Innovative Early Warning System for Natural Disasters – Case Study on Earthquakes with Earthquakeguard™ and NowTice™

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Abstract. NowTech has realized Earthquakeguard™ a Rapid Alerting System of Seismic Events – Earthquake Early Warning System, based on a special sensor that does not generate fake alarms. Using this kind of sensors this innovative system is also able to provide a high precise and reliable structural monitoring system, furthermore these sensors are suitable to carry out seismic micro zonation studies and researches for hazard estimation.

REGOLA is a dynamic organization, developing fully in-house products with a modular approach. The ultimate purpose is to deliver comprehensive seamlessly-integrated software solutions and ready-to-use independent applications, keeping the whole technological framework open to external sources and standard integrations with 3rd party providers. Regola's Nowtice™ is the cloud service designed to send out critical warnings and simple notifications, thought for Organizations and Institutions who need to communicate effectively, timely and controlled, especially in case of emergency situations.

The article explains how these solutions can be combined in order to create an innovative early warning system focused on earthquakes.

Keywords: Earthquake · Early Warning System · EWS · Mass alerting system · Public warning system

1 Introduction

Public Warning Systems are needed to protect the lives of people in case of major emergency by warning the public of impending disasters. Tornados, tsunamis, hurricanes, floods, natural volcanic, and releases of deadly gas are examples of dangerous situations where PWS can save lives. Chemical plants, hydroelectric plants in dams and nuclear facilities are required to have the ability to notify the surrounding population of an industrial accident. There is no doubt that effective early warning systems have substantially reduced deaths and injuries from severe weather events [1].

This article introduces about the possibility that new technologies offer to extend this experience to earthquakes. Such events are unpredictable, wide and disruptive but

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today exist the possibility to manage this events to build an early warning system who produces reliable alert with a significant advance of time that can be exploited to take some proactive actions and save lives. Moreover, this article describes in detail the characteristics of a modern mass alert system which is part of a public warning system. One of the best advantages of an integrated, modern mass alert system is the ability to provide people with **two-way communication**. Public warning systems of the past only spread emergency alerts, giving people information but neglecting the power of the environment to contribute valuable information.

Today's culture is much different. With social media, Internet Of Things (IOT) hardware and smart cities, people have become part of the stories they document, as they unfold. Regular citizens provide eye-witness accounts, IOT sensors provide live streams of data, as well as commentary, insight, and feedback. These ground-level accounts of situations not only inform the public of what's going on, but give first responders and public safety officials invaluable insight into the chronological order of events, the needs of the people involved, and a play-by-play of the event itself. This knowledge helps shape strategy, align proper response personnel, inform surrounding areas of potential danger, and better direct people in harm's way.

Muting these self-proclaimed reporters by removing their ability to respond to alerts seems archaic these days. People expect to be part of the conversation as well as part of the solution. Companies must provide this conversational, two-way dialogue in their emergency communication plan as much as for the company as for the employees. Mass alerts can include links to additional information and forums, provide a social media page where employees can upload pictures and videos, construct message boards in mobile apps, and much more to encourage participation.

In case of an **earthquake** what was mentioned before it is extremely true, thus a modern Early Warning System (EWS) should be connected to a new Public warning system capable to interconnect emergency agencies and the population. But the main challenge of Earthquake EWS is to avoid false alarms in order be fully accepted by the population who must trust it. In this document is described an innovative Earthquake EWS that can 'foresee' the arrival of the earthquake without generating false alarm. This EWS is connected with a platform that manage the mass alert communication using the new technologies and characteristic described above. The combination of these two technologies can help emergency manager to build a more proactive and efficient network able to the forecast and manage earthquakes.

2 EEWS – Earthquake Early Warning System - EarthQuakeGuard

NowTech is an Italian company which has its own corporate focus on environmental and structural monitoring systems. NowTech has realized an Earthquake Early Warning System (EEWS) named 'EarthQuakeGuard' that doesn't generate fake alarms.

