Moving Picture, Audio and Data Coding
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MPAI Technical Specification

Connected Autonomous Vehicle - Architecture
MPAI-CAV

V1

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Technical Specification
Connected Autonomous Vehicle (MPAI-CAV) - Architecture V1

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1 Introduction (Informative)

Since the first Motorwagen saw the light in 1886, many inventions have given automobiles the ability to be more responsive to human needs and to facilitate their use. A short list includes electric ignition starter, car radio, car key, power steering, cruise control, electric windows, intermittent windshield wipers, anti-lock braking system (ABS), digital dashboard displays, electromagnetic parking sensors, on-board diagnostics, mobile connection, satellite navigation, reversing camera, automatic parking, driver assistance features, etc.

Starting from the first 1939 experiments, many efforts have given automobiles some “self-driving” capabilities. Recently, the Society of Automotive Engineers (SAE) in the USA has developed a Level-based classification of cars that have “self-driving” capabilities [14]. Today, self-driving cars are not only technically possible, but several implementations also exist. They promise to bring benefits that will positively affect industry, society, and the environment, such as:

1. Replacing human error with a machine less prone to errors.
2. Giving humans more time for rewarding activities, such as interpersonal communication.
3. Optimising the use of vehicles and infrastructure.
4. Reducing congestion and pollution.
5. Supporting elderly and disabled people.

Therefore, the transformation of what can be called today’s “niche market” into tomorrow’s vibrant mass market is a goal of high industrial importance with positive impacts on society and individuals. The goal could be achieved by relying on market forces and waiting for users to demand cars with progressively higher SAE Levels. Moving Picture, Audio, and Data Coding by Artificial Intelligence (MPAI), the international unaffiliated, non-profit organisation developing AI-enabled data coding standards, believes that a component-based standardisation process is more effective.

The approach should be implemented in three standardisation steps:

1. A Reference Model specifying functions and interfaces of subsystems and components.
2. Functional Requirements of Data Types exchanged between components.
3. Technologies supporting the processing of Data Types.

This approach offers various advantages:

1. <u>Research can</u>:
1.1. Concentrate on different individual components.
1.2. Optimise components while keeping unchanged the Functional Requirements of interfaces.

2. Industry can promote the definition of Data Formats when:
2.1. Research results are mature.
2.2. A component is needed.
3. Component manufacturers can:
3.1. Develop optimised component solutions based on publicly available specifications.
3.2. Bring their standard-confirming components to market.
4. Car manufacturers can:
4.1. Access an open global market of components.
4.2. Benefit from components with standard functions and interfaces.
4.3. Test components for conformance using standard procedures.
5. Regulators can use tools to oversee the development of the market.
6. Users can rely on CAVs whose operation they can explain.

In this Introduction and in the following Chapters, the following conventions apply:
1. Terms beginning with a capital letter are defined in Table 1 if they are specific to this Technical Specification and in Table 18 if they are shared with other MPAI Technical Specifications.
2. Words beginning with a capital letter that have an equivalent word beginning with a small letter represent the "digital twin" of that word.
3. Chapters and the Annexes are Normative unless they are labelled as Informative.

2 Scope

Technical Specification: Connected Autonomous Vehicle (MPAI-CAV) – Architecture (in the following also called MPAI-CAV – Architecture) specifies the Architecture of a Connected Autonomous Vehicle (CAV) based on a Reference Model comprising:
1. A CAV broken down into Subsystems for each of which the following is specified:
1.1. Functions
1.2. Input/output Data
1.3. Topology of Components
2. Each Subsystem broken down into Components of which the following is specified:
2.1. Functions
2.2. Input/output Data.

Each Subsystem is assumed to be implemented as an AI Workflow (AIW) made of Components implemented as AI Modules (AIM) executed in an AI Framework (AIF) as specified by the AI Framework (MPAI-AIF) Technical Specification [4]. In the following, Systems will be Annex 1 - Chapter 3 provides a high-level introduction to MPAI-AIF.

The structure of MPAI-CAV – Architecture is the following:
- Chapter 3 collects Normative definitions applicable to this Technical Specification.
- Chapter 4 collects Normative and some Informative references.
- Chapter 5 Normatively specifies the Subsystem-level Architecture.
- Chapters 0-7-0-9 Normatively specify the individual Subsystem Architectures.
- Chapter 10 includes Informative elements of the so-called Communication Device enabling CAV Subsystems to communicate with their peers in other CAVs.

Users of this Technical Specification should note that:
1. The input/output Data of Subsystems and Components have known semantics io maximise CAV Explainability.
2. No support of specified CAV Subsystems and Components is mandated.

3. Only the software Interfaces with the mechanical components of a CAV are specified, but not the mechanical components activated by the Interfaces.
4. An implementation may merge a set of Components into one provided the external interfaces are preserved. Merged Components, however, may have reduced Explainability.
5. No assumption is made on the location carrying out the processing required by the CAV.
6. Processing, collection, and storage of information should be performed according to the laws applicable to the location.

This Technical Report has been developed by the Connected Autonomous Vehicle group of the Requirements Standing Committee. MPAI plans on specifying the Functional Requirements of the Formats of the I/O Data to/from Subsystems (AIW) and AIMs and other aspects in future Technical Specifications.

3 Terms and definitions

Table 1 and Table 18 define the CAV-specific Terms and the general MPAI Terms, respectively.

Table 1 - Terms and Definitions

Note A dash "-" preceding a Term in this Table means the following:

1. If the font is normal, the Term in the table without a dash and preceding the one with a dash should be placed before that Term. The notation is used to concentrate in one place all the Terms that are composed of, e.g., the word Audio followed by one of the words Object, Scene, and Scene Descriptors.
2. If the font is *italic*, the Term in the table without a dash and preceding the one with a dash should be placed after that Term. The notation is used to concentrate in one place all the Terms that are composed of, e.g., the word Attitude preceded by one of the words Social or Spatial.

Term	Definition
Accelerometer Data	A Data Type representing the acceleration forces acting on a CAV.
Alert	A Data Type representing environment-related elements that should be treated with priority by the Obstacle Avoider AIM.
AMS-MAS Command	A Data Type representing the command issued by the Autonomous Motion Subsystem instructing the Motion Actuation Subsystem to change the Ego CAV's Spatial Attitude SA_A at time t_A to Spatial Attitude SA_B at time t_B.
AMS-HCI Response	A Data Type representing the response of the Motion Actuation Subsystem during and after the execution of an HCI-AMS Command.
Attitude	
- *Social*	A Data Type representing an element of the internal status of a human or avatar related to the way they intend to position themselves vis-à-vis the context, e.g., "Confrontational", "Respectful".
- *Spatial*	A Data Type representing the CAV's Position, Orientations and their velocities and accelerations at a given time.
Audio	A Data Type representing analogue signals generated by information perceptible by a human using the sense of sound.
- Data	A Data Type representing the output of a microphone array capturing the target environment to create the Audio Scene Description used to

	incorporate Environment Audio information in the Basic and Full Environment Representation.
- Object	A Data Type representing an audio object and associated metadata.
- Scene	A Data Type representing an audio scene.
- Scene Descriptors	A Data Type representing the Audio Data and produced by the Audio Scene Description AIM using previous Basic Environment Representations.
Audio-Visual	A Data Type representing analogue signals generated by information perceptible by a human using the sense of sound and sight.
- Object	A Data Type representing Audio-Visual information and associated metadata.
- Scene	(AV Scene) A Data Type representing an audio-visual scene.
- Scene Descriptors	A Data Type representing the outdoor and indoor Audio-Visual Scene in terms of Audio-Visual Objects that includes the following features: 1. Having a common time-base. 2. Associating co-located audio and visual objects if both are present. 3. Supporting the physical displacement and interrelation (e.g., occlusion) of Audio and Visual Objects over time.
Avatar	A Data Type representing a real or fictitious person in a virtual space rendered to a physical space.
- Model	A Data Type representing the model of a human that a User selects to impersonate the CAV's HCI as rendered by the Personal Status Display AIM.
Basic Environment Representation (BER)	A Data Type representing Environment using information provided by a variety of sensors and including: 1. The Audio-Visual Scene Geometry. 2. The Ego CAV's Spatial Attitude. 3. The Scene Description produced from the available Environment Sensing Technologies. 4. The Road Topology. 5. Other Environment Data.
Body Descriptors	A Data Type representing the motion and conveying information on the Personal Status of the body of a human or an avatar.
Brake	
- Command	A Data Type representing the command issued to the Brakes by the Motion Actuation Subsystem after interpreting an AMS-MAS Command.
- Response	A Data Type representing the Brakes' response to the AMS Command Interpreter in response to a Brake Command.
CAV	See Connected Autonomous Vehicle.
- Aware	An attribute of physical entities possessing some of the sensing and communication capabilities of a CAV without being a CAV, e.g., Roadside Units and Traffic Lights.
- Centre	The point in the Ego CAV selected to have coordinates (0,0,0).
- *Ego*	The Object in the Environment that the CAV recognises as itself.
- Identifier	A Data Type uniquely identifying a CAV and carrying information, such as: 1. Country code where the CAV has been registered. 2. Registration number in that country. 3. CAV manufacturer identifier.

	4. CAV model identifier.
Cognitive State	A Data Type representing the internal status of a human or avatar reflecting their understanding of the context, such as “Confused” or “Dubious” or “Convinced”.
Connected Autonomous Vehicle	(CAV) The information technology-related components of a vehicle enabling it to autonomously reach a Pose by: 1. Understanding human utterances in the Subsystem (HCI). 2. Planning a Route (AMS). 3. Sensing and building a Representations of the external Environment (ESS). 4. Exchanging such Representations and other Data with other CAVs and CAV-aware entities (AMS). 5. Making decisions about how to execute the Route (AMS). 6. Acting on the MAS (AMS).
Data	Information in digital form.
- Format	The standard digital representation of Data.
- Semantics	The meaning of Data.
- Shape	A Data Type representing the volume occupied by a CAV.
- Type	An instance of Data with a specific Data Format.
Decision Horizon	The time interval within which a decision is planned to be implemented.
Descriptor	Coded representation of a text, audio, speech, or visual feature.
Digital Representation	Data corresponding to and representing a physical entity.
Emotion	A Data Type representing the internal status of a human or avatar resulting from their interaction with the context or subsets of it, such as “Angry”, and “Sad”.
Environment	The Digital Representation of the portion of the external world of current interest to a CAV.
- Representation	A Data Type representing the Environment such as produced by an Environment Sensing Technology or derived from the Basic or Full Environment Representation.
- Sensing Technology	(EST) One of the technologies used to sense the environment by the Environment Sensing Subsystem, e.g., RADAR, Lidar, Visual, Ultrasound, and Audio. The Offline Map is considered as an EST.
Face	The portion of a 2D or 3D Digital Representation corresponding to the face of a human.
- Descriptors	A Data Type representing the motion and conveying information on the Personal Status of the face of a human or an avatar.
- ID	The Identifier of a human belonging to a group of humans inferred from analysing the face of the human.
Factor	One of Cognitive State, Emotion, and Social Attitude
Full Environment Representation	(FER) A Data Type representing the Environment that extends the Basic Environment Representations of the Ego CAV with elements of those of other CAVs in range or Roadside Units.
- Audio	The ready-to-render Audio component of the Full Environment Representation Viewer.
- Commands	A Data Type representing the commands issued by a CAV passenger to the HCI to enable navigation in the Full Environment Representation, e.g., select a Point of View, zoom in/out, control sound level.

