RELIABLE APPLICATION SPECIFIC DETECTION OF ROAD USERS WITH VEHICLE ON-BOARD SENSORS

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# DELIVERABLE D6.2

# SENSOR REQUIREMENTS AND SPECIFICATIONS AND SW ARCHITECTURE


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# 1. INTRODUCTION

## 1.1 Relevant software WP6 objectives

In the context of ADOSE **only 'technology-dependent' pre-processing algorithms will be developed:**

a) algorithms implemented into the sensor hardware (e.g. processing pipeline in case of vision sensor like input control, noise removal, image enhancement, output control, …);
b) algorithms on raw data, coming from the sensor hardware, implemented on a PC-based processing which are strictly related to the sensing technology and its demonstration (e.g. 'hot spot' feature extraction in case of low-resolution FIR-camera).

With reference to the software architecture of a typical driver assistance system as defined in ProFusion (PReVENT), **the algorithm development in ADOSE will be only limited to the perception stage and in particular to the sensor and the object refinement** (Figure 1).

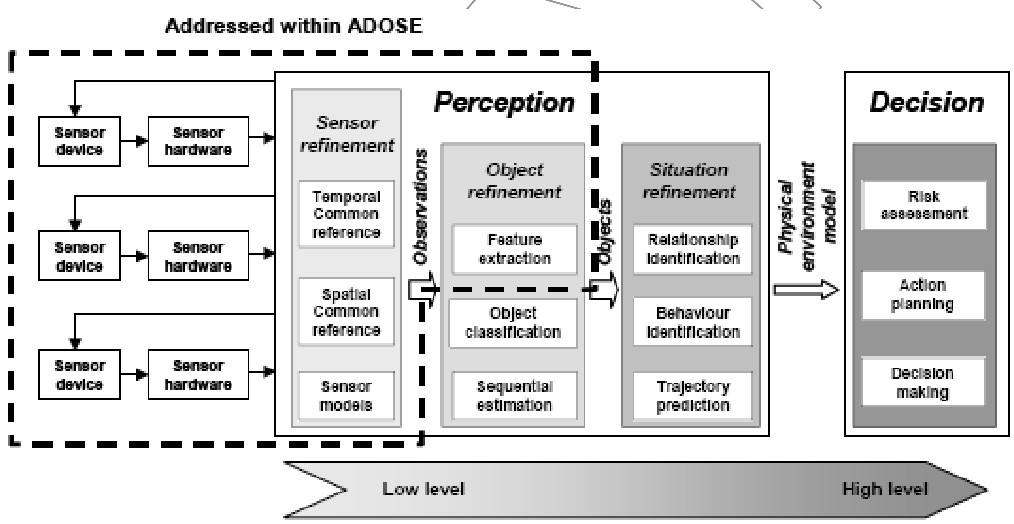



Figure 1 - Data processing tasks of a typical driver assistance system

ProFusion guidelines (PReVENT) will be followed, but algorithm developments will not be extended to Sensor Data Fusion.

For the validation phase two demonstrator vehicles will be set-up with the developed sensors:

- CRF vehicle: FIR camera, multi-functional optical sensor and ranging camera.
- ARC vehicle: silicon retina stereo sensor, scanning radar for tag detection and radio communication system.

The sensor modules will be interfaced to a PC-based processing hardware (embedded PC) installed on car and the visualisation of raw and pre-processed data will be carried out (it is not developed the application).

## 1.2 Purpose of this document

The purpose of the present document is to define preliminarily the ADOSE sensor specifications related to the communication bus, protocol and data format, and to provide a rough overview of the software architectures. These activities are planned in the context of Task 6.1.

D6.2 deliverable report will be updated during the project as soon as the sensor design phase will be completed and the final decisions will be taken on the configuration of the sensor prototypes (hardware interfaces, bus, protocols, etc.). For these reasons the current report is marked as "Draft".

The following issues will be discussed in the document:

- Hardware interfaces between the sensor and the ECU
- Type of data and format
- Software architectures
- Plan of software tests

Milestone M6.2 *"Sensor specifications and SW architecture"* was planned in month 10. The planned means of verification in Annex I are the availability of the sensor specifications (software) and the description of the software architectures. Of course they have to be intended as a preliminary version for the above mentioned reasons.

# 2. LIST OF ADOSE SENSORS

ADOSE addresses five breakthrough sensing technologies, with the goal to improve the current state-of-the-art in terms of performance, reliability and costs:

- **Sensor 01: FIR (BOSCH)**
  FIR-add-on sensor (FIR), with good thermal and spatial resolution at lower cost, to be combined to a high resolution imager for enhanced night vision applications (more reliable obstacle detection and classification).
- **Sensor 02: MFOS (CRF)**
  Low-cost multi-functional and multi-spectral CMOS vision sensor (MFOS), detecting critical environmental parameters (fog, rain, …) and providing, at the same time, information on the driving scenario (oncoming vehicles, VRUs in night conditions, …).
- **Sensor 03: 3DCAM (IMEC)**
  High spatial resolution and low-cost 3D range camera (3DCAM), based on 3D packaging, optical CMOS and laser radar technologies for short range safety requirements (high-speed object recognition and distance measurement, e.g. for Pre-crash).
- **Sensor 04: HR-TAG (VTT)**
  Harmonic radar combined to passive nonlinear reflector and active tags (HR-PTAG and HR-ATAG), enabling easy detection of traffic obstacles and vulnerable road users, and their identification, even in dark or adverse weather conditions.
- **Sensor 05: SRS (ARC)**
  High temporal resolution and low-cost bio-inspired silicon retina stereo sensor (SRS), addressing time critical decision applications.

# 3. COMMUNICATION BUS AND DATA

The following data are summarized for each sensor in a table format:

- **Control Data Specifications**
  Description of the communication with the sensor (bus type, data format, data type) to control and read its working parameters
- **Output Data Specifications**
  Description of the communication with the sensor (bus type, data format, data type) to read raw data for pre-processing
- **HW interfaces requirements**
  Description of the hardware interfaces between the sensor and the ECU to guarantee the full sensor functionality.

