A cloud robotics architecture for an emergency management and monitoring service in a smart city environment

G. Ermacora, A. Toma, B. Bona, M. Chiaberge, M. Silvagni, M. Gaspardone, R. Antonini

***Abstract*— Cloud robotics is revolutionizing not only the robotics industry but also the ICT world, giving robots more storage and computing capacity and opening new scenarios that blend the physical with the digital world. In this vision new IT architectures are required to manage robots, retrieve data from them and create services to interact with users. In this paper a possible implementation of a cloud robotics architecture for the interaction between users and UAVs is described. Using the latter as monitoring agents, a service for fighting crime in urban environments is proposed. Thus we hope this will make a contribution towards the development of smart cities.**

I. INTRODUCTION

A new approach to robotics is arising, which exploiting the emerging technologies on the internet and cloud computing [1]. While in the past the robot was seen as a unique device that carried out all the computation and storage processes onboard, presently we are witnessing the dawn of cloud robotics. As Steve Cousins said "no robots is an island" [2]. This brings us to a shift where "robot intelligence" which was once local for every single robot, will now be managed by a higher and more powerful "centralized brain" located in the cloud architecture [3]. This breakthrough opens new scenarios where robots are seen as agents, can share knowledge and information[4] by relying on remote servers for most of their computational load and data storage.

The cloud robotics approach involves the software abstraction of each robot, abstracted from the hardware layer, and presenting ad hoc APIs to ease its management and the process of writing code on it. Even non robotics experts can now write programs without knowing the specific robot software architecture, simply by calling the precise APIs from their code [5]. Furthermore, once the API has been approved and tested, this approach facilitates the structure of the program and reduces the possibility of errors. In this way both beginners and experts that want to build a service do not need to know in detail the dynamics and the technical features of the required robot.

This paper presents a *platform of cloud robotics* and its related *services*. The platform provides an abstraction layer of each robot accessible via APIs and offers support to services available to final users [5].

The number of applications that see UAV as interesting devices for environment monitoring is growing. Indeed users can access to services built by fetching data from UAVs, such as telemetry or video streaming.. As this paper illustrates, these services, which are part of the IT architecture, can be accessed via web or other devices, such as smartphone applications.

When UAVs are required for search and rescue or emergency interventions:

1. User sends a request to the service.
2. The request is automatically forwarded to the platform.
3. The platform transforms the request into a mission in a lower level language message.
4. Depending on the mission the message will be deployed to either a single or a swarm of UAVs

The platform is designed to be resilient in case of failure. The message is conceived as a buffer of data containing the minimum mission requirements. If the UAV loses the connection from the platform it is still able to accomplish the task. The platform can also accept real-time reconfigurations after the mission has been submitted to the UAVs.

In this paper the architecture previously outlined for emergency management and monitoring services is described. A real security problem in a urban context is proposed as a test case in this paper; urban spaces monitored by cameras are not an efficient way to decrease crime rates since criminal events e.g., theft, robbery, rape tend to occur in unmonitored zones. Thus the aim of this test case is to apply this cloud architecture, based on ROS [6], to crime prevention. In the case of aggression the user requests the emergency service from the IT architecture, by providing GPS coordinates and an identification number. The IT architecture organizes a UAV to reach him/her for offering monitoring and support. In the meantime a police officer will use the service to see the current position of the UAV, its telemetry and video streaming from its camera.

In this paper there is a first step towards a more complete idea of cloud robotics. In fact the future developments of this project aim to:

- Add robots of really low capabilities or not compliant with ROS framework to the cloud architecture

This work is in collaboration with Telecom Italia Lab.

