Disaster Swarm Robot Development: On Going Project

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***Abstract*—This paper dealt with the development of disaster robot, especially for earthquake and tsunami. The necessary of robot arise after several tragedy including natural and man-made disaster. Several consideration on developing disaster robot also discussed, including on mobility and locomotion aspects. Some robots that have been created and robots that are in the process of completion and future plans are also discussed. Swarm robot is considered as an ideal platform since in the disaster field usually cluttered and unstructured environment in which usually in very narrow area. Therefore, by the swarm robot platform, the size of each robot usually small enough to pass the narrow area, and if necessary the robot could working together to achieve certain taks such as some limited rescue operation.**

Keywords—disaster robot; mobility; locomotion; control; navigation

I. INTRODUCTION

Indonesia is one of the country that prone to the disaster due to its location - known as "Pacific Ring of Fire"- in which a series of active volcanoes, oceanic trenches, and plate movements exist. In 40,000 km horseshoe shape "Ring of Fire" start from Latin America, USA, Canada, Japan, China, Indonesia and Australia, there are 452 volcanoes (more than 75% of the world's active and dormant volcanoes). Apparently, about 90% of the world's eartquakes and 81% of the world's largest eartquakes occur along the zone [1].

Moreover, Indonesia is the country with the high risk of disasters, such as flood, volcano eruption, landslide, forest fires, eartquake and tsunami. According to UN-International Strategy for Disaster Reduction (UN-ISDR), in terms of the number of population reside in disaster-prone area, Indonesia is the first out of 265 countries for tsunami in which 5.4 million people stay in the area; the first out of 162 countries for landslide in which 197 thousand people dwelled; the third out of 153 countries for eartquake in which 11 million people living there [2].

World Bank have reported that Indonesia together with 35 countries have high risk of mortality due to disaster, in which 40 percent of the population reside in disaster-prone area, about 95.2 million people, a fantastic number for humanity problem [3].

Hence, to develop national resilience to the disaster contingency, the local capacity building is needed, including disaster risk and climate change assessment based on reliable statistical data. The using of appropriate technology in disaster early warning and mitigation systems are necessary, by supporting and strengthening research, development and revitalization of local wisdom through integrated knowledge management systems and publicly accessible [4].

The utilization of robot in disaster mitigation as in [5][6] in which Robin Murphy was one of the pioneer in the field [7]. Murphy employs robot for search and rescue operation of wreckage of New York World Trade Center, 2001. Due to the fact that the 110 floors were totally damage and exuviate to be piles of iron and concrete, then the using of radar to inspect the disaster area and the dog for searching the victim were impossible. The using of robot similar to the tank shape offers the new approach to the SAR team when the robot could enter some very narrow and cluttered area, which otherwise impossible to be accessed by human team. The robot could search 10 people, unfortunately, none could be saved [8].

Another milestone of the utilization of robot for disaster, when 9.0 magnitude earthquake followed by 15 meter tsunami happen in Fukushima Japan on 11 March 2011 and has caused severe damage to the Fukushima Daichi nuclear power plant. Three nuclear reactors badly damage due to hydrogen explosion, and unexpected uncontrolled nuclear reaction occur in another building. Hence, it was dangerous if human enter for inspection due to radioactive material exposed in the building. S.Tadokoro of Tohoku University lead a team that using the robot to the area [9]. Before the robot enter the disaster area, it must be adapted to the field encountered, such as tolerance of electronics components to the radiation, communication functions in the affected areas, and also putting additional radiation sensors to the robot. Nevertheless, the task that must be done is not easy, because the field is difficult to handled due to, among others, the mobility of the robot that must be in accordance with the field encountered, the robot intelligence that still in very limited, and irregular and easy to collapse building. The robots used in the field not only from Tadokoro's group, but also coming from University of California at Los Angeles (UCLA), Jet Propulsion Lab (NASA) and US Defence Advanced Research Projects Agency (DARPA).