### 3.1 Sensor 01: FIR

| | |
|---|---|
| **Description** | FIR-Sensor for hot spot detection as add-on sensor for sensor data fusion with a NIR night vision system. |
| **Responsibility** | Bosch |
| **Control data specifications** *(bus, data format, data)* | The FIR-add-on sensor consists of a MEMS-sensor array integrated with an analog sensor front end and a FPGA based control electronics board with low level signal processing.<br><br>A USB 2.0 full speed interface is realized for communication with the system.<br><br>The FIR-camera configuration and the read request commands use 4Byte control words transmitted over the USB 2.0 full speed interface.<br><br>The following control words will be available:<br>- Init USB-Interface/FPGA<br>- Init MEMS-Chip (trigger calibration routines)<br>- Configure read-out modus (frame rate etc.)<br>- Read request |
| **Output data specifications** *(bus, data format, data)* | The embedded FIR-system outputs a data vector of 9.8KB with a specific control header for each pre-processed FIR-Image. The communication goes over a USB 2.0 full speed interface. The data rate sums up to 122.5KB/s for a frame rate 12.5Hz or doubles to 245KB/s for 25Hz. The frame rate can be configured with a 4Byte control message via USB-interface. The transfer of every FIR-image is triggered with 4Byte control word. |
| **Hardware interface requirements** | USB 2.0 full speed interface for communication with the FIR-system.<br>Power supply of approx. 1.0A/12V is required for the FIR-camera demonstrator including FPGA board and internal power supplies. |

Table 1 - Communication and data bus of FIR sensor

## 3.2 Sensor 02: MFOS

| | |
|---|---|
| **Description** | *Multifunctional and multispectral optical sensor for frontal view monitoring and sensing of environmental parameters.* |
| **Responsibility** | *CRF* |
| **Control data specifications** *(bus, data format, data)* | ▪ *Bus: I2C control interface (native or over USB)*<br>▪ *Input data format: 8-16-32 un-signed integer-iReal*<br>▪ *Input data: integration time, AGC, response (linear, logarithmic), frame rate, ROI selection, etc.*<br>▪ *Output data format: 8-16-32 un-signed integer-iReal*<br>▪ *Output data: dark average current, thermal information, …* |
| **Output data specifications** *(bus, data format, data)* | ▪ *Bus: USB 2.0*<br>▪ *Output data format: 12 bit RAW image*<br>▪ *Output data: 1024x512 12 bpp image* |
| **Hardware interface requirements** | ▪ *Analogic and digital general purpose I/O for illuminator driving (fog/rain functions), diagnostic, holder temperature monitoring*<br>▪ *Interface for control data*<br>▪ *Interface for output data*<br>▪ *Trigger for syncronisation with FIR camera* |

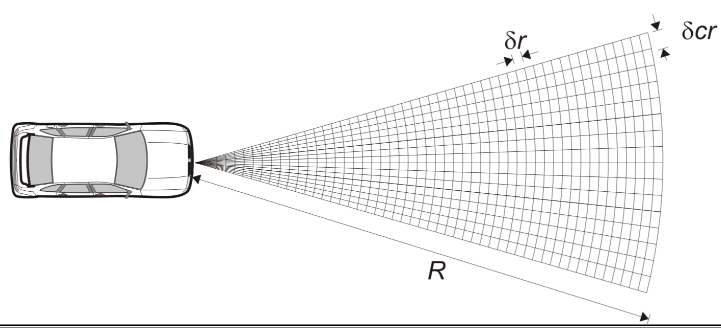
Table 2 - Communication and data bus of MFOS sensor

### 3.3 Sensor 03: 3DCAM

| | |
|---|---|
| **Description** | *3D camera for Pre-Crash warning and preparation of front/rear impact* |
| **Responsibility** | *IMEC* |
| **Control data specifications**<br>*(bus, data format, data)* | *Depending on the choice of standard used for communication and the vehicle data bus chosen, the interface to the sensor system can be done using one of the following standard interfaces: Gigabit Ethernet, Camera Link, Firewire, USB, LVDS, etc.*<br>*The optimum approach for data exchange is to use the same bus for camera control and for sensor data transfer.*<br><br>*The operation of the camera electronics (e.g. integration time, frame rate, ROI selection, etc) can be programmed by accessing its internal configuration registers. The format of the data is:*<br>*Bit 15 (MSB): Read/Write*<br>*Bits 14 to 8: Register address*<br>*Bits 7 to 0: Data to be written* |
| **Output data specifications**<br>*(bus, data format, data)* | *The camera can output both the values of the configuration registers and the image data.*<br>*If we assume 16 bit words are used to communicate, the format of the output data could be:*<br>*One word to indicate if it is a register or an image data. In the case of image data, also to indicate if it is distance or illumination information (i.e. range or grayscale mode) and the start of the frame.*<br>*For register data, one word with the same format as the described in the input data.*<br>*For image data, in principle there would only be information in the lower 10 bits of the word.* |
| **Hardware interface requirements** | *- Interface for vehicle data bus (LVDS; USB, …)*<br>*- Trigger for synchronization with the illuminator*<br>*- For system testing issues, the camera will also provide a number of analog and digital signals to override the interface to the vehicle bus.* |

