Investigation Report of the Rescue Problem at Hanshin-Awaji Earthquake in Kobe

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Abstract

The Great Hanshin-Awaji (Kobe) Earthquake killed more than 6,500 on January 17, 1995. Many people barely escaped from the debris and actively saved buried lives. Rescue facilities are really important for the robust social systems. Robotics and mechatronics are effective for advanced rescue equipment and systems. However, there are only small number of research and development performed until now. In order for robotics researchers to start, analysis of the tasks and requirements is necessary. In this research, the processes of rescue activities just after the disaster were investigated. Specifications of rescue robotic facilities are proposed on the basis of the analysis.

1 Introduction

The Hanshin-Awaji Earthquake killed more than 6,500 citizens in Kobe on January 1, 1995. 80,000 wooden houses were fully collapsed and the number of sufferers were more than 1 million. The damage of the basic infrastructures exceeded 100 billion US dollars. Most victims were killed as they were buried under their own houses.

As measures against earthquakes, it is very important to build strong buildings, to secure information/communication/transportation facilities, and develop technology for recovery from the disaster. From the view point of "saving lives" and "not to lose lives," it is equally important to research robots, equipment and systems for rescue or assisting rescue as it is very unlikely that all buildings will be made earthquake-proof soon. It is reported that in the Great Hanshin-Awaji Earthquake, a fairly large number were killed by pressure. Death from pressure does not necessarily means instantaneous death, and actually there are many witness reports that they heard cries for help from under the debris for the initial two hours after the earthquake. Research and invention of rescue facilities by many researchers from various aspects will lead in future to rescue of those people who could not be saved this time.

In research and development in this field, it is important to review how actual rescue activities were carried out in the Great Hanshin-Awaji Earthquake. Investigation actual rescue activities performed and promotion of the common knowledge on this basis among researchers will result in development of new rescue facilities based on new concepts improving the effectiveness.

In this report, based on the investigation rescue just after the disaster, it discusses how rescue robotic equipment/systems should be.

2 Study on Rescue Operation

Intensive interviews were performed to students, civilians, the Self-Defense Forces, and fire brigades.

2.1 Rescue Process

By summing up the cases, it becomes clear that the following common processes are required for rescue operations.

1. Searching for people.
   To find people buried. To specify locations and estimate buried conditions.
2. Excavation of the debris.
   Dig a hole to reach people by destroying obstacles (furniture, tatami floorboards, pillars, beams, walls, concrete, etc.), to take them outside, and to make secure space to pull out people through.
3. Rescuing people.
   Pull out people outside, treat them promptly, and then transfer them to hospitals.

2.2 Searching for Human Bodies

Upon summarizing the survey, following points have become clear regarding searching for human bodies:

1. The efficiency of searching for people is the bottle neck of the efficiency of rescue operations.

2. Whether or not they are dead or alive, it is necessary to search for human bodies.
3. Clues that lead to discovery of people.
   Voices of people overheard, information supplied by family, landlord, neighbors, resident association helped locate people.
4. Estimation of locations of people.
   Estimated by direction of voices and room plans of houses.
5. Identification of locations of people.
   Getting into holes and looking around, groping about, listening to voices, asking them to hit the floorboard, asking them if they could see the flashlight beam, or discovering part of bodies of people.
6. The second floor and the first floor slipped in different directions and collapsed.
7. People buried under fallen walls could not easily be found.
8. Many people lost the sense of touch.
9. Flashlights.
   Although they were indispensable, they were not available in enough quantity and their batteries lasted only for a short time.
10. Search machines/dogs.
    Sound detectors furnished to the fire brigade as rescue equipment were used for searching for people but they were not useful as they picked up external noise. Search dogs were tried, but there was a problem that all activities must be once stopped as they were sensitive to the smell of surrounding people and noise. After all, the number of people found by the dogs was 0. The equipment which picks up heart beat by electromagnetic wave has a problem that it picks up heart beat of someone nearby. In case of search in highly populated areas, robustness to noise is necessary.

