (AIF) Reference Model and its Components*

MPAI Application Standards normatively specify:

1. *For the AIMs*: the Function, and the Semantics and Formats of the input and output data but not the internal architecture, which may be based on AI or data processing, and implemented in software, hardware or hybrid software and hardware technologies.
2. *For the AIWs*: the Function, the Semantics and Formats of the input and output data, and the Connections between and among the AIMs.

MPAI defines Interoperability as the ability to replace an AIW or an AIM Implementation with a functionally equivalent Implementation. MPAI also defines 3 Interoperability Levels of an AIW that executes an AIW. The AIW may have 3 Levels:

*Level 1 –* Implementer-specific and satisfying the MPAI-AIF Standard.

*Level 2 –* Specified by an MPAI Application Standard.

*Level 3 –* Specified by an MPAI Application Standard and certified by a Performance Assessor.

MPAI is the root of trust of the MPAI Ecosystem [1] offering Users access to the promised benefits of AI with a guarantee of increased transparency, trust and reliability as the Interoperability Level of an Implementation moves from 1 to 3. Additional information is provided by Annex 3.

# Scope of the MPAI-CAV Use Cases

There are several reasons why standards for the IT part of Connected Autonomous Vehicles (CAV) components should be developed:

1. the different nature of the interacting technologies making up a CAV.
2. the sheer size of the future CAV market [9].
3. the need for users and regulators alike to be assured of CAV safety, Reliability and Explainability.

At this point in time, a traditional approach to standardisation might consider CAV standards premature and some affected industries may not even be ready yet to consider them. CAVs, however, at best belong to an industry still being formed, that is expected to target the production of economic affordable units in the hundreds of millions p.a., with components to be produced by disparate sources. A competitive market of standard components can reduce costs and make CAV confirm their promise to have a major positive impact on environment and society.

A CAV Reference Model (RM) identifying components and their interfaces is required to accelerate the definition of standard components. Progression from research to standardisation can unfold as a series of proposals from research suggesting components and interfaces to standardisation, and standardisation either requesting more results, or refining the results, or adopting the proposals. Eventually, industry will receive a set of specifications for standard component functions and interfaces to be implemented as best available technology allows. Implementation in products will rely, as a minimum, on the know-how of those who have driven the development of the specific­ations.

*Connected Autonomous Vehicles* (MPAI-CAV) is an MPAI standard project seeking to define identified CAV standard components and their interfaces. MPAI-CAV comprises 4 Subsystems corresponding to Use Cases for each of which a Reference Model (RM) is defined. Each RM includes an AI Workflow (AIW) with a set of interconnected AI Modules (AIM).

*Table 1* identifies the names and the acronyms and characterises the 4 Subsystems.

*Table 1 – The 5 MPAI-CAV Subsystems*

|  |  |  |
| --- | --- | --- |
| **Subsystem name** | **Acr.** | **Function** |
| *Human-CAV Interaction* | HCI | Handles human-CAV interactions. |
| *Environment Sensing Subsystem* | ESS | Acquires information from the Environment via a variety of sensors. |
| *Autonomous Motion Subsystem* | AMS | Issues commands to drive the CAV to the intended destination. |
| *Motion Actuation Subsystem* | MAS | Provides Environment information and receives/actuates motion commands in the physical world. |

Each of the 4 subsystems is defined for implementation as an instance of the MPAI-defined AI Framework (AIF) [2].

The Subsystems Reference Models identify and describe the requirements of the data types received or generated by the AIMs in each Subsystem. The Reference Models allows researchers to select data, define testing setups, propose update of interfaces, conduct contests, consider the influence of external components, and subdivide workload in a way that allows unambiguous comparison of results.

Unlike those of previously published papers (e.g., [10]), the Reference Models of this document have the following features:

1. They adopt a holistic approach that includes all IT components of a CAV.
2. Are based on AIF-AIW-AIM [2] as the unifying model to determine the Functions and the Data Formats of all CAV components.
3. Rely on AI Modules (AIM) having Functions and Data Formats that are being or already specified in other MPAI standards.
4. Focus on the Data Formats between AIMs rather than focus on the AIMs themselves because their internals are not part of a standard but left to proprietary implementations.
5. Envision a process where research is seamlessly integrated with a subsequent standardisation process.

The purpose of this document is:

1. To collect and describe the 4 identified Subsystems.
2. To identify the functions, and the input and output data of the AIWs that implement the Subsystems.
3. To identify the Topology of the AIMs making up the AIWs.
4. To identify the Functions, and the input and output Data Formats of the AIMs required to realise the AIWs.

Chapter 6 provides the functional requirements to be satisfied by the data formats identified in points 4. above and the connections identified in point 3 above.

# Terms and definitions

*Table 2* defines the terms used in this document. Terms are organised by the CAV Subsystems identified in *Figure 3*. The general MPAI Terms are defined in *Table 16*.

*Table 2 – Definition of Terms used in this document organised by Subsystems*

|  |  |  |
| --- | --- | --- |
| Legend | AMS | Autonomous Motion Subsystem |
|  | CAV | Connected Autonomous Vehicle |
|  | ESS | Environment Sensing Subsystem |
|  | HCI | Human-CAV Interaction |
|  | MAS | Motion Actuation Subsystem |

|  |  |  |
| --- | --- | --- |
| **SubS** | **Term** | **Definition** |
| AMS | Command | High-level instructions whose execution allows a CAV to reach a Goal. |
| AMS | Decision Horizon | The estimated time between the current State and the Goal. |
| AMS | Full World Representation (FWR) | A description of Environment using the CAV’s and other CAVs’ Basic World Representations. |
| AMS | Goal | The planned State at the end of the Decision Horizon. |
| AMS | Path | A sequence of Poses 𝑝𝑖 = (𝑥𝑖,𝑦𝑖,zi,𝜃𝑖) in the Offline Map. |
| AMS | Pose | Coordinates and orientation of the CAV in the Offline Map *p* = (𝑥,𝑦,z,𝜃) |
| AMS | Route | A sequence of Way Points |
| AMS | State | CAV’s Pose, Orientations and 1st and 2nd order time derivatives at a given time. |
| AMS | Traffic Rules | The digital representation of the traffic rules applying to a Waypoint. |
| AMS | Trajectory | A sequence of States (s1,s2,…si) and the expected time each State will be reached. |
| AMS | Way Point | A point 𝑤𝑖 given as a coordinate pair (𝑥𝑖, 𝑦𝑖), in an Offline Map |
| CAV | Connected Autonomous Vehicle | A vehicle capable to autonomously reach an assigned Pose by understanding human utterances, planning a route, sensing and interpreting the environment, exchanging information with other CAVs and acting on the CAV’s motion subsystem. |
| CAV | Health | The condition, e.g., mechanical, of an AIW (Subsystem) or an AIM. |
| CAV | Reference Model | The collection of the following resources:   1. AIW and their input/output data. 2. AIMs and their input/output data and connections. |
| CAV | Subsystem | One of the 4 components making up the CAV. |
| ESS | Basic World Representation (BWR) | A digital representation of the Environment created with information available from the CAV’s ESS and an Offline Map or provided by another CAV in range. |
| ESS | Environment | The portion of the world of current interest to the CAV. |
| ESS | Global Navigation Satellite System (GNSS) | One of the systems such as GPS, Galileo, Glonass. BeiDou, Quasi Zenith Satellite System (QZSS) and Indian Regional Navigation Satellite System (IRNSS). |
| ESS | Inertial Measurement Unit | An inertial positioning device, e.g., odometer, accelerometer, speedometer, gyroscope etc. |
| ESS | Offline Map | An offline-created map of a location and associated metadata. |
| HCI | Command | High-level instructions whose execution allows a CAV to reach a Goal. |
| HCI | Concept (Face) |  |
| HCI | Concept (Speech) |  |
| HCI | Emotion |  |
| HCI | Face |  |
| HCI | Gesture |  |
| HCI | Intention |  |
| HCI | Meaning |  |
| HCI | Response | Feedback autonomously generated by the CAV in response to a Command. |
| HCI | Speech |  |
| MAS | Motion Data |  |

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2. Technical Specification: AI Framework (MPAI-AIF) V1; https://bit.ly/30vp63g.
3. Technical Specification: Technical Specification: Multimodal Conversation (MPAI-MMC) V1; https://bit.ly/30vp63g.
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# Subsystems

MPAI-CAV seeks to standardise all IT components that enable the implementation of a Connected Autonomous Vehicle (CAV), i.e., a system capable of executing the command to move its physical body autonomously – save for the exceptional intervention of a human – based on the analysis of

1. The data produced by a range of CAV sensors exploring the Environment.
2. The information transmitted by other sources in range, e.g., CAVs and roadside units (RSU).

*Figure 2* depicts the context and the actors where a CAV operates:

1. Other CAVs.
2. Roadside Units (RSU).
3. CAV-aware vehicles.
4. Pedestrians.
5. Traffic lights

A picture containing icon

Description automatically generated

*Figure 2 – The environment where a CAV operates*

MPAI-CAV includes 4 Subsystems:

**Human-CAV interaction (HCI)** recognises the human having right to the CAV, responds to humans’ commands and queries, provides extended environment representation (Full World Representation) for humans to use, senses human activities during the travel and may activate other Subsystems as required by humans.

**Environment Sensing Subsystem (ESS)** acquires information from the environment via a variety of sensors and produces a representation of the environment (Basic World Representation), i.e., its best guess given the sensed data.

**Autonomous Motion Subsystem (AMS)** computes the Route to destination, uses different sources of information – CAV sensors, other CAVs and transmitting units – to produce a Full World Representation and gives commands that drive the CAV to the intended destination.

**Motion Actuation Subsystem (MAS)** provides non-electromagnetic and non-acoustical environment information¸ receives and actuates motion commands in the physical world.

The interaction of the 4 subsystems in depicted in *Figure 3*:



*Figure 3 – The CAV subsystems*

The following high-level workflow illustrates the operation of the CAV envisaged by this docum­ent.

A *human* with appropriate credentials requests the CAV, via *Human-CAV Interaction*, to take the human to a given place.

*Human-CAV Interaction* authenticates the human, interprets the request, and passes a command to the *Autonomous Motion Subsystem*. Later, instructions can be integrated/ corrected.

*Autonomous Motion Subsystem*:

Requests *Environment Sensing Subsystem* to provide the current Pose.

Computes the Route.

Issues the start command.

*Environment Sensing Subsystem* computes and sends the Basic World Representation to *Aut­onomous Motion Subsystem* and CAVs in range*.*

*Autonomous Motion Subsystem*:

Receives and fuses the Basic World Representations to compute the Full World Representation.

Computes a Path.

Issues commands to *Motion Actuation Subsystem* to move the CAV accordingly.

While the CAV moves, humans

Interact and hold conversation with *Human-CAV Interaction* and/or other humans on board.

Issue commands.

Request views of the environment (Full World Representation) etc.

Interact with (humans in) other CAVs.

## Human-CAV Interaction (HCI)

### Use Case description

Human-CAV Interaction operated based on the principle that the CAV is impersonated by an avatar, selected/produced by the CAV rights-holder. The CAV avatar features are:

1. Visible: head, face and torso.
2. Audible: speech embedding as much as possible the sentiment, e.g., emotion, that would be displayed by a human driver.

The CAV’s avatar is reactive to:

1. The Environment, e.g., it can show an altered face if a human driver has done what it considers an improper action.
2. A human, e.g., it shows an appropriate face to a human in the cabins who has made a joke gazing at them.
3. Etc.

