

RAWSEEDS

Robotics Advancement through Web-publishing
of Sensorial and Elaborated Extensive Data Sets

*Raw seeds can be consumed as they are...
or be the start for the growth of new results.*



RAWSEEDS

WorkPackage 2

Deliverable D2.1

Raw Data (indoor)

Accompanying Document

PART 1 OF 2: DATASETS

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1. Introduction

Deliverables D2.1 and D2.2 include the datasets collected in - respectively - indoor and outdoor environments. Such explorations have been performed with the mobile robot designed and set up by WorkPackage 1 of RAWSEEDS. D2.2 also includes the datasets recorded in mixed, i.e. outdoor+indoor, locations.

While the main content of Deliverables D2.1 and D2.2 are the datasets, additional data and information are needed to make these datasets fully usable. The additional data is attached to the datasets, while the additional information is available in the form of two *Accompanying Documents*: the present one, associated to D2.1; and a similar one, associated to D2.2.

Notwithstanding the numbering, D2.2 was due - and actually delivered - *before* D2.1. This was due to changes in the schedule of the project (subsequent to an Amendment to the Contract) and to the need to perform outdoor acquisitions during the summer to avoid weather-related problems. The collection of the data for both Deliverables and the successive processing, formatting and verification of those data have been performed in accordance with the indications of Deliverables D1.1 (*Roadmap - indoor*) and D1.2 (*Roadmap - outdoor*) and with the recommendations of WorkPackage 3 (which is dedicated to data verification and validation).

WorkPackage 3 performed a thorough analysis of the datasets and of their associated data and documentation, and generated a set of recommendations to improve and maximize their quality. The results of the work of WorkPackage 3 are collected into two Deliverables: D3.1 (*Preliminary data validation*) and D3.2 (*Final data certification*). D3.1 was the result of a validation work performed on preliminary datasets, specifically generated to make such work possible: by the time when the final datasets were collected, all the issues raised by Deliverable D3.1 had been addressed and solved, as documented by D3.2. Deliverable D3.2 states, indeed, that RAWSEEDS' final datasets reach the required quality standards; it also introduces some suggestions to improve the usability of such datasets and to correct minor imperfections. These suggestions have been implemented as well, both in the datasets and in Deliverables D2.1 and D2.2. Therefore, at the time of delivery of this document, RAWSEEDS' datasets and all associated information (including this document) are compliant with the recommendations of WorkPackage 3.

As said above, the datasets form the core and the bulk of D2.1, but additional material is required for their best use. This material comes in the form of associated data (such as calibration data for the cameras) and in the form of descriptions and explanations. For this reason, both Deliverable D2.1 and Deliverable D2.2 are actually constituted by three elements:

1. the datasets;
2. the associated data;
3. the additional descriptions and explanations.



Parts 1 and 2 (according to the list above) of D2.1 have been published electronically on a server set up by RAWSEEDS. Publication within a single document was not an option, as massive amounts of data are involved (more than one TByte). Part 3 is given by this document, which includes all the information needed to access and use parts 1 and 2. This is the reason why the title of the present document is not simply "Deliverable D2.1" but "Deliverable D2.1 - Accompanying Document".

For practical reasons, this Accompanying Document has been split into two separate documents: Part 1 (Datasets) and Part 2 (Ground Truth Collection and Validation). This has been done to facilitate consultation by the users of RAWSEEDS' datasets, as the kind of information included into the two parts are conceptually different.

Part 1 includes all the information needed to use the datasets, including a complete description of the procedures chosen to acquire the data and to calibrate the sensors.

Part 2 describes in detail how the ground truth associated to the datasets has been generated and validated. However, *this knowledge is not needed to simply use the ground truth*. Therefore, the consultation of Part 2 is only needed by people wanting to scrutinize closely the characteristics of RAWSEEDS' ground truth, or to base on RAWSEEDS' approach to ground truth collection and validation to perform further work in that field.

Notwithstanding the separation between Part 1 and Part 2, they are actually two parts of the same document. For this reason, section numbering have been made coherent between them, allowing to easily reunite them - if needed - to form a single document.



2. Access to the datasets

The datasets included in Deliverable D2.1 are hosted on a server set up expressly by RAWSEEDS for the validation to be performed. Such server is connected to the internet, and therefore is reachable by any computer having internet access: anyway, access to the datasets is currently restricted to the Partners and to the EU Officers. In fact - as specified by the Annex I to RAWSEEDS' Contract - the datasets of Deliverable D2.1 are not, at this stage of the project, to be distributed to the public. For the time being, their use is limited to the Partners, who are validating them and building upon them the Benchmark Problems.

The datasets will be released publicly and freely when the associated Benchmark Problems will be. Such public release will be done through electronic publication on the official website of the project, i.e.,

<http://www.rawseeds.org>

This section will describe the content of the server hosting the datasets and the procedure to be used to gain access to it. Once the datasets will be published on the internet, the following procedure will be voided, and the associated data and user account will be removed¹.

2.1 How to reach the datasets

[...]

NOTE: IN THE VERSION OF DELIVERABLE D2.1 PUBLISHED ON RAWSEEDS' WEBSITE, THIS SECTION HAS BEEN EDITED OUT FOR SECURITY REASONS.

2.2 Directory structure of the datasets

The content of the RAWSEEDS-Datasets directory is subdivided into several subdirectories: their hierarchy and content are described by the following scheme. Directory names are in bold; indentation is used to represent the fact that a given directory is internal to another, higher-level one.

RAWSEEDS-Datasets (General container for the datasets and all the associated information.)

Calibration (Data and results of the calibration activities performed on the sensors.)

¹ Please note that, for security reasons, the versions of Deliverable D2.1 and Deliverable D2.2 published on the project's website lack the information about server access. Public diffusion of access information to servers is, in fact, not advisable.



Calibration_NN, where *NN* is a two-digit integer (Complete set of data and results for one of the calibration procedures applied to the robot. The two-digit number *NN* identifies the specific procedure considered. As the characteristics of the sensors can change from one dataset to the other, more than one of these directories can be present.)

Images (Images used for the calibration, plus the complete streams from which they were extracted. In this way a user - if so she desires - can perform her own calibration of the cameras, possibly using images different from those who were chosen by RAWSEEDS' staff.)

All_images (Complete calibration video streams, one for each camera. The images actually used for camera calibration by the RAWSEEDS staff have been extracted from these streams.)

Used_for_calibration (Subsets of images, one for each camera, chosen by the RAWSEEDS staff for the calibration of the cameras.)

Results (Results of the calibration procedure, i.e., the Matlab files produced by the calibration procedures. Such procedures will be described in section 3.2.)

FRONTAL (Calibration results for the frontal monocular camera.)

OMNI (Calibration results for the omnidirectional camera.)

SVS (Calibration results for the SVS trinocular system.)

Datasets (Sensor data gathered by the robot.)

Indoor (Datasets gathered in indoor environments.)

LOCATION_DATE_TYPE, where *LOCATION* is the name of a location for data-gathering experiments chosen between those described by Deliverable D1.2, *DATE* identifies the day on which the dataset was gathered - in the format *YYYY-MM-DD* - and *TYPE* can be "Static" or "Dynamic"; if two or more datasets of the same type have been generated on the same day and in the same location, a further lowercase letter ("a", "b", and so on) is attached to the *DATE* to differentiate between them (Within this directory there is one file for each of the sensor streams recorded during a single exploration session by the robot. The name, number and type of such files will be described in section 2.3 of this document.)

Calibration_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the calibration data for the dataset. The content of such a directory has already been described above.)

Drawings_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the executive drawings associated to the



dataset. The content of such a directory will be described below.)

FileFormats_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the file formats used for the dataset. The content of such a directory will be described below.)

SensorPositions_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the sensor positions used for the dataset. The content of such a directory will be described below.)

Mixed (Datasets gathered in mixed - i.e., partly indoor and partly outdoor - environments. These datasets are described in Deliverable D2.2.)

LOCATION_DATE_TYPE, where *LOCATION* is the name of a location for data-gathering experiments chosen between those described by Deliverable D1.2, *DATE* identifies the day on which the dataset was gathered - in the format YYYY-MM-DD - and *TYPE* can be "Static" or "Dynamic"; if two or more datasets of the same type have been generated on the same day and in the same location, a further lowercase letter ("a", "b", and so on) is attached to the *DATE* to differentiate between them (Within this directory there is one file for each of the sensor streams recorded during a single exploration session by the robot. The name, number and type of such files will be described in section 2.3 of this document.)

Calibration_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the calibration data for the dataset. The content of such a directory has already been described above.)

Drawings_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the executive drawings associated to the dataset. The content of such a directory will be described below.)

FileFormats_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the file formats used for the dataset. The content of such a directory will be described below.)

SensorPositions_NN, where *NN* is a two-digit integer (Symbolic link to the directory containing the sensor positions used for the dataset. The content of such a directory will be described below.)

Outdoor (Datasets gathered in outdoor environments. These datasets are described in Deliverable D2.2.)

LOCATION_DATE_TYPE, where *LOCATION* is the name of a location for data-gathering experiments chosen between those described by Deliverable D1.2, *DATE* identifies the day on which the dataset was gathered - in the format YYYY-MM-DD - and *TYPE* can be "Static" or "Dynamic"; if two or more datasets of the same type have been generated on the same day and in the same location, a further lowercase letter ("a", "b", and so on) is attached to the *DATE* to



differentiate between them (Within this directory there is one file for each of the sensor streams recorded during a single exploration session by the robot. The name, number and type of such files will be described in section 2.3 of this document.)

Calibration_NN, where *NN is a two-digit integer* (Symbolic link to the directory containing the calibration data for the dataset. The content of such a directory has already been described above.)

FileFormats_NN, where *NN is a two-digit integer* (Symbolic link to the directory containing the file formats used for the dataset. The content of such a directory will be described below.)

Drawings_NN, where *NN is a two-digit integer* (Symbolic link to the directory containing the executive drawings associated to the dataset. The content of such a directory will be described below.)

SensorPositions_NN, where *NN is a two-digit integer* (Symbolic link to the directory containing the sensor positions used for the dataset. The content of such a directory will be described below.)