- Visual	The ready-to-render Visual component of the Full Environment Representation Viewer.
Gesture	A Data Type representing the movement of the body or part of it, such as the head, arm, hand, and finger, often a complement to a vocal utterance.
Global Navigation Satellite System (GNSS)	One of the systems providing global navigation information such as GPS, Galileo, Glonass, BeiDou, Quasi Zenith Satellite System (QZSS) and Indian Regional Navigation Satellite System (IRNSS).
Goal	The Spatial Attitude planned to be reached at the end of a Decision Horizon.
HCI-AMS Command	A Data Type representing high-level instructions issued by HCI to AMS to request it to reach a destination.
Identifier	A Label that is uniquely associated with an Object.
Inertial Measurement Unit	An inertial positioning device, e.g., odometer, accelerometer, speedometer, gyroscope etc.
Instance ID	An Instance of a class of Objects and the Group of Objects the Instance belongs to.
Latitude	A Data Type representing the angular distance of a place north of the earth's equator measured in degrees [7].
LiDAR	A Data Type representing analogue signals generated by information captured by an active time-of-flight sensor operating in the µm range – ultraviolet, visible, or near infrared light (900 to 1550 nm).
- Data	A Data Type representing Data captured by a LiDAR sensor.
- Scene Descriptors	A Data Type representing the LiDAR Data and produced by the LiDAR Scene Description AIM using previous Basic Environment Representations.
Longitude	A Data Type representing the angular distance of a place west of the Greenwich meridian measured in degrees [7].
Machine	Synonym with Human-CAV Interaction Subsystem.
- Avatar	The ready-to-render Avatar produced by the Personal Status Display.
- Speech	The ready-to-render synthetic speech produced by the Personal Status Display.
Map Scene Descriptors	A Data Type representing the Offline Map Data complemented by the previous Basic Environment Representations in the common Scene Description Format.
MAS-AMS Response	A Data Type representing the Response of AMS Command Interpreter integrating the Response from Brakes, Steering Wheel, and Wheel Motors. The MAS-AMS Responses contain the value of the Spatial Attitudes of the Ego CAV at intermediate Poses with the corresponding Times.
Meaning	A Data Type representing an input text such as syntactic and semantic information.
Microphone Array Geometry	A Data Type representing the position of each microphone comprising a microphone array and characteristics such as microphone type, look directions, and array type.
Modality	One of Text, Speech, Face, or Gesture.
Model	A Data Type representing: 1) A ready-to-be animated object with its features, or 2) An Artificial Neural Network.
Object	A Data Type representing an object sensed by an EST and produced by an EST-specific Scene Description including the following elements:

	1. Timestamp. 2. Identifier of the Scene Description AIM that has generated the Object. 3. Alerts. 4. Spatial Attitude of the Object and its estimated accuracy referred to the CAV Centre. 5. Bounding box. 6. Object type (2D, 2.5D, and 3D).
- ID	The Identifier uniquely associated with a particular class of Objects, e.g., hammer, screwdriver, etc.
Odometer Data	A Data Type representing the distance from the start up to the current Pose measured by the number of wheel rotations times the tire circumference (π x tire diameter).
Offline	
- Map	A previously created digital map of an Environment and associated metadata.
- Map Data	A Data Type representing the Data provided by an Offline Map in response to a given set of coordinate values.
Orientation	A Data Type representing the set of the 3 roll, pitch, yaw angles indicating the rotation around the axes of a CAV obtained from the CAV's sensors: - Roll: around the principal axis X. - Pitch: around the Y axis. Y has an angle of 90˚ counterclockwise (right-to-left) with the x axis. - Yaw: around the Z axis perpendicular to and out of the ground.
Other Environment Data	Data Types representing information acquired by the Motion Actuation Subsystem and complementing the spatial data such as weather, temperature, air pressure, humidity, ice and water on the road, wind, fog etc.
Path	A Data Type representing a sequence of Poses.
Personal Status	A Data Type representing the ensemble of information internal to a person expressed by 3 Factors (Cognitive State, Emotion, Social Attitude) conveyed by one or more Modalities (Text, Speech, Face, and Gesture).
Point of View	The Spatial Attitude of a user looking at the Environment.
Portable Avatar	A Data Type providing context information and allowing the rendering of an Avatar as intended by the Portable Avatar producer.
Pose	A Data Type representing Position and Orientation of the CAV as captured by the CAV sensors.
Position	A Data Type representing the current coordinates of a CAV as captured by the CAV sensors.
RADAR	A Data Type representing analogue signals generated by information captured by an active time-of-flight sensor operating in the operating in the 24-81 GHz range.
- Data	A Data Type representing the Visual Data captured by a RADAR sensor.
- Scene Descriptors	A Data Type representing the Visual Data captured by RADAR and produced by the RADAR Scene Description AIM using previous Basic Environment Representations.
Remote AMS	AMS of a CAV or CAV-Aware entity in range.
Remote HCI	HCI of a CAV or CAV-aware entity in range.
Road State	A Data Type representing the state of the road the CAV is traversing such as detours and road conditions. Road State may be inferred by the AMS

	from internally available information or received from an external source via a communication channel.
Road Topology	A Data Type representing the Position of the Road Signs (Traffic Poles, Road Signs, Traffic Lights) and the Taxonomy-based semantics of the Road Signs.
Roadside Unit	A wireless communicating device located on the roadside providing information to CAVs in range.
Route	A Data Type representing a sequence of Waypoints.
Scene Descriptors	A Data Type representing the combination of EST-specific 2D, 2.5D, or 3D Scene Descriptors used by an EST Scene Description in an EST-specific time window.
Speaker ID	The Identifier of a human belonging to a group of humans inferred from analysing the speech of the human.
Speech	A Data Type representing analogue speech sampled at a frequency between 8 kHz and 96 kHz with 8, 16 and 24 bits/sample, and linear quantisation.
Speech Model	A Data Type representing the Speech Descriptors characteristic of a speaker used to generate the Personal Status Display's synthetic speech.
Speedometer Data	A Data Type representing the speed of a CAV as measured by the sensor.
Steering Wheel	
- Command	A Data Type representing the command issued to the Steering Wheel by the Motion Actuation Subsystem after interpreting an AMS-MAS Command.
- Feedback	A Data Type representing the Steering Wheel's response to the AMS Command Interpreter in response to a Steering Direction Command.
Subsystem	A high-level subdivision of a CAV.
Text	A series of characters drawn from a finite alphabet represented using a Character Set.
- *Recognised*	The Text produced by a speech recogniser.
- *Refined*	Text resulting from the Language Understanding AIM's refinement of Recognised Text produced by a Speech Recognition AIM.
Traffic	
- Rules	A Data Type representing the traffic rules applying to an Environment as extracted from the local Traffic Signals based on the local traffic rules.
- Signals	A Data Type representing the traffic signals on a road and around it, their Spatial Attributes, and the semantics of the traffic signals.
Trajectory	A Data Type representing a sequence of Spatial Attitudes and the expected time each Spatial Attitude will be reached.
Ultrasound	A Data Type representing analogue signals generated by information captured by an ultrasonic sensor, an active time-of-flight sensor typically operating in the 40 kHz to 250 kHz range.
- Data	A Data Type representing the Data provided by an ultrasonic sensor.
- Scene Descriptors	A Data Type representing the Visual Data captured by Ultrasound and produced by the Ultrasound Scene Description AIM using previous Basic Environment Representations.
Visual	A Data Type representing analogue signals generated by information perceptible by a human using the sense of sight.
- Data	A Data Type representing the Visual Data captured by a Visual sensor.
- Object	A Data Type representing a visual object and associated metadata.

- Scene	A Data Type representing a visual scene.
- Scene Descriptors	A Data Type representing the Visual Objects of an Environment, their Spatial Attitudes, and associated Visual Scene Geometry.
Waypoint	The coordinates of a point on an Offline Map.
Wheel Motor	
- Command	A Data Type representing the command issued to the Wheel Motors by the Motion Actuation Subsystem after interpreting an AMS-MAS Command.
- Response	A Data Type representing the Wheel Motors' response to AMS Command Interpreter in response to a Wheel Motor Command.

4 References

4.1 Normative References

1. MPAI; The MPAI Statutes; https://mpai.community/statutes/.
2. MPAI; The MPAI Patent Policy; https://mpai.community/about/the-mpai-patent-policy/.
3. MPAI; Technical Specification: Governance of the MPAI Ecosystem (MPAI-GME) V1.1; https://mpai.community/standards/mpai-gme/.
4. MPAI; Technical Specification: AI Framework (MPAI-AIF) V2; https://mpai.community/standards/mpai-aif/.
5. Technical Specification: Context-based Audio Enhancement (MPAI-CAE) V2, https://mpai.community/standards/mpai-cae/.
6. MPAI; Technical Specification: Multimodal Conversation (MPAI-MMC) V2; https://mpai.community/standards/mpai-mmc/.
7. Technical Specification: Object and Scene Description (MPAI-OSD) V1, https://mpai.community/standards/mpai-osd/.
8. MPAI; Technical Specification: Portable Avatar Format (MPAI-PAF) V1; https://mpai.community/standards/mpai-paf/.
9. ISO 19111:2019 - Geographic information.

4.2 Informative References

10. MPAI: Framework Licence: Connected Autonomous Vehicle (MPAI-CAV) – Architecture; https://mpai.community/wp-content/uploads/2023/09/N1306-Framework-Licence-MPAI-Connected-Autonomous-Vehicle-MPAI-CAV-Architecture.pdf
11. MPAI; Technical Specification: MPAI Metaverse Model (MPAI-MMM) – Architecture V1; https://mpai.community/standards/mpai-mmm/.
12. ISO 8855:2011 – Road vehicles – Vehicle dynamics and road-holding ability – Vocabulary
13. SAE; Vehicle Dynamics Terminology J670_202206; https://www.sae.org/standards/content/j670_202206/
14. SAE; Levels of Driving Automation J3016; https://www.sae.org/binaries/content/assets/cm/content/blog/sae-j3016-visual-chart_5.3.21.pdf

5 Model of Connected Autonomous Vehicle

5.1 Functions of Connected Autonomous Vehicle

A Connected Autonomous Vehicle is defined as a physical system that:

1. Converses with humans by understanding their utterances, e.g., a request to be taken to a destination.
2. Senses the environment where it is located or traverses like the one depicted in *Figure 1*.
3. Plans a Route enabling the CAV to reach the requested destination.
4. Autonomously reaches the destination by:

4.1. Moving in the physical environment.
4.2. Building Digital Representations of the Environment.
4.3. Exchanging elements of such Representations with other CAVs and CAV-aware entities.
4.4. Making decisions about how to execute the Route.
4.5. Actuating the CAV motion to implement the decisions.

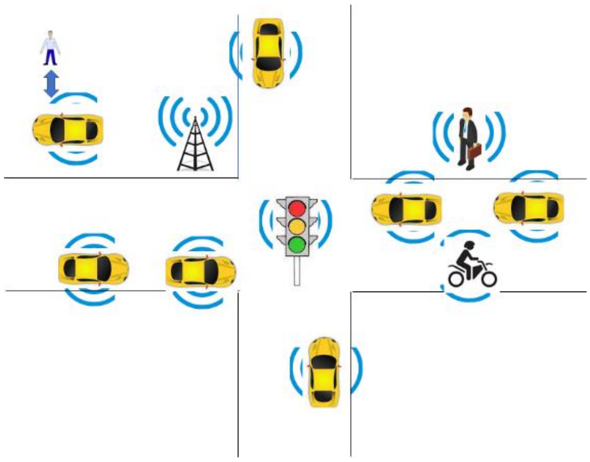

Figure 1 - An environment of CAV operation

5.2 Reference Architecture of Connected Autonomous Vehicle

The MPAI-CAV Reference Model is composed of four Subsystems:

1. Human-CAV Interaction (HCI).
2. Environment Sensing Subsystem (ESS),
3. Autonomous Motion Subsystem (AMS).
4. Motion Actuation Subsystem (MAS).