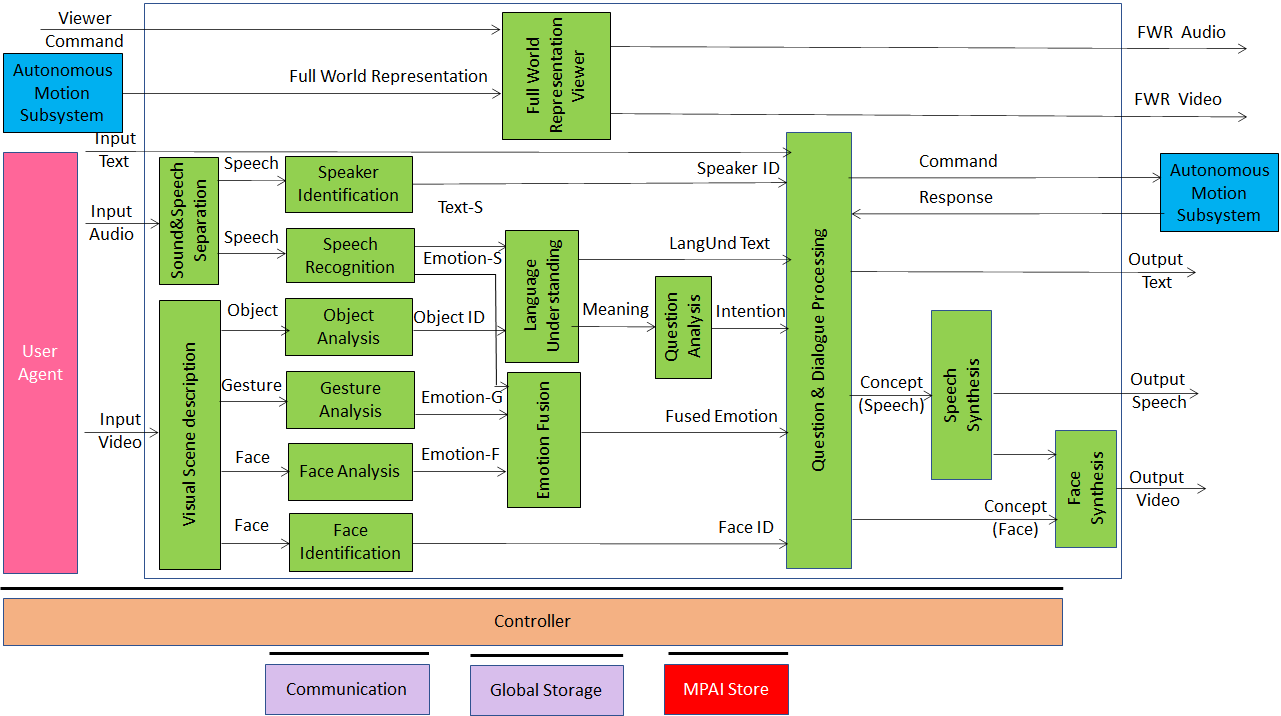
Other forms of interaction are:

1. CAV authenticates humans interacting with it.
2. A human issues commands to a CAV, e.g.:
   1. Commands to Autonomous Motion Subsystem, e.g.: go to a Waypoint or display Full World Representation (see 5.3), etc.
   2. Other commands, e.g.: turn off air conditioning, turn on radio, call a person, open window or door, search for information etc.
3. A human entertains a dialogue with a CAV, e.g.:
   1. CAV offers a selection of options to human (e.g., long but safe way, short but likely to have interruptions).
   2. Human requests information, e.g., time to destination, route conditions, weather at destination etc.
   3. Human entertains a casual conversation.
4. A CAV monitors the passenger cabin, e.g.:
   1. Physical conditions, e.g., temperature level, media being played, sound level, noise level, anomalous noise, etc.
   2. Passenger data, e.g., number of passengers, ID, estimated age, destination of passengers.
   3. Passenger activity, e.g., level of passenger activity, level of passenger-generated sound, level of passenger movement, emotion on face of passengers.
   4. Passenger-to-passenger dialogue, two passengers shake hands, or passengers hold everyday conversation.

It is important to point out that, although vehicles can exhibit different levels of autonomy, the exhibited autonomy should always be adjustable [1]. The system should recognise people as intelligent agents it should inform and be informed by. A CAV should be able to change its level of autonomy to one of several levels during its operation. Such an adjustment may be initiated by a human, another system, or the CAV itself. An important benefit of adjustable, user-centred autonomy is increased user acceptance of the system [47].

### Reference architecture

*Figure 4* represents the Human-CAV Interaction (HCI) Reference Model.



*Figure 4 – Human-CAV Interaction Reference Model*

The operation of the HCI is the following:

1. A human approaches the CAV.
2. The human is identified as follows
   1. The speech of the human is separated from the environment audio.
   2. The human is identified by their speech.
   3. The human object is separated from the environment.
   4. The human is identified by their face.
3. In the cabin:
   1. The locations and identities of the passengers are determined.
   2. Meaning and emotion are extracted from speech, face and gesture.
   3. Object information is extracted from video.
   4. Emotions are fused.
   5. Intention is derived.
   6. Concept (Speech) and Concept (face) are produced to animate the CAV avatar with a realistic gazing.
   7. Human commands are issued and responses from Autonomous Motion Subsystem processed
   8. Full World Representation is presented to let humans get a complete view of the Environment.

Depending on the technology used (data processing or AI), the AIMs in *Figure 4* may need to access external information, such as Knowledge Bases, to perform their functions. While not represented in *Figure 4*, they will be identified, if required, in the AI Modules subsection.

### Input and output data

*Table 3* gives the input/output data of Human-CAV Interaction.

*Table 3 – I/O data of* *Human-CAV Interaction*

|  |  |  |
| --- | --- | --- |
| **Input data** | **From** | **Comment** |
| Audio | User Outdoor | User authentication  User command |
| Text | User Outdoor | User authentication  User command |
| Text | Passenger Cabin | Social life of user  Commands or interaction with CAV |
| Audio | Passenger Cabin | User’s social life  Commands or interaction with CAV |
| Video | Passenger Cabin | Social life of user  Commands or interaction with CAV |
| Full World Representation | Autonomous Motion SS | For processing by FWR Viewer |
| **Output data** | **To** | **Comments** |
| Text | Autonomous Motion SS | Commands to be executed |
| Synthetic Speech | Passenger Cabin | CAV’s response to passengers |
| Synthetic Face | Passenger Cabin | CAV’s response to passengers |
| Full World Representation | Passenger Cabin | For passengers to view external world |

### AI Modules

*Table 4* gives the AI Modules of the Human-CAV Interaction depicted in *Figure 4*.

*Table 4* *– AI Modules of* *Human-CAV interaction*

|  |  |
| --- | --- |
| **AIM** | **Function** |
| **Speech detection and separation** | 1. Separates relevant speech vs non-speech signals 2. Detects request for dialogue. |
| **Speaker identification** | Recognises speaker. |
| **Speech recognition** | 1. Analyses the speech input. 2. Generates text and emotion output. |
| **Object and gesture analysis** | 1. Analyses video to identify object. 2. Produces ID of the object in focus. 3. Analyses video. 4. Produces motion and mean­ing of gesture. |
| **Face recognition** | 1. Analyses the video of the face of a human. 2. Recognises the human’s identity. |
| **Face analysis** | 1. Analyses the video of the face of a human. 2. Extracts emotion and meaning. |
| **Language understanding** | 1. Analyses natural language expressed as text using a language model (embedded in AIM). 2. Produces the meaning of the text. 3. Identifies Object ID. |
| **Emotion recognition** | Produces Final Emotion by fusing Emotions from Speech, Face and Gesture. |
| **Question analysis** | 1. Fuses Meanings of Speech, Face and Gesture. 2. Analyses the meaning of the sentence. 3. Determines the Intention. 4. Outputs Final Meaning. |
| **Question & dialog processing** | 1. Receives Speaker ID and Face ID. 2. If speaker ID and face ID match, then:    1. Produces a command to Autonomous Motion SS.    2. Analyses user’s emotion, intention, meaning and/or question, text.    3. Produces Concept (speech) and Concept (face). 3. Else, responds appropriately. |
| **Speech synthesis** | Converts Concept (Speech) to Output Speech. |
| **Face animation** | Converts Concept (Face) to Output Video. |
| **Full World Representation Viewer** | 1. Receives Full World Representation (FWR) 2. Presents a FWR view as instructed by human via FWR Com­mands. |

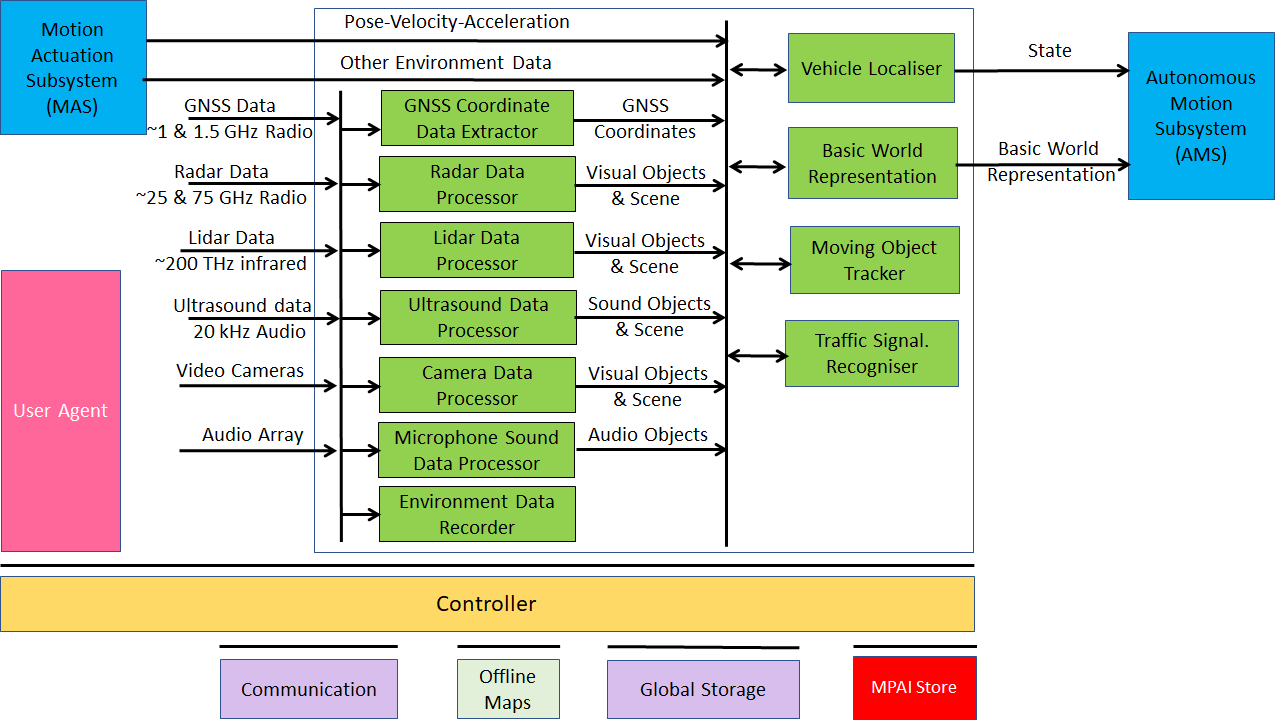
## Environment Sensing Subsystem (ESS)

### Use Case description

The purpose of the ESS is to acquire all sorts of electromagnetic and acoustic data directly from its sensors and other physical data of the Environment (e.g., temperature, pressure, humidity etc.) and of the CAV (Pose, Velocity, Acceleration) from Motion Actuation Subsystem with the main goal of creating the Basic World Representation.