The solution relies on distributed monitoring sensor network connected to a main remote server that collects and evaluate in real time the ground acceleration and ground motion of the area covered by the sensor network.

If a sensor detects a seismic event, it quickly sends information and data to the main server that checks if other network sensors have detected the same event before sending alert notifications to the enabled devices in the affected area. The double check procedure and the main features of the RSS-1 detectors (described later) ensure the absence of fake alarm notifications (Fig. 1).

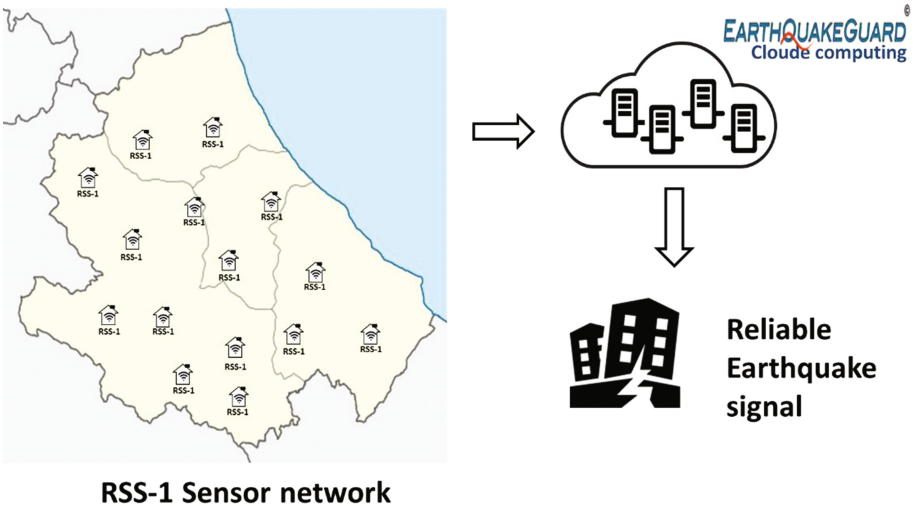

Fig. 1. Basic architecture of the solution

2.1 The Sensing and Monitoring Station RSS-1

The RSS–1 sensing and monitoring station is the sensor unit of this innovative EEWS. It can detect the full three-dimensional angular displacement (360°) of the structure on which is installed either in static and dynamic mode. This feature allows the sensor to be accurately trimmed on the structure where is installed hence it can generate very accurate tilt and twist information.

RSS–1 can detect angular displacements from a minimum variation of approximately 0.014° over all planes in the three dimensions, even obtaining the direction of the movements (Table 1).

Table 1. RSS-1 measures

Accelerometer	
Measures	Inclinometer
	Thermal (used for real time inclination measure compensation)
	PGA (Peak Ground Acceleration) PGV (Peak Ground Velocity) PGD (Peak Ground Displacement)

The minimum detectable acceleration is approximately 1 mm/s2, it is enough to sense the effects of any cracks, implosions or instant sagging of a pillar or slab; furthermore, the vertical axis monitoring can detect any subsidence or variation in altitude, hardly perceptible phenomena by traditional instruments. The RSS–1 is equipped by a seismic detector with the resolutions of the Table 2.

Table 2. Resolutions of RSS-1 sensor

Acceleration resolution	0,00025 g (2.45 mm/s^2)
Inclination resolution	0,014° (0.244 mm per meter of height)

2.1.1 Accelerometer Measurements

The three axes acceleration measures are acquired with 0.00025 g sensitivity and are dynamically performed. The embedded high-sensitivity digital accelerometers of RSS-1 allow the acquisition of very low acceleration values with excellent performance in terms of signal/noise ratio and error rate in the digitization process (14 bit of conversion resolution).

The digital band pass filter isolates and identify weak and strong signals due to natural elements such as wind and other atmospheric phenomena; the detector is also immune to anthropic elements that interact with the structure (Table 3).