G. Ermacora, A. Toma and M. Silvagni are with DIMEAS, Politecnico di Torino, Torino, Italy, {gabriele.ermacora, antonio.toma, mario.silvagni}@polito.it

B. Bona is with DAUIN, Politecnico di Torino, Torino, Italy, basilio.bona@polito.it

M. Chiaberge is with DET, Politecnico di Torino, Torino, Italy, marcello.chiaberge@polito.it

M. Gaspardone and R. Antonini are with Telecom Italia Lab, Torino, Italy, {marco.gaspardone, roberto1.antonini}@telecomitalia.it

- Add a network and database repository (e.g. Roboearth [7]) to improve services for monitoring and emergency management. We could also add capabilities of cloud computing and storage e.g. a face detection algorithm to recognize aggressors running on the cloud

This work will have to find a tradeoff between relaying all the intelligence on the cloud and giving robots a resilient capacity. The cloud approach makes the robot however dependent on the reliability of the Internet connection, especially in this test case, it is important to respect mission constraints and maintain the control of UAVs in the case of connection problems.

Roadmap of the paper. The paper is structured as follows: *Section 2* describes the service from the user and police officer side in. The cloud robotics platform structure and mechanism is explained in *Section 3.* The hardware and UAV implementation is presented in *Section 4.*

II. WEB SERVICES AND INTERFACES

In this paper two interfaces to service are presented:

- a user-side interface which requests help and assistance from the UAV;
- A police-side interface for monitoring and fleet management.

The first interface requires a device in order to send the help request. The device sends a POST request, over HTTP protocol, to an ad hoc server listening on a predefined URL and port. In the POST request there are the GPS coordinates at the moment of the emergency call and an Identification Number.

The problem of an easy and efficient interaction between the user and the device in emergency situation is not trivial. The theories of Donald Arthur Norman about Human Computer Interaction distinguish intention from action [8], whether the user wants to send a help request or it is just an error of interaction. In this case we developed an Android-based application since this operating system offers an easy and affordable way to create mobile software. There are other devices that can accomplish the same goal (e.g. an ad hoc designed bracelet, a smart watch, etc.). These topics are not the focus of this paper; therefore will be further investigated in future works.

The usage of the Android application is as follows :

- the user knows in advance that is going to enter in an harmful zone. He/she activates the application in his/her smartphone, running it in background
- the user sends the help request by swiping a button. The application starts sending the POST request with GPS coordinates and user's phone number as Identification Number. The swipe button has been chosen in order to reduce errors in the interaction. This particular widget in fact is widely adopted for the incoming phone call or to activate the smartphone from sleeping mode.
- In case of false positive or error the user can stop the help request swiping on a similar widget on the opposite side of the screen.
- The application is designed to produce a loud alarm while sending an help request.

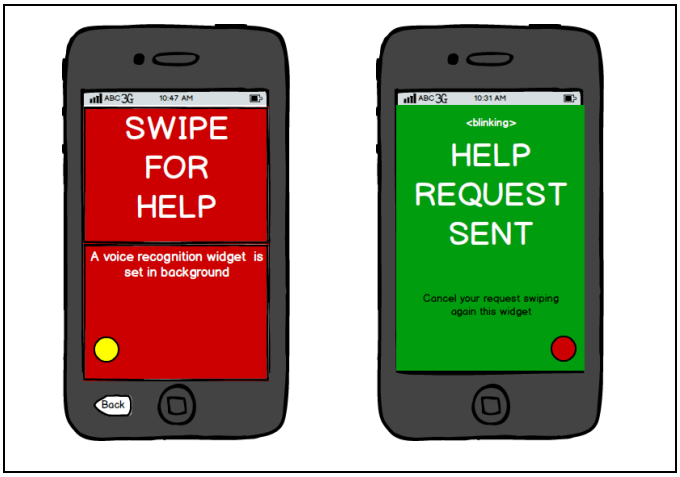

Figure 1 : two screenshots of the application in wireframe. On the left the asking request activity and on the right the confirmation of the help request and the widget to delete the help request.

In this case we call the Android application *interface* and not *service* since it is not using the presented API from the IT architecture. It just send a POST request to a web server that will utilize the service.

The second interface is addressed to the police force. The officer accesses all the information about the UAV collected by telemetry and video streaming via a web browser. In this way he/she can know the actual position of the UAV, displayed on a map embedded in the web page. Information about remaining estimated time and distance for mission accomplishment are also made available. In addition, the video streaming from the UAV camera can offer assistance to the person in emergency. In this case the service is build exploiting the API presented from the IT architecture, so we call it a *service*.