Table 3 - Communication and data bus of 3DCAM sensor

## 3.4 Sensor 04: HR-TAG

| | |
|---|---|
| **Description** | *Short and long range radar sensor operating in the band 76-81 GHz. Parallel transmission at two frequencies enabling unambiguous separation between tag equipped VRUs and other objects.* |
| **Responsibility** | *VTT* |
| **Control data specifications**<br>*(bus, data format, data)* | ▪ *Interface/bus: to be decided later (USB, Firewire or Ethernet)*<br>▪ *Input data format: to be decided later*<br>▪ *Input data: mode specification (SRR or LRR), output data (Raw data or preprocessed data)*<br>▪ *Output data format: to be decided later*<br>▪ *Output data: sensor status information* |
| **Data output specifications**<br>*(bus, data format, data)* | *Data bus and format to be decided (Firewire, USB or Ethernet)*<br><br>*The content of the output data from the sensor is a 10 Hz update containing the following:*<br>– *One 150x16 array of 16 bit values general reflections RCS level*<br>– *One 150x16 array of 16 bit values of transponder reflections*<br>– *One 10x1 array of 16 bit giving the status of the sensor*<br><br>*This corresponds to a total 48100 16bits values per second, a data rate of 769.6 Kb/s from the sensor.*<br><br>*If raw data is to be transmitted from the sensor the datarate would increase to 6 Mb/s.*<br><br>*Each 150x16 grid of data corresponds to the physical map of the radar resolution as seen in the figure below. One grid is related to general reflectors giving an estimated RCS value of the scattering from the different resolution cells. The other grid is related to tags. The cells with no tags have zero value.*<br><br> |

| | |
|---|---|
| | Figure 2 - The physical representation of the harmonic radar data grid.<br><br>*The size of the grid in terms of data is independent of the mode of operation in the radar. The physical region which the data represents however is mode dependent.*<br><br>*For SRR (short range radar operation) the physical dimension of the gird corresponds to:*<br><br>*Max R = 37.5 m*<br>*$\delta r$ = 0.25 m*<br>*$\delta cr$ = 2 degrees ( (R x $\pi$) /90 in meters)*<br><br>*For LRR (long range radar operation) the dimension of the grid corresponds to:*<br><br>*Max R = 150 m*<br>*$\delta r$ = 1 m*<br>*$\delta cr$ = 2 degrees ( (R x $\pi$) /90 in meters)* |
| **Hardware interface requirements** | *To be decided (USB, Firewire or Ethernet)* |

Table 4 - Communication and data bus of HR-TAG sensor

## 3.5 Sensor 05: SRS

| | |
|---|---|
| **Description** | *Sensor for stand alone short range sensing based on two silicon retina imagers for pre-crash warning/preparation of side impacts.* |
| **Responsibility** | *ARC* |
| **Control data specifications** *(bus, data format, data)* | ▪ *100 MBit/s Ethernet interface*<br>▪ *IP Address and Port configurable*<br><br>▪ *Input data format: UDP or TCP*<br>▪ *Input data: start sensor, stop sensor, write configuration , read configuration register, dump complete configuration*<br><br>▪ *Output data format: UDP or TCP*<br>▪ *Output data: acknowledge of input data, error messages* |
| **Output data specifications** *(bus, data format, data)* | ▪ *100 MBit/s Ethernet interface*<br>▪ *IP Address and Port configurable*<br><br>▪ *Data format: UDP or TCP*<br>▪ *Data: information about the distance of the objects that have been detected.* |
| **Hardware interface requirements** | ▪ *100/1000 MBit/s Ethernet interface.*<br>▪ *12V DC power supply from a stable source* |

Table 5 - Communication and data bus of SRS sensor

# 4. SOFTWARE ARCHITECTURE

Starting from the graphical representation of the data processing tasks of a typical driver assistance system (Figure 3), a preliminary description of each software development task is provided for all ADOSE sensors:

- FIR+NIR (MM)
- 3DCAM (MM/IMEC)
- RADAR+TAG (PARAGON)
- SRS (ARC)

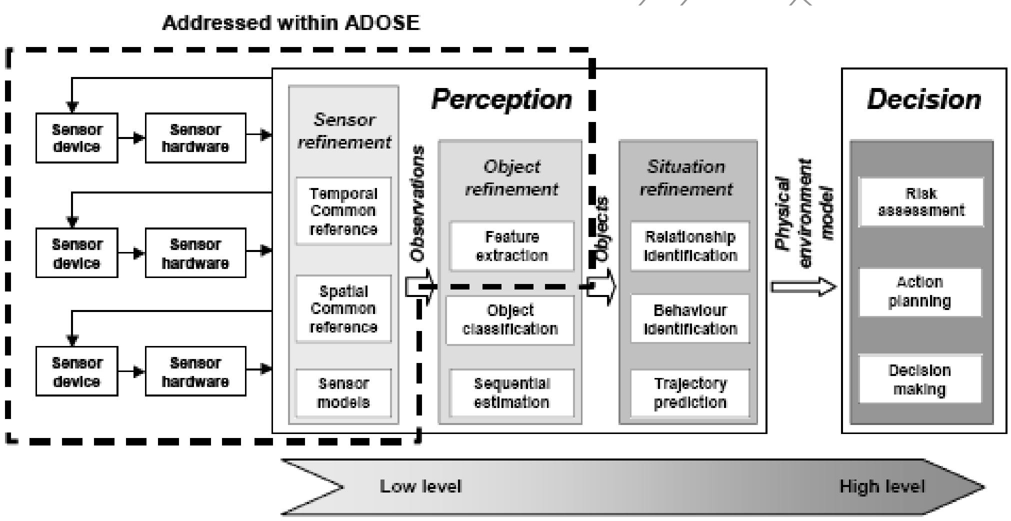



Figure 3 - Data processing tasks of a typical driver assistance system

## 4.1 FIR and NIR system

The software developed in this stage will first focus on the enhancement of the data coming from the vision sensor. This can be done considering, as first step, every single sensor, in order to get the image and to apply image enhancement techniques (noise removal, increasing resolution and contrast, …) and enhancing the proper features of each sensor in order to improve the system behavior and to ease the feature extraction that will be done in a later stage.
A second step consists in finding a common spatial reference and a common temporal reference between the FIR and the NIR sensors, allowing a fast correspondence between the data and the information given by the sensors.

#### 4.1.1 Image enhancement

Image enhancement techniques are used to emphasize and sharpen image features for display and analysis purposes; they are application-specific and often empirically developed.

Enhancement methods operate in the spatial domain by manipulating the pixel data or in the frequency domain by modifying the spectral components. Some enhancement algorithms use both the spatial and frequency domains.

Image enhancement techniques include: (1) pointwise operations, where each pixel is modified according to a particular equation that is not dependent on other pixel values; (2) mask operations, where each pixel is modified according to the values of the neighbor pixels (using convolution masks); (3) global operations, where all the pixel values in the image (or sub-image) are taken into consideration.
Spatial domain processing methods include all three types, but frequency domain operations, by nature of the frequency transforms, are global operations. Of course, frequency domain operations can become "mask operations," based only on a local neighborhood, by performing the transform on small image blocks instead of the entire image.