Docs (Accessory documentation necessary or useful to use the datasets, including this document.)

Drawings (Executive drawings of the locations covered by the datasets.)

Drawings_NN, where *NN is a two-digit integer* (Directory that includes one or more CAD files describing the locations explored by the robot. It can also include accessory files (e.g., lists of features extracted from the CAD files). The two-digit number NN identifies the specific set of CAD files considered.)

FileFormats (File formats used for the sensor data.)

FileFormats_NN, where *NN is a two-digit integer* (Description of one of the sets of file formats used for the datasets. The two-digit number NN identifies the specific set considered. As the characteristics of the sensors - e.g., their operating mode - can change from one dataset to the other, more than one of these directories can be present.)

SensorPositions (Position of the sensors onboard the robot during the data-acquisition sessions.)

SensorPositions_NN, where *NN is a two-digit integer* (Description of one of the sets of sensor positions used for the datasets. The two-digit number NN identifies the specific set considered. As such positions can change from one dataset to the other, more than one of these directories can be present.)

Utils (Utilities that can prove useful to perform operations on the datasets, such as formatting.)



The RAWSEEDS-Datasets directory includes a text file, called README, with a brief summary of the above information.

2.3 Contents of each dataset

Note on ground truth systems. *The systems that RAWSEEDS set up to gather ground truth data have been described and analyzed in Additional Deliverable AD2.3. The systems of AD2.3 are based on an RTK-GPS system for outdoor and mixed datasets, and on a multiple-camera setup (used to recognize, localize and track suitable markers attached to the robot) for indoor datasets. To further enhance the scientific quality of Deliverable D2.1 and the precision of RAWSEEDS' data, in the final acquisition sessions for indoor data the Consortium decided to employ also a second ground truth gathering system. This second system, operated in parallel to the vision-based one, was completely independent from it and based on an array of four Sick LMS200 laser range finders. The ground truth published along with RAWSEEDS' datasets is obtained by fusion of the two available ground truth data streams, in order to attain the best possible quality.*

Part 2 of this document is completely dedicated to the description, analysis and validation of the systems and procedures adopted by RAWSEEDS for indoor ground truth collection and processing. Reading of Part 2 is not required to use RAWSEEDS' datasets.

In Section 2.2 we showed that each indoor dataset is associated to a directory within the file system of the server. The contents of such a directory are a set of symbolic links and a set of files.

The links are the following:

- a link to the directory containing the calibration data pertaining to the dataset considered;
- a link to the directory containing the executive drawings pertaining to the dataset considered;
- a link to the directory containing the file formats pertaining to the dataset considered;
- a link to the directory containing the sensor positions pertaining to the dataset considered.

The files contain the sensor data of the dataset and the associated ground truth data, one stream per file. A description of the sensors mounted on the robot will be given in Section 3. Specifically, each dataset is composed of the following files:

- **FRONTAL**: data stream from the front-mounted Unibrain Fire-I monocular camera.



- **GROUNDTRUTH:** ground truth data describing portions of the trajectory of the robot. The details about the procedures used to generate such data are available in Part 2 of the present document.
- **HOKUYO_FRONT, HOKUYO_REAR:** data streams from the front- and rear-mounted Hokuyo URG-04LX laser range finders.
[Note: these sensors are designed for indoor applications, and have been verified to be "useless for SLAM in outdoor datasets taken in daylight" by WorkPackage 3 (please see Deliverable D3.1). Nonetheless, their data streams have been included into the datasets so that the user can have a sample of the kind of data that such sensors produce in outdoor environments. In addition to that, the Hokuyo sensors are perfectly usable in the indoor parts of mixed datasets.]
- **IMU_STRETCHED:** data stream from the Xsense MTi inertial measurement unit, with timestamps stretched as suggested by Deliverable D3.1.
- **ODOMETRY_XYT:** data stream from the odometer of the robot, both raw and geometrically processed in order to express the pose of the robot in a global x,y,θ reference system. This system is the *odometry reference system* of the robot which will be described in section 3.1.2, considered in the initial pose of the robot.
- **OMNI:** data stream from the omnidirectional camera (Prosilica GC1020C color camera, configured with a Region Of Interest of 640x640 pixel).
- **SICK_FRONT, SICK_REAR:** data streams from the Sick LMS291 (front) and LMS200 (rear) laser range finders.
- **SONAR:** data streams from the sonar belt composed of 12 Maxbotix EZ-2 emitters/receivers.
- **SVS_R, SVS_L, SVS_T:** data streams from the binocular Videre Design STH-DCSG-VAR system (R and L, standing for Right and Left) and from the third DCSG camera that, in conjunction with it, forms a trinocular system (T, standing for Top).

All the files of each dataset have been compressed with the Bzip2 lossless compression algorithm (<http://en.wikipedia.org/wiki/Bz2>) to reduce their storage occupation and download time. The only exception are image files, which are already compressed: they could not benefit from being compressed again, so they were not. When many files of the same content had to be compressed, they have been reunited in a single .tar file ([http://en.wikipedia.org/wiki/Tar_\(file_format\)](http://en.wikipedia.org/wiki/Tar_(file_format))) before compression. Therefore, RAWSEEDS' data files must be uncompressed, and in some case extracted from a .tar archive, before they can be used. These operations are standard ones, and they can be performed by any of the many existing bzip2- and tar-compatible programs, available for all software platforms.

The format of the data contained in the data files will be described in the following section of this document.



2.4 Data formats

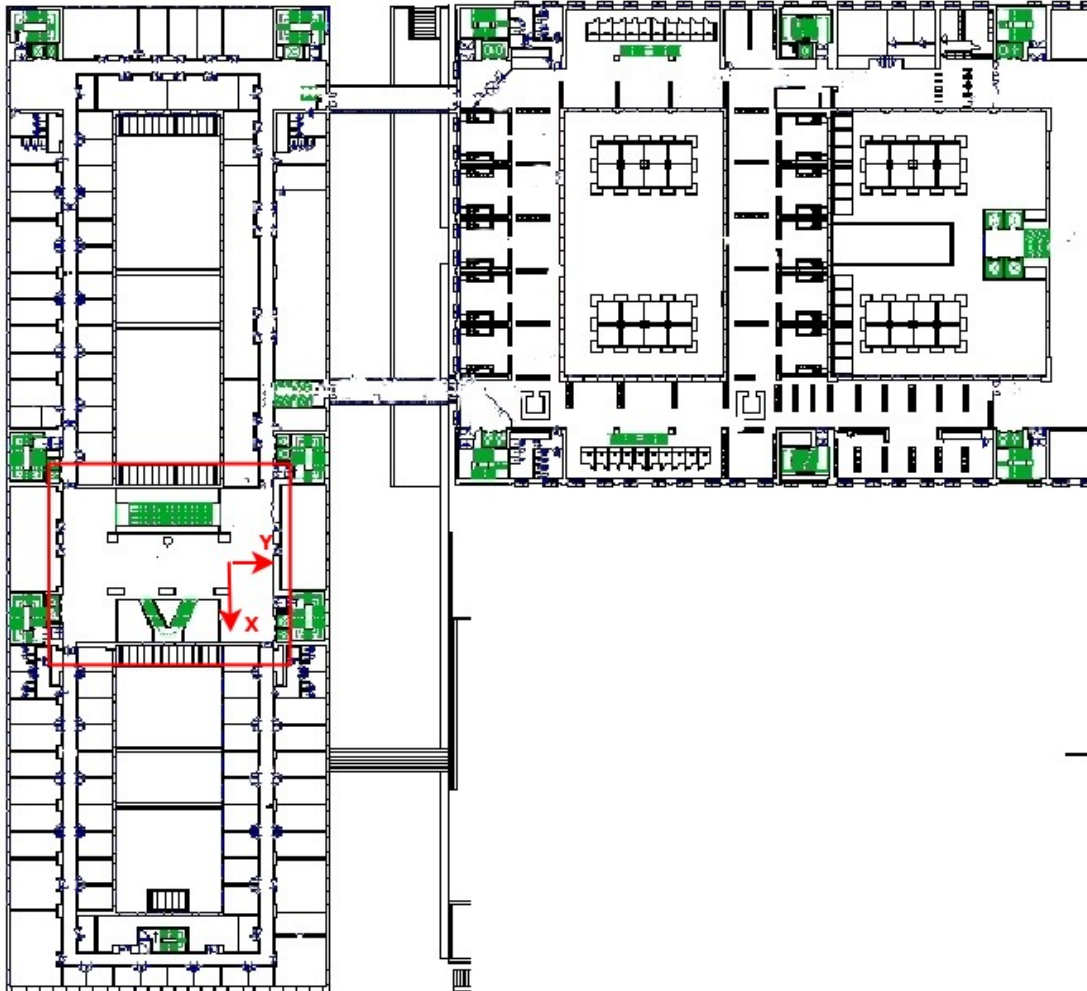
The format of the data included into the stream files comprised into a dataset is as follows:

- **FRONTAL:** the filename of each image is the timestamp ([seconds.microseconds], from the 00:00 of January 1st, 1970); each file follows the PNG format, 320x240 3*8bpp (color); nominal frame frequency = 30Hz;
- **GROUNDTRUTH:** after decompressing the file you get a .csv file, the fields are:
 - Timestamp [seconds.microseconds]
 - X [m]
 - Y [m]
 - Theta [rad]
 - C_xx
 - C_xy
 - C_xt
 - C_yx
 - C_yy
 - C_yt
 - C_tx
 - C_ty
 - C_tt

where the C values are the elements of the covariance matrix.

Nominal GT Laser frequency = 50Hz.

The spatial coordinates refer to an arbitrary, fixed frame of reference set on the floor of the area of the environment where the ground truth collection systems were located. Such reference frame (along with all the details connected to ground truth collection and validation) is described in detail in Part 2 of this Deliverable; the following figure shows how it is positioned on the executive drawing of the area explored by the robot within the Bicocca location.



