VIEW-FINDER : EUROPEAN PROJECT AIMING CRISIS MANAGEMENT TOOLS AND THE ROBOTICS ASSISTANCE TO FIRE-FIGHTING SERVICES

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Objective of the project

In the event of an emergency due to a fire or other crisis, a necessary but time consuming pre-requisite, that could delay the real rescue operation, is to establish whether the ground or area can be entered safely by human emergency workers. The objective of the VIEW-FINDER project is to develop robots which have the primary task of gathering data. The robots are equipped with sensors that detect the presence of chemicals and, in parallel, image data is collected and forwarded to an advanced Control station (COC). The robots will be equipped with a wide array of chemical sensors, on-board cameras, Laser and other sensors to enhance scene understanding and reconstruction. At the control station the data is processed and combined with geographical information originating from a web of sources; thus providing the personnel leading the operation with in-situ processed data that can improve decision making. The information may also be forwarded to other forces involved in the operation (e.g. fire fighters, rescue workers, police, etc.). The robots connect wirelessly to the control station. The control station collects in-situ data and combines it with information retrieved from the large-scale GMES-information bases. It will be equipped with a sophisticated human interface to display the processed information to the human operators and operation command.
We'll essentially focus in this paper to the steps entrusted to the RMA and PIAP through the work-packages of the project.

1. WP1: The User and System requirements, the Disaster Management Action Plan (DMAP) and the Crisis Management Information System (CMIS)

Beside the analysis of the structural national regulations, a questionnaire has been set up and submitted to the partners of V-F in order to define the basic objectives expectations and requirements of the National Authorities in charge of the Civil Protection and Fire-Fighting Services, define the major constraints related to the possible use of the V-F R&D and results, obtain a useful description of the actual Intervention Services, including the legal and/or normative obligations of the organizational administrative and operational Intervention Chains, define the End-Users specific requirements and define realistic validation scenarios
From the answers it appeared that the V-F should **prioritary** lead to:

- the development of performing crisis management tools related to the municipal, provincial and federal urgency and intervention plans (PUI)
- the development of an Intelligent Information System implying a convivial interfacing (communication) between the intervention levels (on site Commando Post and Crisis Centres)

Among other, a typical scenario has been proposed by/with the support of the End-Users, the crash of an airplane on/near a military/civilian zone with the support of the 1 Wing Air Base (located in Beauvechain-Belgium).

The usefulness of the Robotics Assistance was also analyzed on base of statistical intervention types, as summarized in the next table:

Nature of intervention	Number of interventions	Number of men/hours
fire	215	4244
flooding	196	7537
water supply	398	6474
pollution	1198	14868
pollution	1198	14868
road accident	248	1739
collapse	26	250
explosion	7	71
explosion	7	71
storm	43	464
water rescue	68	2360
bomb alert	3	62
bomb alert	3	62
nests of wasps	42	59
transports and roadwork's	261	4866
humanitarian intervention	174	12120
preventive intervention	76	2099
logistic intervention	375	9857
demonstration / exercise	104	5134
demonstration / exercise	104	5134
legal aid	81	4023
other	116	5803
Total	**3631**	**81769**

VIEWFINDER results - Network of Graphical data among Crisis Centers **and/or** Gathering of 'Visual' data on the field - should be requested in 38 % (blue). A swarm of small robots equipped with olfactory and navigation sensors as well as with ad-hoc communications systems linking them with Fire-fighters inside smoked and/or polluted buildings could also be useful (yellow): this study has been entrusted to the FW6 European Project GUARDIANS [3]

1.1. **Disaster Management Action Plan [2]**

The Disaster Management Action Plan (DMAP) is a generic management tool covering the whole crisis life cycle. It supports the decision makers and the emergency workers with crucial information, walkthroughs, and scenarios, which guide them through the management process of a crisis in an efficient and effective way. The DMAP is a part of the CMIS [1] software tools.
The key appliances of the VF system are the robots which are designed to navigate on an individual or cooperative but semi-autonomously base within a crisis area. The purpose is to gather chemical and visual data of a zone which might be inaccessible for men. The COC is the local Control Operations Center, located nearby the emergency ground, and can be considered as a decentralized command post of the permanent crisis centre. It is staffed with crisis managers and technicians and combines :

- **A Base station (BS):**

–The BS is the main control station from which operators, which are specialists in robot control, manage the robots by giving them high-level instructions. By doing this, they monitor the intervention of the robots. This means that they can renew task assignments or detail tasks of an individual robot.
Besides the monitoring duty, the operators will also be trained to interpret the raw data gathered from the sensors, which they will send to the COC.

- **A Crisis Management Information System (CMIS):**

The CMIS is the nerve centre of the COC. It is a local access point of information to the crisis coordination services in the COC, enabling real-time coordination of the View-Finder robot data with higher level information and crisis coordination decisions, coming from the Permanent Coordination Center, which can be found on a national or either regional level.