### Reference architecture

*Figure 5* gives the Environment Sensing Subsystem Reference Model.



*Figure 5 – Environment Sensing Subsystem Reference Model*

The typical series of operations carried out by the Environment Sensing Subsystem (ESS) is given below. The sequential description of steps does not imply that an action is only carried out after the preceding one has been completed.

1. The CAV gets its Pose and other environment data from:
   1. Global Navigation Satellite System (GNSS).
   2. Vehicle Localiser in ESS.
   3. Other Environment data (e.g., weather, air pressure etc.).
   4. Coordinates data (Pose, Orientation and their time derivatives).
2. The CAV creates a Basic World Representation (BWR) by:
   1. Acquiring available Offline maps of its current Pose.
   2. Fusing Visual, Lidar, Radar and Ultrasound data.
   3. Updating the Offline maps with
      1. Other static objects.
      2. All moving objects.
      3. All traffic signalisation.
3. The CAV compresses and stores a subset of the sensor data on board the ESS.

### Input and output data

*Table 5* gives the input/output data of Environment Sensing Subsystem.

*Table 5 – I/O data of* *Environment Sensing Subsystem*

|  |  |  |
| --- | --- | --- |
| **Input data** | **From** | **Comment** |
| Pose-Velocity-Acceleration | Motion Actuation Subsystem | To be fused with GNSS data |
| Other Environment Data | Motion Actuation Subsystem | Temperature etc. to be added to Basic World Representation |
| Global Navigation Satellite System (GNSS) | ~1 & 1.5 GHz Radio | Get Pose from GNSS |
| Radio Detection and Ranging (RADAR) | ~25 & 75 GHz Radio | Get RADAR view of Environment |
| Light Detection and Ranging (LIDAR) | ~200 THz infrared | Get LiDAR view of Environment |
| Ultrasound | Audio (>20 kHz) | Get 20 kHz view of Environment |
| Cameras (2/D and 3D) | Video (400-800 THz) | Get visible view of Environment |
| Microphones | Audio (16 Hz-16 kHz) | Get Audible view of Environment |
| **Output data** | **To** | **Comment** |
| State | Autonomous Motion Subsystem | For Route, Path and Trajectory |
| Basic World Representation | Autonomous Motion Subsystem | Locate CAV in Environment |

### AI Modules

*Table 6* gives the AI Modules of Environment Sensing Subsystem.

*Table 6 – AI Modules of* *Environment Sensing Subsystem*

|  |  |
| --- | --- |
| **AIM** | **Function** |
| **GNSS Data Coordinate Extractor** | Computes global coordinates of CAV. |
| **Radar Data Processor** | Extracts visual scene and objects from radar. |
| **Lidar Data Processor** | Extracts visual scene and objects from lidar. |
| **Ultrasound Data Processor** | Extracts visual scene and objects from ultrasound. |
| **Camera Data Processor** | Extracts visual scene and objects from camera. |
| **Environment Sound Data Processor** | Extracts audio scene and objects from microphone. |
| **Environment Data Recorder** | Compresses/records a subset of data produced by CAV sensors and processed data at a given time. |
| **Vehicle Localiser** | Estimates the current CAV State in the Offline Maps. |
| **Moving Objects Tracker** | Detects, tracks and represents position and velocity of Environment moving objects. |
| **Traffic Signalisation Recogniser** | Detects and recognises traffic signs to enable the CAV to correctly move in conformance with traffic rules. |
| **Basic World Representation Fusion** | Creates Basic World-Representation by fusing Offline Map, moving and traffic objects, and other sensor data |

## CAV-to-Everything (V2X)

Earlier versions of this document envisaged a special subsystem dedicated to communication with entities external to the CAV. In the current version, communication external to the is handled directly by Subsystems in need for communication, e.g., the Autonomous Motion Subsystem.

### Use Case description

To improve its Environment perception capabilities, a CAV exchanges information via radio with other entities, e.g., CAVs in range and other CAV-aware communication devices such as Roadside Units and Traffic Lights in a secure fashion. The current version of this document does not consider the secure CA-to-CAV communication.

Multicast Communication adopted when a CAV broadcasts its identity and in case of heavy data types, e.g., Basic World Representation (BWR). Unicast mode may be used in other cases.

A Communication Device outside of the MPAI-AIF Trusted Zone of the Autonomous Motion Subsystem (AMS) in in charge of communication. The Device communicates with any AIF of the CAV which has communication needs or from which the Communication Device has received data.

The flow of operations of the Communication Device when handling communication with other CAVs or with devices having CAV functionality (e.g., a traffic light or a roadside unit) is:

1. Receives identities broadcasted by CAVs in range.
2. Establishes unicast sessions with CAVs in range. Issues to be considered are:
   1. Can a CAV’s Communication Device handle a large number of sessions?
   2. Can the AMS process data from a large number of different CAVs?
   3. Which application protocol is used by the Communication Device?
   4. Does the delay inherent in a unicast protocol have an impact?
3. Creates a list of CAVs in range with which it has established a session.
4. Sends the list with Basic World Representations (BWR) received via broadcast to the Autonomous Motion Subsystem (AMS).
5. ESS sends its own BWR to the Communication Device.
6. Communication Device broadcasts BWR in encrypted form with a key that is only known to CAVs in range that have an open unicast session with the Communication Device.

Note: no decision has been made on whether a CAV should send/receive Full World Representations (FWR).

The Communication Device is also made aware of the nature of the CAV and CAV-like device:

1. Traffic light.
2. Fire Truck.
3. Police.
4. Ambulance.
5. Flock Leader.

CAVs should communicate using a protocol that assigns a slice of the available transmission rate to each CAV based on the number of CAVs.

### Input and output data

#### CAVs within range

*Table 7* gives the data types a CAV broadcasts to CAVs in range via its Communication Device.

*Table 7 – I/O data of* *CAV’s Communication Device*

|  |  |  |
| --- | --- | --- |
| **Input Data** | **From** | **Comments** |
| Basic World Representation | Other CAVs | A digital representation of the Environment created by the ESS. |
| CAV Identity | Other CAVs | In principle, this should be the digital equivalent of today’s plate number including Manufacturer and Model information. The need to share this information is TBD. |
| CAV Intention | Other CAVs | The Path and other motion data relevant to other CAVs |
| Full World Representation | Other CAVs | A digital representation of the Environment created by fusing all available Basic World Representations. The need to share this information is TBD. |
| Information Messages | Other CAVs | Typical messages a CAV can broadcast. Potentially important messages for CAVs are given by [45, 46]   1. CAV is an ambulance. 2. CAV carries an authority. 3. CAV carries a passenger with critical health problem. 4. CAV has a mechanical problem of an identified level. 5. Works and traffic jams ahead 6. Environment must be evacuated 7. .... |
| **Output Data** | **To** | **Comments** |
| Basic World Representation | Other CAVs | Same as input for all other input data. |
| Full World Representation | Other CAVs | A digital representation of the Environment obtained from the fusion of all available Basic World Representations. The need to share this information is TBD. |

#### CAV-aware equipment

Examples of such equipment are traffic lights, roadside units, vehicles with CAV communication capabilities. The following data may be exchanged:

1. Identity and coordinates (exact coordinate reference).

Static Full World Representation regularly updated via download (may be part of the Offline Map).

Current objects in Environment.

State (Green-Yellow-Red) of traffic light and time to change state.

Lane markings.

Speed limits.

Pedestrian crosswalks

General information on the Environment (e.g., one way street etc.)

Etc.

Such equipment can:

1. Act as any other CAV in range.
2. Have the authority to organise motion of CAVs in range.

#### Other non-CAV vehicles

Other vehicles can be scooters, motorcycles, bicycles, other non-CAV vehicles, possibly transmitting their position as derived from GNSS. No response capability is expected. Vehicle may also have the capability to transmit additional information, e.g., identity, model, speed.

#### Pedestrians

Their smartphones can transmit their coordinates as available from GNSS. No response capability is expected.

## Autonomous Motion Subsystem (AMS)

### Use Case description

The typical series of operations carried out by the Autonomous Motion Subsystem (AMS) is described below. Note that the sequential description does not imply that an operations can only be carried out after the preceding one has been completed.

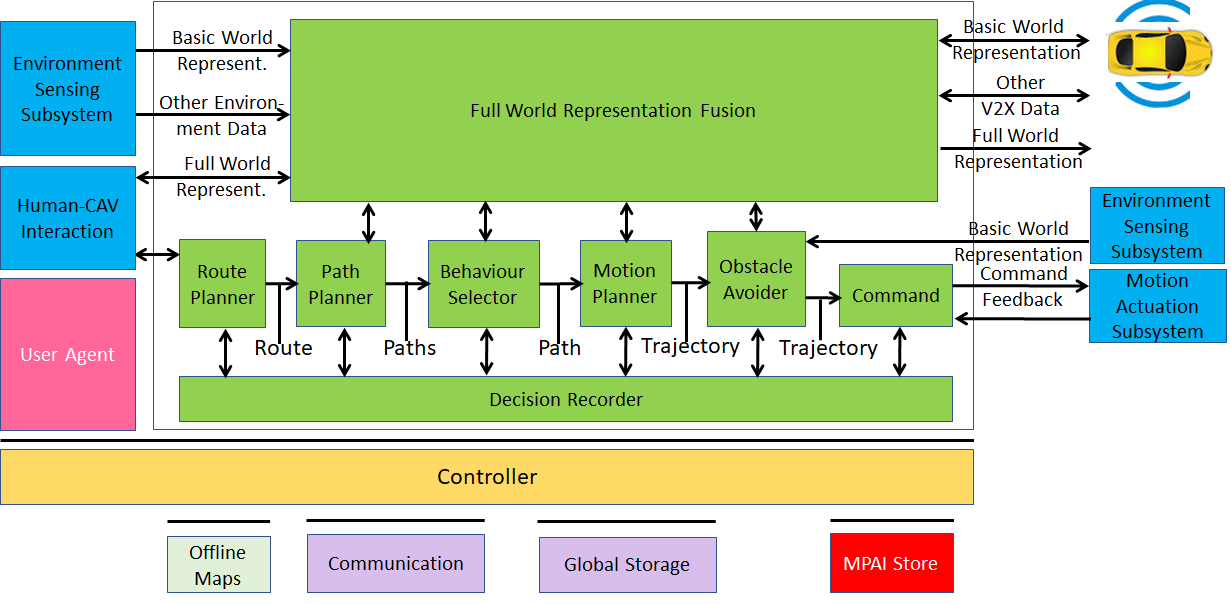
1. Human-CAV Interaction requests Autonomous Motion Subsystem to plan and move the CAV to the human-selected Pose. Dialogue may follow.
2. Computes the Route satisfying the human’s request.
3. Receives the current Basic World Represen­tation from Environment Sensing Subsystem.
4. While moving, CAV
   1. Transmits the Basic World Representation and other data to CAV-to-Everything.
   2. Receives Basic World Representations and other data from CAV-to-Everything.
   3. Produces the Full World Representation by fusing its own Basic World Representation with those from other CAVs in range.
   4. Plans a Path connecting Poses.
   5. Selects behaviour to reach intermediate Goals acting on information about the Goals other CAVs in range intend to reach.
   6. Defines a Trajectory that
      1. Complies with general traffic rules and local traffic regulations
      2. Preserves passengers’ comfort.
   7. Refines Trajectory to avoid obstacles.
   8. Sends the Motion Actuation Subsystem Commands to take the CAV to the next Goal.
5. Stores the data resulting from a decision (Route Planner, Path Planner etc.)