The Subsystems are represented in *Figure 2* where the arrows refer to the exchange of information between Subsystems and between a Subsystem and other CAVs or CAV-aware systems. The sensing of the Environment and the Motion Actuation are represented by icons.

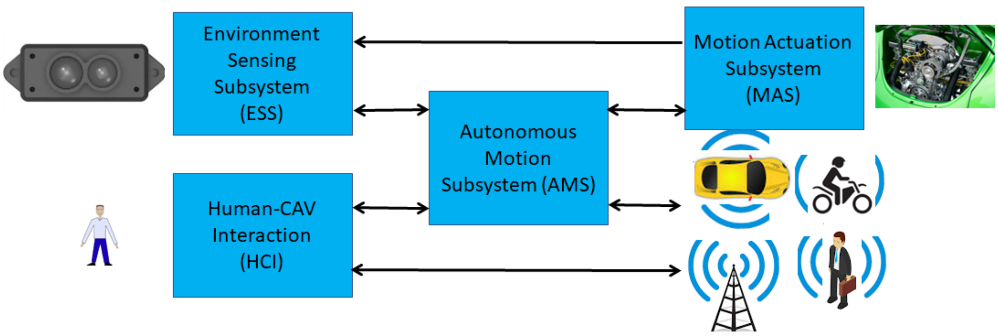

Figure 2 – The MPAI-CAV subsystems

The operation of a CAV unfolds according to the following workflow:

Human	Requests the CAV, via *HCI*, to take the human to a destination.
HCI	1. Authenticates humans.

	2. Interprets the request of humans. 3. Issues commands to the *AMS*.
AMS	1. Requests *ESS* to provide the current Pose.
ESS	1. Computes and sends the Basic Environment Representation (BER) to *AMS*.
AMS	1. Computes and sends Route(s) to *HCI*.
HCI	1. Sends travel options to Human.
Human	1. May integrate/correct their instructions. 2. Selects and communicates a Route to *HCI*.
HCI	1. Communicates Route selection to *AMS*.
AMS	1. Sends the BER to the *AMS*s of other CAVs. 2. Computes the Full Environment Representation (FER). 3. Decides best motion to reach the destination. 4. Issues appropriate commands to *MAS*.
MAS	1. Executes the Command. 2. Sends response to *AMS*.
Human	1. Interacts and holds conversation with other humans on board and the *HCI*. 2. Issues commands to *HCI*. 3. Requests *HCI* to render the FER. 4. Navigates the FER. 5. Interacts with humans in other CAVs.
HCI	Communicates with *HCI*s of other CAVs on matters related to human passengers.

5.3 I/O Data of Connected Autonomous Vehicle

Table 2 gives the input/output data of the Connected Autonomous Vehicle.

Table 2 - I/O data of Human-CAV Interaction

Input data	From	Comment
Audio (Outdoor)	Environment	For User authentication, command, conversation, etc.
Audio (Indoor)	Cabin Passengers	User's social life and commands/interaction with HCI
Visual (Outdoor)	Environment	Commands/interaction with HCI
Visual (Indoor)	Cabin Passengers	User's social life and commands/interaction with HCI
LiDAR	Cabin Passengers	Commands/interaction with HCI
Inter HCI Information	Remote HCI	From Ego CAV and Remote CAV
RADAR	Environment	Captured Environment by RADAR
LiDAR Data	Environment	Captured Environment by LiDAR
Visual Data (2/D and 3D)	Environment	Captured Environment by cameras
Ultrasound Data	Environment	Captured Environment by Ultrasound
Audio Data	Audio (16 Hz-20 kHz)	Captured Environment by Microphone Array
Inter AMS Information	Remote AMS	From Ego CAV and Remote CAV
Global Navigation Satellite System (GNSS) Data	~1 & 1.5 GHz Radio	Various GNSS Data sources
Other Environment Data	Environment	Temperature, Air pressure, Humidity, etc.
Wheel Motor Response	Wheel Motor	Forces wheels rotation, gives feedback.
Steering Wheel Response	Steering Wheel	Moves wheels by an angle, gives feedback.
Brake Response	Brakes	Acts on brakes, gives feedback.

Output data	To	Comment
Inter HCI Information	Remote HCI	Ego CAV and Remote CAV
Machine Personal Avatar	Cabin Passengers	HCI's avatar when conversing
Inter AMS Information	Remote AMS	To Ego CAV and Remote CAV
Wheel Motor Command	Wheel Motors	Activates/suspends wheels rotation, gives feedback.
Steering Wheel Command	Steering Wheel	Moves wheels by an angle, gives feed-back.
Brake Command	Brakes	Acts on brakes, gives feedback.

6 Human-CAV Interaction (HCI)

6.1 Functions of Human-CAV Interaction

The Human-CAV Interaction (HCI) Subsystem performs the following high-level functions:

1. Authenticates humans e.g., for the purpose of letting them into the CAV.
2. Interprets and executes commands provided by humans, possibly after a dialogue, e.g., to go to a Waypoint, issue commands such as turn off air conditioning, open window, call a person, search for information, etc.
3. Displays Full Environment Representation to passengers via a viewer and allows passengers to navigate and control the viewing.
4. Interprets conversation utterances with the support of the extracted Personal Statuses of the humans, e.g., on the fastest way to reach a Waypoint because of an emergency, or during a casual conversation.
5. Displays itself as a Body and Face with a mouth uttering Speech showing a Personal Status comparable to the Personal Status that a human counterpart (e.g., driver, tour guide, interpreter) would display in similar circumstances.

The HCI operation is highly influenced by the notion of *Personal Status*, the set of internal characteristics of conversing humans and machines. See Annex 0 Section 5.

6.2 Reference Architecture of Human-CAV Interaction

Figure 3 gives the Reference Model of Human-CAV Interaction (HCI) Subsystem supporting the case of a group of humans approaching the CAV from outside the CAV and sitting inside the CAV.

The HCI operation in the outdoor and indoor scenarios unfolds as follows:

1. Audio Scene Description AIM creates the Audio Scene Description in the form of 1) Audio (Speech) Objects corresponding to each speaking human in the Environment (close to the CAV) and 2) Audio Scene Geometry.
2. Visual Scene Description creates the Visual Scene Descriptors in the form of Descriptors of 1) Faces and the Bodies corresponding to each human in the Environment (close to the CAV) and 2) Visual Scene Geometry.
3. Speech Recognition recognises the speech of each human.
4. Spatial Object Alignment Identifies Audio, Visual, and Audio-Visual Objects, from Audio and Visual Scene Geometries.
5. Spatial Object Identification produces Object ID from Physical Objects, Body Descriptors, and Visual Scene Geometry.
6. The Full Environment Representation (FER) Viewer renders the FER in response to FER navigation Commands.
7. Language Understanding produces the Refined Text and extracts the Meaning.

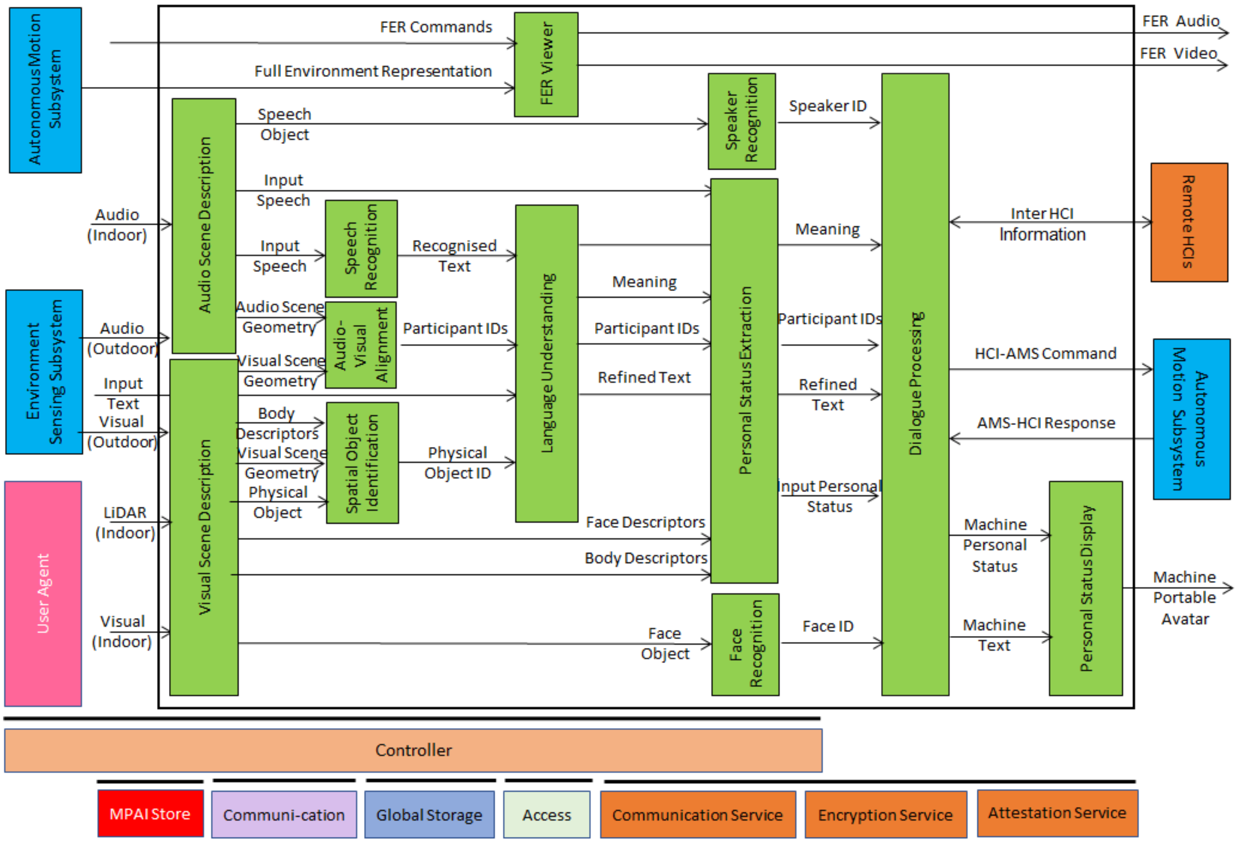

Figure 3 – Human-CAV Interaction Reference Model

8. The Speaker Recognition and Face Recognition AIMs authenticate the humans the HCI is interacting with. The processing of these two AIMs may be carried out remotely.
9. The Personal Status Extraction AIM extracts the Input Personal Status from Meaning, Speech, Face Descriptors, and Body Descriptors.
10. The Dialogue Processing AIM:
10.1. Validates the human Identities.
10.2. Produces Machine Text and Machine Personal Status.
11. The Personal Status Display produces the ready-to-render Machine Portable Avatar [8] conveying Machine Speech and Machine Personal Status.
11.1. Issues commands to the Autonomous Motion Subsystem.
11.2. Receives and processes responses from the Autonomous Motion Subsystem.
11.3. Communicates with Remote HCIs.