Table 3. RSS-1 accelerometer specification

Maximum detectable acceleration	2 g
Maximum sampling rate	200 Hz (200 samples per second)
Acceleration resolution	0,00025 g (2.45 mm/s^2)
Inclination resolution	0,014° (0,244 mm per meter of height)
BPF (Band Pass Filter)	1,5 Hz–25 Hz
Sampling resolution	14 Bit

2.1.2 Inclination Measurements

Notwithstanding the usefulness of the dynamic measurements, to perform accurate diagnosis of a possible damage due to seismic stress, it is necessary the acquiring of static or slow dynamic measurements. The RSS-1 allows static displacement measurements.

The system compares the dynamic detected trends with inclinometers measures to provide the trim evolution of the monitored structure.

The embedded Inclinometers have a high sensitivity (0.014° sexagesimal) an excellent signal/noise ratio and a bandwidth that allows you to correctly identify the inclinations associated with the first vibration modes frequencies of the structure (few Hz).

The RSS–1 detector can provide an absolute inclination relative to the horizon, it assumes as a reference the first value acquired after the verification of the correct positioning and installation of the tool.

The inclination values are compensated by the embedded thermal sensor through detected temperature; it makes possible to monitor the variation of the tilt data to detect

any abnormal results compared to the typical daily and seasonal temperature excursion; the compensations are usually never more than a hundredth of a degree.

2.1.3 Independent Tests

All the specification of RSS-1 reported in this article was verified by an independent centre specialized in Earthquake engineering [2].

2.2 RSS-1 Applications

This innovative sensor station allows you to realize a highly accurate detailed surveys and analysis on structure trim of the monitored building; this is really helpful for the structural safety and stability check. The RSS–1 allows a high accurate displacements description. Its characteristic, described before, ensure a substantial time advance on the drift of a hypothetical shift of the structure or building that manifests tendency to collapse.

2.2.1 Structural Monitoring

The structural monitoring is made by more than one RSS–1 detector installed in the same structure, both for single-storey buildings and multiple-storey buildings.

Usually this kind of application is realized installing multiple detectors in the same building but placing them in the radial and tangential direction of the structure; this configuration allows the comparing and combining of relative displacement and then the modelling of complex structure in a three-dimensional vision. The RSS-1 detector can be used for structural and trim monitoring of:

- single-storey buildings
- multiple-storey buildings
- bridges
- viaducts
- dams
- any other structure…

2.2.2 Seismic Monitoring and Seismic Micro-Zoning (PGA, PGV, PGD)

Starting from the recorded values RSS-1 can discriminate the seismic or micro-seismic activities through the evaluation of the following parameter: PGA - Peak Ground Acceleration, PGV - Peak Ground Velocity, PGD - Peak Ground Displacement. The estimation of PGA, PGV, PGD is done using the following measures:

- two measurements for mutually orthogonal horizontal components of acceleration, velocity or displacement
- one vertical measurement of acceleration, velocity or displacement

The acquiring of the real-time accelerogram based on the three axes data make possible the early identification of the Primary seismic wave (P-wave); the first seismic

wave that occur after an earthquake with a prominent compression component. Any Earthquake rise 3 types of Seismic Waves [3, 4] (Fig. 2):

- P wave (Primary)
- S wave (Secondary)
- R/L waves (Surface waves)