The algorithms will be developed to enhance the specific features of the images grabbed from both FIR and NIR sensors, and to communicate to the sensors the adjustments of the parameters needed to achieve the best image available in each environmental condition (**Figure 4**). Besides ego-motion, also vibrations or oscillations represent a source of noise to be taken into account.

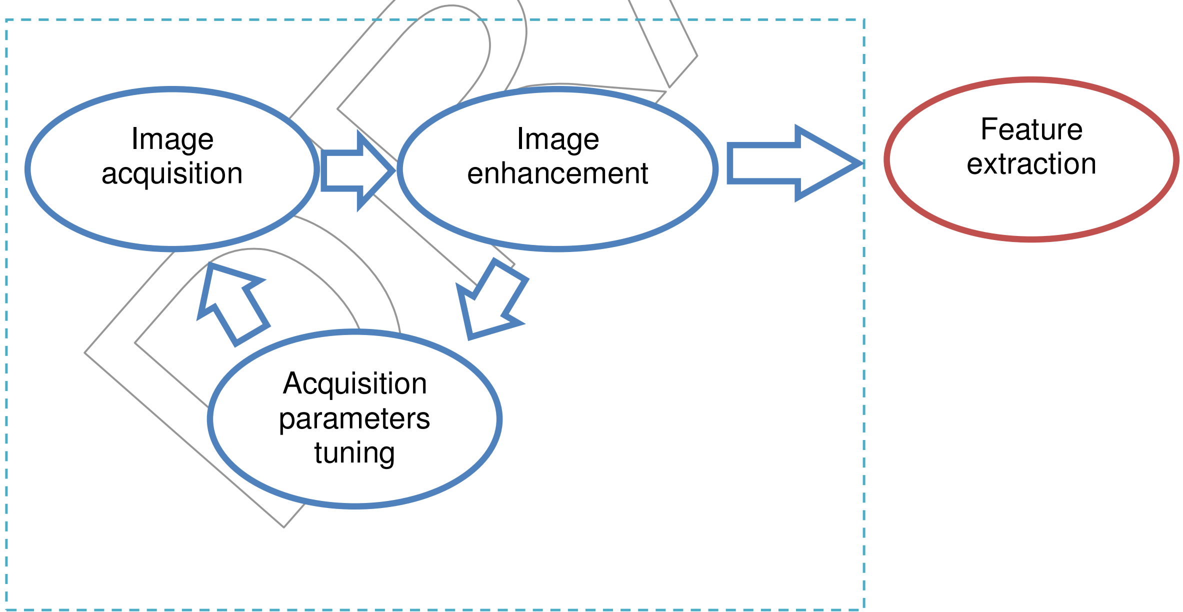



Figure 4 - Image enhancement algorithms

Other issues are related to specific environmental conditions in outdoor environments. In fact, temperature and illumination conditions can vary and can be barely controlled. Especially for illumination, extreme situations like direct sunlight or strong reflections must be faced. In addition, other light sources, such as car headlights or reflectors, might be present in a typical automotive scene.

To enhance the perception of the camera a dedistortion process will be applied to the NIR camera. By means of a grid placed perpendicular to the sensor axis, through a software tool, each cross point of the grid will be pinpointed and then the look up table will be computed. According to the sensor dimension the LUT for the NIR camera will be 1.72 MB. An example of distorted and dedistorted images is shown in **Figure 5**. Due to the small resolution of the FIR camera, no dedistortion process will be applied on this sensor.