6.3 I/O Data of Human-CAV Interaction

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

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

Input data	From	Comment
Full Environment Representation	Autonomous Motion Subsystem	Rendered by Full Environment Representation Viewers
Full Environment Representation Commands	Cabin Passengers	To control rendering of Full Environment Representation
Audio (Outdoor))	Environment Sensing Subsystem	User authentication User command

		User conversation
Audio (Indoor)	Cabin Passengers	User's social life Commands/interaction with HCI
Visual (Outdoor)	Environment Sensing Sub-system	Commands/interaction with HCI
Visual (Indoor)	Cabin Passengers	User's social life Commands/interaction with HCI
LiDAR	Cabin Passengers	User's social life Commands/interaction with HCI
AMS-HCI Response	Autonomous Motion Sub-system	Response to HCI-AMS Command
Inter HCI Information	Remote HCI	HCI-to-HCI information
Output data	**To**	**Comments**
Full Environment Representation Audio	Passenger Cabin	For passengers to hear external Environment
Full Environment Representation Visual	Passenger Cabin	For passengers to view external Environment
Inter HCI Information	Remote HCI	HCI-to-HCI information
HCI-AMS Command	Autonomous Motion Sub-system	HCI-to-AMS information
Machine Portable Avatar	Cabin Passengers	HCI's avatar.

6.4 Functions of Human-CAV Interaction's AI Modules

Table 4 gives the functions of all Environment Sensing Subsystem AIMs.

Table 4 - Functions of Human-CAV Interaction's AI Modules

AIM	Function
Audio Scene Description	Produces the Audio Scene Descriptors using the Audio captured by the appropriate (indoor or outdoor) Microphone Array.
Visual Scene Description	Produces the Visual Scene Descriptors using the visual information captured by the appropriate indoor visual sensors (Visual and LiDAR) or outdoor visual sensors.
Speech Recognition	Converts speech into Recognised Text.
Audio-Visual Alignment	Identifies Audio, Visual, and Audio-Visual Objects.
Physical Object Identification	Provides the ID of the class of objects of which the Physical Object is an Instance
Full Environment Representation Viewer	Converts the Full Environment Representation produced by the Autonomous Motion Subsystem into Audio-Visual Scene Descriptors that can be perceptibly rendered by the Viewer.
Language Understanding	Refines the Recognised Text by using context information (e.g., Instance ID of object).
Speaker Recognition	Provides Speaker ID from Speech Object.
Personal Status Extraction	Provides the Personal Status of a passenger.
Face Recognition	Provides Face ID from Face Object.
Dialogue Processing	Provides: 1. Machine Text containing the HCI response.

	2. Machine Personal Status.
Personal Status Display	Produces Machine Personal Avatar.

6.5 I/O Data of Human-CAV Interaction's AI Modules

Table 5 gives the input/output data of the Human-CAV Interaction AIMs.

Table 5 - I/O Data of Human-CAV Interaction's AI Modules

AIM	Input	Output
Audio Scene Description	Audio (outdoor) Audio (indoor)	Speech Objects Audio Scene Description
Visual Scene Description	Visual (outdoor) Visual & LiDAR (indoor)	Face Descriptors Body Descriptors Physical Objects Visual Scene Description
Speech Recognition	Speech Object	Recognised Text
Physical Object Identification	Physical Object Body Descriptors	Physical Object ID
Full Environment Representation Viewer	FER Commands	FER Audio FER Visual
Language Understanding	Recognised Text Personal Status Physical Object ID	Meaning Personal Status Refined Text
Speaker Recognition	Speech Descriptors	Speaker ID
Personal Status Extraction	Meaning Speech Object Face Descriptors Human Descriptors	Personal Status
Face Recognition	Face Object	Face ID
Dialogue Processing	Speaker ID Meaning Refined Text Personal Status Face ID AMS-HCI Response	AMS-HCI Commands Machine Text Machine Personal Status
Personal Status Display	Machine Text Machine Personal Status	Machine Personal Avatar

7 Environment Sensing Subsystem (ESS)

7.1 Functions of Environment Sensing Subsystem

The Environment Sensing Subsystem (ESS) of a Connected Autonomous Vehicle (CAV):

1. Uses all Subsystem devices to acquire as much as possible information from the Environment as electromagnetic and acoustic data.
2. Receives an initial estimate of the Ego CAV's Spatial Attitude generated by the Motion Actuation Subsystem
3. Receives Environment Data (e.g., temperature, pressure, humidity, etc.) from the Motion Actuation Subsystem.
4. Produces a sequence of Basic Environment Representations (BER) for the journey.

5. Passes the Basic Environment Representations to the Autonomous Motion Subsystem.

7.2 Reference Architecture of Environment Sensing Subsystem

Figure 4 gives the Environment Sensing Subsystem Reference Model.

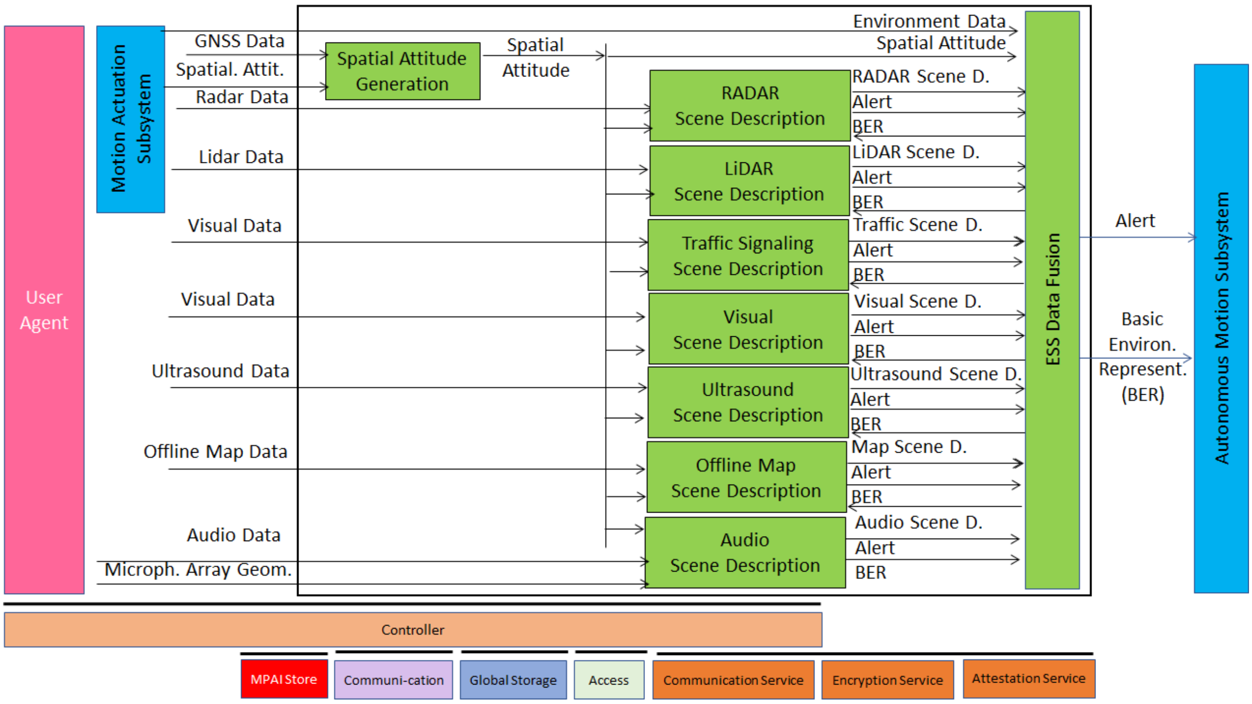

Figure 4 – Environment Sensing Subsystem Reference Model

The typical sequence of operations of the Environment Sensing Subsystem is:

1. Compute the CAV's Spatial Attitude using the initial Spatial Attitude provided by the Motion Actuation Subsystem and the GNSS.
2. Receives Environment Sensing Technology (EST)-specific Data, e.g., RADAR Data provided by the RADAR EST.
3. Produce and send EST-specific Alert, if necessary, to Autonomous Motion Subsystem.
4. Access the Basic Environment Representation at a previous time if necessary.
5. Produce EST-specific Scene Descriptors, e.g., the RADAR Scene Descriptors.
6. Integrate the Scene Descriptors from different ESTs into the Basic Environment Representation.

Note that *Figure 4* assumes that:

1. Traffic Signalisation Recognition produces the Road Topology by analysing Visual Data. The model of *Figure 4* can easily be extended to the case where Data from other ESTs is processed to compute or help compute the Road Topology.
2. Environment Sensing Technologies are individually processed. An implementation may combine a single Scene Descriptors from two or more ESTs preserving the relevant interfaces.

7.3 I/O Data of Environment Sensing Subsystem

The currently considered Environment Sensing Technologies (EST) are:

1. Global navigation satellite system or GNSS (~1 & 1.5 GHz Radio).
2. Geographical Position and Orientation, and their time derivatives up to 2nd order (Spatial Attitude).
3. Visual Data in the visible range, possibly supplemented by depth information (400 to 700 THz).

4. LiDAR Data (~200 THz infrared).
5. RADAR Data (~25 & 75 GHz).
6. Ultrasound Data (> 20 kHz).
7. Audio Data in the audible range (16 Hz to 20 kHz).
8. Spatial Attitude (from the Motion Actuation Subsystem).
9. Other environmental data (temperature, humidity, ...).

Offline Map data can be accessed either from stored information or online.

Table 6 gives the input/output data of the Environment Sensing Subsystem.

Table 6 - I/O data of Environment Sensing Subsystem

Input data	From	Comment
Radar Data	~25 & 75 GHz Radio	Capture Environment with Radar
Lidar Data	~200 THz infrared	Capture Environment with Lidar
Visual Data	Video (400-800 THz)	Capture Environment with cameras
Ultrasound Data	Audio (>20 kHz)	Capture Environment with Ultrasound
Offline Map Data	Local storage or online	cm-level data at time of capture
Audio Data	Audio (16 Hz-20 kHz)	Capture Environment or cabin with Microphone Array
Microphone Array Geometry	Microphone Array	Microphone Array disposition
Global Navigation Satellite System (GNSS) Data	~1 & 1.5 GHz Radio	Get Pose from GNSS
Spatial Attitude	Motion Actuation Subsystem	To be fused with GNSS data
Other Environment Data	Motion Actuation Subsystem	Temperature etc. added to Basic Environment Representation
Output data	**To**	**Comment**
Alert	Autonomous Motion Subsystem	Critical information from an EST.
Basic Environment Representation	Autonomous Motion Subsystem	ESS-derived representation of external Environment

7.4 Functions of Environment Sensing Subsystem's AI Modules

Table 7 gives the functions of all AIMs of the Environment Sensing Subsystem.

Table 7 - Functions of Environment Sensing Subsystem's AI Modules

AIM	Function
RADAR Scene Description	Produces RADAR Scene Descriptors and Alert from RADAR Data.
LiDAR Scene Description	Produces LiDAR Scene Descriptors and Alert from LiDAR Data.
Traffic Signalisation Recognition	Produces Road Topology of the Environment from Visual and LiDAR Data.
Visual Scene Description	Produces Visual Scene Descriptors and Alert from Visual Data.