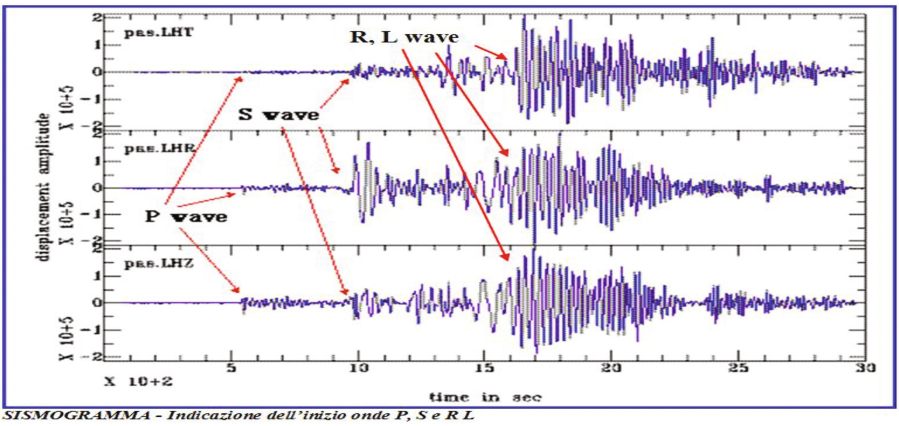

Fig. 2. Three types of seismic waves P, S, R/L

The P wave is the one that arrives first, more quickly than the others, but, fortunately, less dangerous since it is compression wave and usually it does not generate heavy damages.

The S wave travels about to half of the P Wave's speed and is a transverse wave and causes dangerous shakings.

The R/L Waves are the surface waves originated at the epicentre by a combination of P and S waves.

Surface waves travel along big distances before losing all the energy; R/L waves are the most damaging waves because generate vertical and horizontal oscillations of structures.

Fortunately, R/L Waves are slowest than the other Seismic Waves (about to 1/3 of the P-waves speed). Earthquake guard exploit this characteristic of the R/L waves to 'predict' the earthquake before it is felt by the population.

The PGA, PGV and PGD parameters are mutually independent, thus in case of an earthquake it is possible to have a high value of PGA and at the same time a low value of PGD and vice versa. The detection of maximum acceleration, maximum velocity and maximum displacement is useful but it is even more useful the estimation of time trends.

Build a Monitoring Sensor Network

To build an effective monitoring sensor network is necessary to install an adequate number of sensor in the territory who need to be monitored.

The minimal monitoring unit is composed by 2 sensors placed from 5 to 12 km of distance one to the other. This minimal unit can cover a territory of 80/100 Km2.

In order to increase the sensitivity of the network it is recommended to install more sensors. The finest sensitivity is reached installing sensors every 5 km.

The Fig. 3 show a placement project proposed to the governor of the Abruzzo region of Italy near the main city of 'Aquila' where exist a geological fault. The network cover an area of 625 Km^2 (25 km × 25 km) and use 16 sensors.

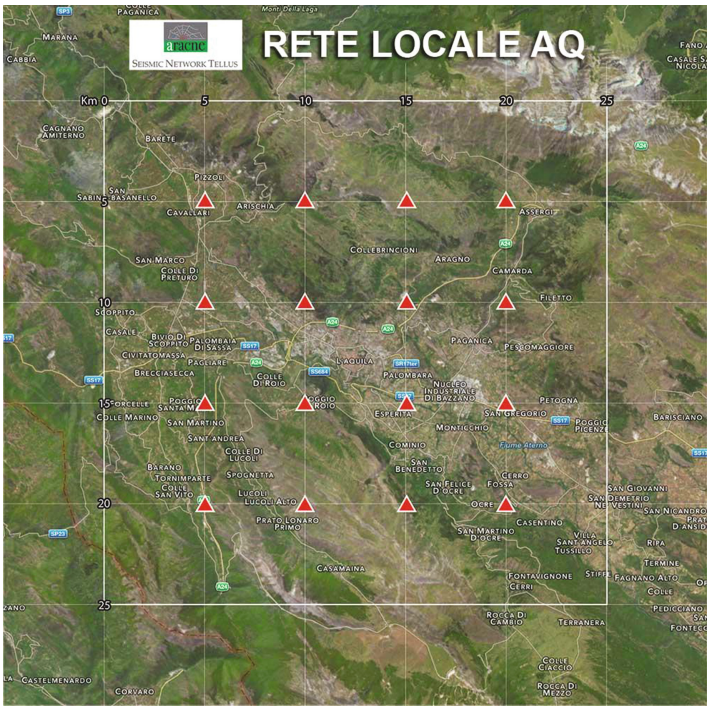

Fig. 3. RSS-1 placement project in Abruzzo region of Italy

In general, the density of the sensors should be higher on the geological fault, as depicted in the Fig. 3, and the sensor placed on a grid to promptly detect every seismic movement.