2.3 Excavation of the Debris

The following points became clear about excavation of debris.

1. Rescuing order.
   People calling out were dug out one by one. While rescue activities were going on, there were other voices from various places. But as the time went by they become faded out.
2. On objects to be excavated.
   Objects to be excavated were the debris of roof tiles, floorboards, beams, furniture, earth and futon.
3. On works performed.
   Works performed were digging, removing, cutting, breaking, hitting, prying, pulling, taking out, digging out, chiseling, shaving, raking out, peeling off, destroying, inserting, felling, shredding, carrying out, transporting, lifting, dragging, putting in, grouping about, illuminating, disposing, and use of leverage. It has many points in common with civil demolition works.
4. Danger associated with excavation.
   There was danger of houses collapsing as their pillars were cut or furniture was removed. When they were cut, houses were supported by square timbers or blocks to prevent danger.
5. It was dangerous to dig horizontally.
6. Glass shards and futon turned out to be unexpectedly large obstacles.
7. Number of equipment.
   Since the damage scale was enormous, the number of equipment available was definitely insufficient.
8. Bars were very useful as a hand tool.
9. Cutting wooden debris.
   Narrow chain saws that can be inserted into a 20–30 cm wide crevice were useful.
10. Jacks of private cars.
    Jacks of private cars had several weak points. They required wide space in the debris to insert them. They could not be placed on the unstable or soft and frail base. Size of their head was small. Their stroke was small. However, depending upon where they were used, they were helpful. When there were a number of people available, it was much faster to rely on them. These jacks were also effective in alleviating pain of those got jammed in.
11. Chain blocks.
    Chain blocks were used for similar purposes as jacks. Their support was built with fallen beams and pillars.
12. Power supply.
    In case of rescue forces, electricity was supplied relatively easily by portable generators. But in the case of the general public, it was not available in many cases.
13. Removal work of the debris.
    In almost all cases, it was done by hand. As there were too many things done by hand, physical burden was so enormous that workers often could not move hands any more due to muscle pains. It was also a problem that there was no space to dump debris excavated.
14. Heavy construction machinery.
    They were highly effective in rescue operations, but as the width of roads was reduced by fallen houses, they could not be used in many cases. Also, when there were chances of survivors under the debris, use of heavy machines was extremely dangerous. Even if people were already dead there

was a problem that their use could damage their bodies.

15. Cooperation of work by heavy machinery and people.
    Besides rough work such as removal of a large quantity of debris, there were meticulous works such as digging. Therefore, the cooperation is necessary.
16. Rescue by experts.
    Since scale of the damage was so large, it was not possible to rely only on fire brigades and work of volunteers was necessary.

2.4 Handling Human Bodies

The following points became clear about handling people.

1. Order of rescue priority.
   Priority was given to rescue people certainly alive. When their death was confirmed rescue operation was often discontinued.
2. Pulling out people out of the debris by hand.
   Since workers were forced to work in a difficult posture, it was very hard work. To pull out people sideways, stretchers designed to sandwich a body were useful. As center of such stretchers did not bend, they could carry out bodies without damaging them.
3. Danger to workers.
   Each time when an aftershock struck, it could cause further destruction of houses and workers themselves were often exposed to danger.
4. Working environment.
   Although it was very dense with dust particles, when workers wore a mask, it was difficult for them to breathe due to extremely hard work.
5. Psychological support.
   While rescuing sufferers, it was important to call to them with considerate and encouraging words.
6. A large quantity of blanket and stretchers were required to transport those saved out of the debris.
7. Path of transportation.
   As it was on top of or inside the debris, transportation was difficult. To secure the path of transportation, it was contrived to lay tatami on the debris.
8. Hospitals.
   Although those saved were transported to nearby hospitals, they could not receive satisfactory treatment as the hospitals themselves were damaged, flooded with the injured, and short of medicine, equipment, doctors and nurses. Transportation to hospitals in nearby prefectures took a very long time due to extremely heavy traffic congestion.
9. Guidance of rescue forces.
   Rescue forces from other prefectures and the Self-Defense Forces were not familiar with locations and it took them a long time to reach working sites or to start working.