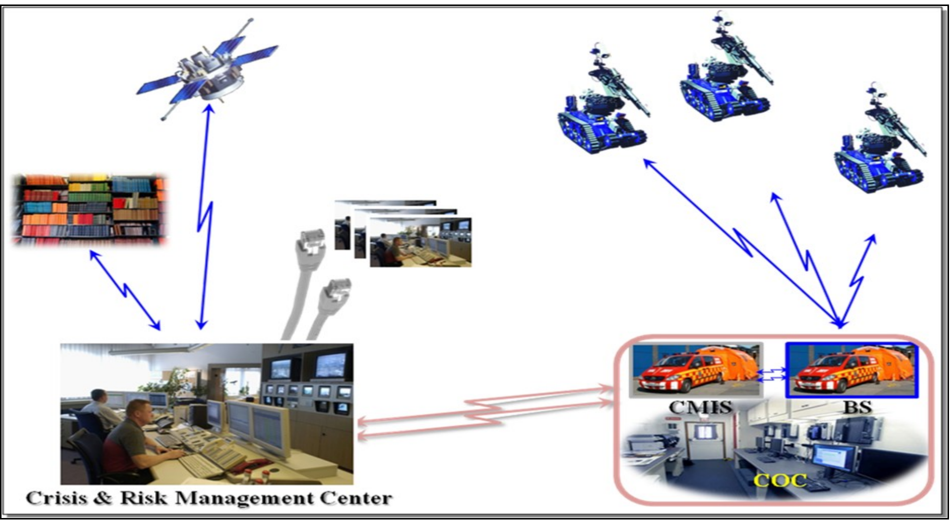

Figure 1. The general View-Finder System Architecture

The DMAP provides three types of information to the end-users :

- Standards and Terminology

  They include glossaries and industrial standards about dangerous products (industrial and chemical products, radiological products, etc.) which might be found on the emergency ground, national and international legislation and regulations with regard to emergency management, information about emergency management organizations, etc.

- Crisis event walkthroughs

  These walkthroughs are particular recommended procedures and methods to manage a particular crisis, measures for manipulating dangerous products and directives and recommendations to deal with them, list of authorities involved in different crisis situations, etc.

- Mission templates

  The mission templates consist of pre-compiled, standardized tools facilitating the work of the emergency workers and crisis managers. They also include guides and situations, gathered from users, which will orient the emergency workers and crisis managers by proposing pre-recorded situations of similar emergencies with the adequate solutions provided (lessons learned) to this particular case.

An example of the DMAP tools is the “Hazards guide” this tool is a compendium of strategies to counter specific hazards situations and products:

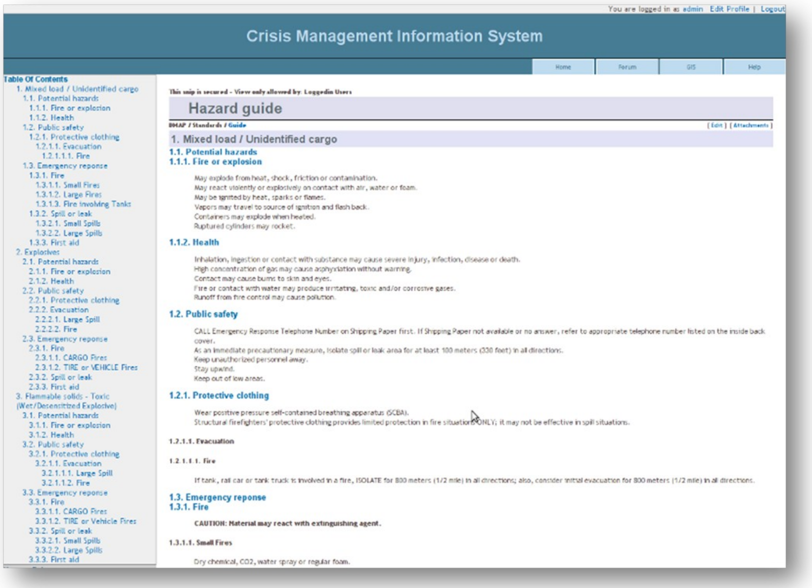

Figure 2. DMAP – Hazards guide

1.2. **The Crisis Management Information System [4]**

Several reasons convince us to employ **Ubuntu** as development and testing platform: Ubuntu is a very stable operating system based in the Debian distribution; it is also very popular and gaining momentum. The popularity of Ubuntu suggests that there will be research opportunities for those who are interested in deploying the CMIS. Popularity of Ubuntu also demonstrates that the distribution will be around for awhile so the instructions done in this guide will still be valid for future tests and implementations of the CMIS. Moreover the philosophy of the distribution is such that Ubuntu is committed to using up to date drivers and cutting edge technology and it is a main requirement of the proposed system.
The choice of **Apache** as web-server is quite logical, we need a powerful, flexible, well known and manageable web server to serve subsystems of the CMIS. Additionally the tools used for very important pars of the systems, as the GIS, were developed and tested with this web server. Concerning the implementation of the GIS module in the CMIS, we used several technologies together in order to make the system works. The web container **Tomcat** is used to make our server side applications (servlets) run. It's the heart of the GIS subsystem since the tools used are servlets which need a container to be deployed and executed.
The GIS tools is based on the use of the following applications and frameworks: **GeoServer**, a geographical data server, which stores and serves raster maps, **GeoMajas**, a framework which consumes and presents the maps served by Geoserver enriching them with layers which present the sensors' data, the sensors data are collected from the base station with a tool written by the RMA researchers, the **CMI.jar** application.
All the data are stored in a spatial database using **PostGis**, a spatial extension built on top of the open-source **PostgreSQL** database.

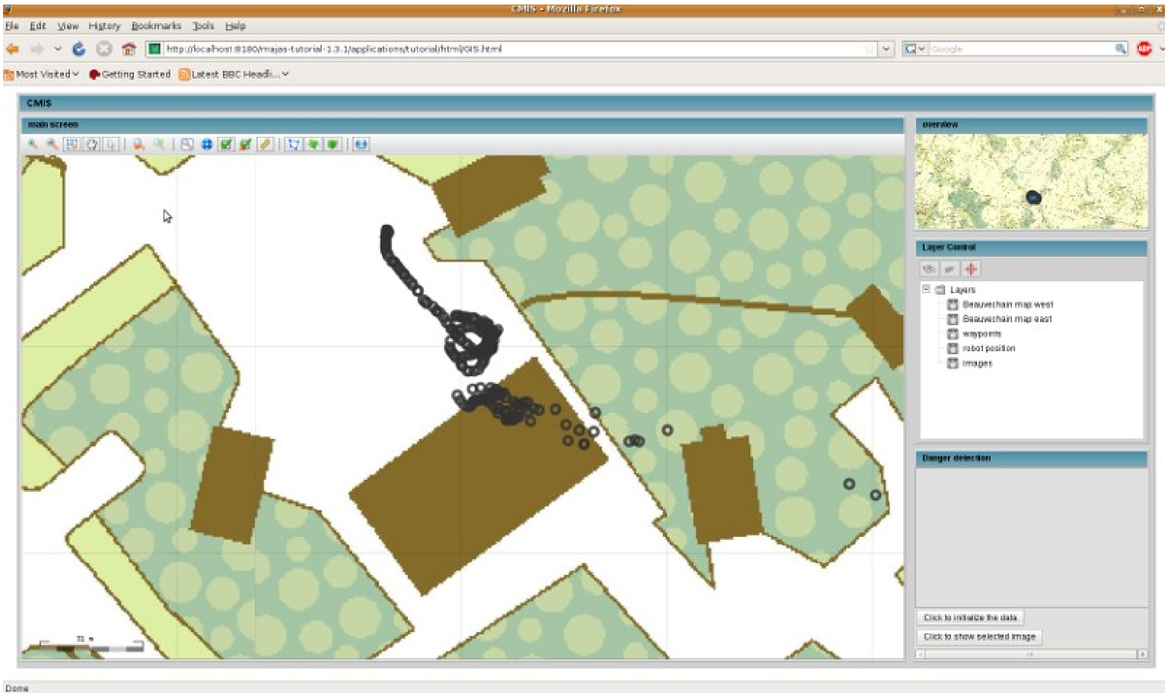

Figure 3. CMIS HMI (from trials on the Air Base of Beauvechain, May 2009)

As can be seen on the previous figure, the screen is subdivided in several pane, each with a specific function. First of all, the toolbar can be seen right about the main image. There are the tools we configured in the toolbar.xml file. These are mainly to focus, zoom or de-zoom the main picture. On the top right is the overview map pane, and just below is the layer description pane. This tool is very important since we can show, hide or refresh the data received by the cmis.jar. To manipulate a layer, one must choose it by clicking it, then click on one of the 3 icons just above. These icons are for showing/hiding a selected layer, adding label to the selected layer, snipping the selected layer. The last pane in the lower right corner is for showing the sensors' data, clicking on the button to show the data table (configured in the postgis.xml file).