The AMS should be designed in such a way that different levels of autonomy, e.g., those indicated by SAE International [9], are possible depending on the amount and level of available func­tionalities.

### Reference architecture

*Figure 6* gives the Autonomous Motion Subsystem Reference Model.

A human activates the CAV requesting to be transported to a waypoint. This activates the Route Planner and the Path Planner which requests the Full World Representation to Full World Representation Fusion which receives and fuses the Basic World Representations from its own and other CAVs’ Environment Sensing Subsystems. The chain Behaviour Selection-Motion Planner-Obstacle Avoider eventually generates a command which is sent to Motion Actuation Subsystem. The decisions of the said chain are recorded.



*Figure 6 – Autonomous Motion Subsystem Reference Model*

### Input and output data

*Table 8* gives the input/output data of Autonomous Motion Subsystem.

*Table 8 – I/O data of* *Autonomous Motion Subsystem*

|  |  |  |
| --- | --- | --- |
| **Input data** | **From** | **Comment** |
| Command from HCI | Human-CAV Interaction | Human commands, e.g., “take me home” |
| Basic World Representation | Environment Sensing Subsystem | CAV’s Environment representation. |
| Other Environment Data | Environment Sensing Subsystem | E.g., temperature, air pressure. |
| Other V2X Data | Other CAVs | Other CAVs and vehicles, and roadside units. |
| Feedback from MAS | Motion Actuation Subsystem | CAV’s response to Command. |
| **Output data** | **To** | **Comment** |
| Response to HCI | Human-CAV Interaction | MAS’s response to AMS Command |
| Command to MAS | Motion Actuation Subsystem | Macro-instructions, e.g., “in 5s assume a given State”. |
| Full World Representation | Other CAVs | For information to other CAVs |

### AI Modules

*Table 9* gives the AI Modules of the Autonomous Motion Subsystem.

*Table 9 – AI Modules of Autonomous Motion Subsystem*

|  |  |
| --- | --- |
| **AIM** | **Function** |
| **Route Planner** | Computes a Route, through a road network, from the current to the target Pose. |
| **Path Planner** | Generates a set of Paths, considering   1. Current Route. 2. State. 3. Full World-Representation. 4. Traffic Rules. |
| **Behaviour Selector** | Sets a Goal with a Driving Behaviour, to be reached within the Decision Horizon time frame. |
| **Motion Planner** | Defines a Trajectory, from the current State to the current Goal fol­lowing the Behaviour Selector’s Path to the extent possible, satisfying the CAV’s kinematic and dynamic constraints, and considering passengers’ comfort. |
| **Obstacle Avoider** | Defines a new Trajectory to avoid obstacles. |
| **Command** | Instructs the CAV to execute the Trajectory considering the Environment conditions. |
| **Full World-Representation Fusion** | Creates an internal representation of the Environment by fusing infor­mation from itself, CAVs in range and other transmitting units.. |

## Motion Actuation Subsystem (MAS)

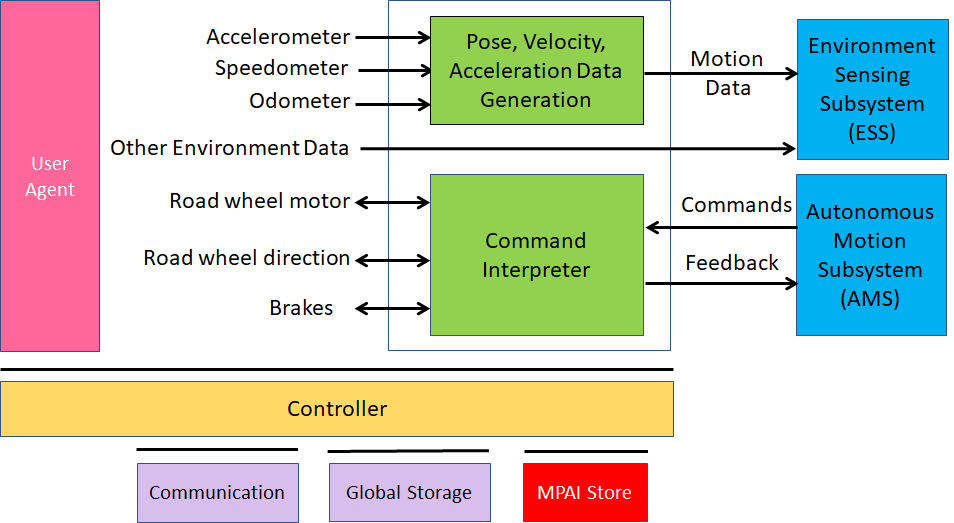
### Use Case description

The Motion Actuation Subsystem:

1. Transmits information gathered from its sensors and its mechanical subsystems to Environ­ment Sensing Subsystem.
2. Receives Command from Autonomous Motion Subsystem.
3. Translates such instructions into specific commands to its own mechanical subsystems, e.g., road wheels, wheel motors, brakes.
4. Receives feedbacks from its mechanical subsystems.
5. Packages feedbacks into high-level information.
6. Send Feedback (high-level information) to Autonomous Motion Subsystem.

### Reference architecture

*Figure 7* represents the Motion Actuation Subsystem Reference Model.



*Figure 7 – Motion Actuation Subsystem Reference Model*

### Input and output data

*Table 10* gives the input/output data of Motion Actuation Subsystem.

*Table 10 – I/O data of* *Motion Actuation Subsystem*

|  |  |
| --- | --- |
| **Input** | **Comments** |
| Odometer | Provides distance data. |
| Speedometer | Provides instantaneous velocity. |
| Accelerometer | Provides instantaneous acceleration. |
| Other Environment data | Provide other environment data, e.g., humidity, pressure, temperat­ure. |
| Road Wheel Motor | Forces road wheels rotation, gives feedback. |
| Road Wheel Direction | Moves road wheels by an angle, gives feedback. |
| Brakes | Acts on brakes, gives feedback. |
| Command from AMS | High-level motion command. |
| **Output** | **Comments** |
| Motion data | Position, velocity, acceleration. |
| Other data | Other environment data. |
| Feedback to AMS | Feedback from Command Converter during and after Command ex­ecution. |

### AI Modules

*Table 11* gives the AI Modules of Autonomous Motion Subsystem.

*Table 11 – AI Modules of Motion Actuation Subsystem*

|  |  |
| --- | --- |
| **AIM** | **Function** |
| **Pose-Velocity-Acceleration Data Generation** | Transforms odometer, speedometer, accelerometer data to standard data format. |
| **Command Interpreter** | Converts AMS Commands into specific actuation commands to Road wheel motor, Road wheel direction and Brakes. Forwards MAS feedbacks to AMS. |

# Functional Requirements

Functional Requirements developed in this document refer to individual technologies identified as necessary to implement MPAI-CAV Use Cases using AIMs operating in an MPAI AI Framework (AIF). They adhere to the following guidelines:

AIMs are defined to allow implementations by multiple technologies (AI, ML, DP).

DP-based AIMs may need interfaces, e.g., to a Know­ledge Base. AI-based AIM will typically require a learning process, however, support for this process is not included in the document. MPAI may develop further requirements covering that process in a future document.

AIMs can be aggregated in larger AIMs. Consequently, some data flows of aggregated AIMs may no longer be accessible.

MPAI has issued Calls for Technologies for the MPAI-MMC [3] and MPAI-CAE [4] standards and acquired a set of first-generation technologies related to some of the data types listed below. MPAI is ready to consider new technologies related to the data Formats requested in this Chapter if:

1. They support new requirements and/or they enhance capabilities.
2. The need to support such new enhanced capability requirements are documented.

## Human-CAV Interaction

### I/O Data summary

For each AIM (1st column), *Table 12* gives the input (2nd column) and the output data (3rd column).

*Table 12 – I/O data of Human-CAV Interaction AIMs*

|  |  |  |
| --- | --- | --- |
| **AIM** | **Input Data** | **Output Data** |
| **Speech Separation** | Input Audio | Separated Speech |
| **Internal AV Scene** | Input Video | Face Objects |
| **Speaker Recognition** | Separated Speech | Speaker ID |
| **Speech Recognition** | Separated Speech | Emotion (Speech)  Text (Speech) |
| **Object and Gesture Analysis** | Input Video | Object ID  Emotion (Gesture) |
| **Face Analysis** | Face Objects | Emotion (Face) |
| **Face Identification** | Face Objects | Face ID |
| **Full World Representation Viewer** | Full World Representation  Viewer Command | FWRV Audio  FWRV Video |
| **Emotion Fusion** | Emotion (Speech)  Emotion (Face)  Emotion (Gesture) | Fused Emotion |
| **Language Understanding** | Text (Speech)  Input Text  Object ID | Text (Language Understanding)  Meaning |
| **Question analysis** | Meaning | Intention |
| **Question and dialogue processing** | Input Text  Speaker ID  Fused emotion  Text (Speech)  Fused Meaning  Intention  Face ID  Face Objects | Command/Request  Feedback/Response  Concept (Speech)  Output Text  Concept (Face) |
| **Speech synthesis** | Concept (Speech) | Output Speech |
| **Face animation** | Concept (Face) | Output Video |

### Audio

Mono-channel Audio is the digital representation of an analogue audio signal sampled at a frequency between 8-192 kHz with a number of bits between 8 bits/sample and 32 bits/sample and a quantisation that is linear or companded.

**To respondents**

Respondents are invited to comment on these definitions and/or provide specific restrictions suitable to CAV-HCI.

### Verbal Interaction

Some commands given to the Autonomous Motion Subsystem are:

1. Go to a Waypoint.
2. How long does it take to get to a Waypoint.
3. Park next to a Waypoint.
4. Drive faster.
5. Drive slowly.
6. Display Full World Representation.

Some of the responses of the Autonomous Motion Subsystem are:

1. Enumeration of possible routes with major features of each route.
2. Enumeration of possible parking places with major features of each place.
3. Announcement of obstacles preventing the expeditious accomplishment of the Command.
4. Announcement that the desired Waypoint has been reached.

**To respondents**

Respondents are requested to propose a coded representation of the above Commands/Responses. Proposals of coded representation of additional Commands/Responses are welcome.

### Concept Expression (Face)

MPAI-MMC [3] specifies a Lips Animation format.

**To Respondents**

In this call, MPAI is looking for a technology that can animate the head and face of an avatar to which the Concept Expression (Face) data structure is provided. The data structure should be capable to convey the following time varying information:

1. The Emotion to be expressed by the avatar face.
2. The speech that should be uttered by the lips.
3. The Emotion embedded in the speech.
4. The Meaning of the speech.
5. The coordinates of the point in space the avatar should be gazing at.
6. The movement of the head.

### Concept Expression (Speech)

MPAI-MMC [3] specifies Text With Emotion as Reply (speech) format.

**To Respondents**

In this call, MPAI is looking for a technology that allow speech synthesis driven by the Concept Expression (Speech) data structure. The data structure should be capable to convey the following time varying information:

1. The text to be synthesised.
2. The Emotion to be embedded in the speech.
3. The Meaning to be embedded in the speech.

### Emotion

MPAI-MMC [3] specifies an extensible 3-level Basic Emotion Set.

**To respondents**

Respondents are requested to comment on the suitability of the technology standardised in [3] for the purpose of supporting human dialogue with a CAV. In case this is considered unsuitable, respondents are requested to motivate their assessment and provide an extension of the MPAI Basic Emotion Set or a new solution.

### Face identity

The Face Identity shall be able to represent the identity of a limited number of faces.