III. THE CLOUD ROBOTICS PLATFORM

Our Cloud Robotics platform is based on the following principles:

- abstracting the complexity of hardware and software at different levels to final developers;
- transferring the intelligence, that normally resides on the robot, to the Internet, i.e. to a Cloud Robotics Platform (remote brain);
- exposing Application Programming Interfaces (APIs), which ease service developments and share the resources amongst different services by:
    - managing deployed applications where parallel computation typically resides, e.g. keep them alive, error management;
    - abstracting platform resources;

- providing developer access, e.g. account management;
- providing multi user access i.e. concurrent access to platform APIs;
- guaranteeing security access, e.g. certified VPN to connect robots.

Starting from these concepts, we have built a robotics platform which mainly consists of three layers :

- Front End which contains APIs to build new services;
- Application which contains all specific applications (the so called "remote brain"), that support APIs above;
- Adaption which contains adapters and drivers to connect different robots, and abstracts their basics functionalities to the above applications and APIs.

Our platform is based on ROS framework [9], as showed in Figure 2, where gray boxes represent ROS nodes. The platform context is composed by two additional layers:

- Robots which contains all robots. They are connected to the platform through specific ROS nodes, named drivers and adapters (Adaption Layer);
- Services which contains all services exploiting APIs exposed by the platform (Front End Layer).

All elements running in Application Layer, represent various applications each implemented by a ROS node. APIs connect all ROS nodes to abstract their interfaces to service developers. The interface of a ROS node is a message that is typically conveyed by the three different communication processes: publish-subscribe, service-client, action-feedback. Therefore a ROS message is identified by its type and its communication process, namely a topic, service or action name; e.g. the ROS message "geometry-msgs/Twist" [9] and its topic can be abstracted by "move" API, where the name is uniquely related to a topic name (/cmd_vel) and the parameter is an object "Twist" having the same format of ROS message above. Once this API is called by a service, the ROS message is composed and published to ROS framework through the addressed topic.

Another example could be represented by NavData message abstraction, in this case the "get_feedback" API subscribes the related topic (/navdata) and registers a callback to be notified every time NavData message is published on this topic. The previous examples show the one-to-one relation between ROS messages (and their related topics or services) and APIs

The shift from the concept of ROS framework to the concept of ROS Container means introducing a management system (outside ROS framework). This traverses all layers where ROS nodes reside; so the ROS container includes the ROS framework and adds to it the following managing elements:

- WatchDog System (WDS): to manage ROS nodes;
- Message Discovery Function (MDF): to enable or disable APIs according to ROS messages.

Those will be better explained in the following paragraphs. Other important issues to be considered are Security and Concurrency.

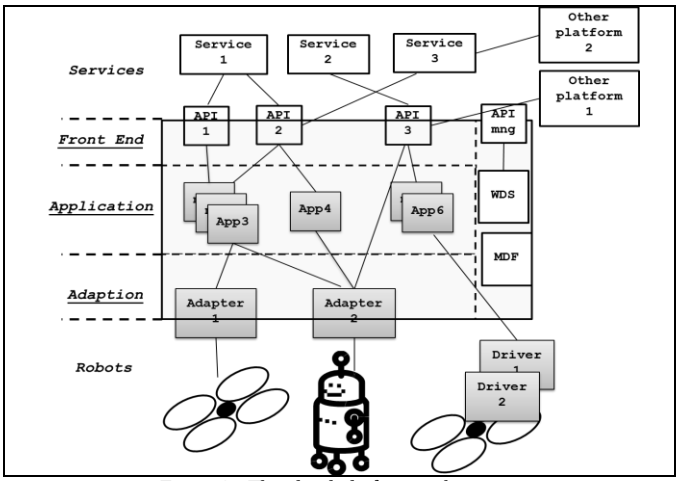

Figure 2 : The cloud platform architecture

Security needs some specific infrastructure and has to be guaranteed at the platform gates, i.e. Front End and Adaption layers. APIs must be safely accessed after a registration phase, where developers are identified and specific security keys are provided. Robots are connected to the platform via-VPN, if possible certified, in order not to be easily accessed by hackers. Security keys are installed at robot side.