Ultrasound Scene Description	Produces Ultrasound Scene Descriptors and Alert from Ultrasound Data.
Online Map Scene Description	Produces Online Map Data Scene Descriptors from Online Map Data.
Audio Scene Description	Produces Audio Scene Descriptors and Alert from Audio Data.
Spatial Attitude Generation	Computes the CAV Spatial Attitude using information received from GNSS and Motion Actuation Subsystem with respect to CAV Centre.
Environment Sensing Subsystem Data Fusion	Receives critical Environment Representation as Alert and Scene Descriptors from the different ESTs. The Basic Environment Representation (BER) includes all available information from ESS that enables the CAV to define a Path in the Decision Horizon Time. The BER results from the *integration* of: 1. The different Scene Descriptors generated by the different EST-specific Scene Description AIMs. 2. Environment Data. 3. The Spatial Attitude of the Ego CAV (Figure 5).

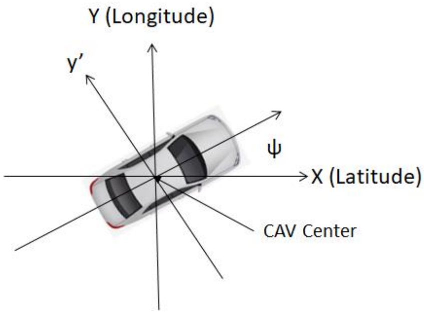

Figure 5 – Spatial Attitude in a CAV

7.5 I/O Data of Environment Sensing Subsystem's AI Modules

For each AIM (1st column), Table 8 gives the input (2nd column) and the output data (3rd column) of the Environment Sensing Subsystem. Note that the Basic Environment Representation in column 2 refers to the previously produced BER.

Table 8 - I/O Data of Environment Sensing Subsystem's AI Modules

AIM	Input	Output
Radar Scene Description	Radar Data Basic Environment Representation	Alert Radar Scene Descriptors
Lidar Scene Description	Lidar Data Basic Environment Representation	Alert Lidar Scene Descriptors
Traffic Signalisation Recognition	Visual Data Basic Environment Representation	Alert Road Topology
Visual Scene Description	Visual Data Basic Environment Representation	Alert Lidar Scene Descriptors
Ultrasound Scene Description	Ultrasound Data Basic Environment Representation	Alert Ultrasound Scene Descriptors
Map Scene Description	Offline Map Data	Alert

	Basic Environment Representation	Map Scene Descriptors
Audio Scene Description	Audio Data Basic Environment Representation	Alert Audio Scene Descriptors
Spatial Attitude Generation	GNSS Data Spatial Attitude form MAS	Spatial Attitude
Environment Sensing Subsystem Data Fusion	RADAR Scene Descriptors LiDAR Scene Descriptors Road Topology Lidar Scene Descriptors Ultrasound Scene Descriptors Map Scene Descriptors Audio Scene Descriptors Spatial Attitude Other Environment Data	Alert Basic Environment Representation

8 Autonomous Motion Subsystem (AMS)

8.1 Functions of Autonomous Motion Subsystem

The functions of the Autonomous Motion Subsystem (AMS) are:

1. Receive a request to reach a destination as instructed by Human-CAV Interaction (HCI).
2. Request current Pose to Environment Sensing Subsystem (ESS).
3. Converse with HCI and settle on final Route.
4. Receive Basic Environment Representation (BER) from ESS.
5. Broadcast appropriate BER subsets to Remote AMSs.
6. Respond to specific Remote AMS requests.
7. Produce Full Environment Representation.
8. Generate Paths (Plath Planner).
9. Generate Goal and Trajectory (Motion Planner).
10. Check whether Trajectory can be implemented (Obstacle Avoider).
11. Issue Command to Motion Actuation Subsystem.

8.2 Reference Architecture of Autonomous Motion Subsystem

Figure 6 gives the Autonomous Motion Subsystem Reference Model.

This is the operation of the Reference Model:

1. A human requests the Human-CAV Interaction to take them to a destination.
2. HCI interprets request and passes interpretation to the AMS.
3. The AMS activates the Route Planner to generate a set of Waypoints starting from the current Pose, obtained from the Full Environment Representation, up to the destination.
4. The Waypoints enter the Path Planner which generates a set of Poses to reach the next Waypoint.
5. For each Path, the Motion Planner generates a Trajectory to reach the next Pose.
6. Obstacle Avoider receives the Trajectory and checks if an Alert was received.
7. If an Alert was received, Obstacle Avoider checks whether the implementation of the Trajectory creates a collision.
    a. If a collision is indeed detected, Obstacle Avoider requests a new Trajectory from the Motion Planner.
    b. If no collision is detected, Obstacle Avoider issues a Command to Motion Actuation Subsystem.

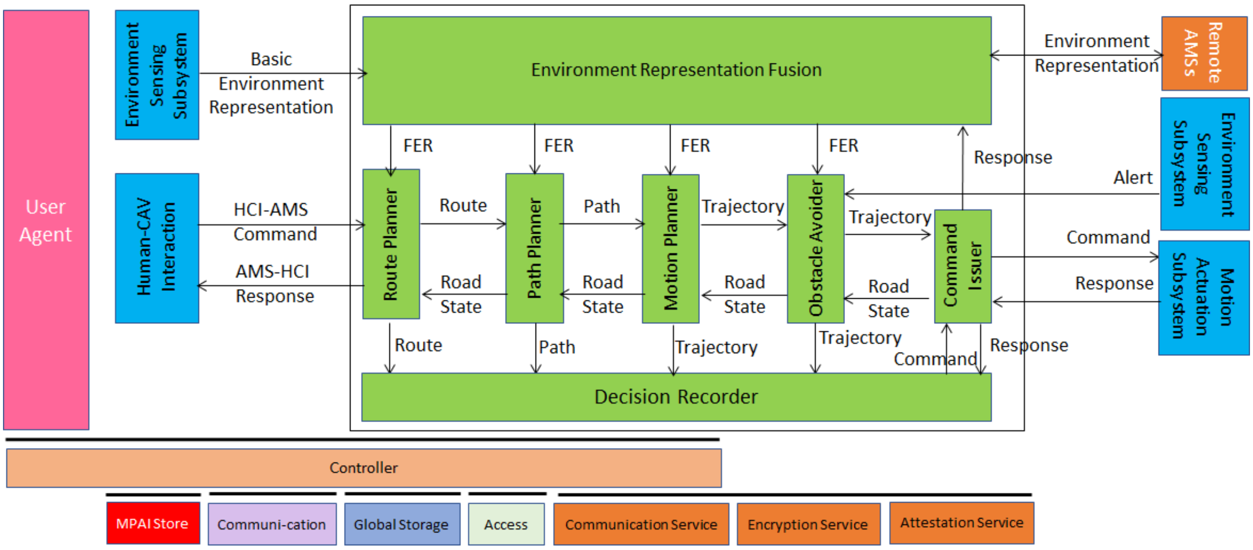

Figure 6 – Autonomous Motion Subsystem Reference Model

8. The Motion Actuation Subsystem sends MAS-AMS Response about the execution of the Command.
9. The AMS, based on the MAS-AMS Responses received potentially conveying changes in the Environment, can decide to discontinue the execution of the earlier Command and issue another AMS-MAS Command instead.
10. The decision of each element of the said chain may be recorded in the Decision Recorder (“black box”).

8.3 I/O Data of Autonomous Motion Subsystem

Table 9 gives the input/output data of Autonomous Motion Subsystem.

Table 9 - I/O data of Autonomous Motion Subsystem

Input data	**From**	**Comment**
Basic Environment Representation	Environment Sensing Subsystem	CAV’s Environment representation.
Alert	Environment Sensing Subsystem	Critical information from an EST in ESS.
HCI-AMS Command	Human-CAV Interaction	Human commands, e.g., “take me home”
Environment Representation	Remote AMSs	Other CAVs and vehicles, and roadside units.
MAS-AMS Response	Motion Actuation Subsystem	CAV’s response to AMS-MAS Command.
Output data	**To**	**Comment**
AMS-HCI Response	Human-CAV Interaction	MAS’s response to AMS-MAS Command
AMS-MAS Command	Motion Actuation Subsystem	Macro-instructions, e.g., “in 5s assume a given Spatial Attitude”.
Environment Representation	Remote AMSs	For information to other CAVs

8.4 Functions of Autonomous Motion Subsystem's AI Modules

Table 10 gives the AI Modules of the Autonomous Motion Subsystem.

Table 10 - Functions of Autonomous Motion Subsystem's AI Modules

AIM	Function
Full Environment Representation Fusion	Creates an internal representation of the Environment by fusing information from itself, Remote AMSs, and other CAV-aware entities.
Route Planner	Computes a Route, through a road network, from the current to the target destination.
Path Planner	Generates a set of Paths, considering: 1. Route. 2. Spatial Attitude. 3. Full Environment Representation. 4. Traffic Rules.
Motion Planner	Defines a Goal and a Trajectory to reach the Goal using the Spatial Attitude satisfying the CAV's kinematic and dynamic constraints and considering passengers' comfort.
Obstacle Avoider	Checks whether the Trajectory is compatible with any Alert information. If it is, it passes the Trajectory to the Command Issuer. If it is not, it requests a new Trajectory. If Command Issuer informs Obstacle Avoider that AMS-MAS Commands cannot be executed, Obstacle Avoider may issue a "discontinue previous Command" and forward to the appropriate upstream AIM, possibly up to the Route Planner. This may decide to communicate the Road State to the Human-CAV Interaction Subsystem.
Command Issuer	Instructs the MAS to execute the Trajectory considering the Environment conditions and receives MAS-AMS Responses about the execution. Based on the Response the Road State may be communicated to the Obstacle Avoider.
Decision Recorder	Records decisions by Route Planner, Path Planner, Motion Planner, Obstacle Avoider, Command Issuer.

8.5 I/O Data of Autonomous Motion Subsystem's AI Modules

Table 11 gives, for each AIM (1st column), the input data (2nd column) and the output data (3rd column) of Autonomous Motion Subsystem.

Table 11 - CAV Autonomous Motion Subsystem data

CAV/AIM	Input	Output
Environment Representation Fusion	Basic Environment Representations from ESS or Remote AMSs Other data from Remote AMSs	Full Environment Representation
Remote AMSs	See Table 15	See Table 15
Route Planner	Full Environment Representation Offline maps Road State	Route Estimated time of arrival
Path Planner	Route Full Environment Representation Offline maps Road State	Set of Paths

Motion Planner	Set of Paths Full Environment Representation Road State	Trajectory
Obstacle Avoider	Trajectory Full Environment Representation Alert Road State	Trajectory
Command Issuer	Trajectory MAS-AMS Response	AMS-MAS Command
Decision Recorder	Route Path Trajectory AMS-MAS Command MAS-AMS Response	Recorded Data

The AMS may harvest available bandwidth and utilise it to send a version of the Full Environment Representation that is compatible with the available mobile bandwidth.

9 Motion Actuation Subsystem (MAS)

9.1 Functions of Motion Actuation Subsystem

The Motion Actuation Subsystem:

1. Transmits spatial and environmental information gathered from its sensors and mechanical subsystems to the Environment Sensing Subsystem.
2. Receives AMS-MAS Commands from the Autonomous Motion Subsystem.
3. Translates AMS-MAS Commands into specific Commands to its own mechanical subsystems, e.g., brakes, steering wheel, and wheel motors.
4. Receives Responses from its mechanical subsystems.
5. Packages Responses into a MAS-AMS Response.
6. Sends MAS-AMS Responses to Autonomous Motion Subsystem.
7. During the execution, the MAS may send MAS-AMS Responses containing Spatial Attitudes and other data obtained through actuation of its mechanical subsystems, e.g., ice on the road, at intermediate Poses/Times.

9.2 Reference Architecture of Motion Actuation Subsystem

Figure 7 represents the Motion Actuation Subsystem Reference Model.