- **HOKUYO_FRONT, HOKUYO_REAR:** after decompressing the file you get a .csv file, the fields are:
 - Timestamp [seconds.microseconds]
 - R1...R681 range data [m] (in steps of $360^\circ/1024$)
 - nominal scan frequency = 10Hz;
- **IMU_STRETCHED:** data stream from the Xsense MTi inertial measurement unit, with timestamps stretched as suggested by Deliverable D3.1. After uncompressing the file you get a .csv file, the fields are:
 - Timestamp [seconds.microseconds]
 - # of range data [unitless]
 - Sample counter (modulus $2^{16} - 1$) [unitless]
 - Acceleration along X [m/s^2]
 - Acceleration along Y [m/s^2]
 - Acceleration along Z [m/s^2]
 - Angular velocity around X [rad/s]
 - Angular velocity around Y [rad/s]
 - Angular velocity around Z [rad/s]



- Earth's magnetic field along X [a.u. (arbitrary units normalized to Earth's field strength)]
- Earth's magnetic field along Y [a.u.]
- Earth's magnetic field along Z [a.u.]
- R1..R9 Orientation matrix, row after row [unitless]
- nominal scan frequency = 128Hz;
- **ODOMETRY_XYT**: data stream from the odometer of the robot, sampled at a 50Hz nominal frequency. The raw "tick count" stream from the odometer has also been processed in order to express the pose of the robot on an x,y, θ reference system (with reference to the pose of the robot at the start of the odometry stream). The x and y axes are positioned as in the robot reference system, which will be described in section 3. After decompressing the file you get a .csv file, the fields are:
 - Timestamp [seconds.microseconds]
 - Rolling counter [signed 16bit integer]
 - TicksLeftWheel (raw data) [ticks]
 - TicksRightWheel (raw data) [ticks]
 - X [m]
 - Y [m]
 - Theta [rad]
- **OMNI**: the filename of each image is the time-stamp ([seconds.microseconds], from the 00:00 of January 1st, 1970); each file follows the PNG format, 640x640 3*8bpp (color); nominal frame frequency = 15Hz;
- **SICK_FRONT, SICK_REAR**: after decompressing the file you get a .csv file, the fields are:
 - Timestamp [seconds.microseconds]
 - # of range data [unitless]
 - Angular offset [1/4 degree]
 - R1...R181 range data [m]
 - nominal scan frequency = 75Hz;
- **SONAR**: after decompressing the file you get a .csv file, the fields are:
 - Timestamp [seconds.microseconds]
 - Rolling Counter [16 bit unsigned integer, wraps at 65535]
 - Group of sensors [1, 2, 3] (please see section 3.1.2.2 for details)
 - Reading² of sensor 1 in group [m]
 - Reading of sensor 2 in group [m]
 - Reading of sensor 3 in group [m]
 - Reading of sensor 4 in group [m]
- **SVS_R, SVS_L, SVS_T**: the filename of each image is the time-stamp ([seconds.microseconds], from the 00:00 of January 1st, 1970); each file follows the PNG format, 640x480 8bpp (grayscale); nominal frame frequency =

2 A value of 0 indicates a problem in the reading, probably due to crosstalk. A value of 9.999 indicates an hardware fault. No hardware faults should occur during normal operation, while problems in the reading are quite common and not to be considered a defect. Expect very long sequences of 0 for a particular sensor or couple of sensors.



15Hz.



3. The datasets

This section of the document presents RAWSEEDS' indoor datasets and gives a description of each of them, along with a comprehensive overview of the sensor systems used to gather the data. The aim of this section is that of providing the user of the datasets with a general knowledge of their properties, and to let her select the datasets which are more fitting for a specific application.

3.1 Sensors used to generate the data

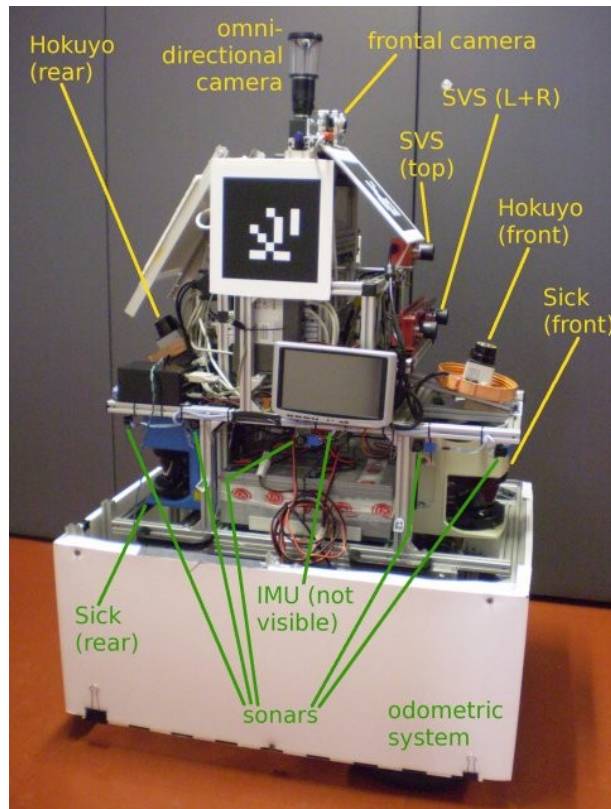
Correct interpretation of the data within the datasets of Deliverable D2.1 requires the knowledge of the type and characteristics of the sensors used to acquire them. This section describes such sensors.

3.1.1 Description of the sensor systems

We give here, for convenience, the list of sensors mounted onboard the Robocom robot for indoor data collection. As a matter of fact, this list coincides with the corresponding one in Deliverable D2.2 except for two aspects:

1. the absence of the GPS unit, useless in indoor locations because GPS reception is impossible within buildings;
2. the presence of a belt of sonar sensors (and associated electronics); physical positioning of such sensors will be described in section 3.1.2.

The following figure shows the robot used for the data acquisitions, and the sensors mounted on board of it when configured for indoor operation. A comparison with an image of the robot in the setup for outdoor data collection shows visible differences, and especially the presence of visual tags and of an external, rectangular hull covering the lower part of the robot body. Such passive elements were introduced to allow - or, in the case of the hull, to facilitate - the operation of the ground truth collection systems used for indoor environments. More details about such operation are available in Part 2 of this document.



The sensors mounted on the robot are the following:

1. Odometric system fitted to the Robocom robotic base.
2. Binocular vision system, composed of a two-camera Videre Design STH-DCSG-VAR system (two FireWire, B/W, 640x480 pixel cameras mounted on a common mechanical frame that allows for an adjustable baseline). Trinocular vision system is realized combining the binocular STH-DCSG-VAR with an additional Videre Design DCSG camera (the same camera used by the STH-DCSG-VAR). Although CMOS, these cameras feature a global shutter, which is important for shooting dynamic scenes or from a moving observer (both things happen in our case).
<http://www.videredesign.com/sthdcs svar.htm>,
<http://www.videredesign.com/Templates/dcs g.htm>
3. Color monocular vision is covered by an Unibrain Fire-i 400 camera (FireWire, color, 640x480 pixel). The YUV4:2:2 output stream is transformed into RGB through suitable postprocessing of the data.
http://www.unibrain.com/Products/VisionImg/Fire_i_400_Industrial.htm
4. Omnidirectional color vision is obtained by using a Prosilica GC1020C color GigE Vision camera fitted with a hyperbolic mirror built by Vstone. The camera was configured for partial-frame acquisition, with a ROI (Region of Interest) of 640x640 pixels.
<http://www.prosilica.com/products/gc1020.html>,
<http://www.vstone.co.jp/e/EVSC15MR15MR37.pdf>
5. Two Hokuyo URG-04LX laser range finders, mounted respectively on the front and

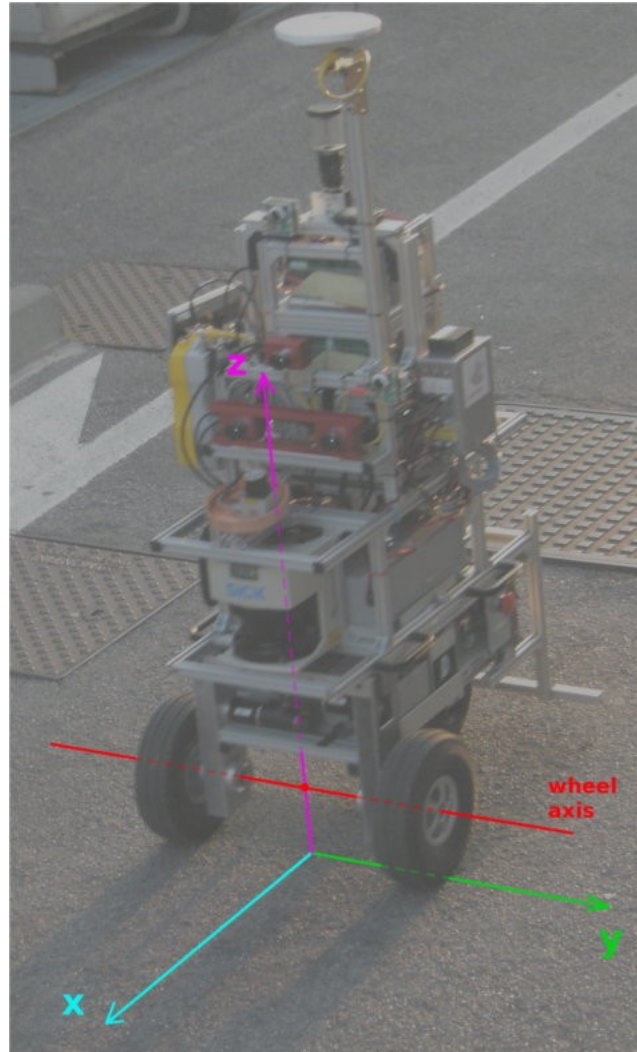


the back of the robot. The scanning planes of the LRSs are tilted down, towards the floor (precise orientation will be given in the following subsection).
<http://www.hokuyo-aut.jp/products/urg/urg.htm>

6. Sick LMS291 and LMS200 laser range finders, mounted on the front and the back of the robot.
<http://mysick.com/partnerPortal/eCat.aspx?c=1&go=FinderSearch&Cat=Row&At=Fa&Cult=English&Category=Produktfinder&FamilyID=267&Selections=8641,0,0,8775,0>
<http://mysick.com/partnerPortal/eCat.aspx?go=FinderSearch&Cat=Row&At=Fa&Cult=English&Category=Produktfinder&FamilyID=267&Selections=8644,0,0,8775,0>
7. Xsense MTi inertial measurement unit (USB, 1,7g full scale acceleration, 150deg/s full scale rate of turn).
http://www.xsens.com/index.php?mainmenu=products&submenu=machine_motion&subsubmenu=MTi
8. Sonar belt composed of 12 Maxbotix EZ-2 ultrasonic emitters/receivers attached to a custom acquisition board, designed and built by Polimi and based on a DSPIC microcontroller.
<http://www.maxbotix.com/uploads/LV-MaxSonar-EZ2-Datasheet.pdf>

3.1.2 Relative pose of onboard sensors

To use the RAWSEEDS datasets it is necessary to know the relative pose of the sensors that generated the streams included into the datasets. This section will provide such information. All the poses will be given with reference to the **odometry reference system** shown in the following picture (the same defined by Deliverable D2.2 and used by the outdoor datasets).