Concurrency needs also to be managed at ROS level, when two or more users access the same service. A ROS message is exchanged with the ROS framework if a service makes access to one of the above specified APIs. Here a ROS node is deputed to manage such message. Therefore this node has to be designed to manage concurrency in a multithread architecture, e.g., the mission planner node (better explained in the following) has to manage two or more drones at the same time.

A. WatchDog System (WDS)

A ROS Node needs to be managed taking into account its life cycle, as showed in Figure 3. A ROS node life cycle (NLC) concept is introduced, represented as a simple Finite State Machine. In this representation the states represent node status and the arrows represent both expected (e.g. start and stop) and unexpected events (e.g. error). For managing such events dedicated management APIs are introduced, which expose basic functionalities to support error check and get or modify nodes status ("on demand" start and stop, get failure node status). Therefore a WatchDog System (WDS) is built to perform the following actions:

- enacting strategy to keep ROS nodes alive, e.g. for each started node a proper WatchDog element runs to keep it alive, in order to prevent accidental failures due to unforeseen causes.
- periodically updating status of each ROS node, for the benefits of the Message Discovery Function (see next paragraph)

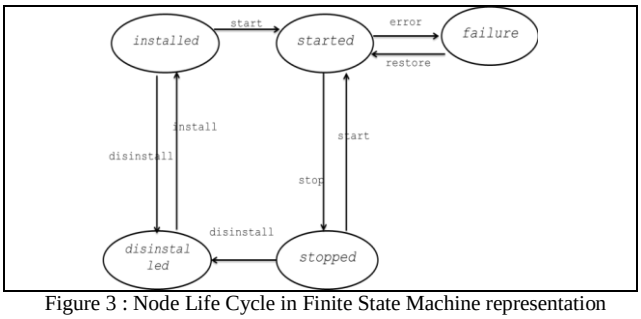

Figure 3 : Node Life Cycle in Finite State Machine representation

B. *The Message Discovery Function (MDF)*

The Message Discovery Function (MDF) enables or disables ROS APIs based on available ROS messages. As example, the standard structure for accessing data from a digital camera in ROS is a "sensor_msgs/Image" message type and a typical /image_raw topic; hence here for ROS message is meant the couple *message type, topic/service/action*. Thus if a ROS message is not present, the ROS API abstracting this message is disabled. Furthermore ROS messages could be related each other, e.g. referring to Figure 4, the message *Msg 1* from Node 1 is related to *Msg 2* from Node 3, so ROS API 1 abstracting message ROS *Msg 1* is also disabled if *Msg 2* is not present. This complex relation between ROS APIs and ROS messages results in a tree structure, where ROS messages are the tree nodes (not to be confused with ROS nodes that contain actually these messages) and ROS APIs are the tree leaves.

Every time a ROS node changes its status, the WDS updates the nodes of the tree accordingly and, as a consequence, the ROS APIs could become available or unavailable. For example if node 3 status is "stopped" or "failure", then ROS APIs 1, 3, 5 and 9 are unavailable, whereas if node 2 status is not "started", both ROS API 3 and 10 are unavailable.

In Figure 5 the management architecture is depicted: the WDS is a set of scheduled processes (WD) in charge of keeping alive ROS nodes and updating their status in the tree structure. MDF element accesses to the tree structure, in order to report, for each ROS API that has to be checked, the visited path to reach it. MDF aims to support error check at ROS API level, e.g. the reported error in case of API 1 unavailability, could be something like this:

API 1 unavailable: msg1 (node 1) started, msg2 (node 2) failure.

To summarize, the new introduced management elements result in a new set of APIs. They are grouped in the following categories:

- Management: HTTP REST APIs, built by us to manage ROS nodes (start, stop and check).
- Message Discovery: HTTP REST APIs, built by us to check ROS APIs status in terms of their availability.

As ROS API it is meant standard javascript ROS API [10].