2.3 NowTech RSS-1 for EX-POST Analysis

The most widely used parameter to earthquake classification is the acceleration time trend, for example it is possible to identify single peak earthquakes or multiple acceleration peaks earthquakes, uniform distributed acceleration earthquakes or irregular distributed acceleration earthquakes.

From the analysis of the accelerogram is also possible the characterization of an earthquake according its duration and its strong-motion stage that can be generally identified by the time in which the acceleration exceeds the threshold value of 0.05 g.

The accelerometric data is useful to perform frequency analysis of the seismic event. An accelerometric dataset is collected through N samples in a T period, the maximum sampling rate ensure 200 samples per second.

The RSS-1 detector collect a dataset useful for frequency domain analysis, it allows you to calculate the Discrete Fourier Transform; the DFT analysis gives information related to the energy of the seismic wave and frequency distribution of peaks.

The following intensity scale (Table 4) incorporating the effects of PGA, PGV, PGD, duration of strong motion phase, and soil-structure interaction shows a correlation between instrumental intensity and potential damage of a seismic event.

Table 4. Intensity scale of earthquake

Instrumental intensity	Acceleration (g)	Velocity (cm/s)	Perceived shaking	Potential damage
I	<0.0017	<0.1	Not felt	None
II–III	0.0017–0.014	0.1–1.1	Weak	None
IV	0.014–0.039	1.1–3.4	Light	None
V	0.039–0.092	3.4–8.1	Moderate	Very light
VI	0.092–0.18	8.1–16	Strong	Light
VII	0.18–0.34	16–31	Very strong	Moderate
VIII	0.34–0.65	31–60	Severe	Moderate to heavy
IX	0.65–1.24	60–116	Violent	Heavy
X+	>1.24	>116	Extreme	Very heavy

3 Nowtice®

Nowtice is the application designed by Regola to send out critical warnings and simple notifications, thought for Organizations and Institutions who need to communicate effectively, timely and controlled, especially in case of emergency situations.

With a single click it's possible to spread any type of information via different medias/channels in order to reach timely the largest number of target recipients, accordingly to specific sending strategies configured and in general fully respecting the users' privacy.

Nowtice is a structured application to comply with any requirement for mass alerting, both for private and for public.

It can trigger different levels of alert by choosing different communication channels.

Nowtice implements a powerful driving force escalation that allows to apply different policies of retry and contact to ensure each recipient is timely notified.

Nowtice leaves the Client to define his own alert strategies with different severity, and for each of them to specify:

- The alerting channel to be used
- The escalation rules
- Target User and/or User Groups

The application allows to insert and maintain all the desired contacts and to collect themselves together in groups. The group management is highly flexible: it allows the definition in hierarchies to different levels, without limits, and it allows the association of a single contact in one or more groups, without duplicating unnecessary communications.

During the alert process the system User will be able to select one or more target groups and/or target contacts. Nowtice will generate a univocal list of resources to be reached and will manage simultaneous dispatches ensuring delivery (or a feedback of error in case of unexpected issue) and presenting real-time results in the application.

The platform allows the alerting of resources with/through various channels, some of these are traditional but at cost, while others are modern and above all free of any additional cost:

- EMAIL: Emails (with or without receipt) to the target recipient(s);
- SMS: SMS to the target recipient(s).
- VOICE: Voice Calls to the target recipient(s) using an automatic functionality named "Text to Speech".
- FAX: FAX to the target recipient(s) associated with the fax number.
- SOCIAL NETWORK: messages/notifications directly on the proprietary (of the Client) Pages or Profiles of the main Social Networks, such as Facebook, Twitter and soon Google+;
- MOBILE APPLICATION: push notifications on a specific APP for Smartphone and Tablet, exclusive and distributed free of any charge. This APP, called **FlagMii** is multi-platform and compatible with the major operating systems like iOS, Android and Windows Phone.
- WEB SITES, INTRANET;
- ROAD LIGHT SYSTEMS/PANELS, SMART TV;
- RADIO: message delivery to any resource equipped with radio terminals, both analog and digital.