As can be seen from the picture, the origin of the odometry reference frame is the vertical projection on the floor plane of the median point of the wheel axis, and the z axis is vertical. Therefore, both the x and y axes lie on the floor. The angle called "theta" in the file formats described in the preceding sections is measured starting from the x axis, growing (as usual) counterclockwise when seen from above the ground.

In the following part of this section we will give the positions of the sensors as measured in the reference system just described. Sensor positions have been measured manually with great care, except for front-looking cameras. In the latter case, the positions were computed with the following procedure (the reliability of which has been validated while doing similar measurements for Deliverable D2.2):

1. A test panel sporting a calibration pattern, with an associated reference system, has been positioned in a known position (measured manually) with respect to the odometry reference system. In this way, the transformation (i.e., the rototranslation) between odometry system and pattern system was known.



2. The calibration pattern on the test panel has then been localized using the data from the front-looking cameras: this has been done with the same Matlab toolbox used to calibrate the cameras, described in section 3.2, with the intrinsic calibration parameters listed in that section. The transformations between the reference systems of each camera and that of the pattern were therefore assumed to be known.
3. Finally, for each camera the rototranslation from the odometry system to the camera system was obtained by composing the transformations from odometry system to pattern system and from pattern system to camera system.

We will now consider the sensors one at a time, specifying for each of them the position and the orientation. However, it is first necessary to specify the points on the sensors that the given positions are referred to. We will start, then, by defining such measured points for each category of sensors.

Cameras (SVS, frontal, omnidirectional)

Point measured: optical center.

GPS

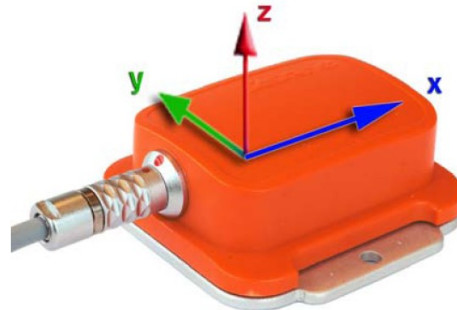
Point measured: intersection between the axis of the threaded hole on the base of the GPS antenna and the plane of that base.

Laser range finders (Sick, Hokuyo)

The center of the rotating mirror reflecting the laser light defines a circumference. Point measured: center of such circumference.

Inertial Measurement Unit

Point measured: median point of the line joining the two fixing holes, on the metal base of the sensor. Please note that the Xsens MTi has its own internal reference system, as shown in the picture below (and indicated on the enclosure of the sensor).



The MTi is positioned on the robot in such a way that each of its own axes is oriented as the axis of the robot's odometry reference system bearing the same name. In other words, between the odometry reference frame and the IMU's frame there is only a translation, but no rotations.

Finally, below is the list of the poses of the sensors in the robot's odometry reference system defined above. Linear measurements are in mm, and angular measurements are in degrees. Tolerance for manually measured positions is $\pm 1\text{mm}$ for linear measurements and $\pm 1.5^\circ$ for angular measurements.

FRONTAL camera

x = -171mm
y = -115mm
z = 1068mm

Orientation: horizontal optical axis, camera pointing towards $x = +\infty$, long side of the CCD horizontal

HOKUYO_FRONT

x = 94mm
y = 7mm
z = 700mm

Orientation: sensor pointing towards $x = +\infty$, scan plane tilted towards the floor of a 12.5° angle by rotating the sensor around a line parallel to the y axis and passing through the aforementioned coordinates

HOKUYO_REAR

x = -463mm
y = -1mm
z = 704mm

Orientation: sensor pointing towards $x = -\infty$, scan plane tilted towards the floor of a 12.5° angle by rotating the sensor around a line parallel to the y axis and passing through the aforementioned coordinates

**IMU**

x = -192mm

y = -7mm

z = 537mm

Orientation: metal baseplate below the sensor and horizontal, connector pointed towards $x = -\infty$ (note: as already said, between the odometry reference frame and the IMU's own frame there is only a translation)

ODOMETRY

x = 0mm

y = 0mm

z = 0mm

Orientation: please see the picture in the preceding part of this section

OMNIDIRECTIONAL CAMERA

x = -236mm

y = 2mm

z = 1083mm

Orientation: vertical optical axis, camera pointing towards $z = +\infty$, long sides of the CCD parallel to the y axis (note: only a 640x640 pixel portion of the CCD has been used; the bottom side of the image produced corresponds to the side of the CCD nearer the front of the robot)

SICK_FRONT (LMS291)

x = 80mm

y = 0mm

z = 450mm

Orientation: horizontal scanning plane, sensor pointing towards $x = +\infty$

SICK_REAR (LMS200)³

x = -463mm

3 As an additional verification of the positions of the Sick units, such positions have been compared to the results (in terms of relative position) obtained by application of the ICP algorithm to align a single scan of both the Sick laser range scanners with a precise map of an environment. (For additional information about ICP and the reference map, please see Part 2 of this Deliverable.) The results (in terms of displacement of the rear-facing Sick with reference to the front-facing one, measured in the odometry reference frame of the robot) are the following:

$$x_{\text{rear}} - x_{\text{front}} = -0.5287\text{m}; \quad y_{\text{rear}} - y_{\text{front}} = -0.0061\text{m}; \quad \text{relative rotation is negligible}$$

Considering that the sensors (and the manual laser range finder used to build the map) are affected by errors, and that the walls of the environment were a few tens of meters apart, these measurements show a remarkable correspondence with the manual ones and also confirm the precision of the Sick laser range finders.



$y = 1\text{mm}$

$z = 454\text{mm}$

Orientation: horizontal scanning plane, sensor pointing towards $x = -\infty$

SVS_RIGHT (i.e., the camera of the SVS pair positioned on the side of $y = -\infty$)

$x = -20\text{mm}$

$y = -82\text{mm}$

$z = 745\text{mm}$

Orientation: horizontal optical axis, camera pointing towards $x = +\infty$, long side of the CCD horizontal (note: distance between the symmetry axes of the lenses of the SVS stereo pair = 182mm, along the y axis)

SVS_LEFT (i.e., the camera of the SVS pair positioned on the side of $y = +\infty$)

$x = -20\text{mm}$

$y = 98\text{mm}$

$z = 745\text{mm}$

Orientation: horizontal optical axis, camera pointing towards $x = +\infty$, long side of the CCD horizontal (note: distance between the symmetry axes of the lenses of the SVS stereo pair = 182mm, along the y axis)

SVS_TOP

$x = -40\text{mm}$

$y = 5\text{mm}$

$z = 867\text{mm}$

Orientation: horizontal optical axis, camera pointing towards $x = +\infty$, long side of the CCD horizontal

SONAR

The 12 emitters/sensors that constitute the sonar belt are subdivided into 3 groups of 4 sensors each. Groups of sensors are fired in a circular way (1->2->3->1 and so on), while the 4 sensors in each group are fired simultaneously. This pattern reduces the crosstalk between adjacent sensors, while allowing a sustained data rate (20/3 Hz). The following table specifies which of the 12 physical sensors are included into each of the 3 groups. Each physical sensor is identified by a number.

Group	<i>1st sensor of group</i>	<i>2nd sensor of group</i>	<i>3rd sensor of group</i>	<i>4th sensor of group</i>
1	physical sensor 1	physical sensor 4	physical sensor 7	physical sensor 11
2	physical sensor 2	physical sensor 5	physical sensor 8	physical sensor 10
3	physical sensor 3	physical sensor 6	physical sensor 9	physical sensor 12

Group associations of physical sensors 10 and 11 break the symmetry of the pattern.



This is due to the fact that by connecting them in the expected order there was a problem of unknown nature in the readings, probably due to some crosstalk effect: to solve it, sensors 10 and 11 have been switched.

The positions of the 12 physical sensors with reference to the odometric reference frame are specified in the following table. All measurements are in mm.

Physical sensor	X	Y	Z	theta
1	95	-128	560	-30
2	-20	-146	560	-90
3	-220	-146	560	-90
4	-410	-146	560	-90
5	-540	-128	560	-150
6	-560	72	560	-180
7	-540	128	560	150
8	-410	146	560	90
9	-220	146	560	90
10	95	128	560	30
11	-20	146	560	90
12	115	82	560	0

3.2 Calibration procedures

This section describes the procedures followed to generate the calibration data which are included into the datasets of Deliverable D2.1 and D2.2. As already said in section 2, the datasets also include all the data that an user needs - if she so desires - to repeat the calibrations: either with the same images used by RAWSEEDS or with other images from the same image stream. Please note that the calibration procedures adopted by RAWSEEDS were modified in accordance with the indications expressed by Deliverable D3.1: all calibration procedures and data associated to Deliverables D2.1 and D2.2 comply with such indications, as documented by Deliverable D3.2.

All camera calibration data have been determined using the Camera Calibration Toolbox for Matlab by Jean-Yves Bouguet, available at http://www.vision.caltech.edu/bouquetj/calib_doc/.