2.5 Points Indicated by Fire Brigades

2.5.1 Comments on the Rescuing Tools and Equipment Currently Furnished

There were following comments on the tools and equipment.

1. Engine cutters caused a problem that their exhaust gas filled in the debris. Small electric cutters were useful.
2. Air hammers and electric hammer drills were convenient.
3. It took a long time for supply of fuel for equipment using mixed fuel as its mixing ratio differed from on equipment to another.
4. Strikers were good for breaking concrete blocks but its striking force could not be adjusted for wooden houses.
5. The rescue force tool was effective for drilling holes in earthen walls.

2.5.2 Characteristics of Rescuing Activities After the Earthquake

Rescuing activities after the earthquake differed from the normal rescuing activities in the following points.

1. Neighboring residents were mobilized to rescuing activities.
2. To prevent a large number of casualties by fire, priority was given to checking the spread of fire than rescuing the buried people.
3. Priority was given to rescuing survivors.
4. Rescue force members could not take a rest.
5. Exchange of information could not be made.

2.5.3 Rescue of People in Fallen Fireproof Buildings

The following problems were pointed out:

1. It took a long time to rescue people waiting for rescue in the crushed middle floor of fireproof buildings.
2. As floors were slipped in different directions and crushed, it was very difficult to confirm their locations by drilling a hole from the upper floors.

3. Because of equipment they had, rescue by the police force and the Self-Defense Force was impossible. Sometimes, there was no way but to wait for arrival of heavy machinery as the equipment of the fire brigade was not powerful enough.
4. Large heavy machinery could not be used for excavation at the initial stage as there were chances of survivors under the debris.
5. In rescuing people by heavy machinery, investigators and the rescue force members could not work in close cooperation.
6. Tools available were short in number and not capable enough.
7. In some cases, engine cutters and gas cutting apparatus could not be used as there was danger that they could start fire.
8. It was difficult to secure safety of the rescue force members. It was life-risking work.

2.5.4 Rescue of People from Fallen Wooden Buildings

The following points were indicated.

1. There were many people buried alive on the first floor. It was necessary to remove the second floor, furniture, futon mat, and clothes requiring a lot of work and hands. Human wave tactics using residents proved effective.
2. In many cases, large heavy machinery was not available or even if it was available it could not be used as there were chances of survivors. For removal of beams, elaborate work was necessary for manually cutting them by saws and chain saws.
3. Cutting pillars and beams caused danger of houses to collapse.
4. Destruction of walls, earth of roof tiles, etc., generated tremendous amount of dust particles. However, dust mask were almost unavailable.
5. In some cases lives could not be saved because of spreading fire.

2.5.5 Rescue of People from Fallen Light-Weight Steel Construction Buildings

The following points were indicated.

1. Many buildings were half broken and rescue activities were exposed to danger.
2. Various types of work such as removal of the concrete debris, cutting of steel frames, and removal of wooden materials were required. Effective use of various rescue equipment like engine cutters, large rescue tools, chain saws, large heavy machinery, etc., was necessary.
3. There was slab plate under the floorboard or cement floor and it tool a long time to remove it.
4. As it was necessary to crawl to advance while cutting steel frames, it caused tremendous fatigue.
5. Heavy staffs such as H iron beams and iron wall frames could not be removed without heavy machinery.

3 Requirements for Rescue Robotic Equipment and Systems

3.1 General Matters

General important points are explained below.

1. Universal robots are not practical.
   As described above, work requirements in rescue activities are very versatile. To try to perform all of these by one universal robot is not practical. It is necessary to contrive a system consisting of robotic equipment and human that works effectively as a whole.
2. Equipment is required in a large quantity.
   When a large number of people are buried under the debris in a great disaster, rescue robotic equipment must be available in an extremely large quantity. It must be available immediately after an earthquake. In this respect, ubiquitous rescue robots that can be operated by the general public are ideal in case of a large-scale disaster. That is, equipment that is distributed in a large quantity (as everyday commodities) and can be operated easily without any special training. It is possible that such equipment is quite different from an advanced robot at present.
3. Equipment that meets local needs is required.
   Japanese houses have unique structure and use unique materials. Japanese streets are made up of a narrow road and utility poles, which are rarely found in advanced countries. Gas pipes sprawl all over the cities. The living style reflects the culture unique to Japan. Without taking these factors sufficiently into consideration, it is impossible to develop effective rescue equipment.