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In Indonesia, to the extent of our knowledge, the works on disaster robot is very limited [10][11]. In this paper, we will introduce several works on disaster robot that being developed by our research group from 2008 to date..

II. Disaster Robot

Disaster robot is mobile robot, or several robot that usually small enough and hence, portable to be operated in disaster area, for searching and rescue of victim, mostly for post disaster time [12]. Disaster robot differ from military robot, because disaster robot should fulfill three design constraints: (i) extreme operation condition, uncluttered and unstructured obstacle available in the field; changing time to time so affect the size, sensor performance and restrict robot motion. (ii) ability to work in the area that could not utilize GPS and very limited wireless communication (iii) ability to operate autonomously but also possible to work together with operators and victims.

Disaster robot will help us to preventing, preparing and dealing with natural and/or man-made disasters that tend to increase recently. When a disaster occurs, it is very likely that we can not enter either due to physical constraint, too dangerous or inefficient. Robot do not replace humans and/or sniffer dogs, but rather as complementary especially to reduce life-threatening risk to them.

Robotics research has made significant progress in making autonomous robots. This is supported both in terms of advances in intelligent control technology and electronic and mechanical components that are reliable, practical and have sophisticated functions that live utilized. For the purposes of robot use in normal circumstances (not in a state of disaster), the robot can easily function as desired. For example, the robot is quite easy to recognize the existence of a tree that is as an obstacle, then make navigation to avoid it. But for disaster situations, let alone robots, but humans often cannot recognize objects and obstacles, because of the turmoil of the field due to disaster. A fully autonomous robot for SAR activities is still unlikely to be realized, so robotic cooperation with operators and other parties involved in rescue operations needs to be designed and integrated, and usually it called as semi-autonomous robot.

One of the pioneers in the field of rescue robots for urban disaster, is a team led by Prof. John Blitch of the University of South Florida, who leads CRASAR (Center for Robotic Assisted Search and Rescue) [8]. The team has been deployed for search and rescue operations at New York's World Trade Center, shortly after the 11 September 2001 terrorist attacks. No fewer than 10 victims have been rescued from the rubble of the building, using the robot technology. Figure 1 shows examples of robots used in the operation, namely (a) "Foster-Miller Solem" and (b) Talon.

Foster-Miller Robot the size of a portable suitcase, non-wired robot that can be controlled remotely. The main sensor is the encoder feedback, 3-axis compass, arm position feedback and CCD camera. The camera is named Solem, placed on the end of a 10-inch robot arm. Talon robot equipped with two cameras and two arms equipped with a clamp. Each is able to face the terrestrial and marine terrain (amphibian).

(a) Foster-Miller Solem (b) Talon

Fig. 1. Robots used during rescue operation of WTC 11 September 2011 victim [13]

The development of robotics for rescue operations rests on two activities, namely platform development [14] [15] and software [16]. Robot platforms used for SAR operations vary, ranging from wheeled robots, chain and/or combination. Snake robots, which are inspired from biological systems, are also used for such purposes [17]. Fire rescue robots are also widely discussed [6]. But there has not been a thorough test on an actual disaster. Throughout the author's experience, there has never been a legged robot used for SAR operations, given that the terrain is very difficult and cannot be predicted easily.

Software development for rescue robots includes the software for robot control, multi-robot collaboration, multi-sensor control and human-assisted robots. For example, automated behavior ideas for shape-shifting robots are proposed by Blitch et.al. [5], whereas multi-robot collaboration can be seen in [18], [19][20]. Multisensor control systems for rescue robots was developed by [21], while software developed to assist human operators through intelligent expert systems and mixed initiative systems can be found at [22].