3.2.1 Calibration of the stereo rig

We need to distinguish two tools, both available in the Camera Calibration Toolbox for Matlab. The first aims at the calibration of single cameras (`calib_gui`), while the second one is devoted to the calibration of stereo rigs (`stereo_gui`). In the stereo tool,



one can activate/deactivate an optimization on the parameters; this optimization bases on the pattern poses available for the stereo rig calibration. It has also to be noted that the calibration of stereo rigs requires that the same set of points, from the same calibration patterns, has to be visible from both the cameras of the rig. We have therefore a trade-off between selecting pattern poses for maximizing the quality of the calibration of the intrinsics for each single camera, and selecting pattern poses for maximizing the quality of the calibration of the extrinsics of the stereo rig. In the first case one aims at getting a good coverage, in terms of the pattern in the different images, of the whole image. On the other hand, one needs to make the pattern always visible from all cameras; this could prevent a good coverage for the image of some camera.

In order to reach the highest calibration quality, we devised two approaches, briefly sketched hereafter.

Approach 1

- 1.1 collect a set of images, for each camera, devoted to the calibration of the intrinsic parameters (images_for_intrinsics);
- 1.2 collect a set of images, for each camera, devoted to the calibration of the extrinsic parameters (images_for_extrinsics);
- 1.3 run the single-camera tool to compute the intrinsics, on the images_for_intrinsics;
- 1.4 run the stereo-rig tool to compute the extrinsics on the images_for_extrinsics, without optimizations;
- 1.5 return the intrinsics, as determined on images_for_intrinsics, and the extrinsics, as determined on images_for_extrinsics.

Approach 2

- 2.1 collect a set of images devoted to the calibration of the extrinsic parameters (images_for_extrinsics);
- 2.2 run the stereo-rig tool to determine the extrinsics on the images_for_extrinsics, with all optimizations;
- 2.3 return the intrinsics and the extrinsics determined on images_for_extrinsics.

It has to be noted that, when saying "collect a set of images", we do not mind whether this is implemented by grabbing images one by one, e.g., by using a program such as Coriander for Linux, or by passing through a large set of images of a previously taken movie and individually selecting the images that are suitable for a given task, i.e., calibration of intrinsics.

As already proved by Deliverable D2.2, the results are in favor of Approach 2, i.e., activating the optimizations on the images for the extrinsics turns into better results, in term of the intrinsics, than working on images collected for the intrinsics. The calibration of the stereo rig has then been performed in full accordance with the approach described by D2.2.



The calibration of the trinocular stereo rig is tackled as the calibration of two binocular stereo rigs (SVS_R - SVS_L + SVS_R - SVS_T), so we will end up with the extrinsics of each rig (right+left, right+top). As one could calibrate also SVS_L - SVS_T, we checked the quality of the two different estimates one could get about SVS_T - SVS_R. Overall we need both SVS_L and SVS_T referred to the SVS_R frame. If we determine SVS_L with respect to SVS_R, then one simpler option is to calibrate SVS_T w.r.t. SVS_R; the alternative is to calibrate SVS_T w.r.t SVS_L, and then to compose this roto-translation with SVS_L w.r.t. SVS_R.

Concluding, the overall calibration procedure we followed is as follows:

1. collect a set of images so that all cameras can observe the same set of pattern points;
2. calibrate the extrinsics and intrinsics for the pair SVS_L and SVS_R, with the stereo-rig tool and optimization for both the cameras;
3. calibrate the extrinsics and intrinsics for the pair SVS_T and SVS_R, with the stereo-rig tool and optimization for both the cameras;
4. selects the best of the two intrinsics for SVS_R obtained from previous steps.

The calibration results obtained with the above procedures are summarized by the following tables.

Left Camera

FC	
1.0e+02 *	
6.604720072425989	0.405892856346161
6.604720072425989	0.405892856346161

CC	
1.0e+02 *	
3.160922999727285	1.315899503813514
2.142798093473395	0.921539486511319

KC	
-0.270077304858834	0.002130182822454
NaN	
-0.000131430244570	0.000253972109216
NaN	
0.198230912855217	0.019896843867179

Relative error on *fc*: 0.061%

Right Camera

FC	
1.0e+02 *	
6.647630154214031	0.402728418818812
6.647630154214031 9	0.402728418818812

CC	
1.0e+02 *	1.335023203781921



3.273481117704479 2.453608840023571	0.868753409922918
--	-------------------

KC	
-0.293857248831788 0.141264589242246 NaN 0.001794955905251 NaN	0.003562608750138 0.010683372944746 0.000203484655742

Relative error on *fc*: 0.060%

Top Camera

FC	
1.0e+02 * 6.626861641514200 6.626861641514200	0.390812338121900 0.390812338121900

CC	
1.0e+02 * 3.250499906082695 2.115485842336762	1.515610031338342 0.956841935551771

KC	
-0.298072113968947 0.156305262357084 NaN -0.000431564086464 NaN	0.004750562523017 0.019735942744656 0.000193523487888

Relative error on *fc*: 0.059%

Extrinsics L → R

om	
0.001803870053541 -0.008015749514463 0.005559799783223	1.0e-03 * 0.117051242592979 0.127020559023965 0.114437505010778

T	
1.0e+02 * -1.808424896413911 -0.006073242247445 -0.044141254847547	0.152984024818949 0.137735219755273 0.139876174735552

Extrinsics L → T

om	
-0.001648544368246 0.010675038991161 0.000287324824845	0.001441142145783 0.002281668951133 0.000120616321499

T	
1.0e+02 *	0.169969250994314



-0.928075507828679	0.163897673461027
1.216606524423006	0.691786381957026
0.217769364998263	

Extrinsics T → R

<i>om</i>	
0.002581670774963	0.001530732272826
-0.018327990126522	0.002425320904170
0.005280295756539	0.000128691621930

<i>T</i>	
1.0e+02 *	
-0.870109138595405	0.172182288334618
-1.217624692411501	0.166025839814743
-0.240148333956877	0.702508796550879

Composition L→R - (T→R * L→T)

(limited to the translational part of the transformations)

0.003291159828563 [mm]
 0.041690566832937 [mm]
 -0.779176672817266 [mm]

As a sample of the kind of images used to calibrate the stereo rig, the picture below shows a subset of the images used to calibrate the left camera of the SVS. The complete set of images is available with the datasets. Please note that visual quality of the images below is low due to the format changes and the resizing necessary to include them into this document.



3.2.2 Calibration of the frontal camera

This device is a low-cost webcam, which has been mounted in order to allow



researchers tackle the difficulties introduced by using such a low-quality device as a sensor. For a higher quality stream, to be used for monocular research, please refer to one of the streams of the trinocular stereo system.

The results of the calibration procedure are the following:

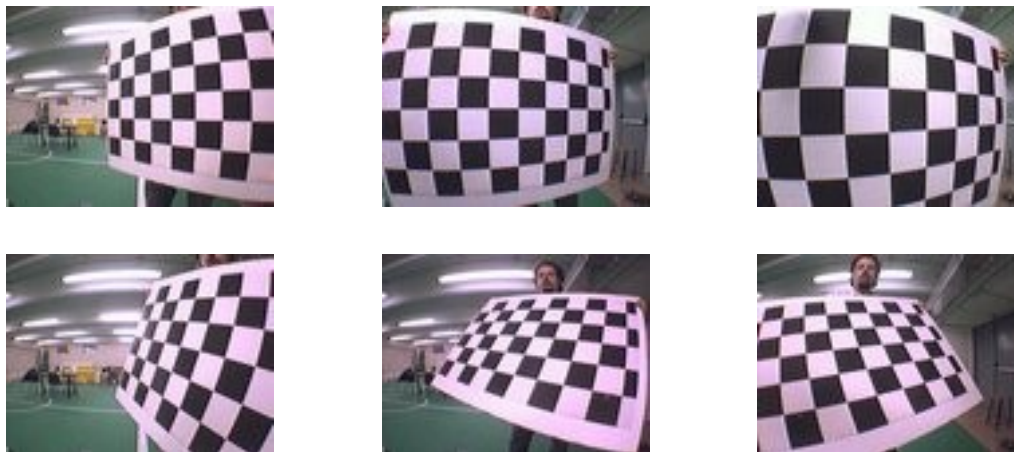
FC	
194.884666947553171	0.384719272656123
194.884666947553171	0.384719272656123

CC	
172.160809356796847	0.528589936049903
125.085931934453242	0.440043192328646

KC	
-0.337533296189144	0.003315213387716
0.139167006118705	0.004806246341895
0.000393444838786	0.000256213747705
<i>NaN</i>	<i>NaN</i>
-0.028870156803311	0.001940250395379

Relative error on fc: 0.197%

As a sample of the kind of images used for calibration, the picture below shows a subset of the images used to calibrate the frontal camera. The complete set of images is available with the datasets. Please note that visual quality of the images below is low due to the format changes and the resizing necessary to include them into this document.



3.2.3 Calibration of the omnidirectional camera

This device is a catadioptric camera, i.e., a normal camera with its optics (the dioptric part) and a catoptric part (the reflective part, i.e., the mirror). The mirror part is a commercial device from the Japanese company Vstone; its shape is hyperbolic, and, when combined with a perspective projection, allows to get images from a Single View Point, virtual in this case, because of the mirror. SVP projection



has useful properties, and can be calibrated similarly to what is done in the context of normal dioptric cameras.