This option foresees a radio network available and the technical availability (in terms of media licenses, drivers, SDK) for software integration;

This system operates in integration with any eventual pre-existing equipment and service, in addition to sensor systems and portable/vehicular radio.

Communication Channels

- PRIVATE CHANNELS: reserved and private communication channels only to a selected set of users.

A classic example might be delivering any potential notification/message to professional teams (or field-responders) with the aim to optimize and fasten the communication process.
With a single click the Client can reach the resources and keep in touch with any single person, with the certainty of delivery offered by certified protocols which was implemented.
This may result evident when rapidly retrieving the resources' availabilities and getting the resulting real-time situational overview in a special application area.

- PUBLIC CHANNELS: communication channels available for public use and targeted to population, with the aim to achieve a mass communication.

With a single click the Client can spread information towards multiple communication channels and timely reach the largest number of recipients.

For each generated alert the system will trace: operator who has created it, date and time, list of involved resources. In any moment it will be possible to look at the alert status, through a specific function, that will consider the following logical values:

- In creation: the alert is under creation;
- Scheduled: an alert being scheduled, which can be sent in different timeframes chosen by the user;
- Pending: the alert is in a Sending status;
- Completed: the forward of the alert was completed to all the recipients;
- Partial: the forward of the alert was completed only partially. The platform displays any single failed transmission, allowing a further retry or to cancel it.

The system will keep the history of the previous sent alerts, which will be available for consultation by the user (having appropriate credentials) in any moment.

For each of them it will be possible to see the level of escalation performed to contact any single resource.

As an example below few highlights on the current use that some clients have implemented:

- Public Safety pre-alerts for earthquake, hydrogeological, fire, ice and snow risks;
- Notifications for Closure of Schools or public places, regarding problems of street practicability;
- Institutional information or advices regarding Events and programs of public interest, being in progress;
- References and/or documents of public interest (weather forecasts, fire bulletins, etc.)
- Specialized Alerts to professional Teams or strategic resources to collect individual availabilities and replies in real time.

Below a brief summary of the points of excellence of Nowtice:

- No need to acquire locally a specific hardware or software;
- No assets to manage;
- CLOUD-based Service, with guaranteed High-Availability and H24 Support;
- Dedicated Web Portal for the use of location capabilities;

- Special SMS Sending for the location of users without the App (by referring to the Web App);
- Integration APIs to allow 3rd Party software providers to integrate.

3.1 FlagMii®

As mentioned above, Nowtice also includes integrated usability of FlagMii, which consists in the possibility to alert contacts with smartphones having the APP FlagMii installed in their devices. According the European Emergency Number Association (EENA) FlagMii is a **112 smartphone app [**5**]** free to use and available either for android or IOS devices.

Thanks to special features integrated with nowtice, "push" notifications will be used to deliver alerts on smartphones. Through FlagMii the user will be able to receive any alert or notification, to read it and also to access to further multimedia content of the alert.

Using the cloud will ensure the Client that every functionality is always available, making possible to locate a caller also without having FlagMii APP installed in the smartphone. By sending a text message with an URL, the caller can be located timely with particular accuracy facilitating the process of emergency response at the site.

FlagMii is designed for the public for a multiple use, among which:

(1) To locate exclusively in case of emergency call, displaying punctually on a cartographic map and in a dedicated portal with secure access;
(2) To receive alerts through the integratation with nowtice, via dedicated and/or customized channels.

In mission-critical contexts the displaying can be performed directly on the eventual pre-existing software system in use by the Client.

FlagMii is a multi-platform APP available for iOS, Android and Windows Phone operating systems.