To control the robot, the use of behavior-based control techniques is an interesting option because in a biological system it consists of many primitive behaviors that need to be synchronized when those properties need to be generated. Then, how a robot can mimic a biological system whose main feature is learning ability? There are several proposals put forward by the researchers. For example, Gomez et al offers hierarchical evolutionary techniques using neuro evolution (artificial neural networks that evolve using genetic algorithms) [23]. The use of multilevel techniques in which online and adaptive learning is done that combines each of these levels by utilizing behavior-based learning algorithms and reinforcement learning proposed by [24]. Unfortunately, the technique requires extensive computer resources, because of the complexity of integration between these levels.

The revolution in the field of ubiquitous computing became a strong foundation for the development of robotics technology, known as ubiquitous robots (ubirobots). By combining stand-alone robots like mobile robots, walker robots and skeleton robots with artificial intelligence and web technology, the ubirobots could be built [25]. The development of smartphone technology and intelligent sensors contribute significantly to the enhanced interaction and perception capabilities of ubirobots. So far, ubirobots are cognitive entities that can move around, sensing, reasoning and proactively performing tasks that are adaptable to changing situations, wherever and whenever [26].

III. First Step of Developed Disaster Robot

The development of the disaster robot that we have done so far began in 2008, with a robot named iSRo (intelligent Search Robot) First Generation, which has 8 degrees of freedom and has 10 primitive behaviors and involves 8 students, 3 of Master Students from ITS and 5 Applied Bachelor PENS students [27]. The project was supported financially by Japan International Cooperation Agency (JICA) and assisted by Prof. Mitsuji Sampei of Tokyo Institute of Technology. To improve the ability to maneuver in the disaster field we have developed iSRO Robot Second Generation (G2) with 10 degrees of freedom, with optimization of mechanism and efficiency [28].

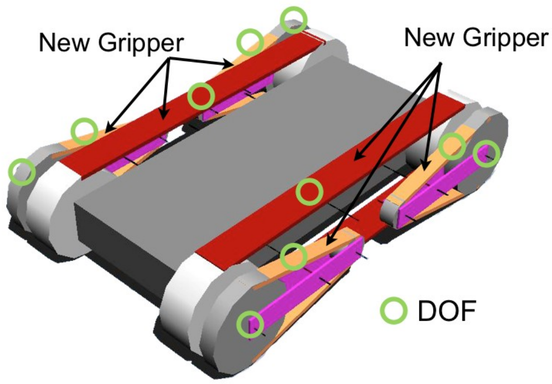


Fig. 2. Design of iSRo robot G2 with 10 degree of freedom

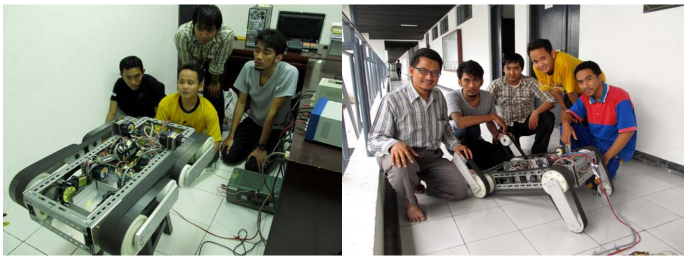
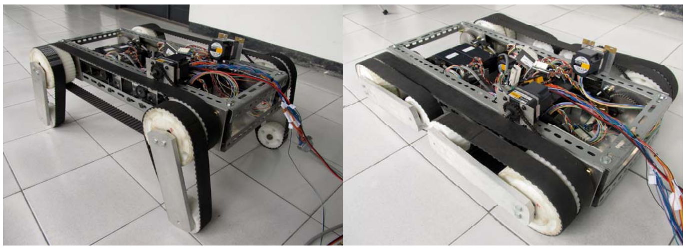
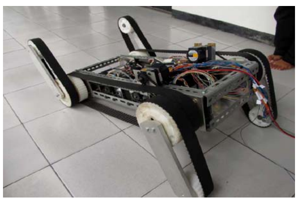


Fig. 3. Prototype of iSRo G2, with no load test



(a) Legged locomotion (b) Whelled locomotion



(c) Legged-whelled locomotion

Fig. 4. Several locomotion of iSRo G2

After the development of iSRo G1.2 which has been modified to 10 degrees of freedom, can not operate properly for technical reasons, then RABBIT team redesigned on multiplatform. Developed iSRo robot G2 also with 10 degrees of completely new freedom as shown in Fig. 2.