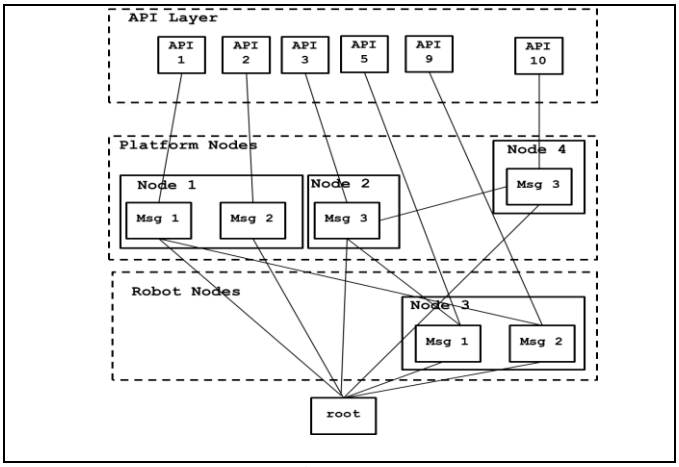

Figure 4: tree structure for Message Discovery Function

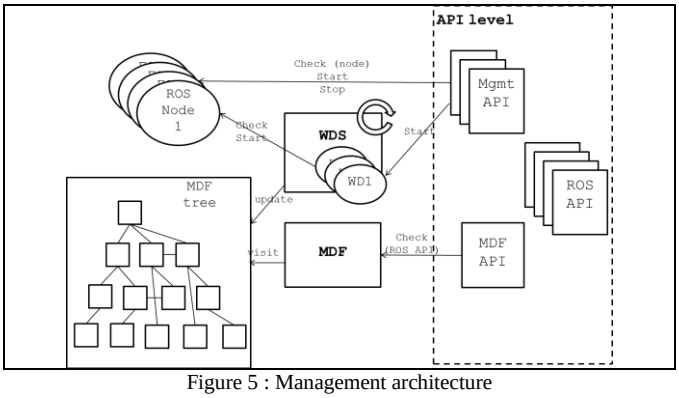

Figure 5 : Management architecture

C. *Emergency and monitor service*

The ROS APIs and nodes supporting the service described in previous chapter, are depicted in Figure 6. The service core logic is implemented in mission planner ROS node, the ROS message and the service/mission are abstracted by **build_mission** API. Thus, in order to build a mission starting from the home GPS position of the UAV to the requested GPS position, a call to **build_mission** API is needed accepting as parameter an object with the following request message structure:

Header *header*
Coordinate *home*
Coordinate *target*

The mission planner receives the above message and optimizes the following cost functions, in order to choose a drone amongst the available ones in terms of:

- Distance to travel
- Drone battery consumption
- Drone battery autonomy

Once a drone is chosen, mission_planner publishes the FlightPlan message in specific topic to chosen drone, by addressing it on namespace basis, and returns that namespace in the following response message structure

String *drone_name*

where *drone_name* is the namespace related to the chosen drone. The drone name previously returned and, as a consequence, strictly linked to emergency request, is used to address following APIs:

- **get_feedback** collects telemetry and sensor data from chosen drone, e.g., GPS current position, in order to feed the drone position to a monitoring system tracking on a geo referenced map.
- **video_streaming** returns the camera video streaming, allowing a remote operator to watch emergency conditions.
- **move** used to remotely operate the drone.

In this service, part of the intelligence is transferred from drone to platform. Indeed the mission is planned at platform side, the drones are simply mission actuators and are connected and managed concurrently by the platform itself. The brain (mission planner and drivers) is kept alive by the WDS platform component and its functionalities (APIs) checked by MDF platform component.

IV. THE AGENTS

The first validation-tests of the overall system have been conducted using a quadrotor as agent. A quadrotor offers several clear advantages with respect to other possible choices (fixed-wing UAVs, terrestrial rover, etc.).
In particular a quadrotor is well-suited for surveillance and monitoring tasks because of its capability to hover above the target. The same is valid also for a standard helicopter architecture, but at the price of more complex mechanics and more difficult control scheme.

On the contrary a quadrotor is easy to maintain and less expensive than a helicopter with similar features (in terms of autonomy and maximum payload weight). Unfortunately a quadrotor is an inherently unstable system [11], and for this reason it requires some electronics (autopilot) to guarantee its stability in standard flights [12].