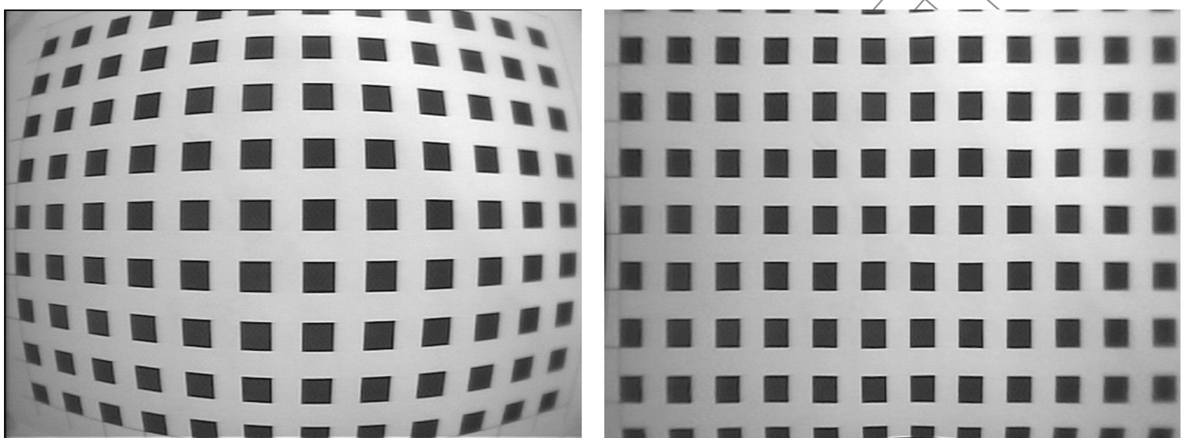


Figure 5 - Dedistortion process

### *4.1.2 Spatial common reference*

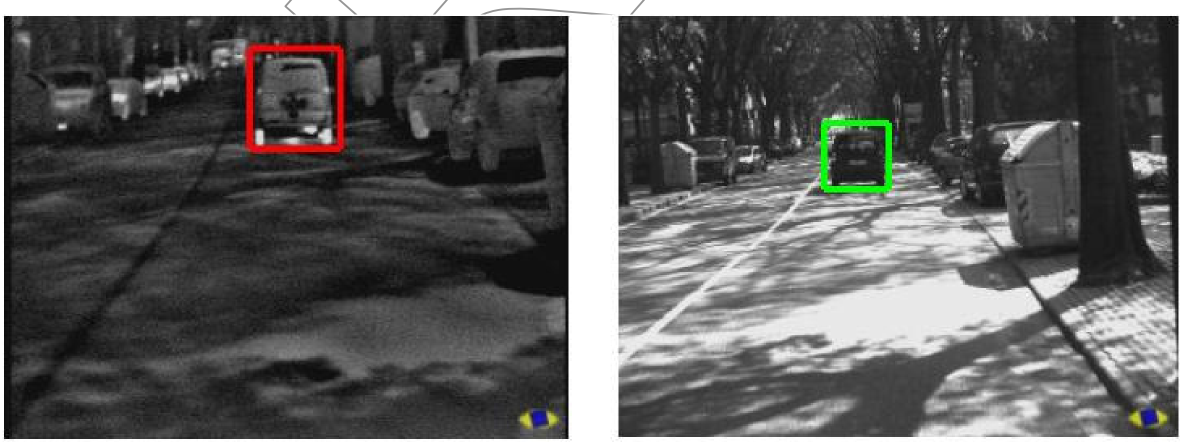


Figure 6 - Spatial common reference

Through the use of the fundamental matrix **F,** a 3x3 matrix which relates corresponding points between the NIR and the FIR cameras, it is possible to have an interrelation between the images coming from two different cameras and thus acquired from two different points of view.
In epipolar geometry, with homogeneous image coordinates *x* and *x'* of corresponding points in a stereo image pair, **F***x* describes a line (an epipolar line) on which the corresponding point *x'* on the other image must lie.

Being of rank two and determined only up to scale, the fundamental matrix can be estimated given at least seven point correspondences. Its seven parameters represent the only geometric information about NIR and FIR sensors that can be obtained through point correspondences alone.
To compute the matrix it is thus necessary a calibration phase to be performed offline.

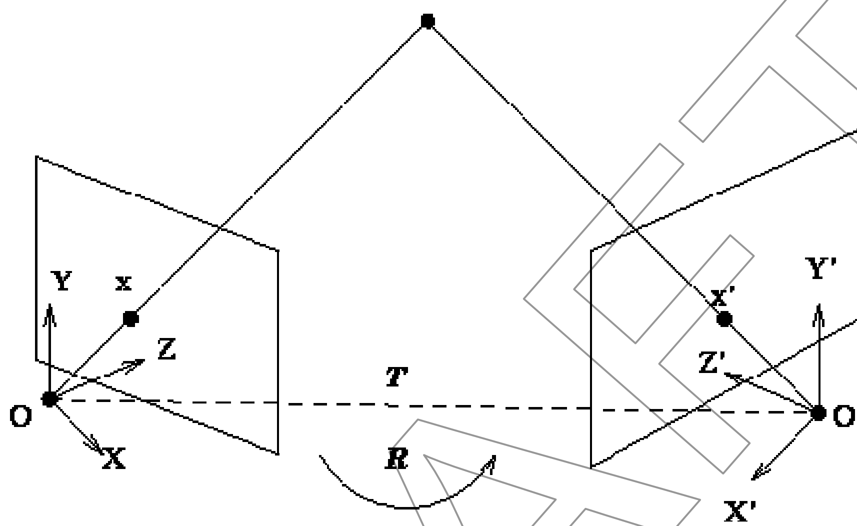



Figure 7 - Cameras position schema

Starting from sensors specifications, it is possible to produce a closed form for interrelation between the images coming from two different cameras and thus acquired from two different points of view.
Let the two cameras be on the same axis, with a distance *b* measured in meters, looking forward.
In this situation the position of a point $(u_1, v_1)$ on the FIR image is related to point $(u_2, v_2)$ on the NIR image with the following equation:

$$u_2 = u_1 \frac{k_2}{k_1} + k_2 \frac{b}{Z} - u_{0,1} \frac{k_2}{k_1} + u_{0,2}$$
$$v_2 = v_1 \frac{k_2}{k_1} - v_{0,1} \frac{k_2}{k_1} + v_{0,2}$$

where $k_1, k_2$ are focal length in pixels, $(u_{0,1}, v_{0,1})$, $(u_{0,2}, v_{0,2})$ are the Principal Points of the two images.

Using sensors with the following specifications (Deliverables D2.1 and D3.1)

- A FIR camera with a 100x50 pixels array and 24° of horizontal FOV
- A NIR camera with a 884x512 pixels array and 30° of horizontal FOV

those parameters can be obtained.

Focal length in pixels for FIR camera is $k_1 = \frac{100}{2\tan(24°/2)} = 235$ pixels and for NIR camera is

$k_2 = \frac{884}{2\tan(30°/2)} = 1650$ pixels.

Let the Principal Point be in the middle of both sensors, the above equation can be written as:

$$u_2 = 7.02 u_1 + 1650 \frac{b}{d} + 91$$
$$v_2 = 7.02 v_1 + 80.5$$

where *b* is the distance between the two cameras (baseline) and *d* the distance of point in the world.
Coverage area can be produced by this equation and the minimum distance $d_0$ where a point can be seen by both cameras is $d_0 = 18.13b$.

### *4.1.3 Temporal common reference*

Synchronization between FIR and NIR sensors has to be taken into account to achieve a temporal common reference. If the two sensors are synchronized or the frame rate of one is a exact multiple of the other, the problem is trivial.
Otherwise if the two frame rate are different, an image buffering will be necessary to perform a further timestamp association of the frames coming from the different sensors.

In the following figure an association example is shown, taking into account that the FIR sensor has a 25 fps frame rate, while the NIR sensor has a 34 fps frame rate as described in Deliverables D2.1 and D3.1.