To calibrate the catadioptric omnidirectional camera, two main toolboxes are available. The one we used is the one whose usage is easier (the tool allows to avoid clicking on all the image points of the calibration pattern). The description of the projection model that this toolbox is the one given in the document "Projection Model" by Christopher Mei, available at

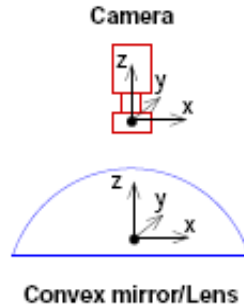
http://www-sop.inria.fr/icare/personnel/Christopher.Mei/articles/projection_model.pdf

The article describing the chosen approach to the calibration is "Single View Point Omnidirectional Camera Calibration from Planar Grids" by Christopher Mei and Patrick Rives, available at

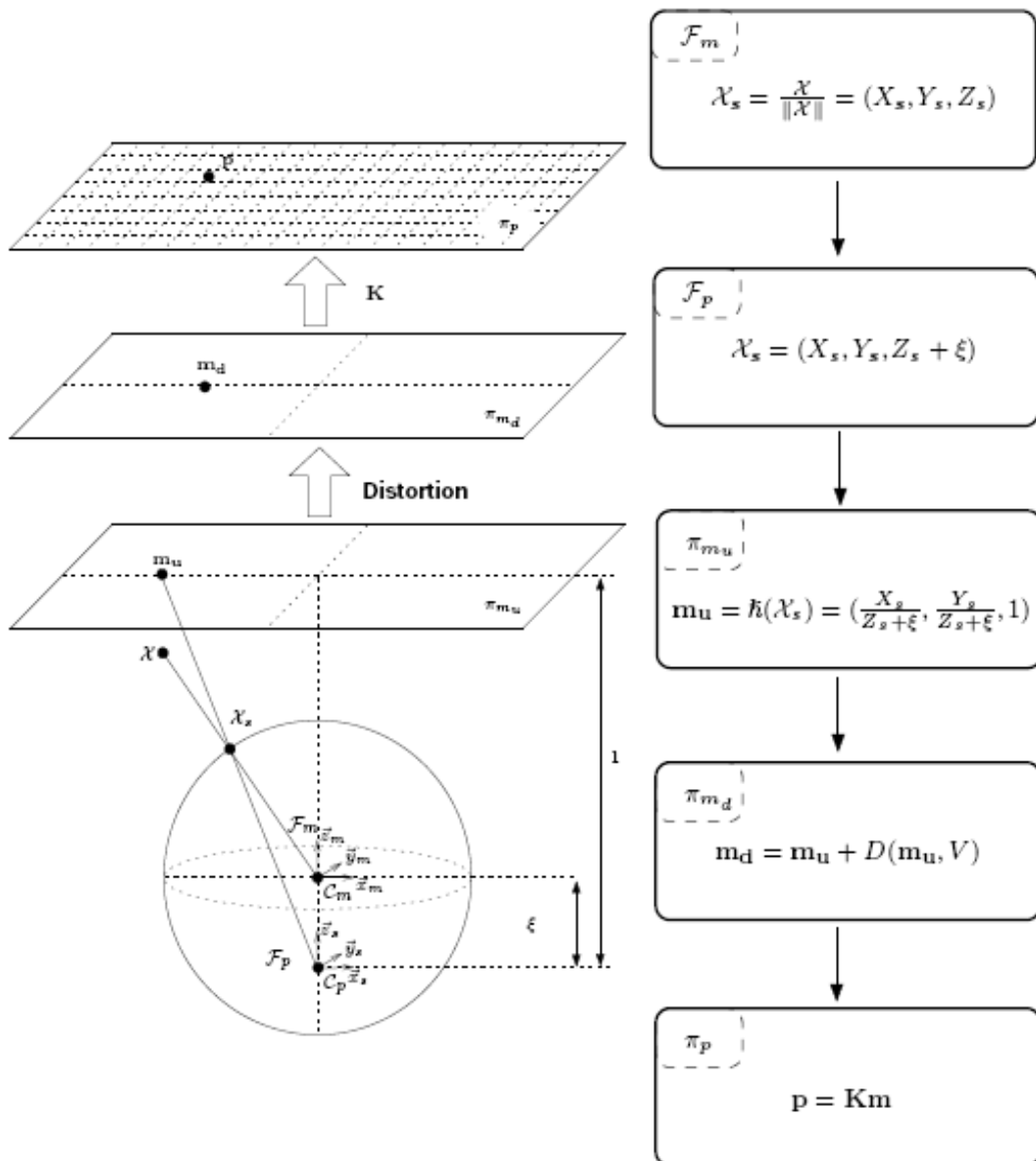
http://www.robots.ox.ac.uk/~cmei/articles/single_viewpoint_calib_mei_07.pdf

For the convenience of the user, we will now copy into this document the description of the projection model we used. Please note that such description has been directly lifted from "Projection Model" by Christopher Mei: use the original document for reference. The following figure shows the choice of axes done for the model.





The projection of 3D points can be done following the steps outlined in the following figure,





with the relationship between (ξ, γ) and the mirror values detailed in the table below:

	ξ	γ
Parabola	1	$-2pf$
Hyperbola	$\frac{d}{\sqrt{d^2+4p^2}}$	$\frac{-2pf}{\sqrt{d^2+4p^2}}$
Ellipse	$\frac{d}{\sqrt{d^2+4p^2}}$	$\frac{2pf}{\sqrt{d^2+4p^2}}$
Planar	0	$-f$
Perspective	0	f
d : distance between focal points		
$4p$: latus rectum		

1. world points in the mirror frame are projected onto the unit sphere,

$$(\mathcal{X})_{\mathcal{F}_m} \rightarrow (\mathcal{X}_s)_{\mathcal{F}_m} = \frac{\mathcal{X}}{\|\mathcal{X}\|} = (X_s, Y_s, Z_s)$$

2. the points are then changed to a new reference frame centered in $C_p = (0, 0, \xi)$,

$$(\mathcal{X}_s)_{\mathcal{F}_m} \rightarrow (\mathcal{X}_s)_{\mathcal{F}_p} = (X_s, Y_s, Z_s + \xi)$$

3. they are then projected onto the normalised image plane,

$$\mathbf{m}_u = \left(\frac{X_s}{Z_s + \xi}, \frac{Y_s}{Z_s + \xi}, 1 \right) = h(\mathcal{X}_s)$$

4. we then add radial and tangential distortion,

$$\mathbf{m}_d = \mathbf{m}_u + D(\mathbf{m}_u, V)$$

5. the final projection involves a generalised camera projection matrix K (with γ the generalized focal length, (u_0, v_0) the principal point, s the skew and r the aspect ratio)

$$\mathbf{p} = \mathbf{K}\mathbf{m} = \begin{bmatrix} \gamma & \gamma s & u_0 \\ 0 & \gamma r & v_0 \\ 0 & 0 & 1 \end{bmatrix} \mathbf{m} = k(\mathbf{m})$$

h^{-1} lifts a the point from $\pi_{\mathbf{m}_u}$ to the sphere :

$$h^{-1}(\mathbf{m}_u) = \begin{bmatrix} \frac{\xi + \sqrt{1 + (1 - \xi^2)(x^2 + y^2)}}{x^2 + y^2 + 1} x \\ \frac{\xi + \sqrt{1 + (1 - \xi^2)(x^2 + y^2)}}{x^2 + y^2 + 1} y \\ \frac{\xi + \sqrt{1 + (1 - \xi^2)(x^2 + y^2)}}{x^2 + y^2 + 1} - \xi \end{bmatrix}$$

Calibration results for the catadioptric camera, obtained by using the above model,



are the following.

GAMMAC	
285.180135944522	0.27550743545995
285.180135944522	1.06016527298585

CC	
327.798058798715	1.00161442066858
313.69238291485	0.00290508601878

KC	
0.0459045244292067	0.00617918796188888
NaN	NaN
0.00132583899587976	0.00043894955019776
-0.00242937868876647	0.00042354563154883
NaN	NaN

XI	
1.05777638031857	0.00764018136554

As a sample of the kind of images used for calibration, the picture below shows a subset of the images used to calibrate the omnidirectional camera. The complete set of images is available with the datasets. Please note that visual quality of the images below is low due to the format changes and the resizing necessary to include them into this document.



3.3 Description of the datasets

What follows is an overview of the datasets of Deliverable D2.1. The datasets are



accessible through the internet, with the procedure described in section 2.1 of this document. In the following of this section, the title of the subsection describing each specific dataset corresponds to the name of the directory containing the dataset on the RAWSEEDS server.

The datasets of Deliverable D2.1 all belong to the category of *indoor datasets*, i.e., datasets entirely recorded within buildings. Each of the datasets is composed of data gathered by the robot on various paths, partially overlapping and organized into multiple *loops* to help the testing of SLAM (Simultaneous Localization And Mapping) algorithms. One of the key performance elements for such algorithms is, in fact, the ability to correctly "close the loop" when the robot returns to a previously visited zone: i.e., the ability to correctly detect that the zone presently explored has been visited before and to update the map built by the algorithm accordingly.

The location in which the datasets of Deliverable D2.1 have been acquired is the Università di Milano-Bicocca, in Milan (Italy). A description of such location, complete with pictures, can be found in RAWSEEDS' Deliverable D1.1 (Indoor Roadmap). The part of the location explored by the robot during the gathering of the datasets of Deliverable D2.1 includes one floor of an office building and the corresponding floor of a nearby building. The two buildings are connected by roofed, glass-walled bridges. They sport a wide range of different of architectural features, which are summarized below.

- Corridors (mainly fairly narrow ones) with doors on their sides, mostly leading to offices. Some of the doors are deeply recessed within the walls, at different depths, so corridor boundaries are far from planar.
- A wide hallway where the starting point for the explorations - and the ground truth equipment - were located. This is a very wide space, with features such as columns, staircases, elevators and escalators.
- Smaller hallways of various types.
- Spaces, of different shapes and dimensions, with tables and chairs.
- Two narrow bridges between buildings, already described above.
- A rather wide and architecturally varied library. This occupies most of a floor of one of the explored buildings. Its main features are: open bookcases (many of these of course), desks, PCs and photocopiers, spaces with tables and chairs - both very open (halls) and more constrained such as rooms - and so on.
- Various kinds of doors and passageways, including security doors for the library.

Terrain is very smooth, with occasional small ridges where junctions between different floor sections are present. Floors are horizontal, the only exception being two slanted planes leading to the bridges (necessary due to the different heights of the corresponding floors of the interconnected buildings). One of these ramps is rather wide and has a moderate slope, while the other is narrower and more sloped. In the executive drawings shown in the following part of this section, the two buildings appear on the left and on the right areas, while the two bridges are shown



as parallel, horizontal, narrow passages connecting the building. The building on the left is the office one, while the one on the right is the one including the library.