**To respondents**

Respondents are requested to propose a face identification system suitable for a limited number of faces.

Proposals of a face identification usable in the context of a company renting CAVs to customers are welcome.

### Face Objects

The CAV uses Face information to recognise a human addressing it outside of the CAV, or inside the CAV. Face information needs additional elements, i.e., the position of the Face in a coordinate system. This is useful to have better understanding of what is happening in the passenger cabin and to have a more natural audio-visual interaction with the passengers.

The current use of Face information is:

1. To identify the Face.
2. To extract Emotion in the Face.
3. To determine the exact location of a passenger in the cabin to animate the CAV Avatar Face so that the Avatar gazes into the eyes of the passenger it is talking to.

**To respondents**

Respondents are invited to propose a Face Objects format satisfying the above requirements to be used as input to Face Analysis and Face Identification.

### Full World Representation

The Full World Representation requirements are developed in the context of Autonomous Motion Subsystem requirements.

**To respondents**

Respondents are invited to read the requirements there.

### Full World Representation Viewer commands

The requirements of FWR interaction will be developed once the FWR requirements are defined.

**To respondents**

Respondents are invited to read the requirements there.

### Intention

MPAI-MMC [3] specifies a digital representation format for Intention.

**To respondents**

Respondents are requested to comment on the suitability of the technology standardised in [3] for CAV purposes.

### Meaning

MPAI-MMC [3] specifies a digital representation format for Meaning.

**To respondents**

Respondents are requested to comment on the suitability of the technology standardised in [3] for CAV purposes.

### Microphone Array Audio

Microphones are used to capture the sound field inside the cabin.

MPAI-CAE specifies Microphone Array Audio [4].

**To Respondents**

Respondents are requested to comment on the usability of the specified technology for MPAI-CAV and/or propose an Audio Array Format suitable to create a 3D sound field representation of the cabin.

### Object Identifier

MPAI-MMC [3] specifies a digital representation format for Object Identifier to be used to identify objects held in the hand of a person.

**To respondents**

Respondents are requested to comment on the suitability of the technology standardised in [3] for CAV purposes.

### Speaker Identity

The current Speaker Identity requirements demand the ability to identify a limited number of Speakers.

**To respondents**

Respondents are requested to propose a Speaker Identification method suitable for a limited number of speakers.

Proposals for a Speaker Identification method usable in a content of a company renting CAVs to customers are welcome.

### Text

MPAI-MMC [3] specifies ISO/IEC 10646, Information technology – Universal Coded Character Set (UCS) [5] as digital Text representation to support most languages in use.

**To respondents**

Respondents are invited to comment on this choice.

### Video

Video is intended for use in the passenger cabin. MPAI-MMC [3] specifies Video as:

1. Pixel shape: square
2. Bit depth: 8 or 10 bits/pixel
3. Aspect ratio: 4/3 or 16/9
4. 640 < # of horizontal pixels < 1920
5. 480 < # of vertical pixels < 1080
6. Frame frequency 50-120 Hz
7. Scanning: progressive
8. Colorimetry: ITU-R BT709 or BT2020
9. Colour format: RGB or YUV
10. Compression, either:
    1. Uncompressed;
    2. Compressed according to one of the following standards: MPEG-4 AVC [6], MPEG-H HEVC [7], MPEG-5 EVC [8]

**To respondents**

Respondents are invited to comment on MPAI’s choice for 2D Video.

Respondents are also requested to propose a data format for an array of cameras having video+depth as the baseline format or other 3D Video data formats.

## Environment Sensing Subsystem

### I/O Data summary

For each AIM (1st column), *Table 13* gives the input (2nd column) and the output data (3rd column). The following 3-digit subsections give the requirements of the data formats in columns 2 and 3.

*Table 13 – Environment Sensing Subsystem data*

|  |  |  |
| --- | --- | --- |
| **AIM or Subsystem** | **Input** | **Output** |
| **Vehicle Localiser** | GNSS Coordinates | State |
| Pose-Velocity-Acceleration |
| Offline Maps |
| **Environment Recorder** | State | -- |
| Basic World Representation |
| Other Environment Data |
| **GNSS Coordinate Data Extractor** | GNSS data | Global coordinates |
| **Radar Data Processor** | Radar data | Visual Objects and Scene |
| **Lidar Data Processor** | Lidar data | Visual Objects and Scene |
| **Ultrasound Data Processor** | Ultrasound data | Visual Objects and Scene |
| **Camera Data Processor** | Camera data | Visual Objects and Scene |
| **Microphone Sound Data Processor** | Microphone data | Sound Objects and Scene |
| **Traffic Signalisation Detector** | Visual Objects and Scene | Traffic signals  Traffic rules |
| **Moving Objects Tracker** | Visual Objects and Scene | Moving objects’ states |
| **Basic World Representation Fusion** | State | Basic World Representation |
| Offline maps |
| Visual Objects and Scene |
| Audio Objects and Scene |
| Environmental Data |
| Static and moving objects |
| Traffic signals |

### Audio Objects

The sound field of the Environment is captured by the external Microphone Array. Objects are extracted and added to the Basic and eventually Full World Representation after receiving information from other CAVs in range.

**To Respondents**

Respondents are requested to propose an Audio Objects and Scene Format that provides information about audio objects identified in the Environment with their semantics and the degree of accuracy with which Audio Objects have been represented.

### Basic World Representation

Data from different information sources, e.g., CAV’s Environment sensors and Offline maps, are combined to one comprehensive Basic World Representation (BWR) [39]. The BWR is a data format available to all CAV functions so that they can base their decisions on the same knowledge base, thus ensuring consistency of system operation.

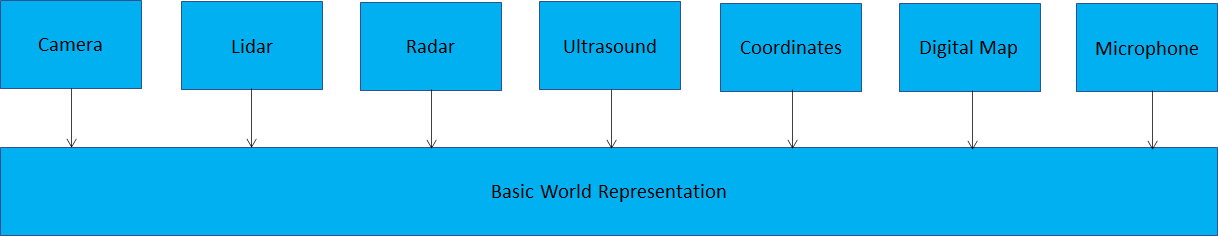


Figure 8 - Sensed Data and Basic World Representation

An established representation for the dense environment models does not exist, and there is no clear consensus which representation is the most suitable.

At this stage MPAI considers 3 types of BWR: 2D, 2.5D and 3D.

The 2D Basic World Representation requirements are:

1. Total scene: a grid-based representation.
2. Static environment: parametric free space representation or alternative representations.
3. Dynamic environment: object-based representation or alternative representations.

The 2.5D

1. The BWR is represeted as:
   1. Static components of the scene
      1. Grid-based.
      2. Object for traffic poles and signals.
   2. Object-based for the dynamic parts.
   3. Topology graph for the road and lane topology.
2. All perceived Audio and Visual Objects that impact the process leading to the definition of a Path in the Decision Horizon Time shall be represented in the BWR.
3. Each Audio and Visual Object in the BWR shall be described by
   1. Its ID.
   2. Its State.
   3. Its physical characteristics, e.g., static, or dynamic.
   4. Its bounding box (as a minimum), its full shape if known, semantics, flags (e.g., warning).
   5. Its semantics (e.g., other CAVs or other objects).
   6. The estimated accuracy of the object.
4. The ground (roads etc.) shall be described with all traffic signalisations, including roads and lane geometry, topology, and lane-specific traffic rules.
5. The BWR should allow for easy validation of a trajectory.
6. The BWR shall include Environmental data (e.g., weather, temperature, air pressure, ice and water on the road, wind, fog etc.)
7. The BWR shall have a scalable representation, i.e., allowing for:
   1. Transmission of the BWR based on required Level of Detail.
   2. Increase of the Environment complexity.
   3. Fast access to critical data.
   4. Fast access to data required by AIMs.
   5. Incremental refinement of Object and Scene.
   6. Updates for Object and Scene from one snapshot to another.
   7. Deliberative and reactive actions.

<https://www.mdpi.com/2079-9292/10/22/2825/pdf> propose an edge-fog-cloud computing-based

road dynamic object-mapping system. Our method processes the data from each connected

car using a standardized form and manages the dynamic information with grid-based

maps.

**To Respondents**

Respondents are requested to propose a Basic World Representation data format satisfying the requirements. Proposals with justified extended requirements will be considered.

### GNSS Coordinates

**To Respondents**

Respondents are requested to provide a format for the coordinates and an estimate of their accuracy.

### GNSS Data

Global Navigation Satellite Systems (GNSS) provide spatial information with different accuracies. GNSS can only be relied on when reception conditions are above a certain level. This excludes GNSS in tunnels or urban canyons.

Some data formats are:

1. GPS Exchange Format (GPX) provides an XML schema providing a common GPS data format that can be used to describe waypoints, tracks, and routes.
2. World Geodetic System (WGS) includes the definition of the coordinate system's fundamental and derived constants, the ellipsoidal (normal) Earth Gravitational Model (EGM), a description of the associated World Magnetic Model (WMM), and a current list of local datum transfor­mations.
3. International GNSS Service (IGS) SSR is a format used to disseminate real-time products to support the IGS (igs.org) Real-Time Service. The messages support multi-GNSS and include corrections for orbits, clocks, DCBs, phase-biases and ionospheric delays. Extensions are planned to also cover satellite attitude, phase centre offsets and variations and group delay variations.

**To Respondents**

Respondents are requested to propose a single GNSS data format that is capable to represent the features of all GNSS types.

### Lidar Data

Radio Detection and Ranging (RADAR), LiDAR and Ultrasound are active sensors based on “time-of-flight”, i.e., they measure distance and speed based on the time it takes for a signal to hit an object and be reflected back.

Unlike Radar, however, it operates in the µm range – ultraviolet, visible, or near infrared light. It sends an electromagnetic signal and receives the reflected signal back. These are the features of a typical eye-safe LiDAR:

1. Has a frequency of ~200 THz and a wavelength ~1.5 µm (the visible range is 0.4 to 0.75 µm).
2. Measures the range in each pixel (called also voxels).
3. Pixel grayscale is measured by the intensity variation of the reflected light.
4. The colour of an object can be measured by using more than one wavelength.
5. Velocity can be measured using the Doppler shift in frequency due to motion, or by measuring the position at different times.
6. Micro-motion can be measured using the Doppler shift measured with a coherent LiDAR.
7. Produces 100 kpoints/frame or 1.35 Mbytes: 32\*3 bits (coordinates) +16 bits (ref­lectance). Today 200 kpoints/frame are reasonable.
8. Angular resolution is 0.1º and the vertical field is 40º.
9. A Lidar scan captured at 25 fps generates 270 Mbit/s, i.e., 33.75 Mbytes/s.

The LAS (LASer) format is a binary file format for LiDAR point cloud data specified by the American Society for Photogrammetry and Remote Sensing (ASPRS) [31].

Pcap isa well-established data format for Lidar scans [32, 33, 34]. Other formats are listed in [36]. E57 is one of them.

**To Respondents**

Respondents are invited to provide a LiDAR data format that facilitates identification, tracking and digital representation of objects having the goal to produce Visual Objects and Scene (Lidar) as required by 6.2.16.