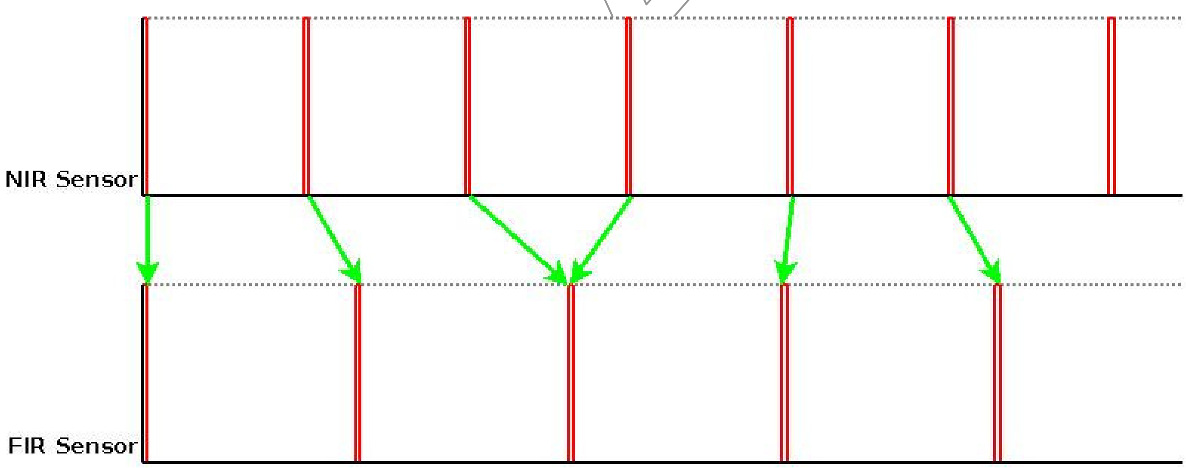



Figure 8 - Temporal common reference

## 4.2 3DCAM

The ranging camera should provide a mapping of the surroundings, coded into an image in such a way that each pixel encodes a distance.
The software that will be developed will be able to give to the user these information showing an image in which the information (encoded distances) is displayed by means of grayscale value or a color scale.
The visualization of the sensor information can be tuned by means of the conversion between 10-bit output data format and 8-bit visualization.

## 4.3 HR-TAG

The reflections from the tags are at a frequency offset from all other reflections in the radar field of view. The detection and identification of the tags is done by a separate receiving system within the harmonic radar that is sensitive only to the transponder reflection frequency. The detection and identification of the tags is thus more a hardware issue. However, the outputs from the transponder receive system still have to be processed to find the positions of the transponders.

The software for harmonic radar has to perform localization of conventional reflections/targets and localization of transponders. The ADOSE harmonic radar uses a triangular frequency modulation as seen in the figure below.

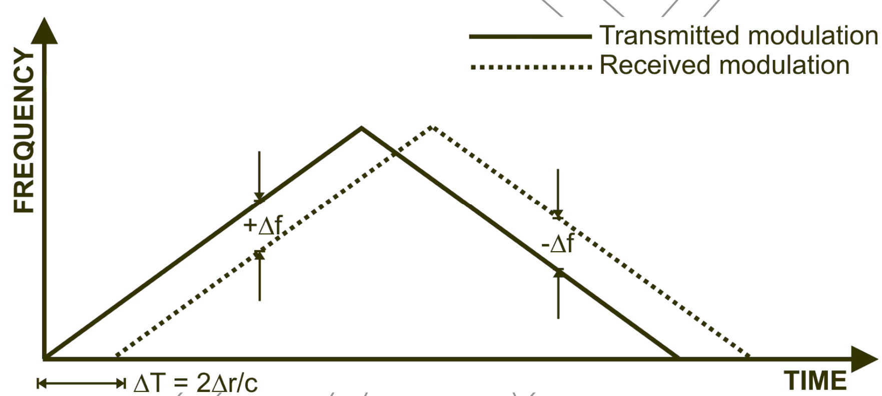



Figure 9 - Triangular frequency modulation

The received signal is mixed with the transmitted signal and filtered resulting in a baseband containing of a set of fixed frequencies that each corresponds to targets at different ranges. For the transponder channel the 'transmitted' signal is fully synthesized in the receiver. There will be separate baseband channels for the conventional returns and the transponder returns.

The frequency content in the baseband channels are found by Fourier transforms. The Fourier transforms are timed with the transmitted waveform such that one can separate up-sweep and down-sweep frequencies.

For a sweep rate $\alpha_f$ in Hz/s the relation between a frequency, $\Delta f_{target}$, and the range to a target, $r_{target}$, after the mixing stage is given by :

$$r_{target} = \frac{c}{2\alpha_f} \Delta f_{target}$$

The actual measured frequency however is influenced by the Doppler frequency. For upsweep one will measure:

$$f_{measured} = -\Delta f_{t\arg et} + f_D \,.$$

For downsweep one would measure:

$$f_{measured} = \Delta f_{t\arg et} + f_D \,.$$

This ambiguity between range and Doppler frequency has to be sorted out in a logical structure where possible combinations of up-sweep and down-sweep frequencies are tested. (This latter process could be simplified by modifying the transmitted waveform to include a period of constant frequency (zero sweep rate) where only Doppler frequencies are measured).

The Enhanced Object Detection software will process the synchronized data from the Harmonic Radar outputs (passive and active tags). The Artificial Intelligence (A.I.) technique to be used will be selected based on the development and equipment specifications produced in WP5 “Harmonic Radar and Tags”. In general A.I. techniques have no special requirements to be applied regarding the radar output data, which simplifies the process and ensures faster response times.
The main objective of the Enhanced Object Detection software is to determine patterns in the coordinates of the passive and active tag reflections once they have been localized in the radar grid. An additional parameter that is necessary to enhance the A.I. technique’s pattern recognition capabilities is the test-vehicle’s velocity, in order to discern between stationery and moving reflections. Groups of identical reflections can also be determined, e.g. road barriers or intersections, even groups of pedestrians and their location with respect to road limits. A.I. techniques can be trained to recognize and match the radar output patterns to several well-known and common road/intersection layout characteristics and their performance can be verified with ease. The simplicity or complexity of the patterns identified by the software will be determined from the definitions and choice of the reference patterns based on the test-scenarios that have been determined in WP1.
Preliminary work for the identification and evaluation of A.I. techniques has begun and will be reported in Deliverable 6.5 “Preliminary algorithms for pre-processing of raw data”.