The prototype iSRo G2, which has resulted from the development of several types of multiplatform robots in previous studies, has undergone a no load test of movement as shown in Fig. 3 and Fig. 4.

The results are then developed into iSRo G2.2 prototype that can be controlled with a wireless joystick. Fig. 5 shows the snapshot of mobility test results from robots that have been developed.

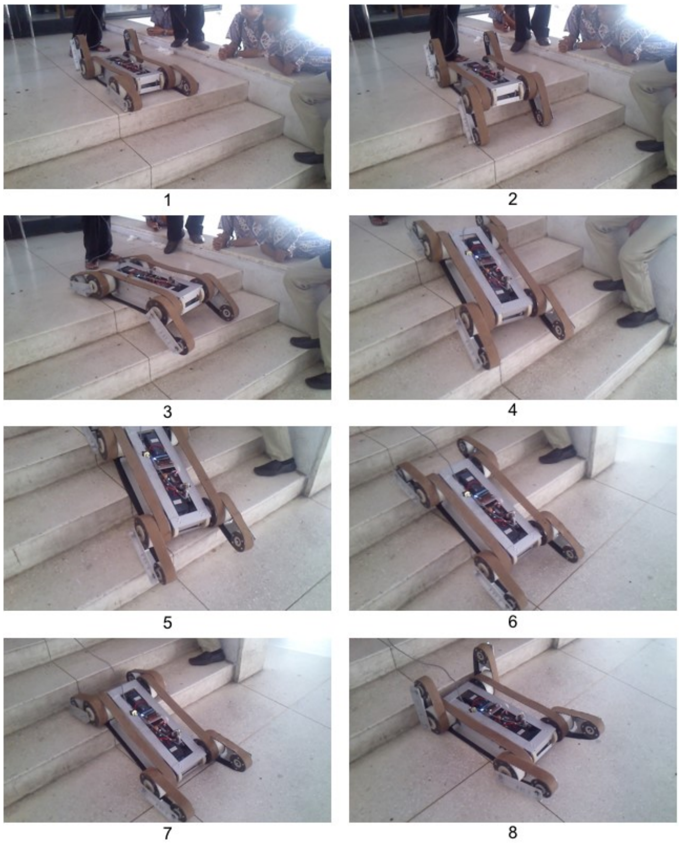


Fig. 5. Snapshot of iSRo G2 running test of down the stairs

IV. Swarm Disaster Robot

The second phase begins in 2016 with the development of swarm robots, i.e. robots in relatively small size and many in number. The robot have the ability to work independently, and/or work together to achieve certain goals. Fig. 6 shows the research roadmap 2016-2021 of our group.

We have plan to develop several swarm robot [29] especially developed for eartquake and tsunami disaster, including ubiquitous robotics that include IoT-based coordination and navigation. We also will propose the national field test for disaster robot to be standard for every disaster robot to test the ability on mobility and locomotion in the disaster area. An early warning systems and disaster awareness of the public to the disaster will also our next step of development.

With the help of funds from Kemristekdikti, through the “Penelitian Unggulan Perguruan Tinggi(PUPT), for two years (2016-2017) we have developing the robot. First, we develop swarm robot, to study how to coordinate and navigate several robots with “leader and follower” scenario (see Fig. 7) Also, we develop a robot based on adaptive morphology design, in which the robot has two mobility of movement, namely flying and crawling, with the name "PENS-FlyCrawl" (see Fig. 8).