FlagMii resolves one of most complicated problem in the emergency response, that is the correct identification of the incident location, especially in case of absence of references and panic status by the caller.

It's a certified APP from Emergency Authorities and compliant with the European Emergency Number 112.

FlagMii channel is provided free of charge because it's contextual to the use of nowtice.

3.2 Two Way Communication Capability Between Agency and Polulation

Today most part of the population uses intelligent mobile devices connected to internet. NowTice and his app Flagmii can really establish a two-communication channel among emergency agencies and the population. But Nowtice can do more and can manage also situation where the person who need to be rescued has not Flagmii app installed on the device. Indeed, with NowTice if the recipient has a simple internet connection then is possible to:

– Organize survey on the fly
– Get feedback any kind of feedback from the population

4 EarthQuakeGuard and Nowtice to Manage Seismic Events

The complete solution is composed by:

- A monitoring network of detectors NowTech RSS-1
- A cloud Server that collect data and rise events
- A network of 'Earthquakeguard actuators'
- The mass alerting system 'Nowtice'

With the process described in the previous section EarthQuakeguard generate a reliable earthquake signal to be exploited by Nowtice and a set of actuators (Fig. 4).

- Nowtice notifies people before the earthquake strong shaking arrives.
- Earthquakeguard actuators: is a set of devices who can take some proactive action that mitigate the risk of damage on the affected territory.

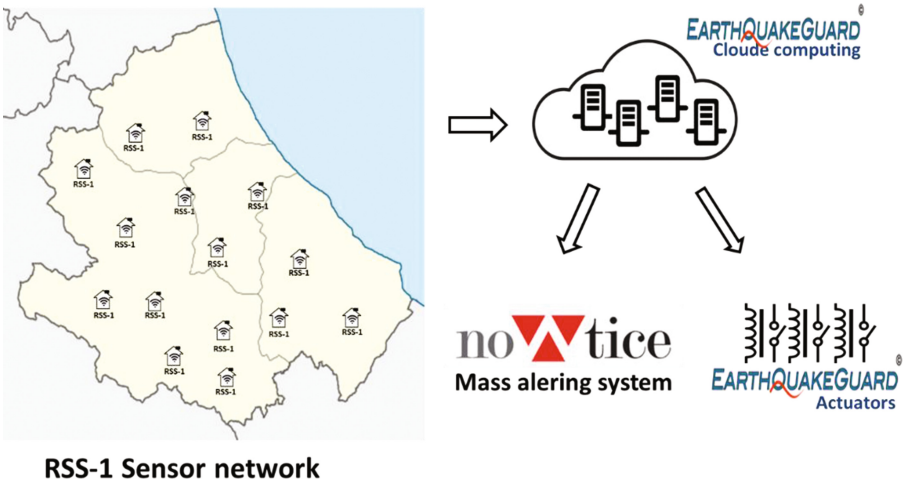

Fig. 4. EEWS complete architecture

Starting from the event detection, EarthQuakeGuard takes less than a second to quickly estimate the affected area, select involved users and send alert notifications through Nowtice (Table 5).

The entire solution has quantifiable capability to predict seismic events. Indeed, the disruptive S or R/L waves of an earthquake arrive later than the others wave (see Sect. 2.2.2), and this delay can be exploited to raise an alert before the earthquake is felt by the population.

The time of prediction (Is the period EarthQuakeguard rise a signal before the earthquake can be felt by the population) depends on three main factors: the distance between

Table 5. EarthQuakeguard response time

T0	Detection and sending time
T0 + 150 ms	Detection and sending time
T0 + 250 ms	Main server receiving
T0 + 400 ms	Double check, affected area identification and transmission time

the epicentre and the RSS-1 stations, the subsoil geomorphology and the hypo-central depth. Considering these variables, the solution can rise an earthquake alert **from 5 s up to 50 s**, before strong shaking arrives.