2. WP2 : The Robots, Navigation, Vision and Chemical Sensors

Two robots are used (from PIAP, Poland and RMA, Belgium):

	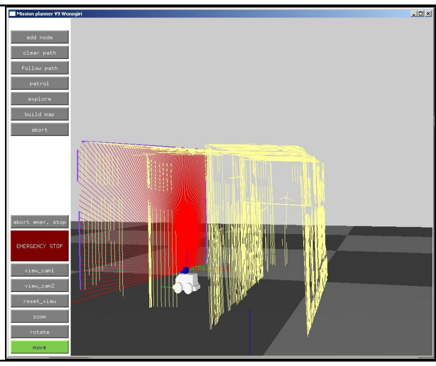	
Red ATRV Jr (PIAP)	PIAP Fast GPU-Based Laser Range Finder LMS SICK 200 results	ROBUDEM (RMA) during the May 2009 trials

Fig.3: the robots of the V-F project

The ARTVJr autonomous mobile robot has been improved for the ViewFinder Application from the software architecture and autonomous navigation point of view. The improvement [15, 16] is based on the investigation of the State of the Art hardware drivers for ATRV Jr functionality and its implementation. The main goal of increased performance is achieved by combining Player/Stage driver for the RFLEX–ATRV Jr onboard real time controller with the View-Finder system based on CORBA/CoRoBa/Mailman communication technologies.

The ROBUDEM is equipped with odometric sensors, a vision system consisting of a Bumblebee2 stereovision system, an RTK DGPS with three antennas, INS and ultrasonic sensors which give distance measurements to obstacles in front of the robot and before the wheels, all being interfaced with the Robot Controller through the adopted on CORBA based CoRoBa Framework [5]

The Chemical Sensor: after discussions with South Yorkshire Fire and Rescue Services following gases and vapors were identified as the target analytes to be detected by the sensor arrays. The analytes can be split into two groups called vapors and gases. The first group includes the compounds which exist in both liquid and gaseous forms at room temperature and normal atmospheric pressure. In the thermodynamic equilibrium, the vapors can be characterized with the parameter of saturated vapor pressure. In contrast, gases could be condensed into the liquid form at low temperatures and/or high pressure

Vapours: Hydrocarbons (hexane, cyclohexane, octane, and higher hydrocarbons constituting petrol), Alcohols (methanol, ethanol, butanol, propanol), Ketones (acetone, ethylmethylketone), Ethers, Aromatics (benzene, toluene, ethylbenzene, xylene,), Chlorohydrocarbons (chloroform, dichlormethane, dichlorethane)

Gases: *Electronegative (oxidising gases):* Oxygen, Chlorine, Hydrogen Chloride, Hydrogen Cyanide (cyanide gas), *Electro-positive (reduction gases):* Hydrogen, Carbon Monoxide, Ammonia, Low hydrocarbons (methane, ethane, butane, propane constituting natural gas), Acetylene

The major objective of the WP2 consisted into the development of an autonomous navigation, implying the exploitation of the vision sensors (Traversability analysis, victim detection, 3D structure from Motion..) and the use of performing SLAM techniques. See further WP6. The adopted method consisted into the implementation of a Behaviour Based Navigation (BBN), based on the successful technique applied in Robotics for the Humanitarian De-mining [9]

The next VF- BBN scheme has been adopted:

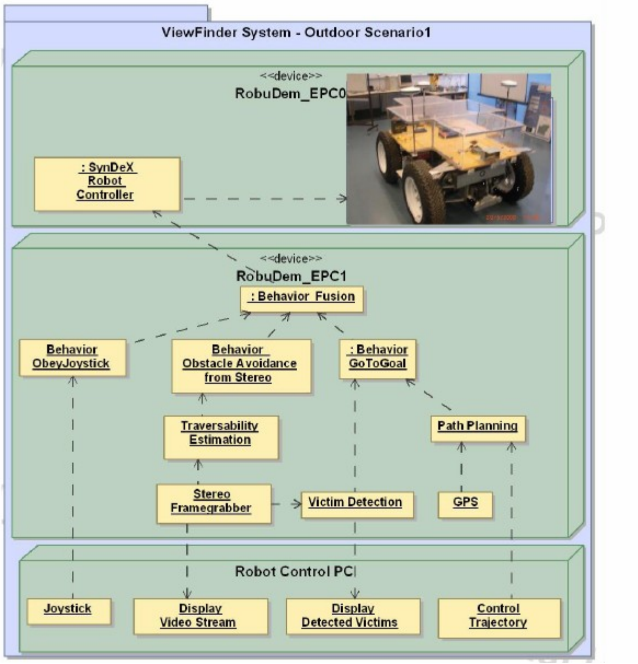

Figure 4. Robudem Control Architecture

A behavior is a function which relates sensor measurements to actions in the form of an objective function. In the case of the robot control, the objective function of each behavior can be regarded as two-dimensional normalized function of robot steering velocity v and direction α . For this setup, three behaviors are defined which relate the abstract sensor information into robot actions. These three behaviors are:

a. **Obey Joystick Commands.** If desired, the human operator can control the robot by means of a joystick. The joystick commands are directly related to the robot steering angle and direction, so the transformation of the joystick control command into an objective function can be performed straightforward by calculating a two-dimensional Gaussian from the joystick input:

$$o_{Joystick}(v,\alpha)=\frac{1}{\sqrt{2\pi^{2}\sigma^{4}}}\exp\left(-\left(\frac{v-v_{Joystick}}{2\sigma^{2}}^{2}+\frac{\alpha-\alpha_{Joystick}}{2\sigma^{2}}^{2}\right)\right)$$

b. **Obstacle Avoidance Using Stereo.** To drive the robot away from obstacles detected by a terrain Traversability analysis algorithm [11], the obstacle image is analyzed. The depth values of pixels corresponding to obstacles are accumulated per vertical line in the image and the resulting function is inverted and normalized. This allows to deduce a function *f* of the viewing angle as shown on the next left figure