For indoor acquisitions, each data-acquisition session had an approximate duration of 30 minutes (exact durations can be obtained from the timestamps included in all the data streams of the datasets). As described in section 2.3, indoor ground truth is represented by two different, independent data streams: one produced by a vision-based system and the other generated by a laser-based system. Both systems were mounted in the widest of the hallways: the path of the robot for most of the data-gathering explorations started and ended in this hallway.

The following part of this section presents the datasets of Deliverable D2.1. For each one of them, the path of the robot is shown superimposed on the executive drawing of the explored area. The path starts from the red circle and ends at the red arrow. Please note that wherever two sections of the actual path were superimposed one on the other, they have been represented instead as roughly parallel, to make the drawings clearer.

Please note that these are indoor datasets only: the outdoor datasets generated by RAWSEEDS are documented by Deliverable D2.2.

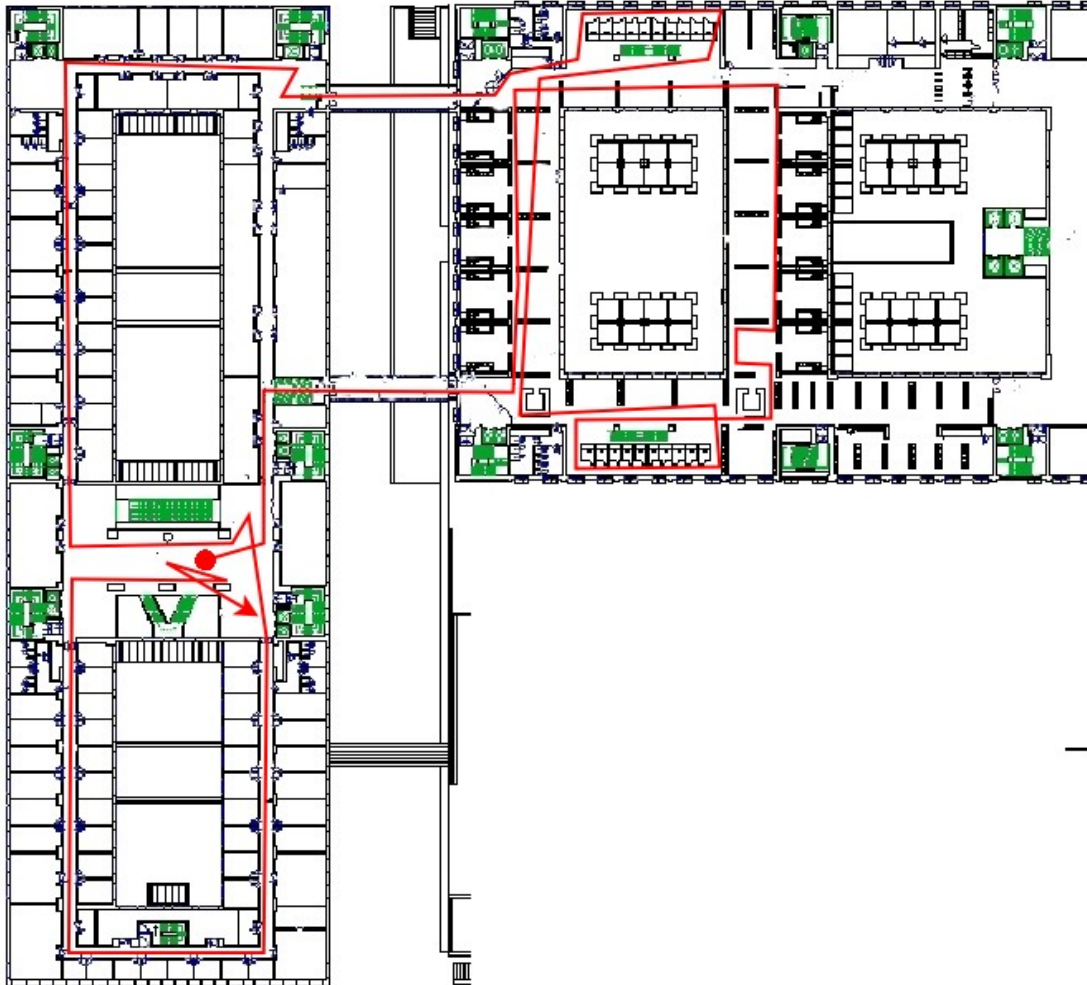


3.3.1 Bicocca_2009-02-25b

Path







Type of dataset and start time

This dataset is static (i.e., does not include moving objects such as people). Lighting is artificial. Start time was February 25, 2009, 12.05PM.

Known defects of the dataset (if any)

No known defects.

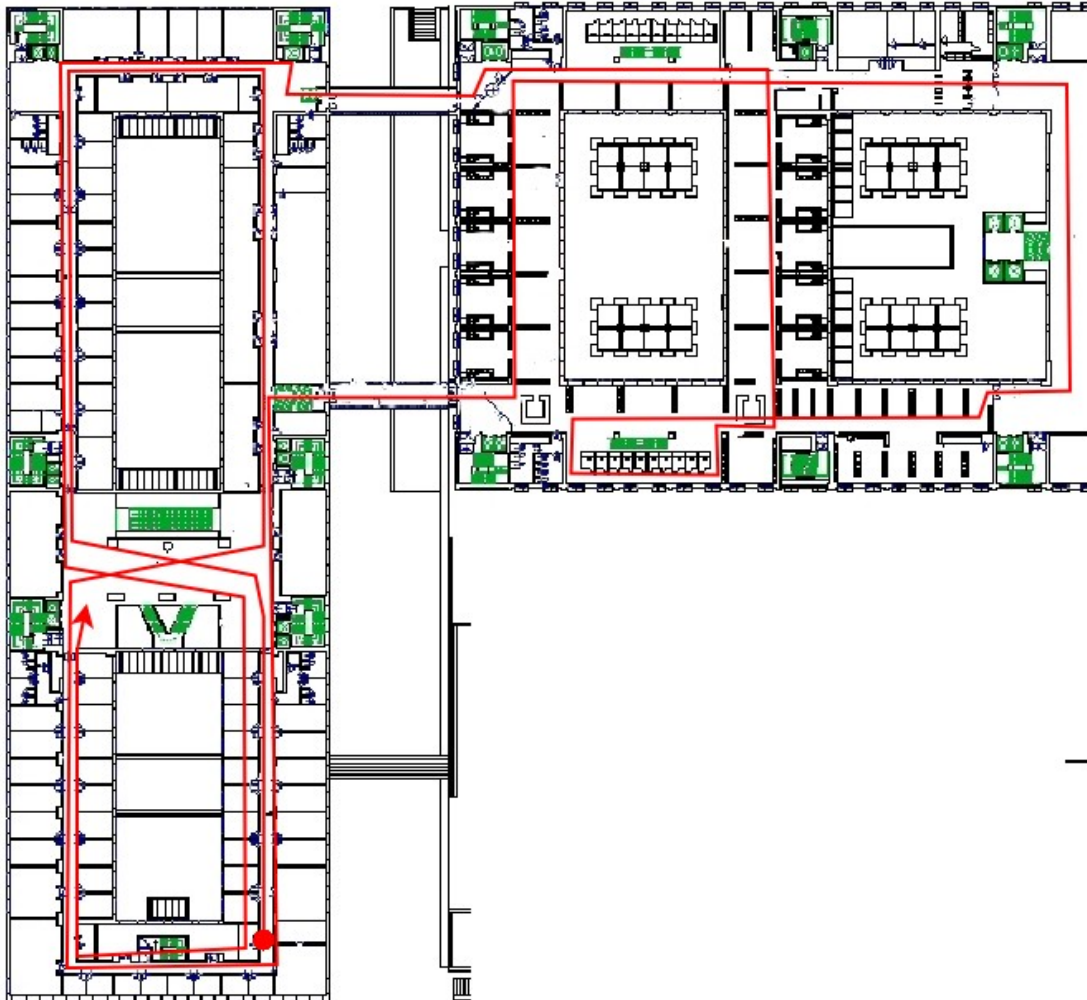
Notes (if any)

No notes.



3.3.2 Bicocca_2009-02-27a

Path



Type of dataset and start time

This dataset is static (i.e., does not include moving objects such as people). Lighting is mainly due to daylight. Start time was February 27, 2009, 7.10AM.

Known defects of the dataset (if any)

No known defects.

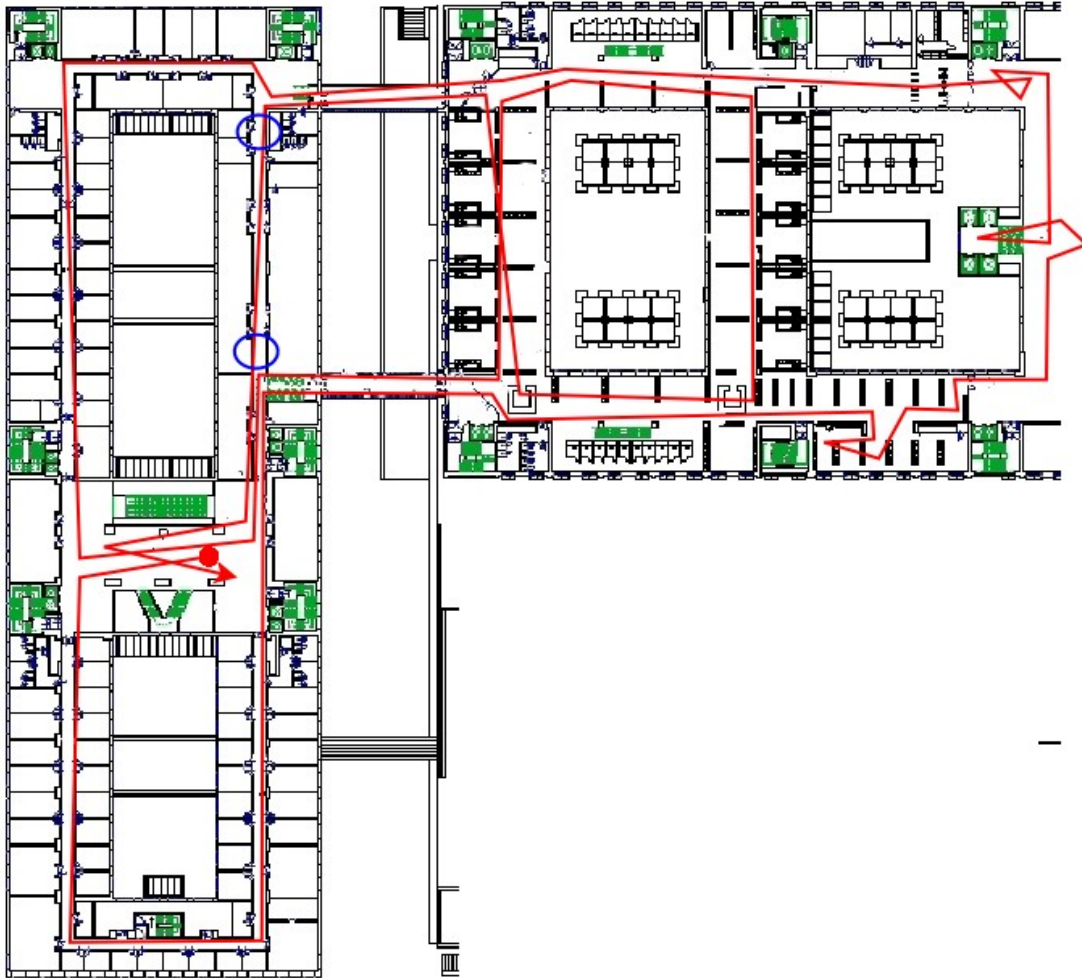
Notes (if any)