### Microphone Array Audio

Microphones are used to capture the external sound for the following purposes:

1. Extract speech addressed to CAV.
2. Create Audio Objects and Scene for use in Basic and Full World Representation.
3. Noise suppression inside the passenger cabin.

MPAI-CAE specifies Interleaved Multichannel Audio [4].

**To Respondents**

Respondents are requested to comment on the usability of the specified technology for MPAI-CAV and/or propose an Audio Array Format suitable to create a 3D sound field representation of the Environment for the stated purposes.

### Moving Object Tracker Data

Moving Object Tracker receives the Visual Objects and Scene data from the different sources – Lidar, Radar, Cameras, Ultrasound, Environment Sound – and provides a list of Visual Objects where each Object has the following associated data:

1. Spatial coordinates
2. Bounding Boxes
3. Coordinated of vertices of Bounding Boxes
4. State
5. Accuracy of the data provided.

**To Respondents**

Respondents are requested to propose a format for the Objects and their list that is friendly to the Basic World Representation format.

### Offline Maps

An Offline Map or HD maps or 3D maps is a roadmap with cm-level accuracy and a high environmental fidelity reporting the positions of pedestrian crossings, traffic lights/signs, barriers etc. at the time the Offline Map has been created.

Worth noting are:

1. Navigation Data Standards [38] calls itself “The worldwide standard for map data in automotive eco-systems”. Their NDS specification covers data model, storage format, interfaces, and protocols.
2. SharedStreets [42] Referencing System is a global non-proprietary system for describing streets.

**To Respondents**

Respondents are requested to propose an Offline Map Format. The Format should support different levels of conformance.

### Radar Data

Radar operates in the mm range. It can detect vehicles (CAVs and trucks) because they typically reflect Radar signals while objects that are smaller and have less reflectance, e.g., pedestrians and motorcycles have a poor reflectance. In a busy environment, the reflections of big vehicles can overcome a motorcycle’s causing missed detection of important objects (e.g., a child next to a vehicle), while a can may produce an image out of proportion to its size.

The main features of Radar are:

1. Measures distance.
2. Is independent of environment.
3. Provides low resolution images.
4. Provides distance (short range radar in the 25 GHz band).
5. Detects objects and measures speed @ ≤ 250 m (long range radar in the 76-77 GHz). Typical long-range radar systems have ranges of 80-200 m. Small antenna because wavelength is ~3.5-4 mm. Atmospheric absorption limits interference with other systems. A multitask 94-GHz pulse Doppler radar has 25-cm radial and 1.5 degrees angular resolution

Radar sensors build a representation of the environment based on the observation of complex, scattered radio waves, from which information of an object’s distance and velocity can be derived.

Known Radar data formats include [35]:

1. OPERA BUFR format [51].
2. hdf5 formats [52].
3. NetCDF files generated by the commercial EDGE software.
4. hdf5 files generated by the commercial GAMIC software.
5. German Weather Services quantitative local scan format (DX).
6. Quantitative composite format (RADOLAN, see German Weather Service, 2004).

**To Respondents**

Respondents are invited to propose a format of Radar images that facilitates identification, tracking and representation of objects having the goal to produce Visual Objects and Scene (Radar) as required by 6.2.17.

### State

State is the set of the following CAV attributes at a given time:

1. Pose, Velocity and Acceleration
2. Orientation, Angular Velocity and Angular Acceleration.

**To Respondents**

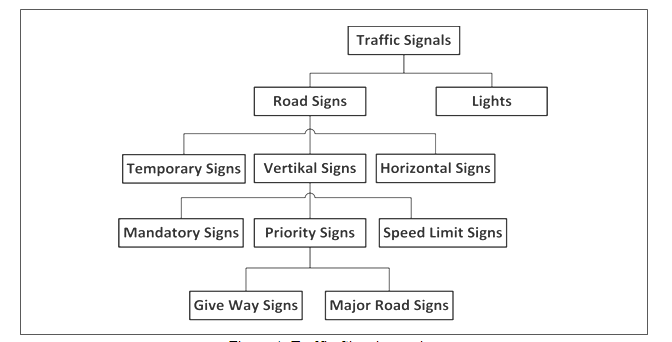
Respondents are requested to propose a State Format suitable for use in CAVs.

### Traffic Signalisation

Traffic Signalisation types are:

1. Traffic signs.
2. Road signs.
3. Placement signs.
4. Acoustic signs.
5. Traffic lights.

They are recognised from camera, lidar, rad, ultrasound images. Possible classification as below (From: https://www.researchgate.net/figure/Traffic-Signals-ontology\_fig4\_271376130).



**To Respondents**

Respondents are requested to propose a set of Traffic Signalisation Descriptors.

### Ultrasound Data

These are the main features of Ultrasound:

1. To operate at frequencies above 20 kHz.
2. To be independent of environment.
3. To yield images with low resolution.
4. To work on a limited range (≤ 10 m)

The Ultrasound File Format initiative has defined the Ultrasound File Format (UFF) format [30].

**To Respondents**

Respondents are invited to propose an Ultrasound Format that facilitates identification, tracking and representation of sound objects with the goal to produce Visual Objects and Scene (Radar) as required by 6.2.18.

### Video Camera data

The output of the video camera is used to produce Visual Objects and Scene (Camera).

**To Respondents**

Respondents are invited to provide a data Format for RGB-D cameras.

### Visual Objects and Scene (Camera)

The expected output is a scene representation used by Moving Object Tracker, Traffic Signalisation Recogniser and Basic World Representation.

**To Respondents**

Respondents are invited to provide a Format for scenes captured by cameras. The format should be sufficiently generic to be capable to be used – or adapted for use– in scenes captured by Radar, Lidar and Ultrasound devices.

### Visual Objects and Scene (Lidar)

The expected output is a scene representation used by Moving Object Tracker, Traffic Signalisation Recogniser and Basic World Representation.

**To Respondents**

Respondents are invited to provide a Format for scenes captured by Lidars. The format should be sufficiently generic to be capable to be used – or adapted for use– in scenes captured by Radar, Video and Ultrasound devices.

### Visual Objects and Scene (Radar)

The expected output is a scene representation used by Moving Object Tracker, Traffic Signalisation Recogniser and Basic World Representation.

**To Respondents**

Respondents are invited to provide a Format for scenes captured by Radars. The format should be sufficiently generic to be capable to be used– or adapted for use – in scenes captured by Lidar, Video and Ultrasound devices.

### Ultrasound Objects and Scene (Ultrasound)

The expected output is a scene representation used by Moving Object Tracker, Traffic Signalisation Recogniser and Basic World Representation.

**To Respondents**

Respondents are invited to provide a Format for scenes captured by Ultrasound. The format should be sufficiently generic to be capable to be used – or adapted for use – in scenes captured by Lidar, Radar and Video devices.

## Autonomous Motion Subsystem

### Summary of Autonomous Motion Subsystem data

*Table 14* gives, for each AIM (1st column), the input data (2nd column) and the output data (3rd column).

*Table 14 – CAV Autonomous Motion Subsystem data*

|  |  |  |
| --- | --- | --- |
| **CAV/AIM** | **Input** | **Output** |
| **Route Planner** | Pose  Destination | Route  Estimated time |
| **Full World Representation Fusion** | State | Full World Representation |
| Offline Maps |
| Basic World Representations |
| **Path Planner** | State | Set of Paths |
| Route |
| Full World Representation |
| Traffic Rules |
| **Behaviour Selector** | State | Path |
| Route |
| Full World Representation |
| **Motion planner** | Path | Trajectory |
| Full World Representation |
| **Obstacle Avoider** | Trajectory  Full World Representation | Trajectory |
| **Command to AMS** | Feedback | Command |
| **Autonomous Motion SS** | CAV identity and model | CAV identity and model |
| **Autonomous Motion SS** | State-Path-Trajectory | State-Path-Trajectory |
| **Autonomous Motion SS** | Basic World Representation | Basic World Representation |
| **Autonomous Motion SS** | Full World Representation | Full World Representation |
| **Autonomous Motion SS** | Messages | Messages |
| **Autonomous Motion SS** | Basic World Representation | Basic World Representation |

### Basic World Representation

Defined in Environment Sensing Subsystem.

**To Respondents**

Those intending to respond should check Basic World Representation in ESS.

### CAV Identifier

The CAV identification system should carry the following information

1. Country where the CAV has been registered
2. Registration number in the country
3. CAV manufacturer identifier
4. CAV model identifier

**To Respondents**

MPAI requests proposals for universal CAV identification system. Justified proposals for inclus­ion of additional data in the CAV Identifier are welcome.

### Command/Response

Defined in Human-to-CAV subsystem.

**To Respondents**

No response requested here. Comments welcome.

### Events

Events is used to provide CAV with information that is useful for its travel.

Examples are:

1. Road blocked at waypoint x,y,z
2. Traffic jam at waypoint x,y,z
3. ...

**To Respondents**

MPAI requests proposals for events, their semantics and coded representation.

### Full World Representation

The FWR is a refined version of the BWR. In addition to the BWR requirements, the following is added:

1. FWR objects should record provenance, i.e., the source (CAV) that provided the information.

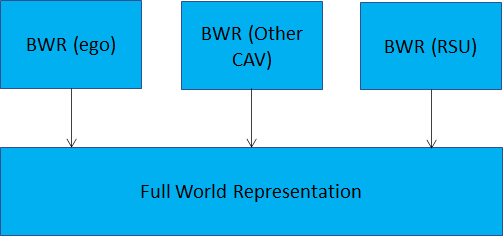


Figure - Full World Representation

### Goal

A particular State.

**To Respondents**

No response requested. Comments welcome.

### Offline map

Defined in Environment Sensing Subsystem.

**To Respondents**

No response requested here. Comments welcome.

### Path

A sequence of Poses in the Offline Map

**To Respondents**

No response requested here. Comments welcome.

### Pose

A sequence of Poses in the Offline Map. The AMS issues micro-commands to MAS in case a Pose cannot be reached from the Pose in a straight line.

**To Respondents**

A format to represent Pose is requested.

### Route

A sequence of Waypoints. A Waypoint is at a sufficient high level in the Route-Path-Trajectory hierarchy.

**To Respondents**

A Route Format compatible with a proposed Offline Map Format is requested.

### State

Defined in Environment Sensing Subsystem.

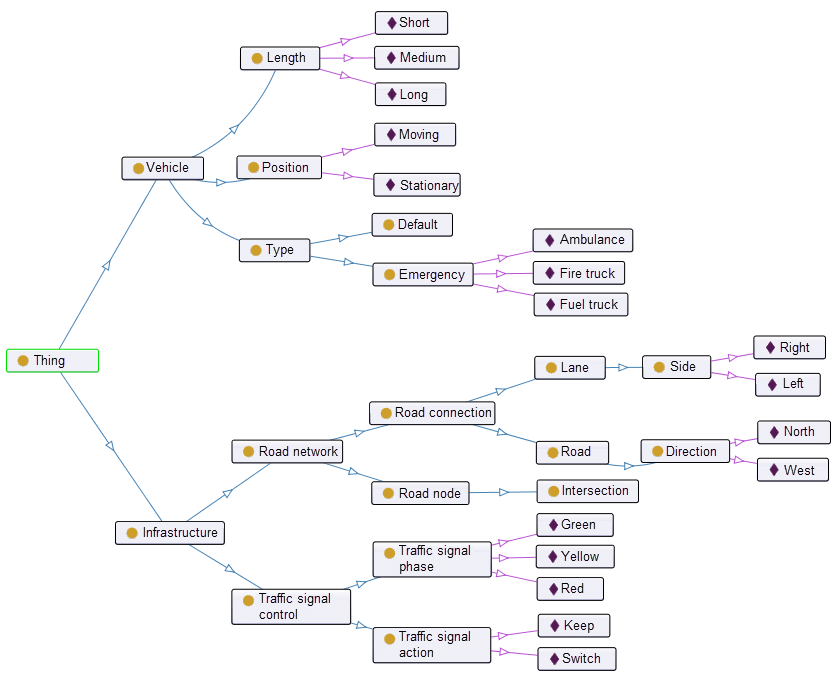
**To Respondents**

No response requested here. Comments welcome.