The solution gives you enough time to:

- Set emergency procedures
- Mitigate risks
- Take protective actions with the **EarthQuake guard actuators.** E.g. dangerous supply can be promptly stopped in case of earthquake)
- Ask people to reach a safer location (or to protect their self under tables or desk)

4.1 The Earthquakeguard Actuators

The Actuators are devices that can react to a seismic event raised by Earthquakeguard. There are several actuators ready-to-use like (Fig. 5):

- Visual and acoustic ALERT notification
- Electricity Grid Detach
- Gas Valve Detach and Block
- Automatic Doors Opening
- Hydro Valve Detach and Block
- Automatic elevators control
- Security Lights control
- Production Lines Releasing

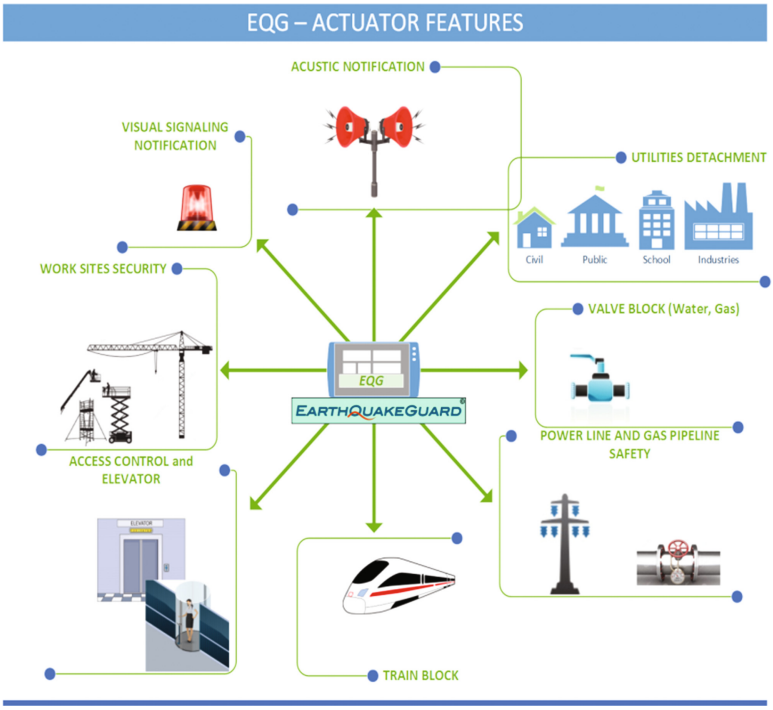

Fig. 5. EarthQuakeGuard actuators

5 Conclusions

Seismic events are still an unpredictable event (time - place - intensity) but this article demonstrates that today it is possible to deal with this event proactively, thanks to the combination of different technologies, with the aim of mitigating the damages resulting from a dangerous earthquake.

The core of the proposed solution is the construction of a seismic monitoring network, widespread in seismic-classified sites, based on NowTech RSS_1 detectors, which, as mentioned in previous sections/chapters, have the feature of not issuing false alarms because they measure uniquely ground acceleration and they are free from anthropic elements. This can be possible because the disruptive earthquake wave, the S and R/L one, arrive from 5 to 50 s. after the first one (see Sect. 2.2.2). This time can be exploited to raise an alert and to trigger a set of actuators (like valves, alarms, etc.) in order, for example, to close supply network or to alert persons who lives in buildings or factories. In other words, the usage of the innovative integrated EarthQuakeGuard/ Nowtice system allows you to safely secure any facility's buildings by suddenly acting on the solenoid valves, emitting an audible and visual alarm by means of sirens so that people can reach a less dangerous position even in the interior of the building. In parallel the system can send massively, using different channels and different criteria, messages who instantly alert Emergency Assistance Agencies, which will also be able to establish

"bi-directional" communication with affected persons from the area affected by the seismic event. Earthquake Early Warning and communication between Emergency Management Agencies and the population is now possible thanks to the use of these innovative systems.

In the era of Smart Cities is not possible to ignore this great potential on earthquake management as well as the contribution that these tools can give to the protection and the safeguard of people.

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