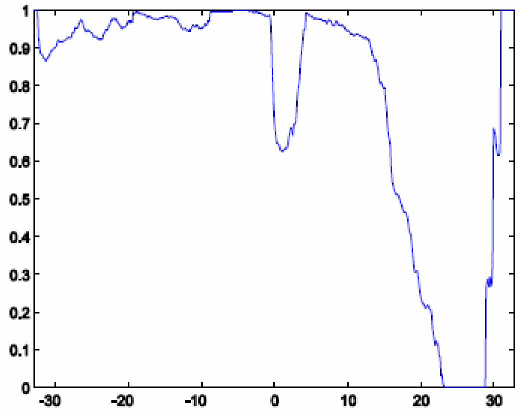

Figure 5. Traversability Analysis in outdoor environment

This function can be regarded as a one-dimensional objective function for obstacle avoidance from stereo input, considering only the viewing / steering angle. This one dimensional objective function can then be extended for velocity as well, using the following formulation:

$$o_{stereo}(v,\alpha)=\frac{f(\alpha)}{1+|vf(\alpha)/c|}$$

c. Go To Goals. The goal seeking behavior is assigned two tasks. First, it points the robot to the goal position and it varies the velocity respective to the distance to the goal. This means the development of the objective function can be split up as

$$o_{GoToGoal}(v,\alpha)=o^{\alpha}_{GoToGoal}(\alpha).o^{v}_{GoToGoal}(v)$$

To calculate these objective functions, the (Euclidian) distance to the goal d_{goal} and heading to this goal θ are calculated from the current robot position given by the GPS system and the current waypoint given by the global path planner. The goal seeking behavior aims to minimize the difference between the robot heading α and the goal heading θ, which can be formulated as:

$$o^{\alpha}_{GoToGoal}=\frac{1}{1+\left(\frac{\alpha-\theta}{\beta}\right)^2}$$

with β the window size which is considered.

The objective function related to the velocity is set up such that the velocity is always high, with the exception that when the robot approaches a goal position, the speed should be reduced. This is expressed as:

$$o^{v}_{GoToGoal}(v)=\begin{cases}\left(\dfrac{v}{v_{\max}}\right)^{2} & \text{if} \quad d_{Goal}>d_{Threshold}\\ \dfrac{1}{1+\left(\dfrac{v}{v_{\max}}\right)^{2}} & \text{if} \quad d_{Goal}<d_{Threshold}\end{cases}$$

The 3 behaviors have then been fused together to form one consistent and globally optimal robot command, to be sent to the robot actuators. The performance of the behavior-based controller depends on the implementation of the individual behaviors as well as on the method chosen to solve the behavior fusion or action selection problem. We have chosen a method to solve the action selection problem, by formulating it as a multiple objective decision making problem, as proposed by Pirjanian in [17]. The applied method is described in [18]

3. WP3 – WP5 : VF System Architecture and Human Machine Interface: the Base Station

For the sake of the clarity, we can imagine the View Finder software architecture as a system organised in two levels: the first level covers the communication between the appliances (robots and sensors) with the external world throughout the base station; the second level covers the communication of the data gathered form the robots (previously adapted and formatted to be exploited) to the crisis managers and the communication between them. The base station is in charge of managing the robots. The CMIS takes the information produced by the robots and the sensors they carry, and relayed through the BS, and provide an interface to this information for the crisis managers