Three different products are used in the validation of the proposed architecture:

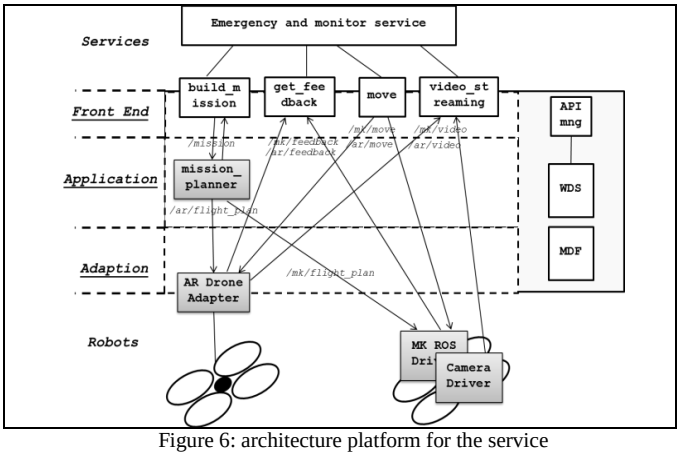

Figure 6: architecture platform for the service

Parrot AR.Drone: The AR.Drone [13] is a commercial low-cost quadrotor solution, fully equipped for remote control via smartphone. It features a front HD camera and the flight stability is ensured by a mother board (running a real-time linux-based operating system) and a navigation board interfaced with the on-board sensors (two cameras, ultrasonic range finders, gyroscopes and accelerometers).
The AR.Drone is mainly conceived for gaming applications, amusement and Augmented Reality videogames, but due to its low-cost, flexibility and the availability of an official SDK, it gained a very good popularity in the academic community.

Mikrokopter: Mikrokopter [14] is a complete auto-pilot designed for the control of generic multi-rotor platforms. It features two different boards: the Flight Control board guarantees vehicle inherent stabilization and altitude-hold function, the Navi Control board adds a set of GPS/Compass based autonomous navigation functions (waypoint navigation, come-home function, position hold mode). The Flight Controller relies on Atmel ATMEGA644 board running at 20MHz, and interfaces with the main inertial sensors (3-axis accelerometer, three gyros, one barometric sensor). Mikrokopter allows the user to take external control of the UAV (i.e., bypassing the radio controller) by means of a dedicated serial protocol.

Micropilot 2128: uPilot 2128 [15] is an auto-pilot board embedding all the peripherals needed for a stable and autonomous quad-rotor flight. This auto-pilot is specifically addressed to professional use and applications, this is reflected by its higher price and its market segment. Though Micropilot uses a completely closed-source software, it offers some tools allowing the user to write his own code. These functions come with an add-on product called "Xtender" [16]; Xtender provides a dedicated dynamic linking library that acts as a intermediate layer between the user code and the autopilot software. Using the functions encoded in the library the developer is able to get access to several low-level parameters of the auto-pilot and can modify their values.

Due to Micropilot's high price and to its relatively young support to multi-copters when compared to other solutions on the market, it is not so common to find academic works that use this hardware.

Notice also that AR.Drone is a commercial ready-to-fly quadrotor while Micropilot and Mikrokopter are just two different models of autopilot electronic boards; in order to fly these require a mechanical frame, four or more motors, the same number of ESCs (Electronic Speed Controllers) and a battery. However since the ROS interface has to communicate directly with the autopilot, from a functional point of view the ROS architecture is not impacted by the general architecture of the agent, therefore this has not been described in detai

The three architectures offer growing functionalities, but also growing difficulties in implementation. Table 1 summarizes their main features and their integration status in ROS environment.