### Traffic rules

The traffic rules should be digitally represented to realise a route [41]. This could be based on an ontology, e.g., Control of vehicles and robots: creating of knowledge bases for mivar decision making systems robots and vehicles. See https://www.researchgate.net/figure/Ontology-for-traffic-signal-control\_fig1\_353182434

<https://www.researchgate.net/publication/339985273_Control_of_vehicles_and_robots_creating_of_knowledge_bases_for_mivar_decision_making_systems_robots_and_vehicles>.



**To Respondents**

MPAI requests a digital representation of traffic rules capable to:

1. Produce traffic rules from a given set of traffic signals.
2. Produce traffic signals from traffic rules.

A Traffic Ontology is a possible solution.

### Traffic Signals

Format to represent traffic signals on a road and around it, i.e., the semantics of the traffic signs. An ontology may be a solution.

**To Respondents**

MPAI requests a Traffic Signals Format capable to represent

1. All traffic signalisations required.
2. The specific local version of traffic signalisation.
3. The coordinates of the traffic signals.

### Trajectory

The Path and the States that allows a CAV to start from a State and reach another State in a given amount of time without violating Traffic Rules and affecting passengers’ comfort.

**To Respondents**

A digital representation of Trajectory is requested.

## Motion Actuation Subsystem

### Summary of Motion Actuation Subsystem data

*Table 15*gives, for each AIM (1st column), the input data (2nd column) from which AIM (column) and the output data (3rd column).

*Table 15 –Motion Actuation Subsystem data*

|  |  |  |
| --- | --- | --- |
| **CAV/AIM** | **Input** | **Output** |
| **Command Interpreter** | Command from AMS  Road Wheel Motor Feedback  Road Wheel Direction Feedback  Brakes Feedback | Feedback to AMS  Road Wheel Motor Command  Road Wheel Direction Command  Brakes Command |
| **Pose, Velocity, Acceleration Data Generation** | Accelerometer  Speedometer  Odometer | Motion Data |

### Accelerometer data

An accelerometer is an electronic sensor that measures the acceleration forces acting on a CAV. An accelerometer measures proper acceleration, i.e., the acceleration of a body in its own instantaneous rest frame, not to be confused with coordinate acceleration, i.e., acceleration in a fixed coordinate system. Therefore, an accelerometer at rest on the surface of the Earth measures an acceleration straight upwards of g ≈ 9.81 m/s2. In free fall (falling toward the centre of the Earth at ≈ 9.81 m/s2) measures zero.

**To Respondents**

Respondents are requested to propose a single Accelerometer data format.

### Brakes Command

The result of the interpretation of AMS Command to Brakes.

**To Respondents**

Respondents are requested to propose a set of command messages.

### Brakes Feedback

The feedback of Brakes to Command Interpreter.

**To Respondents**

Respondents are requested to propose a set of feedback messages.

### Command from AMS

The Command issued by the AMS

**To Respondents**

Respondents are requested to propose a set of high-level command messages.

### Feedback to AMS

The Feedback of Command Interpreter summarising the Feedbacks.

**To Respondents**

Respondents are requested to propose a set of high-level feedback messages

### Motion Data

**To Respondents**

Respondents are requested to propose a Motion Data Format bearing in mind that Motion Data will be used to create the CAV State by adding GNSS information.

### Odometer Data

An odometer converts as the distance travelled the number of wheel rotations times the tire circumference (π x tire diameter) from the start up to the point being considered.

**To Respondents**

Respondents are requested to propose a single Odometer Data Format.

### Other Environment Data

The set of Environment data such as temperature, air pressure, humidity etc.

**To Respondents**

Respondents are requested to propose a set Environment Data Formats.

### Road Wheel Direction Command

The result of the interpretation of AMS Command to Road Wheel Direction.

**To Respondents**

Respondents are requested to propose a set of Road Wheel Direction Commands

### Road Wheel Direction Feedback

The feedback of Road Wheel Direction to Command Interpreter.

**To Respondents**

Respondents are requested to propose a set of Road Wheel Direction Feedbacks

### Road Wheel Motor Command

The result of the interpretation of AMS Command to Road Wheel Motor.

**To Respondents**

Respondents are requested to propose a set of Road Wheel Motor Commands

### Road Wheel Motor Feedback

The feedback of Road Wheel Motor to Command Interpreter.

**To Respondents**

Respondents are requested to propose a set of Road Wheel Motor Feedbacks

### Speedometer

An electronic sensor that measures the instantaneous speed of a CAV.

**To Respondents**

Respondents are requested to propose a single Speedometer data format.

# Data privacy

A CAV can generate or acquire data for which privacy is an important characteristic. Here are some of the functions potentially affected by data privacy or that are liable to become accessible to authorities, e.g., police and judiciary.

## Human-CAV Interaction (HCI)

By having interactions with humans, HCI becomes aware of potentially sensitive information, e.g.:

1. Result of monitoring the passenger cabin.
2. Minute requests from humans, e.g., go to a way point, display Full World Representation, turn off air conditioning, etc.
3. Dialogue with human

## Environment Sensing Subsystem (ESS)

ESS collects large among of environment data for the purpose of creating instantaneous Basic World Representations, e.g.:

1. GNSS gives the position of the CAV and of whatever is perceived by the CAV that is approximate, but sufficiently precise for the intended uses.
2. Radar, Lidar, Ultrasound give variously defined information about what is in the environment surrounding the CAV.
3. Cameras give a 360° panoramic view of the environment where all objects, save those occluded, are visible.
4. External microphones give a complete representation of the external sound field.

A user could create a permanent and certified recording of important data acquired by ESS.

The environment recorder could compress and record all data acquired for a limited amount of time. Some data could be recorded for a longer time.

## CAV to Everything (V2X)

V2X acquires the identity of the CAVs in range and communicates appropriate subsets of the Basic and Full Worlds Representations.

## Autonomous motion subsystem (AMS)

AMS knows the exact waypoints the CAV has passed through and all the commands given to the Motion Actuation Subsystem.

By integrating the Basic World Representations of all CAVs in range and its own, a CAV can create a pretty detailed and extended map of the environment.

Recording the decisions made by the Decision Recorder creates highly critical data.

## Motion Actuation Subsystem (MAS)

MAS acquires position information through its Inertial Measurements Unit.

# Annex 1 – General MPAI Terminology (Normative)

The Terms used in this standard whose first letter is capital and are not already included in *Table 1* are defined in *Table 16.*

*Table 16 – MPAI-wide Terms*

|  |  |
| --- | --- |
| **Term** | **Definition** |
| Access | Static or slowly changing data that are required by an application such as domain knowledge data, data models, etc. |
| AI Framework (AIF) | The environment where AIWs are executed. |
| AI Module (AIM) | A processing element receiving AIM-specific Inputs and producing AIM-specific Outputs according to according to its Function. An AIM may be an aggregation of AIMs. |
| AI Workflow (AIW) | A structured aggregation of AIMs implementing a Use Case receiving AIM-specific inputs and producing AIM-specific inputs according to its Function. |
| AIF Metadata | The data set describing the capabilities of an AIF set by the AIF Implem­enter. |
| AIM Metadata | The data set describing the capabilities of an AIM set by the AIM Implem­enter. |
| Application Programming Interface (API) | A software interface that allows two applications to talk to each other |
| Application Standard | An MPAI Standard specifying AIWs, AIMs, Topologies and Formats suitable for a particular application domain. |
| Channel | A physical or logical connection between an output Port of an AIM and an input Port of an AIM. The term “connection” is also used as a synonym. |
| Communication | The infrastructure that implements message passing between AIMs. |
| Component | One of the 9 AIF elements: Access, AI Module, AI Workflow, Commun­ication, Controller, Internal Storage, Global Storage, MPAI Store, and User Agent. |
| Conformance | The attribute of an Implementation of being a correct technical Implem­entation of a Technical Specification. |
| Conformance Tester | An entity authorised by MPAI to Test the Conformance of an Implem­entation. |
| Conformance Testing | The normative document specifying the Means to Test the Conformance of an Implem­entation. |
| Conformance Testing Means | Procedures, tools, data sets and/or data set characteristics to Test the Conformance of an Implem­en­tation. |
| Connection | A channel connecting an output port of an AIM and an input port of an AIM. |
| Controller | A Component that manages and controls the AIMs in the AIF, so that they execute in the correct order and at the time when they are needed. |
| Data | Information in digital form. |
| Data Format | The standard digital representation of Data. |
| Data Semantics | The meaning of Data. |
| Device | A hardware and/or software entity running at least one instance of an AIF. |
| Ecosystem | The ensemble of the following actors: MPAI, MPAI Store, Implementers, Conformance Testers, Performance Testers and Users of MPAI-AIF Im­plem­en­tations as needed to enable an Interoperability Level. |
| Event | An occurrence acted on by an Implementation. |
| Explainability | The ability to trace the output of an Implementation back to the inputs that have produced it. |
| Fairness | The attribute of an Implementation whose extent of applicability can be assessed by making the training set and/or network open to testing for bias and unanticipated results. |
| Function | The operations effected by an AIW or an AIM on input data. |
| Global Storage | A Component to store data shared by AIMs. |
| Identifier | A name that uniquely identifies an Implementation. |
| Implementation | 1. An embodiment of the MPAI-AIF Technical Specification, or 2. An AIW or AIM of a particular Level (1-2-3). |
| Internal Storage | A Component to store data of the individual AIMs. |
| Interoperability | The ability to functionally replace an AIM/AIW with another AIM/AIW having the same Interoperability Level |
| Interoperability Level | The attribute of an AIW and its AIMs to be executable in an AIF Implem­en­tati­on and to be:   1. Implementer-specific and satisfying the MPAI-AIF Standard *(Level 1)*. 2. Specified by an MPAI Application Standard (*Level 2)*. 3. Specified by an MPAI Application Standard and certified by a Performance Assessor (*Level 3)*. |
| Knowledge Base | Structured and/or unstructured information made accessible to AIMs via MPAI-specified interfaces |
| Message | A sequence of Records. |
| Normativity | The set of attributes of a technology or a set of technologies specified by the applicable parts of an MPAI standard. |
| Performance | The attribute of an Implementation of being Reliable, Robust, Fair and Replicable. |
| Performance Assessment | The normative document specifying the procedures, the tools, the data sets and/or the data set characteristics to Assess the Grade of Performance of an Implementation. |
| Performance Assessment Means | Procedures, tools, data sets and/or data set characteristics to Assess the Performance of an Implem­en­tation. |
| Performance Assessor | An entity authorised by MPAI to Assess the Performance of an Implementation in a given Application domain |
| Port | A physical or logical communication interface of an AIM. |
| Profile | A particular subset of the technologies used in MPAI-AIF or an AIW of an Application Standard and, where applicable, the classes, other subsets, options and parameters relevant to that subset. |
| Record | Data with a specified structure. |
| Reference Model | The AIMs and theirs Connections in an AIW. |
| Reference Software | A technically correct software implementation of a Technical Specific­ation containing source code, or source and compiled code. |
| Reliability | The attribute of an Implementation that performs as specified by the Application Standard, profile and version the Implementation refers to, e.g., within the application scope, stated limitations, and for the period of time specified by the Implementer. |
| Replicability | The attribute of an Implementation whose Performance, as Assessed by a Performance Assessor, can be replicated, within an agreed level, by another Performance Assessor. |
| Robustness | The attribute of an Implementation that copes with data outside of the stated application scope with an estimated degree of confidence. |
| Scope | The domain of applicability of an MPAI Application Standard |
| Service Provider | An entrepreneur who offers an Implementation as a service (e.g., a recommendation service) to Users. |
| Specification | A collection of normative clauses. |
| Standard | The ensemble of Technical Specification, Reference Software, Confor­man­ce Testing and Performance Assessment of an MPAI application Standard. |
| Technical Specification | (Framework) the normative specification of the AIF.  (Application) the normative specification of the set of AIWs belon­ging to an application domain along with the AIMs required to Im­plem­ent the AIWs that includes:   1. The formats of the Input/Output data of the AIWs implementing the AIWs. 2. The Connections of the AIMs of the AIW. 3. The formats of the Input/Output data of the AIMs belonging to the AIW. |
| Testing Laboratory | A laboratory accredited by MPAI to Assess the Grade of Performance of Implementations. |
| Time Base | The protocol specifying how Components can access timing information |
| Topology | The set of AIM Connections of an AIW. |
| Use Case | A particular instance of the Application domain target of an Application Standard. |
| User | A user of an Implementation. |
| User Agent | The Component interfacing the user with an AIF through the Controller |
| Version | A revision or extension of a Standard or of one of its elements. |
| Zero Trust | A cybersecurity model primarily focused on data and service protection that assumes no implicit trust. |