3.2 Searching for Human Bodies

The process of the search for people is made up of 2 steps, determination of location of the buried and evaluation of their situation including communication with them.

Equipment used for these purposes must meet following requirements.

1. It must be capable of searching through the concrete debris, iron frames, timbers, and the earth and sand.

2. It should not require a reference plane.
3. It must be capable of searching for the buried irrespective of whether or not they are conscious or unconscious. If possible, it should be capable of discerning the dead and the alive.
4. It must be capable of searching for the buried without contacting them. It is desirable if it can be remotely controlled.
5. It can be used in all weathers, day and night.
6. Its weight should be light enough for transportation by hand.
7. It can be assembled and ready for use in a short time.
   Rather than high accuracy, ability to search for the buried in a short time is important.
8. It must be battery-driven and operated on car batteries.
9. No special knowledge should be required for its operation, interpretation of the data obtain and judgment.
10. If possible, it is used in routine activities other than in a disaster.
11. Its maintenance should be easy.

3.3 Excavation of the Debris

The following specifications are required for the excavation robotic equipment.

1. It must be lightweight (less than 20 kg) and of simple mechanism.
2. It must be easy to transport and operate. (It can be operated without prior training.)
3. Its mobility should be high. For example, it can travel over the stairs and the debris.
4. It can do several tasks.
5. It is provided with a search light.
6. It is robust against rain, dust and heat.
7. It can be operated on dry cells. (That is, to secure the power source.)
8. Remote-controlled system is sometimes better than autonomous.

These specifications are for the equipment to be developed in a short time range. Apart from such equipment, research and development of equipment on the medium and long term basis are necessary. The investigation has revealed that in comparison with Europe and the US, research in this field is absolutely nonexistent in Japan.

3.4 Handling Human Bodies

The equipment for handling people needs the following abilities.

1. Ability to judge dead or alive and conditions of the buried.
   Determine rescue priorities depending upon their conditions. Judgment can be made using information such as body temperature, blood, voice, etc.
2. Ability to maintain life.
   Diagnose, give first aid and administer drugs. Take measures against dust and ventilation.
3. Ability to reduce burdens.
   Reduce a physical burden and support the sufferers psychologically.
4. Ability to recover people out of debris.
   Pull the buried through a hole without injuring them until they are ready for transportation. This ability associates with the master-slave technology and therapy technology.
5. Ability to transport.
   Transport from top of the debris to an alley, from an alley to a main street, from a main street to a nearby hospital and from a nearby hospital to a remote big hospital is necessary.
6. Ability to secure safety of workers.

3.5 Other Matters

In addition, the following abilities are important.

1. Ability of communication and guidance.
   This ability is for guidance of rescue forces and performance of their tasks, transportation of and first aid to the sufferers, evacuation of the refugees, identification of people and confirmation of materials, and transmission of information to outside. It is important that it meets emergency need and simultaneous occurrence with reliability. It should accumulate, relay and select information locally in a distributed manner.
2. Preparation of a robust organization and infrastructure against a disaster.

4 Conclusions

As described above, rescue robotic equipment has so many technical, scientific and social problems to be solved. For this reason, the rescue robotics is a very challenging field from the viewpoint of the robotics and mechatronics technology. It is desired that each of those problems be solved and conventional rescue equipment improved by robotics, mechatronics, and sensor/information technologies. It will save human lives in the great earthquake that is predicted to strike in future. It is hoped that many people become interested in this field and join the research.

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It should be added that the contents of this report are based on the investigation and discussion by the members of the above technical section and independent from the official view of the governmental organizations concerned.

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