TABLE I. QUADROTORS FEATURES AND INTEGRATION STATUS IN ROS ENVIRONMENT

	Market	**Command**	**Telemetry link**	**Autonomous navigation**	**SDK**	**ROS support**
AR.Drone	Videogames /Hobby	Smartphone (via wifi)	Wifi (TCP/UDP packages)	☹	☺	☺
Mikrokopter	Hobby/ Photographer	Radio controller	UART (Custom Serial Protocol)	😐	☹	😐
Micropilot 2128	Professional applications	Radio controller	UART (Custom Serial Protocol)	☺	☺	☹

Notice that the only platform adequately supported in ROS is AR.Drone; a ROS node for Mikrokopter has also been written [17], but it requires flashing a software patch on the Flight Control board firmware and thus it has been excluded from this study, since we aim at maintaining the compatibility with the standard version of the cited auto-pilot; finally there is not any ROS node dedicated to microPilot support.
Therefore two different ROS interfaces have been written from scratch, one dedicated to Mikrokopter and the second to Micropilot. We choose to manage these nodes differently from the AR.Drone one. In fact the AR.Drone is well-suited for short-range mission and it is acceptable to maintain all its ROS interfaces in the cloud; on the contrary, the Mikrokopter and Micropilot are more likely to be used in long-range GPS-aided missions where a sudden loss of connection with the cloud must not interrupt the mission or – worse – exhibit dangerous behaviours or cause damages and injuries. For this reason, in these latter cases, the ROS driver node runs on a dedicated PC/104 board directly connected to the auto-pilot on the UAV. This choice allows to trigger specific emergency-management routines in case of missing link or communication issues. As depicted in Figure 2 the ROS interface takes the function of *adapter* in the Parrot AR.Drone case, while it should be considered a *driver* for Mikrokopter and Micropilot.
The three described solutions where specifically chosen in order to cover every possible segment of the market and to demonstrate the flexibility of the proposed service in adapting the mission schedule to very different families of available agents. Moreover they easily show the already highlighted difference between the *adapter* and *driver* modules in the cloud platform.

CONCLUSION AND FUTURE WORK

In this paper we propose a test case for cloud robotics for emergency management and monitoring service. We intend to exploit the emerging technologies of web services and mobile applications to use robotics in the proposed cloud architecture. In addition we want to leverage the power of cloud computing in terms of storage and computing e.g. adding the ad hoc cloud engine Roboearth [7]. Experimental results and data will be available in the next few months since the project is under development. A deeper and more complete study of Human Robot Interaction in emergency context will be also part of our future work.

REFERENCES

[1] Mell, Peter, and Timothy Grance. "The NIST definition of cloud computing (draft)." *NIST special publication* 800.145 (2011): 7.
[2] Ken Goldberg, Ben Kehoe , *Cloud Robotics and Automation: A Survey of Related Work.* Electrical Engineering and Computer Sciences University of California at Berkeley
[3] Sanfeliu, Alberto, Norihiro Hagita, and Alessandro Saffiotti. "Network robot systems." *Robotics and Autonomous Systems* 56.10 (2008): 793-797.
[4] Chibani, A., et al. "Ubiquitous robotics: Recent challenges and future trends." Robotics and Autonomous Systems (2013).
[5] Kamei, Koji, et al. "Cloud networked robotics." *Network, IEEE* 26.3 (2012): 28-34.
[6] Quigley, Morgan, et al. "ROS: an open-source Robot Operating System." *ICRA workshop on open source software*. Vol. 3. No. 3.2. 2009.
[7] Waibel, Markus, et al. "Roboearth." *Robotics & Automation Magazine, IEEE*18.2 (2011): 69-82.
[8] Norman, Donald A. "Categorization of action slips." *Psychological review* 88.1 (1981): 1.
[9] http://www.ros.org
[10] http://wiki.ros.org/roslibjs
[11] Hoffmann, Gabriel M., et al. "Quadrotor helicopter flight dynamics and control: Theory and experiment." *Proc. of the AIAA Guidance, Navigation, and Control Conference*. 2007.
[12] Bouabdallah, Samir, and Roland Siegwart. "Backstepping and sliding-mode techniques applied to an indoor micro quadrotor." *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*. IEEE, 2005.
[13] http://ardrone2.parrot.com/
[14] http://mikrokopter.de/en/home
[15] http://www.micropilot.com/
[16] http://www.micropilot.com/products-xtendermp.htm
[17] Sa, Inkyu, and Peter Corke. "Estimation and control for an open-source quadcopter." *Proceedings of the Australasian Conference on Robotics and Automation 2011*. 2011.