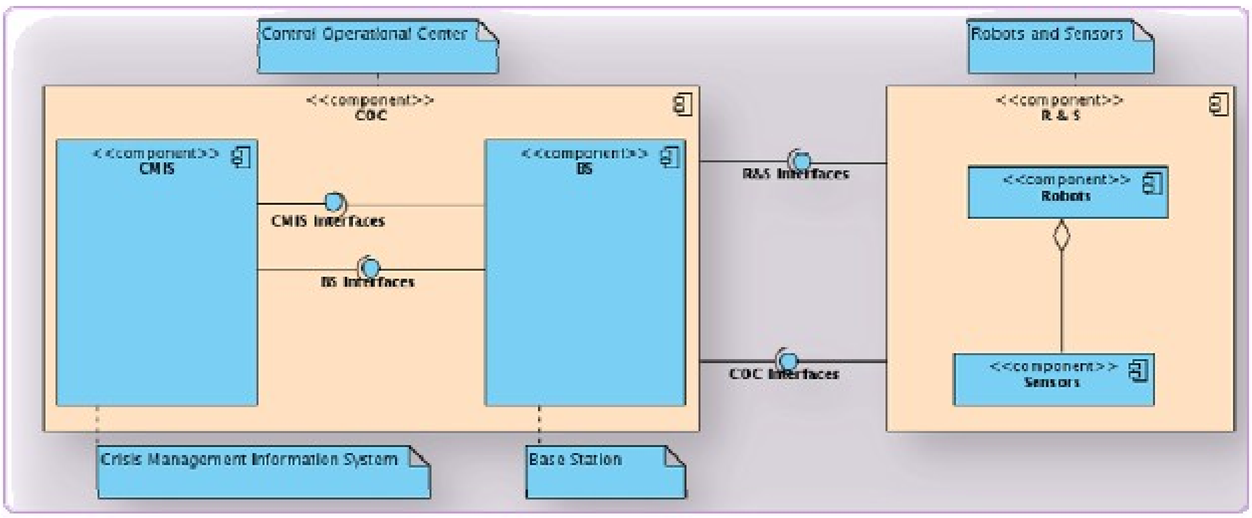

Figure 6. View-Finder Software Architecture

The base station (see figure 7 hereafter) is one of the two components of the VF Control Operation Center (COC), the second one being the CMIS (see par 1.1 above). Together with the robot platforms and their sensors, they constitute the View-Finder system.
In the base station, we identified the following software components, as being part of the base station:
a. Base Station Core (BSC), providing the essential base station services (e.g. housekeeping)
b. Mission Template Editor (MTE), which purpose is to provide tools for edition mission templates
c. Mission Planner, Scheduler and Execution Monitoring (MPSEM), aiming at supporting online mission execution, with supervision tools

d. Mission Data Recorder & Dispatcher (MDRD), recording on-the-fly the whole data flows transiting through the base station and dispatching them to the concerned entities.
e. HMI Clients, providing the overall user interfaces for the robots operations (monitoring and control in particular)
f. Sensor Data Processing (SDP), providing data processing tools to turn rough acquired data into exploitable models and knowledge
In addition, the base station provides interfaces with the CMIS and interfaces with the robots and their sensors, as depicted on the figure hereafter.
All those components have been described in earlier publications [19,20]

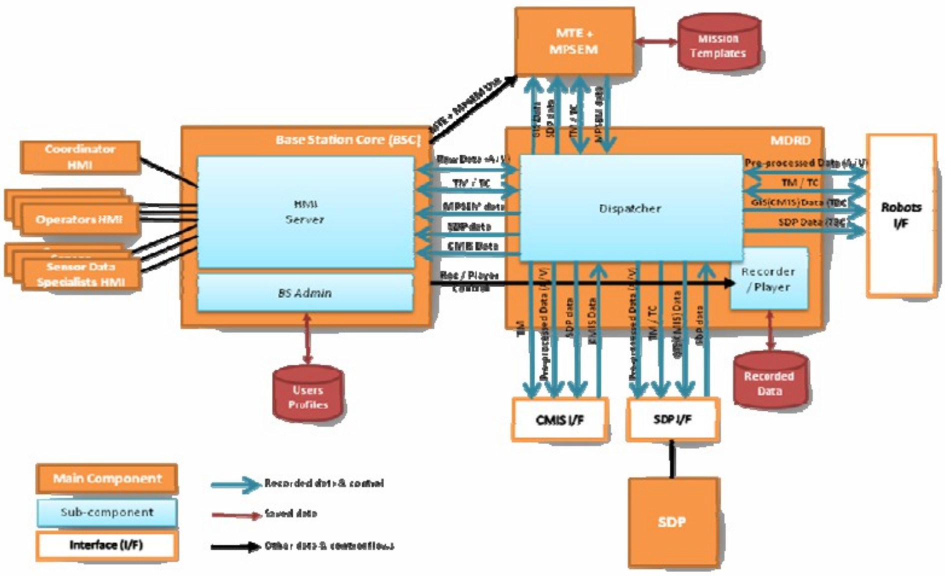

Figure 7. Base Station Components Details and Associated data flows

4. **WP4 Network Communications and Frameworks**

As distributed hybrid robotics systems are becoming more complex and cooperating with each other, there is a need to promote the construction of new systems as composition of reusable building blocks. System modularity and interoperability are key factors that enable the development of reusable software. The V-F project includes the use of a designed generic control framework using CORBA as its communication middleware. Inspired by classical control applications, components have been divided in three categories: sensors, processors and actuators (Figure 8). Sensors have connections with the physical world and they output data to one Event Channel. Processors get their inputs from one Event Channel, they transform data and send the result to another Event Channel. Actuators have output connections with the physical world and received data from one Event Channel. Services can run on any machine in a network and are remotely managed by an administration application. The CoRoBa framework has been described in [5] and a CoRoSIM simulation software has specially been developed for training the VF End-Users [21]