The operation of the Motion Actuation Subsystem unfolds as follows:

1. Other Environment Data are transferred to the Environment Sensing Subsystem.
2. MAS Spatial Attitude Generation sends to Environment Sensing Subsystem the Ego CAV Spatial Attitude computed using Odometer, Speedometer, and Accelerometer.
3. AMS Command Interpreter issues commands by interpreting AMS-MAS Commands received from Autonomous Motion Subsystem to Wheel motor, Steering wheel, and Brakes.
4. MAS Response Analyser sends MAS-AMS Responses by interpreting responses receives from Wheel motor, Steering wheel, and Brakes.

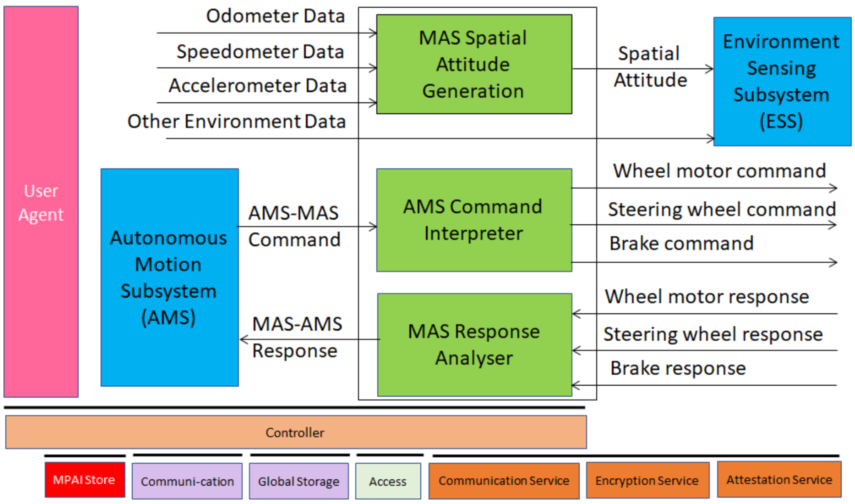

Figure 7 – Motion Actuation Subsystem Reference Model

9.3 I/O Data of Motion Actuation Subsystem

Table 12 gives the input/output data of Motion Actuation Subsystem.

Table 12 - I/O data of Motion Actuation Subsystem

Input	Comments
Odometer	Provides distance data.
Speedometer	Provides instantaneous velocity.
Accelerometer	Provides instantaneous acceleration.
Other Environment data	Other environment data, e.g., humidity, pressure, temperature.
AMS-MAS Command	High-level motion command.
Wheel Motor Response	Forces wheels rotation, gives feedback.
Steering Wheel Response	Moves wheels by an angle, gives feedback.
Brake Response	Acts on brakes, gives feedback.
Output	**Comments**
Spatial Attitude	Position, Orientation and their velocity and acceleration vectors.
Other Environment data	Other environment data, e.g., humidity, pressure, temperature.
Wheel Motor Command	Forces wheels rotation, gives feedback.
Steering Wheel Command	Moves wheels by an angle, gives feedback.
Brakes Command	Acts on brakes, gives feedback.
MAS-AMS Response	Feedback from MAS Response Analyser during and after AMS-MAS Command execution.

9.4 Functions of Motion Actuation Subsystem's AI Modules

Table 13 gives the AI Modules of Autonomous Motion Subsystem.

Table 13 - Functions of Motion Actuation Subsystem's AI Modules

AIM	Function
MAS Spatial Attitude Generation	Computes Ego CAV's Spatial Attitude using GNSS, odometer, speedometer, and accelerometer data.
AMS Command Interpreter	Receives, analyses, and actuates AMS-MAS Commands into specific commands to Brakes, Wheel directions, and Wheel motors.

MAS Response Analyser	Receives and analyses responses from Brakes, Wheel direction, and Wheel motor. Assembles and forwards the MAS-AMS Response to AMS.

9.5 I/O Data of Motion Actuation Subsystem's AI Modules

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

Table 14 - I/O Data of Motion Actuation Subsystem's AI Modules

CAV/AIM	Input	Output
MAS Spatial Attitude Generation	Odometer Speedometer Accelerometer	Spatial Attitude
AMS Command Interpreter	AMS-MAS Command	Brake Command Wheel Motor Command Steering Wheel Command
MAS Response Analyser	Brake Response Steering Wheel Response Wheel Motor Response	MAS-AMS Response

10 CAV-to-Everything (V2X) (Informative)

To enhance its own capabilities to perceive the Environment, a CAV exchanges information via radio with other entities, e.g., Remote AMSs may be achieved via secure channels.

V2X is the CAV component that allows the CAV Subsystems – Human-CAV Interaction and Autonomous Motion Subsystems – to communicate to peer entities external to the Ego CAV. For instance, the HCI of a CAV may send/request information to/from the HCI of another CAV or an AMS may send/request the BER to/from the AMS of another CAV.

10.1 V2X Communication

V2X may be achieved via different communication protocols. A CAV may use multicast or unicast to send CAVs in range information it has become aware of by using the V2X communication interface. For instance, while executing a Command, the MAS of CAV may become aware of ice on the road. The AMS may decide to broadcast that information to CAVs in range. Unicast may be used for communication between the Ego CAV and a specific CAV.

Multicast Communication may be used when a CAV broadcasts large amounts of data such as the Basic Environment Representation (BER). The BER data format should be scalable to enable transmission of the more important elements of the BER in case the number of CAVs is large.

Communication with Remote CAVs is managed by a Communication Device. Here is an example of the operation flow of the Communication Device communicating with Remote CAVs:

1. Receive identities broadcasted by Remote AMSs.
2. Establish unicast sessions with Remote AMSs.
3. Create a list of Remote CAVs with which it has established a session.
4. Sends the Ego CAV's information to Remote AMSs.

10.2 Input and output data

10.2.1 CAVs within range

Table 15 gives the Data Types a CAV broadcasts to CAVs in range via its Communication Device.

Table 15 - I/O data of CAV's Communication Device

Input Data	**From**	**Comments**
CAV Identity	Remote AMSs	In principle, this should be the digital equivalent of today's plate number including Manufacturer and Model information.
Basic Environment Representation	Remote AMSs	A scalable subset of the digital representation of the Environment created by the ESS.
Information Messages	Remote AMSs and/or HCIs	Possible messages received by a CAV: 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**
CAV Identity	Remote AMSs	In principle, this should be the digital equivalent of today's plate number including Manufacturer and Model information.
Basic Environment Representation	Remote AMSs	Same as input for all other input data. BER accuracy depends on available bandwidth.
Information Messages	Remote AMSs and/or HCIs	Typical messages as above.

10.2.2 CAV-aware equipment

Examples are traffic lights, roadside units, and vehicles with CAV communication capabilities. The following data may be included in an exchange between CAVs:

1. Identity and Spatial Attitude.
2. Static Full Environment Representation that is regularly updated.
3. State (Green-Yellow-Red) of traffic light and time to change state.
4. Lane markings.
5. Speed limits.
6. Pedestrian crosswalks.
7. General information on the Environment (e.g., one way street etc.)

CAV-aware equipment:

1. Can act as any other CAV in range.
2. May have the authority to organise motion of CAVs in range.

10.2.3 Other non-CAV vehicles

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

10.2.4 Pedestrians

Their smartphones can transmit their Spatial Attitudes. No response capability is expected.

Annex 1 - MPAI Basics (Informative)

Note: This Annex includes some general information on MPAI Technical Specifications components of which are used or referenced in this MPAI-CAV – Architecture Technical Specification. The text is informative. Normative text is provided by the appropriate Technical Specifications whose references are provided in Section 4.1.

1 General

In recent years, Artificial Intelligence (AI) and related technologies have been introduced in a broad range of applications, have started affecting the life of millions of people and are expected to do so even more in the future. As digital media standards have positively influenced industry and billions of people, so AI-based data coding standards are expected to have a similar positive impact. Indeed, research has shown that data coding with AI-based technologies is generally *more efficient* than with existing technologies for, e.g., compression and feature-based description.

However, some AI technologies may carry inherent risks, e.g., in terms of bias toward some classes of users. Therefore, the need for standardisation is more important and urgent than ever.

The international, unaffiliated, not-for-profit Moving Picture, Audio and Data Coding by Artificial Intelligence (MPAI) Standards Developing Organisation has the mission to develop *AI-enabled data coding standards*. MPAI Application Standards enable the development of AI-based products, applications, and services.

2 Governance of the MPAI Ecosystem

As a rule, MPAI standards include four documents: Technical Specification, Reference Software Specification, Conformance Testing Specification, Performance Assessment Specification. The last type of Specification includes standard operating procedures to enable users of MPAI Implementations to make informed decisions about their applicability based on the notion of Performance, defined as a set of attributes characterising a reliable and trustworthy implementation. Technical Reports may be published to provide information about a particular technical area.

An MPAI Standard is a collection of a variable number of the 5 document types.

Figure 8 depicts how the MPAI ecosystem of conforming MPAI implementations operates.

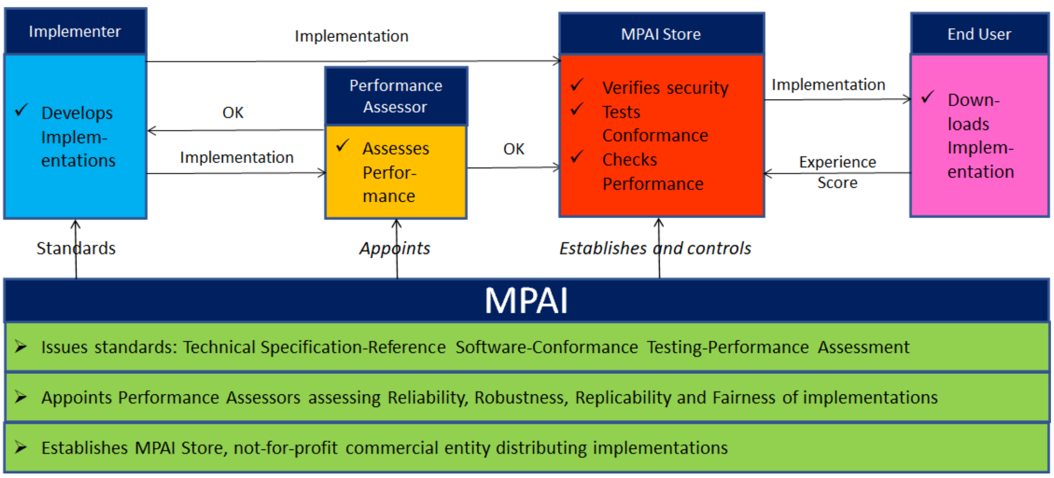

Figure 8 – The MPAI ecosystem operation

Technical Specification: Governance of the MPAI Ecosystem identifies the following roles in the MPAI Ecosystem:

Table 16 - Roles in the MPAI Ecosystem

MPAI	Publishes Standards. Establishes the not-for-profit MPAI Store. Appoints Performance Assessors.
Implementers	Submit Implementations to Performance Assessors. Submit Implementations to the MPAI Store.
Performance Assessors	Inform Implementation submitters and the MPAI Store if Implementation Performance is acceptable.
MPAI Store	Assign unique ImplementerIDs (IID) to Implementers in its capacity as ImplementerID Registration Authority (IIDRA)[1]. Verify security and Test Implementation Conformance.
Users	Download Implementations and report their experience to MPAI.