## 4.4 SRS

The software developed in this stage will focus on the processing of the events from the stereo SRS imagers. The difference to standard monochrome or colour cameras is the data acquisition of the SRS. Standard cameras deliver whether full or regions of images. The SRS delivers coordinates of pixels either an intensity change has happened [1].

In a first step, the acquired data stream from both the left and the right SR imager is converted into a special data format optimized for processing event based data. Afterwards some pre-processing algorithms are processed, e.g. noise reduction, rectification and morphological operations. These techniques make it easier to process computer vision algorithms. For noise reduction the image data can be filtered with a median filter. Rectification is an important step, when block-based stereo algorithms are used. For feature-based approaches the rectification would be an unnecessary overhead. Morphological operations can be used to get linked regions of pixels which can be labelled as one connected area. There are two basic morphological operations: the “erosion” and the “dilatation”. Combinations of these operations are called "opening" and "closing". These operations are used for preparing the stereo images for the following image processing steps like segmentation and labelling. For labelling a flood fill algorithm can be used. This algorithm labels all linked areas with a number so that the regions can be identified. The main task of the stereo vision sensor is the extraction of depth information from the viewed scenery by matching the events of the left and right images against each other. To achieve this, block-based and feature-based algorithm approaches have already been evaluated [2]. After processing these steps, the system should be able to detected objects.

The SRS also consists of an embedded system and peripheral components. The processing framework, which is an application that is executed on an embedded system, allows the execution of the vision algorithm [3]. The peripheral components are the imagers and the Ethernet interfaces. The embedded system uses a pre-emptive real-time operating system.

During the start up of the system, an initialization task initializes the internal structures and configures all peripheral devices. A control task communicates with applications executed on a computer for control purpose. Thereby, the system can be dynamically configured during image processing. A timer task is responsible to ensure a continuous processing speed. There are two mechanisms that assure the stability of the application. These are a run-time check function and a memory check function. Furthermore, there is a debug task that is responsible for data transfers for debug purposes. This task has the lowest priority of the system. A capturing task handles the image acquisition of the two imagers and an output task transmits the processed data to other peripheral components.

# 5. SOFTWARE TEST PLANS

The planning of the software debugging and test procedures is provided in this chapter; the goal is to assess in the proper way the following requirements:

- Full functionality of the communication buses
- Correctness of the exchanged specific application data
- Full functionality of the implemented software tasks
- Software robustness (e.g. long sessions of continuous operation of the software itself)
- Software reliability (e.g. evaluation of the algorithms in different testing conditions - environmental, meteorological, lighting, traffic scenario, … -

## 5.1 FIR and NIR

| | |
|---|---|
| **Description** | *High resolution MFOS camera to be combined to a low-resolution FIR camera for warning night vision applications.* |
| **Responsibility** | *MM* |
| **Sensor control bus** | USB 2.0 bus<br>▪ *Presence of errors in the communication (checked by querying an already known parameter of the sensor, i.e. the chip version ID)*<br>▪ *Bus performances: speed , delay time* |
| **Sensor output bus** | USB 2.0 bus<br>▪ *Presence of errors in the communication (i.e. test procedure by setting the integration time to zero and then checking the grabbed image)*<br>▪ *Frame rate (i.e. test procedure checking the number of grabbed images in predefined time intervals)* |
| **Processing pipeline at sensor level** | ▪ *Setting of CMOS sensor parameters:*<br>*- Integration time (checked by analysing the grabbed image, saturised image, etc.)*<br>*- Analog gain control (checked by analysing the grabbed image, saturised image, etc.)*<br>*- Response/dynamic range (checked by analysing an high contrast scene)*<br>▪ *Setting of CMOS pre-processing parameters:*<br>*- Noise suppression (checked by comparing the video output with this function enabled and disabled)*<br>*- Data enhancement and visualization (checked by enabling and disabling the processing pipeline*<br>▪ *Actuation time of the setting modifications (checked by grabbing* |

| | |
|---|---|
| | *a sequence of frames while one parameter is changing, and analyzing the frames offline)* |
| **Sensor refinement at perception stage** | ▪ *Temporal synchronism with FIR camera (e.g. checked by grabbing a customized chopper with both the cameras and comparing the acquired images)*<br>▪ *Common spatial reference with FIR camera (checked by performing an offline elaboration of a set of sequence of artificial images representing a scene grabbed with the two cameras)*<br>▪ *Disabling of the function in case of bad weather condition (visibility, rain,…) (checked by producing artificially the bad weather conditions)* |
| **Object refinement at perception stage** | *Some features of the perception stage can be tested in offline mode, that is by analyzing a locally saved sequence of previously captured frames*<br>*The main functionalities to be tested are:*<br>▪ *Feature extraction*<br>▪ *Object detection (e.g. hot spots)*<br>▪ *Tracking of objects (hot spots, VRUs)* |

Table 6 - Software test plans of FIR-NIR system

## 5.2 3DCAM

| | |
|---|---|
| **Description** | *3D camera for Pre-Crash Warning and preparation of front/rear impact* |
| **Responsibility** | *MM with support of IMEC* |
| **Sensor control bus** | *Depending on the type of interface chosen (Firewire, USB, Ethernet, etc, …)*<br>• *Presence of errors in the communication (i.e. check that writing to the configuration registers occurs without problems)*<br>• *Bus performances: speed , delay time* |
| **Sensor output bus** | *Depending on the type of interface chosen (Firewire, USB, Ethernet, etc, …)*<br>• *Presence of errors in the communication (i.e. test procedure by setting the a particular set of method parameters in order to know the right response of the camera)*<br>• *Frame rate (i.e. test procedure checking the number of grabbed images in predefined time intervals)* |

| | |
|---|---|
| **Processing pipeline at sensor level** | • *Setting of sensor parameters:*<br>*- Basic operating settings (checked by analysing the grabbed image for different predetermined settings and under controlled scene illumination)*<br>*- Response/dynamic range (checked by analysing an high contrast scene)*<br>• *Setting of processing circuit parameters:*<br>*- Basic operating settings (checked by analysing the grabbed image for different predetermined settings and under controlled scene illumination)*<br>• *Setting of distance measurement method parameters:*<br>*- Analyze the data for different predetermined settings for shutter duration, number of acquisitions, etc.* |
| **Sensor refinement at perception stage** | • *Temporal synchronism with the illuminator (checked by grabbing a range image of a scene where there is only a cooperative object in the range detection of the camera)*<br>• *Precise overlap of the illuminator/sensor FOV (checked by acquiring a scene where a object is entering in the field of view of the camera from one side, it moves and finally disappears on the other side)*<br>• *Disabling of the function in case of bad weather condition (visibility, rain,…) checking by producing artificially the bad weather conditions* |
| **Object refinement at perception stage** | *The main functionalities to be tested are:*<br>▪ *Feature extraction*<br>▪ *Object detection*<br>▪ *Tracking of objects* |