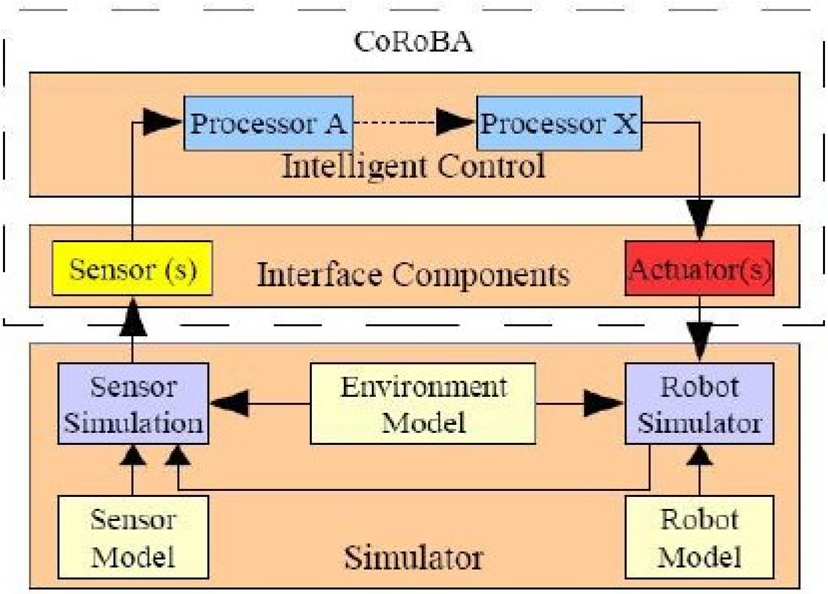

Figure 8: CoRoBa and CoRoSIM

In the View-Finder, in addition to the classical Quality of service (QoS) criteria, the following are also important:

- Fair bandwidth allocation.
- Message prioritization.

The types of data that compose the traffic in the View-Finder network comprise multimedia (video) streams, sensor readings, control commands, status messages, navigation commands, and critical messages. Each of these data types has different characteristics and QoS requirements. Therefore the View-Finder Project uses the MAILMAN protocol communication. The reader may refer to [14].

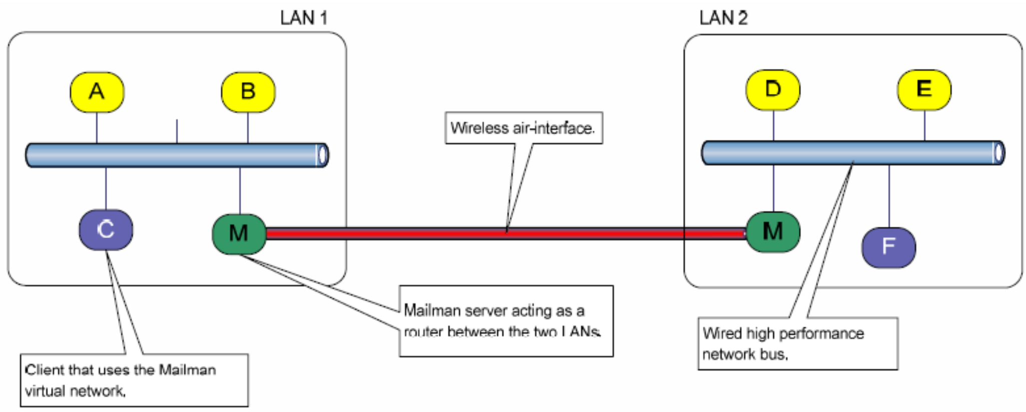

Figure 9. A typical Mailman configuration

Experiments have been made to measure the bandwidth required by typical CoRoBA components for controlling a Robot and to evaluate the practical control distance inside a building and outside: in this last case, communications (VIDEO as well as RADIO) till 150m don't pose any problem. However, inside a building and taking into account with the criteria, Mailman gives better results as can be deduced from several experiments in different conditions:

Site	*Distance from base station (metres)*	*Description*	*Maximum bandwidth (kilo bytes / second)*	*End-to-end Latency (milliseconds)*	**Jitter (milliseconds)**
1	57	LOS[1]	370	23.62	9
2	63	NLOS[2], indoor, 1 concrete wall	257	23.37	9
3	168	NLOS, outdoor, behind enbankment, obstacles	212	26.21	11
4	240	NLOS, in a tunnel, behind 2 fire trucks	62	28.17	35
5	360	NLOS, outdoor	No signal	-	-
6	106	NLOS, indoor, several thin walls	180	26.04	15
7	130	NLOS, outdoor, behind building, additional thick wall	30	24	56