3 AI Framework

In general, MPAI Application Standards are defined as aggregations – called AI Workflows (AIW) – of processing elements – called AI Modules (AIM) – executed in an AI Framework (AIF). 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 AIF that executes an AIW. The AIW and its AIMs 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 offers 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 on Interoperability Levels is provided in [1].

Figure 9 depicts the MPAI-AIF Reference Model under which Implementations of MPAI Application Standards and user-defined MPAI-AIF Conforming applications operate [4].

MPAI Application Standards normatively specify:
1. The Syntax and Semantics of the input and output data.
2. The Functions of the AIW and the AIMs.
3. The Connections between and among the AIMs of an AIW.

It should be noted that an AIM is defined by its Function and data, but not by its internal architecture, which may be based on AI or data processing, and implemented in software, hardware or a hybrid of software and hardware technologies.

MPAI Standards are designed to enable a User to obtain, via standard protocols, an Implementation of an AIW and of the set of corresponding AIMs and execute it in an AIF Implementation. The

[1] At the time of publication of this Technical Report, the MPAI Store was assigned as the IIDRA.

MPAI Store in *Figure 9* is the entity from which Implementations are downloaded. MPAI Standards assume that the AIF, AIW, and AIM Implementations may have been developed by independent implementers. A necessary condition for this to be possible, is that any AIF, AIW, and AIM implementations be uniquely identified. MPAI has appointed an ImplementerID Registration Authority (IIDRA) to assign unique ImplementerIDs (IID) to Implementers.[2]

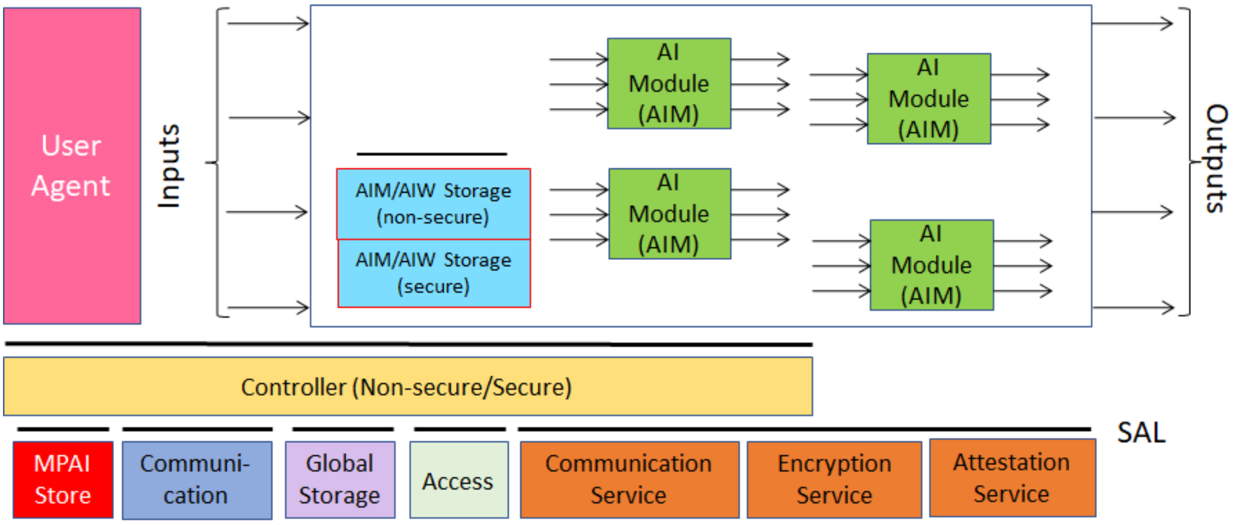

Figure 9 – Reference Model AI Framework (MPAI-AIF) V2

4 Portable Avatar Format

Technical Specification: Portable Avatar Format (MPAI-PAF) specifies:

1. The Portable Avatar Format and related Data Formats allowing a sender to enable a receiver to decode and render an Avatar as intended by the sender.
2. The Personal Status Display Composite AI Module allowing the conversion of a Text and a Personal Status to generate a Portable Avatar.
3. The AI Framework (MPAI-AIF)-conforming AI Workflows and AI Modules composing the Avatar-Based Videoconference Use Case also using Data Types from other MPAI Technical Specifications.

The Portable Avatar Format Data Type includes information on Avatar ID, Time, Placement, Visual Environment, Spatial Attitude, Model, Body Descriptors, Face Descriptors, Ready-to-Render Avatar, Language Preference, Speech, Text, and Personal Status. All elements of the Portable Avatar Format are optional.

5 Personal Status

5.1 General

Personal Status is the set of internal characteristics of a human or a machine making a conversation. Reference [5] identifies three Factors of the internal state:

1. *Cognitive State* is a typically rational result from the interaction of a human/avatar with the Environment (e.g., “Confused”, “Dubious”, “Convinced”).
2. *Emotion* is typically a less rational result from the interaction of a human/avatar with the Environment (e.g., “Angry”, “Sad”, “Determined”).

[2] At the time of publication of this Technical Specification, the MPAI Store was assigned as the IIDRA.

3. *Social Attitude* is the stance taken by a human/avatar who has an Emotional and a Cognitive State (e.g., "Respectful", "Confrontational", "Soothing").

The Personal Status of a human can be displayed in one of the following Modalities: *Text*, *Speech*, *Face*, or *Gesture*. More Modalities are possible but not currently supported, e.g., the body itself as in body language, dance, song, etc. The Personal Status may be shown by only one of the four Modalities or by two, three or all four simultaneously.

5.2 Personal Status Extraction

Personal Status Extraction (PSE) is a composite AIM that analyses the Personal Status conveyed by Text, Speech, Face, and Gesture – of a human or an avatar – and provides an estimate of the Personal Status in three steps:

1. *Data Capture* (e.g., characters and words, a digitised speech segment, the digitised video containing the hand of a person, etc.).
2. *Descriptor Extraction* (e.g., pitch and intonation of the speech segment, thumb up of a raised hand, the right eye winking, etc.).
3. *Personal Status Interpretation* (e.g., one of Emotion, Cognitive State, or Attitude).

Figure 10 depicts the Personal Status estimation process:

1. Descriptors are extracted from Text, Speech, Face Object, and Body Object. Depending on the value of Selection, Descriptors can be input from an AIM upstream.
2. Descriptors are interpreted and the specific indicators of the Personal Status in the Text, Speech, Face, and Gesture Modalities are derived.
3. Personal Status is obtained by combining the estimates of different Modalities of the Personal Status.

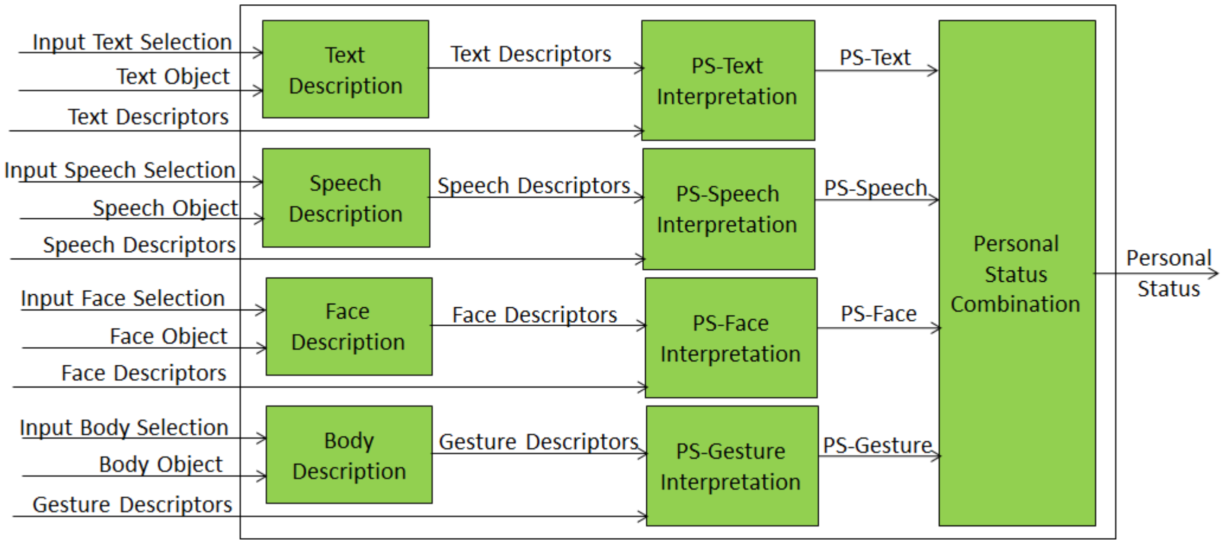

Figure 10 – Reference Model of Personal Status Extraction

An Implementation can combine, e.g., the PS-Gesture Description and PS-Gesture Interpretation AIMs into one AIM, and directly provide PS-Gesture from a Body Object without exposing PS-Gesture Descriptors.

5.3 Personal Status Display

A Personal Status Display (PSD) is a Composite AIM receiving Text and Personal Status and generating an avatar producing Text and uttering Speech with the intended Personal Status while the avatar's Face and Gesture also show the intended Personal Status. The Personal Status driving the avatar can be extracted from a human or can be synthetically generated by a machine because of its conversation with a human or another avatar.

Figure 11 represents the AIMs required to implement Personal Status Display.

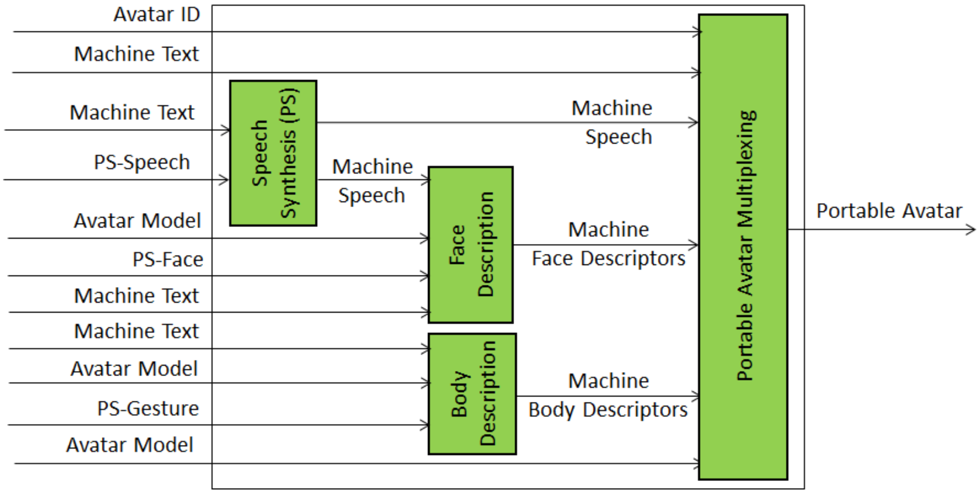

Figure 11 – Reference Model of Personal Status Display

The Personal Status Display operates as follows:

1. Avatar ID is the ID of the Portable Avatar.
2. Machine Text is synthesised as Speech using the Personal Status provided by PS-Speech.
3. Machine Speech and PS-Face are used to produce the Machine Face Descriptors.
4. PS-Gesture and Text are used for Machine Body Descriptors using the Avatar Model.
5. Portable Avatar Multiplexing produces the Portable Avatar.

6 Human-machine dialogue

Figure 12 depicts the model of the MPAI Personal-Status-based human-machine dialogue.

Audio Scene Description and Visual Scene Description are two front-end AIMs. The former produces Physical Objects, Face and Body Descriptors of the humans, and Visual Scene Geometry; the latter produces Audio Objects and Audio Scene Geometry.