No notes.



3.3.3 Bicocca_2009-02-26b

Path



Type of dataset and start time

dynamic lamps

This dataset is dynamic (i.e., does include moving objects such as people). Lighting is artificial. Start time was February 26, 2009, 7.30PM.

Known defects of the dataset (if any)

No known defects.

Notes (if any)

Some big bins, initially located in the positions encircled in blue, were moved by

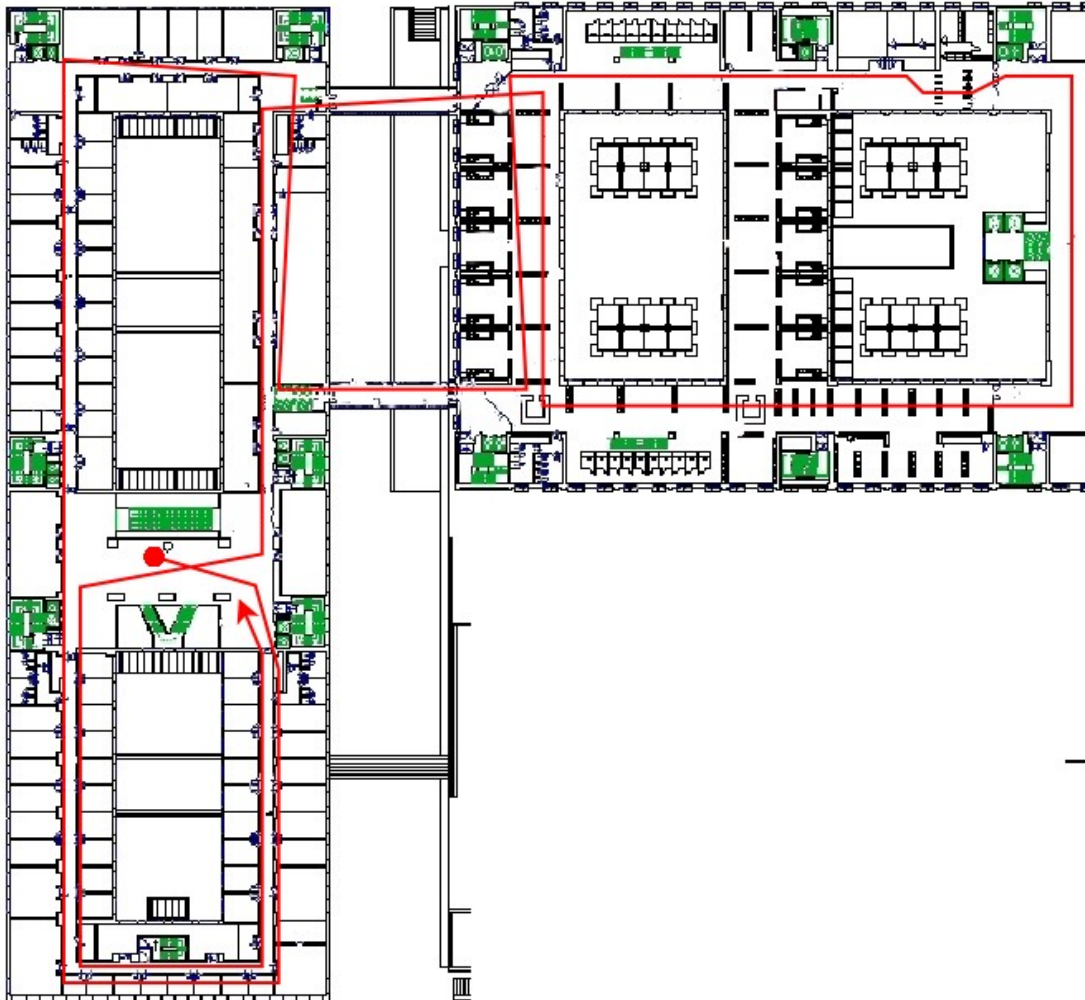


janitors during the course of the data acquisition.



3.3.4 Bicocca_2009-02-25a

Path



Type of dataset and start time

dynamic daylight

This dataset is dynamic (i.e., does include moving objects such as people). Lighting is mostly due to daylight. Start time was February 25, 2009, 12.00AM.

Known defects of the dataset (if any)

No known defects.

Notes (if any)

While the robot was traversing one of the glass-walled passageway between the two

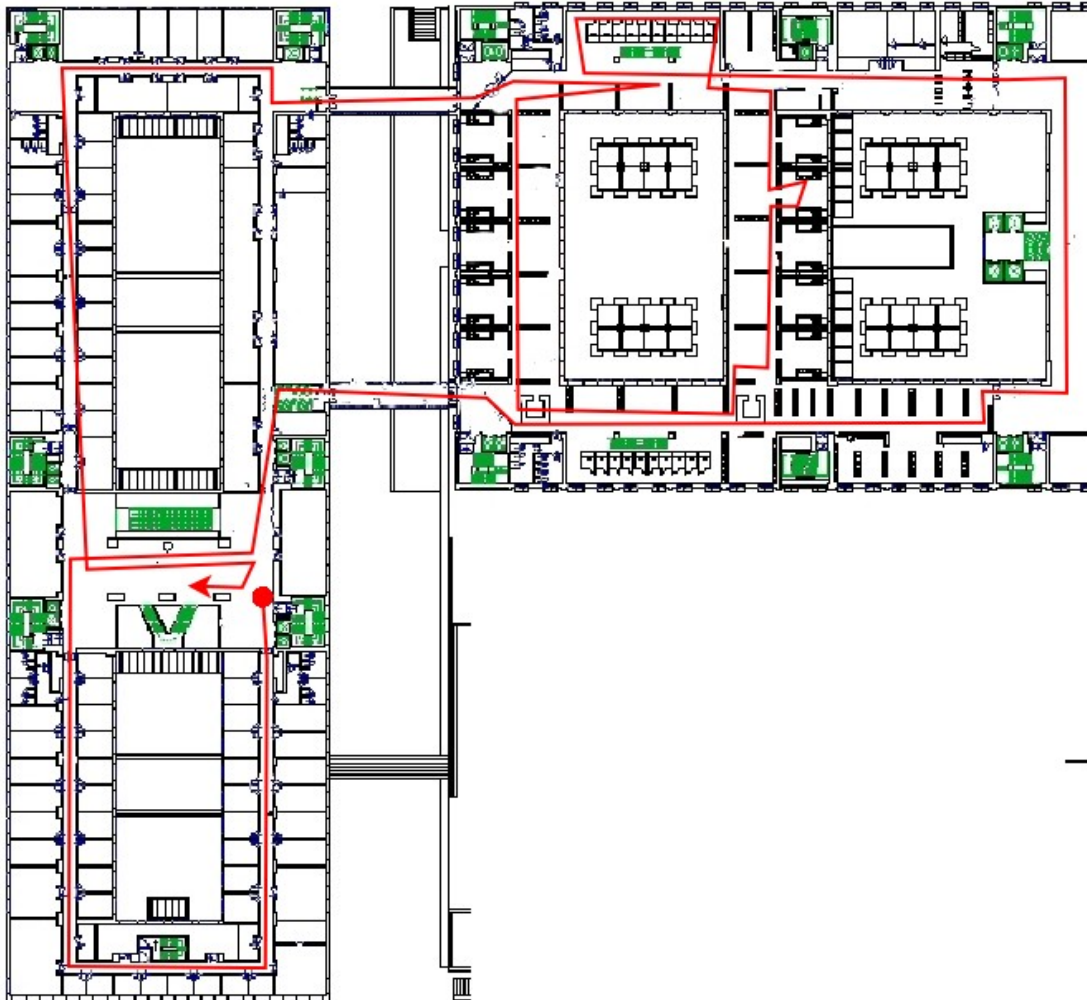


buildings explored during this dataset, an anomalous sequence of frames (with a duration of around 35 seconds) was produced by the frontal camera. Such sequence includes frames that are alternatively dark and over-saturated, and was most probably triggered by the intense natural illumination that the passageway was exposed to. This issue was caused by an unwanted oscillation of the automatic exposure control of the low-cost monocular camera used, an event that (although unusual) is representative of the performance shortcomings of commercial, low-cost cameras. Actually, the frontal camera was chosen within this class of devices exactly to include into the datasets a stream that was affected by the typical limitations of low-end vision sensors.



3.3.5 Bicocca_2009-02-26a

Path



Type of dataset and start time

dynamic daylight

This dataset is dynamic (i.e., does include moving objects such as people). Lighting is mostly due to daylight. Start time was February 26, 2009, 12.20AM.

Known defects of the dataset (if any)

No known defects.

Notes (if any)

No notes.