# Annex 2 - Notices and Disclaimers Concerning MPAI Standards (Informative)

The notices and legal disclaimers given below shall be borne in mind when [downloading](https://www.mpai.community/resources/) and using approved MPAI Standards.

In the following, “Standard” means the collection of four MPAI-approved and [published](https://www.mpai.community/resources/) documents: “Technical Specification”, “Reference Software” and “Conformance Testing” and, where applicable, “Performance Testing”.

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# Annex 3 – The Governance of the MPAI Ecosystem (Informative)

**Level 1 Interoperability**

With reference to **Error! Reference source not found.**, MPAI issues and maintains a standard – called MPAI-AIF – whose components are:

1. An environment called AI Framework (AIF) running AI Workflows (AIW) composed of inter­connected AI Modules (AIM) exposing standard interfaces.
2. A distribution system of AIW and AIM Implementation called MPAI Store from which an AIF Implementation can download AIWs and AIMs.

|  |  |
| --- | --- |
| Implementers’ benefits | Upload to the MPAI Store and have globally distributed Implementations of   * AIFs conforming to MPAI-AIF. * AIWs and AIMs performing prop­rietary functions executable in AIF. |
| Users’ benefits | Rely on Implementations that have been tested for security. |
| MPAI Store | * Tests the Conformance of Implementations to MPAI-AIF. * Verifies Implementations’ security, e.g., absence of malware. * Indicates unambiguously that Implementations are Level 1. |

**Level 2 Interoperability**

In a Level 2 Implem­entation, the AIW must be an Implementation of an MPAI Use Case and the AIMs must con­form with an MPAI Applicati­on Standard.

|  |  |
| --- | --- |
| Implementers’ benefits | Upload to the MPAI Store and have globally distributed Implementations of   * AIFs conforming to MPAI-AIF. * AIWs and AIMs conforming to MPAI Application Standards. |
| Users’ benefits | * Rely on Implementations of AIWs and AIMs whose Functions have been reviewed during standardisation. * Have a degree of Explainability of the AIW operation because the AIM Func­tions and the data Formats are known. |
| Market’s benefits | * Open AIW and AIM markets foster competition leading to better products. * Competition of AIW and AIM Implementations fosters AI innovation. |
| MPAI Store’s role | * Tests Conformance of Implementations with the relevant MPAI Standard. * Verifies Implementations’ security. * Indicates unambiguously that Implementations are Level 2. |

**Level 3 Interoperability**

MPAI does not generally set standards on how and with what data an AIM should be trained. This is an important differentiator that promotes competition leading to better solutions. However, the performance of an AIM is typically higher if the data used for training are in greater quantity and more in tune with the scope. Training data that have large variety and cover the spec­trum of all cases of interest in breadth and depth typically lead to Implementations of higher “quality”.

For Level 3, MPAI normatively specifies the process, the tools and the data or the characteristics of the data to be used to Assess the Grade of Performance of an AIM or an AIW.

|  |  |
| --- | --- |
| Implementers’ benefits | May claim their Implementations have passed Performance Assessment. |
| Users’ benefits | Get assurance that the Implementation being used performs correctly, e.g., it has been properly trained. |
| Market’s benefits | Implementations’ Performance Grades stimulate the development of more Performing AIM and AIW Implementations. |
| MPAI Store’s role | * Verifies the Implementations’ security * Indicates unambiguously that Implementations are Level 3. |

**The MPAI ecosystem**

The following is a high-level description of the MPAI ecosystem operation applicable to fully conforming MPAI implementations:

1. MPAI establishes and controls the not-for-profit MPAI Store (step 1).
2. MPAI appoints Performance Assessors (step 2).
3. MPAI publishes Standards (step 3).
4. Implementers submit Implementations to Performance Assessors (step 4).
5. If the Implementation Performance is acceptable, Performance Assessors inform Implementers (step 5a) and MPAI Store (step 5b).
6. Implementers submit Implementations to the MPAI Store (step 6); The Store Tests Confor­mance and security of the Implementation.
7. Users download Implementations (step 7).

Text

Description automatically generated with low confidence

*Figure 10 – The MPAI ecosystem operation*

The Ecosystem operation allows for AIW and AIF Implementations to be:

1. Proprietary: security is verified and Conformance to MPAI-AIF Tested (Level 1).
2. Conforming to an MPAI Application Standard: security is verified and Conformance to the relevant MPAI Application Standard Tested (Level 2).
3. Assessed to be Reliable, Robust, Fair and Replicable (Level 3).

and have their Interoperability Level duly displayed in the MPAI Store.

# Annex 4 – Datasets for CAV research

**nuScenes**

The nuScenes dataset (https://nuscenes.org/) is a large-scale autonomous driving dataset with 3d object annotations. It features:

* Full sensor suite (1x LIDAR, 5x RADAR, 6x camera, IMU, GPS)
* 1000 scenes of 20s each
* 1,400,000 camera images
* 390,000 lidar sweeps
* Two diverse cities: Boston and Singapore
* Left versus right hand traffic
* Detailed map information
* 1.4M 3D bounding boxes manually annotated for 23 object classes
* Attributes such as visibility, activity and pose
* New: 1.1B lidar points manually annotated for 32 classes
* New: Explore nuScenes on SiaSearch
* Free to use for non-commercial use

For a commercial license contact nuScenes@motional.com

nuImages is a large-scale autonomous driving dataset with image-level 2d annotations. It features:

* 93k video clips of 6s each (150h of driving)
* 93k annotated and 1.1M un-annotated images
* Two diverse cities: Boston and Singapore
* The same proven sensor suite as in nuScenes
* Images mined for diversity
* 800k annotated foreground objects with 2d bounding boxes and instance masks
* 100k 2d semantic segmentation masks for background classes
* Attributes such as rider, pose, activity, emergency lights and flying
* Free to use for non-commercial use

**Road Hazard data**

Otonomo real-time Road Hazard data from connected passenger vehicles powers diverse road safety use cases, including mapping, accident predictions, smart cities and many more. The Otonomo Vehicle Data Platform secures, cleanses and normalizes the hazard data to make it more valuable and accessible for diverse use cases.

https://info.otonomo.io/hazard-data-datasheet-lp

# Annex 5 – ETSI Technical Report

ETSI specifies the Collective Perception Service (CPS) in its Technical Report [23]. The CPS includes the format and generation rules of the Collective Perception Message (CPM).

The CPM message format is (H=header, C=container, M=mandatory, O=optional).

*Table 17 – ETSI Collective Perception Message format*

|  |  |  |  |
| --- | --- | --- | --- |
| PDU header | H | M | protocol version, message ID and Station ID. |
| Management | C | M | transmitter type (e.g., vehicle or RSU) and position. |
| Station Data | C | O | transmitter heading, velocity, or acceleration etc. |
| Sensor Information | C | O | transmitter (e.g., speed, heading, or acceleration)  capabilities of the vehicle’s sensors. |
| Perceived Object | C | O | detected objects (e.g., distance, speed and dimensions)  time at which the measurements were done.  A CPM can report up to 128 detected objects |
| Free Space Addendum | C | O | free space areas/volume within the sensor detection areas |

Every 0.1s a CPM is generated if one of the 3 conditions is satisfied

no CPM has been generated in the last 1s

a new object has been detected

since last CPM sending info about a previously detected object (it must have an ID)

the following attributes have changed:

Absolute position ΔP > 4 m

Absolute speed ΔV > 0.5 m/s

more than 1s has passed (ΔT > 1 s).

ETSI makes use of a common coordinate system. A vehicle can communicate its absolute coordinates roll, pitch and yaw (Attitude).

Different CPM generation rules have been investigated [24].

# Annex 6 – Some CAV Communication Technologies

The following categories of vehicular communication are part of the literature or industry effort:

|  |  |  |
| --- | --- | --- |
| V2V | Vehicle-to-Vehicle | communication between vehicles to exchange information about the speed and position of surrounding vehicles |
| V2I | Vehicle-to-Infrastructure | communication between vehicles and road infrastructure. |
| V2X | Vehicle-to-Everything | communication between a vehicle and any entity that may affect, or may be affected by, the vehicle |
| V2R | Vehicle-to-Roadside | communication between a vehicle and Road Side Units (RSUs). |
| V2P | Vehicle-to-Pedestrian | communications between a vehicle and (multiple) pedestrian device(s) and to other vulnerable road users, e.g., cyclists, in close proximity |
| V2S | Vehicle-to-Sensors | communication between a vehicle and its sensors on board |
| V2D | Vehicle-to-Device | communication between a vehicle and any electronic device that may be connected to the vehicle itself |
| V2G | Vehicle-to-Grid | communication with the power grid to sell demand response services by either returning electricity to the grid or by throttling their charging rate |
| V2N | Vehicle-to-Network | broadcast and unicast communications between vehicles and the V2X management system and also the V2X AS (Application Server) |
| V2C | Vehicle-to-Cloud | communication with data centres and other devices connected to the internet |

Technologies exist that support at least some aspects of the communication types of the table:

Radio access, e.g., visible light communication, mmWave, Cellular-V2X, and 5G

Radio resource management (RRM) for vehicular communication using cellular technology

3GPP Release 14: air interfaces and core network technologies to support V2X communic­ation.

Vehicular ad hoc network (VANET)

Dedicated Short-Range Communication (DSRC): 5.9 GHz band with a range of ~300 metres.

Software defined vehicular networks (SDVN)

Internet of vehicles (IoV)

Protocol stack of the intelligent transportation system (ITS)

Cooperative Awareness Messages (CAMs) messages related to the status of CAV’s sent via wireless broadcast in VANETs.

Cooperative or collective perception improve CAV’s perception beyond the sensors’ detection range.

Traffic situation can be extracted from Local dynamic map (LDM) that aggregates CAMs.