Body Descriptors, Physical Objects and Visual Scene Geometry are used by the Spatial Object Identification AIM. Audio-Visual Alignments aligns the Audio and Visual Objects. This provides the identifier of the Physical Object the human body is indicating by using the Body Descriptors and the Scene Geometry. The Speech extracted from the Audio Scene Descriptor is recognised and passed to the Language Understanding AIM together with the Physical Object ID. The AIM provides a Refined Text and Meaning (semantic, syntactic, and structural information extracted from input data).

Face and Body Descriptors, Meaning and Speech are used by Personal Status Extraction to extract the Personal Status of the human. Dialogue Processing produces a textual response with an associated machine Personal Status that is congruent with the input Text (Language Understanding) and human Personal Status. The Personal Status Display Composite AIM produces a Portable Avatar Data Type.

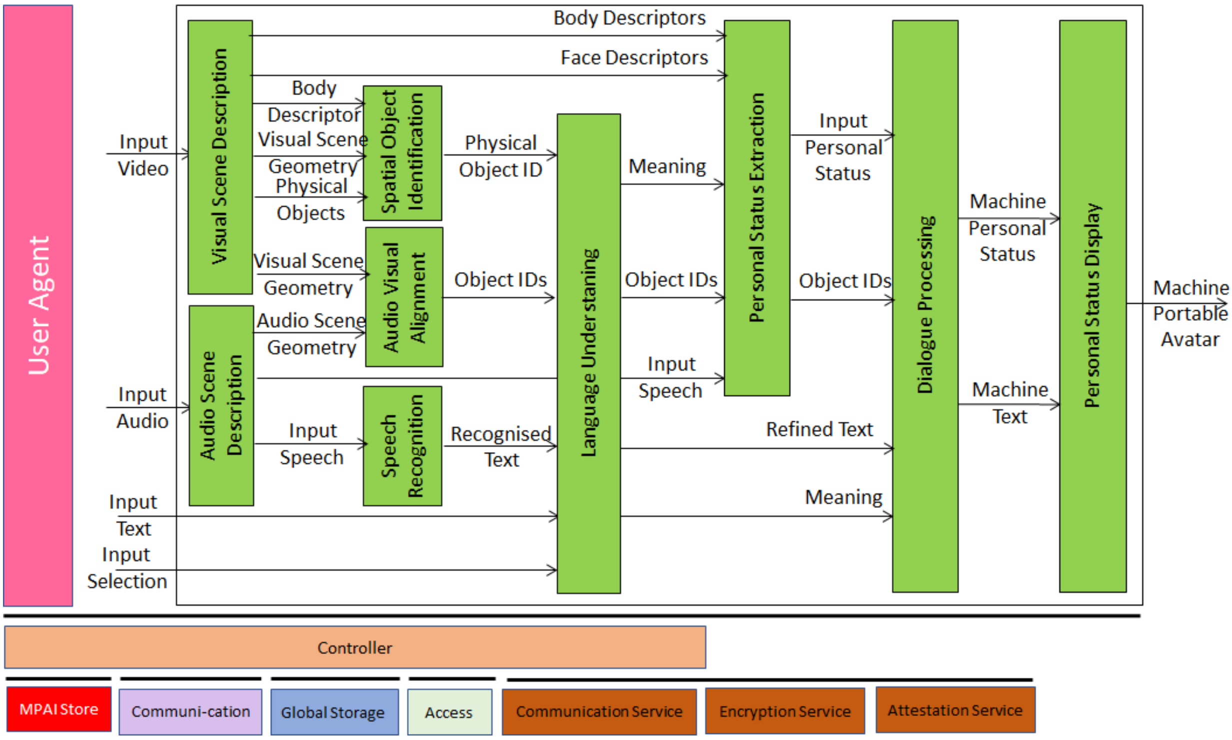

Figure 12 - Personal Status-based Human-Machine dialogue

7 MPAI Metaverse Model

The MPAI Metaverse Model (MPAI-MMM) – Architecture

1. Defines a Metaverse Instance (M-Instance) as a set of Processes providing some or all the following functions:
   1.1. To sense data from U-Locations.
   1.2. To process the sensed data and produce Data.
   1.3. To produce one or more M-Environments populated by Objects that can be either digitised or virtual, the latter with or without autonomy.
   1.4. To process Objects from the M-Instance or potentially from other M-Instances to affect U- and/or M-Environments using Object in ways that are:
      1.4.1. Consistent with the goals set for the M-Instance.
      1.4.2. Effected within the capabilities of the M-Instance.
      1.4.3. Complying with the Rules set for the M-Instance.
2. Specifies:
   2.1. The Operation Model of an M-Instance.
   2.2. Functional Requirements of 4 types of Process (Programs executing in an M-Instance).
   2.3. Analyses nine Use Cases including the Drive a Connected Autonomous Vehicle Use Case.
   2.4. A set of Functional Profiles.

Table 17 gives a summary description of the CAV-Oriented MPAI-MMM Use Case. The following should be noted:

1. CAV_A and CAV_B are two CAVs.
2. Each CAV produces a metaverse instance (M-Instance).
3. In the Use Case, a passenger of CAV_A wants to see the landscape of CAV_B as reproduced in the Metaverse Instance of by CAV_B.
4. HCI_A and AMS_A are two Users, i.e., two Processes representing the CAV_A passenger. Ditto for CAV_B.

5. Table 17 uses the Actions defined by the MPAI-MMM - Architecture. For simplicity, some Actions are represented by commonly used words rather than by the formal words of MPAI-MMM Architecture.
6. The Use Case shows that MPAI-MMM - Architecture can be used to represent the operation of an Implementation of MPAI-CAV - Architecture.

Table 17 - A CAV-oriented MPAI Metaverse Model Use Case

HCI_A	1. <u>Authenticates</u> humans (e.g., recognises their voice). 2. <u>Interprets</u> human's message ("I want go home"). 3. <u>Sends</u> corresponding command to AMS_A (represents human in CAV_A's M-Instance)
AMS_A	1. <u>Gets a representation</u> of the real world from the Environment Sensing Subsystem of CAV_A (ESS_A) to understands *where* it is. 2. <u>Asks</u> Route Planner for selection of "Routes to home". 3. <u>Sends</u> selection of Routes to HCI_A.
HCI_A	1. <u>Communicates</u> choices of Route to human (e.g., spoken version of AMS_A's response). 2. <u>Interprets</u> human's final choice (e.g., recognises their voice). 3. <u>Sends</u> command to AMS_A (e.g., execute Route #2).
AMS_A	1. Mutually <u>authenticates</u> AMS_B (nearby CAV). 2. <u>Improves</u> its real-world perception by "watching" AMS_B's real world view. 3. <u>Activates</u> AMS_A's Processes eventually leading to sending a command to MAS_A.
AMS_B	1. <u>Improves</u> its real-world perception by watching AMS_A's real world view. 2. <u>Activates</u> AMS_B's Processes leading to sending a command to MAS_B.
HCI_A	1. Mutually <u>authenticates</u> HCI_B. 2. <u>Watches</u> CAV_B's Full Environment Representation.

Annex 2 - General MPAI Terminology

Table 18 defines the Terms used in this Technical Specification with a capitalised first letter that are not already included in Table 1.

Note: To concentrate in one place all the Terms that are composed of a common name followed by other words (e.g., the word Data followed by one of the words Format, Type, or Semantics), the definition given to a Terms preceded by a dash "-" applies to a Term composed by that Term without the dash preceded by the Term that precedes it in the column without a dash.

Table 18 - 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 Model (AIM)	A data 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 AIW-specific inputs and producing AIW-specific outputs according to the AIW Function.
Application Standard	An MPAI Standard designed to enable a particular application domain.
Channel	A connection between an output port of an AIM and an input port of an AIM. The term "connection" is also used as synonymous.
Communication	The infrastructure that implements message passing between AIMs.
Component	One of the 7 AIF elements: Access, Communication, Controller, Internal Storage, Global Storage, Store, and User Agent
Composite AIM	An AIM aggregating more than one AIM.
Component	One of the 7 AIF elements: Access, Communication, Controller, Internal Storage, Global Storage, Store, and User Agent
Conformance	The attribute of an Implementation of being a correct technical Implementation of a Technical Specification.
- Testing	The normative document specifying the Means to Test the Conformance of an Implementation.
- 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.
- Format	The standard digital representation of Data.
- Type	An instance of Data with a specific Data Format.
- Semantics	The meaning of Data.
Descriptor	Coded representation of a text, audio, speech, or visual feature.

Digital Representation	Data corresponding to and representing a physical entity.
Ecosystem	The ensemble of actors making it possible for a User to execute an application composed of an AIF, one or more AIWs, each with one or more AIMs potentially sourced from independent implementers.
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.
AIM/AIW Storage	A Component to store data of the individual 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) conforming with a Use Case of an MPAI Application Standard.
Implementer	A legal entity implementing MPAI Technical Specifications.
ImplementerID (IID)	A unique name assigned by the ImplementerID Registration Authority to an Implementer.
ImplementerID Registration Authority (IIDRA)	The entity appointed by MPAI to assign ImplementerID's to Implementers.
Instance ID	Instance of a class of Objects and the Group of Objects the Instance belongs to.
Interoperability	The ability to functionally replace an AIM with another AIW having the same Interoperability Level
- Level	The attribute of an AIW and its AIMs to be executable in an AIF Implementation and to: 1. Be proprietary (Level 1) 2. Pass the Conformance Testing (Level 2) of an Application Standard 3. Pass the Performance Testing (Level 3) of an Application Standard.
Knowledge Base	Structured and/or unstructured information made accessible to AIMs via MPAI-specified interfaces
Message	A sequence of Records transported by Communication through Channels.
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.
- Assessment	The normative document specifying the Means to Assess the Grade of Performance of an Implementation.
- Assessment Means	Procedures, tools, data sets and/or data set characteristics to Assess the Performance of an Implementation.
- Assessor	An entity Assessing the Performance of an Implementation.
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	A data structure 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.
Standard	A set of Technical Specification, Reference Software, Conformance Testing, Performance Assessment, and Technical Report 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 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 3 - Notices and Disclaimers Concerning MPAI Standards (Informative)

The notices and legal disclaimers given below shall be borne in mind when downloading and using approved MPAI Standards.

In the following, "Standard" means the collection of four MPAI-approved and published documents: "Technical Specification", "Reference Software" and "Conformance Testing" and, where applicable, "Performance Testing".

Life cycle of MPAI Standards

MPAI Standards are developed in accordance with the MPAI Statutes. An MPAI Standard may only be developed when a Framework Licence has been adopted. MPAI Standards are developed by especially established MPAI Development Committees who operate on the basis of consensus, as specified in Annex 1 of the MPAI Statutes. While the MPAI General Assembly and the Board of Directors administer the process of the said Annex 1, MPAI does not independently evaluate, test, or verify the accuracy of any of the information or the suitability of any of the technology choices made in its Standards.

MPAI Standards may be modified at any time by corrigenda or new editions. A new edition, however, may not necessarily replace an existing MPAI standard. Visit the web page to determine the status of any given published MPAI Standard.

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Annex 4 - Patent Declarations

MPAI-CAV – Architecture has been developed according to the process outlined in the MPAI Statutes [1] and the MPAI Patent Policy [2].

The following table will include the entities who will declare to agree to licence their standard essential patents reading on MPAI-CAV – Architecture according to the Framework Licence: Connected Autonomous Vehicle (MPAI-CAV) - Architecture [10]:

Entity	**Name**	**email address**