5. WP6 Map Building and Reconstruction

RMA in cooperation with his partner DUTH [22] developed four software tools

5.1. **Vision-based Simultaneous Localization and Mapping [6]**

In the outdoor application the robot ROBUDEM uses a single monocular camera to extract natural features in the scene. These features are used as landmarks in the built map. The SLAM problem is tackled as a stochastic problem using an Extended Kalman Filtering to maintain a state vector, $\mathbf{X}$, consisting of the robot state, $\mathbf{y_R}$, and map feature states, $\mathbf{x_{Li}}$. It also maintains a covariance matrix, $\mathbf{P}$, which includes the uncertainties in the various states as well as correlations between the states.
Feature are selected using SIFT algorithm and are represented by their 3D position vectors. When a feature is first detected, measurement from a single camera position provides good information on its direction relative to the camera, but its depth is initially unknown. In our application, to estimate the 3D position of the detected features, we use an approach based on epipolar geometry. This geometry represents the geometric relationship between multiple viewpoints of a rigid body and it depends on the internal parameters and relative positions of the camera. Features are not deleted from the map when they leave the field of view, but remain in the map and can be re-observed when the camera moves back and they become visible again.
However, in our application, the accuracy has to be ensured even if no temporary GPS communication happens: for its localization, the ROBUDEM is equipped with a set of sensors: RTK-GPS, inertial navigation system (INS) and Wheel encoders. Each of those sensors, when used separately, is subject to a lot of error sources affecting the accuracy of the obtained robot positioning. Combining the data may improve the SLAM. First results will be acquired by the next trials in Beauvechain (October 2009)

5.2. Victim Detection

In a first attempt at victim detection, we used the standard Viola-Jones [13] detector for face and upper body detection. The first tests were executed on indoor and good quality images. These tests were very successful, 90% of the faces and 80% of the upper bodies were detected. All together the hit rate reached the 95% while the false alarm rate stayed under 5%. However, the target hardware, the ROBUDEM, is going to operate in outdoor environment where the background is various and the illumination is unpredictable. So, outdoor experiments were strongly suggested. Although, the results were better than expected, the false alarm was increased dramatically while the hit rate was decreased to 70% for the upper body and to 30% for the face detection. The conclusion from these tests is that in outdoor environment the face detection based person detection is not viable. Usually it only consumes the computation time without giving any results or any correct results. If the detection was more detailed, the system became too slow with minor success. If the detection was tuned to be faster, the hit rate decreased under 10%. The upper body detection is more robust, it adopts itself to different illuminations much better. The actual overall detection rate reaches 65%, the false alarm is limited to 12%. It is envisaged to track and fuse the successive data with a Kalman Filter for improving those results.

5.3 Environment reconstruction: stereovision and structure from motion

Most attention in the 3D-reconstruction area has been on *stereo*-vision based methods, which use the displacement of objects in two (or more) images. Where stereo vision must be seen as a spatial integration of multiple viewpoints to recover depth, it is also possible to perform a temporal integration. The problem arising in this situation is known as the *Structure from Motion* problem and deals with extracting 3-dimensional information about the environment from the motion of its projection onto a two- dimensional surface. Based upon the observation that the human visual system uses both stereo *and* structure from motion for 3D reconstruction, our research work targets the combination of stereo information in a structure from motion-based 3D-reconstruction scheme. The data fusion problem arising in this case is solved by casting it as an energy minimization problem in a variational framework.

G. De Cubber [23] develops a promising dual approach that still has to face two problems: *the real-time* implementation of the proposed method on the mobile robot and the reconstruction of an *outdoor* environment: his study will not be achieved by the end of the project. He proposes:

(1) *the development of a novel dense structure from motion approach* which fuses sparse and dense information in an integrated variational framework. The aim of this approach is to combine the robustness of traditional sparse structure from motion methods with the completeness of optical flow based dense reconstruction approaches. The base constraint of the variational approach is the traditional image brightness constraint, but parameterized for the depth using the 2-view geometry. This estimation of the geometry, as expressed by the fundamental matrix, is automatically updated at each iteration of the solver. A regularization term is added to ensure good reconstruction results in image regions where the data term lacks information. An automatically updated regularization term ensures an optimal balance between the data term and the regularization term at each iteration step. A semi-implicit numerical scheme was set up to solve the dense reconstruction problem. The solver goes out from an initialization process which fuses optical flow data and sparse feature point matches.

(2)*The development of a novel dense reconstruction method, combining stereo and structure from motion in an integrated framework.*
We propose two approaches for the combination of stereo and motion data in an integrated framework. The first approach relies on more classical global optimization techniques, whereas the second technique uses the theorem of the augmented Lagrangian multipliers to integrate stereo and motion constraints.

6. **Conclusions.**

The very essence of the VIEW-FINDER Intelligent Information System is to integrate disparate elements involved in a crisis situation into an info-structure that allows information to be exchanged readily between all of those elements: crisis centres, relevant forces dealing with the crisis (fire fighters, de-bombing squads, police, etc.), robotics platforms and sensors. This paper introduced some results of the major outdoor tasks entrusted to the partners of the View-Finder project.

Acknowledgment

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