Table 7 - Software test plans of 3DCAM system

### 5.3 HR-TAG

| | |
|---|---|
| **Description** | *Long range and short range radar sensor for detection of objects and identification/detection of tag equipped VRUs.* |
| **Responsibility** | *PARAGON with support of TRIAD* |
| **Sensor control bus** | *Data communication errors are checked using fixed values in parts of the sensor status dataset that is transmitted each 100 ms.* |
| **Sensor output bus** | *The output bus is the same as the control bus.* |
| **Data processing pipeline** | *Setting of SRR or LRR mode:*<br>*Control parameters for transmitted waveforms are available every 100ms* |

Table 8 - Software test plans of HR-TAG system

### 5.4 SRS

| | |
|---|---|
| **Description** | *Sensor for stand alone short range sensing based on two silicon retina imagers for pre-crash warning/preparation of side impacts.* |
| **Responsibility** | *ARC* |
| **Sensor control bus** | *100 MBit/s Ethernet interface*<br>▪ *Communication to IP Address and Port possible*<br>▪ *Presence of errors in communication (querying known parameters, i.e. ID, default configuration)*<br>▪ *Using checksums in control messages* |
| **Sensor output bus** | *100 MBit/s Ethernet interface*<br>▪ *Communication to IP Address and Port possible*<br>▪ *Presence of errors in communication (querying known parameters)* |
| **Data processing pipeline** | ▪ *Development of a test pattern generator for simulating scenarios to allow repeatable testing. The test environment should be able to cover the following scenarios:*<br>• *Noisy scenario*<br>• *Different levels of illumination*<br>• *Different weather conditions*<br>• *Low, medium and high event rate* |

| | |
|---|---|
| | ▪ *All scenarios have a defined result that should be achieved with the algorithm.*<br>▪ *For testing of the vision algorithm in the MATLAB environment all test scenarios are processed and the result of the simulation is compared to the expected output of the test case.*<br>▪ *Similar to the testing of the vision algorithm in the developing environment, the embedded vision system is stimulated by the same test patterns. Thus, the processed data of the Matlab simulation and the embedded solution can be analyzed, compared and evaluated.*<br>▪ *For final testing of the vision algorithm, a road scenario will be developed.*<br>▪ *Both, the results of the simulated vision algorithm and the embedded vision algorithm can be evaluated automatically and tracked. Hence, an ongoing improvement of the software quality can be guarantied.* |

Table 9 - Software test plans of SRS system

# 6. CONCLUSIONS

D6.2 deliverable report is focused mainly on three aspects: (1) data communication between sensors and ECU, (2) main processing blocks to be developed in the project, and (3) software test plans.

For the first item the following data have been summarized for each sensor: (1) Control Data Specifications, (2) Output Data Specifications, and (3) HW interfaces requirements.

Then the description of preliminary software architectures and test plans has been done at different levels (processing pipeline at sensor level, sensor refinement at perception stage, and object refinement at perception stage).

Due to the fact that the ADOSE sensor design is only at an early stage, several issues are still open and consequently hardware interfaces, buses, and data format reported in the document are not final. The description of the processing architecture and of the test plans is also not exhaustive. The report (draft version) is intended as a way to collect all the data necessary for the software development and related sensor demonstration in ADOSE.

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# 8. LIST OF FIGURES

## 9. LIST OF TABLES



## 10. LIST OF ACRONYMS

| | |
|---|---|
| 3DCAM | 3D Range Camera |
| ACC | Adaptive Cruise Control |
| ADOSE | Reliable Application Specific Detection of Road Users with Vehicle On-Board Sensors |
| AGC | Automatic Gain Control |
| ASIC | Application-Specific Integrated Circuit |
| BSD | Blind Spot Detection |
| CCD | Charge Coupled Device |
| CMOS | Complementary metal oxide semiconductor |
| DSP | Digital Signal Processor |
| ECU | Electronic Control Unit |
| FIR | Far InfraRed |
| FOV | Field of View |
| FPGA | Field Programmable Gate Array |
| fps | frames per second |
| GUI | Graphical user interface |
| HR-ATAG | Harmonic Radar with Active Tags |
| HR-PTAG | Harmonic Radar with Passive Tags |
| HW | Hardware |
| I2C | Inter Integrated Circuit |
| IMEC | Interuniversity Microelectronics Centre |
| ITOF | Indirect Time Of Flight |
| JPEG | Joint Photographic Experts Group |

| | |
|---|---|
| LED | Light Emitting Diode |
| LRR | Long Range Radar |
| LUT | Look-Up Table |
| LVDS | Low-voltage differential signaling |
| MEMS | Micro Electro-Mechanical Systems |
| MFOS | MultiFunctional Optical Sensor |
| NIR | Near InfraRed |
| PC | Personal Computer |
| PCB | Printed Circuit Board |
| RCS | Radar Cross Section |
| RFID | Radio Frequency IDentification |
| ROI | Region of Interest |
| SOI | Silicon On Insulator |
| SR | Silicon Retina |
| SRR | Short Range Radar |
| SRS | Silicon Retina Stereo |
| SW | Software |
| TCP | Transmission Control Protocol |
| TOF | Time Of Flight |
| UDP | User Datagram Protocol |
| USB | Universal Serial Bus |
| VIS | Visible light |
| VRU | Vulnerable Road Users |