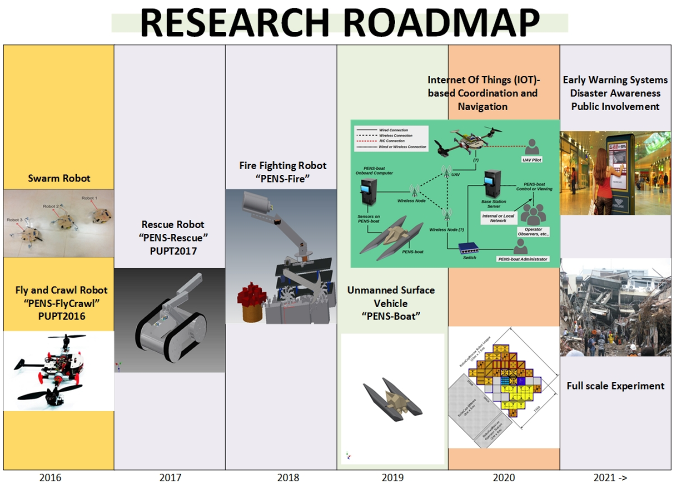


Fig. 6. Research roadmap of our group

With the same funding, in 2017, we plan to build robots that have first-aid capabilities for earthquake and tsunami victims on a limited scale, looking for victims and then - if met - then first aid such as in the form of drinking and / or oxygen (depending on the need in the disaster field). The robot we named "PENS-Rescue".

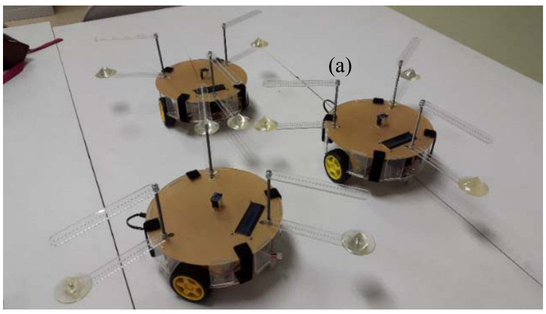


Fig. 7. Developed swarm robot

Fig. 8. Developed adaptive morphology-based flying and crawling robot

The scenario of implementation, as shown in Fig. 9, is as follows. First, the robots will deployed in the disaster area. There are three kind of robots, namely one leader robot and two follower robots. The leader is equipped with camera, to visualize the current state of the field. The second robot is equipped with a tube containing mineral water, for the first aid if there are victims who need water. The provision of mineral water is intended to reduce the level of dehydration of the victims. The second follower robot serves to carry oxygen cylinders, with the aim of helping first aid if the victim has respiratory problems.

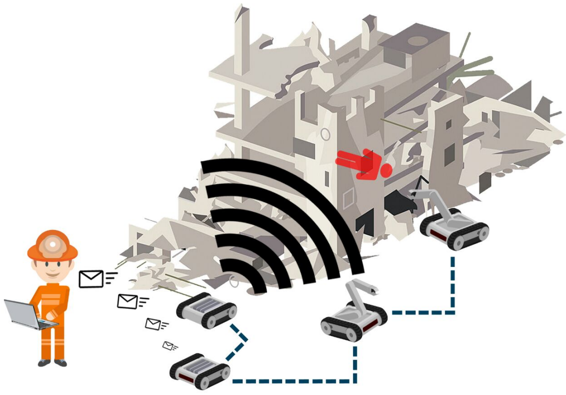


Fig. 9. Scenario of disaster robot implementation

Figure 10 (a) shows the design of the robot leader, while (b) shows the first follower robot carrying the mineral water tube. Figure 10 (c) shows the second robot follower design of the oxygen tube carrier.

(a) Leader robot (b) First follower robot (c) Second follower

Fig. 10. Design of leader and follower disaster robot

Fig. 11. Realization of robot and its field test

Fig. 11 shows realization of the robot and its field test in typical disaster environment. Robot should have capability to explore a cluttered area, in specified time.

Fig. 12 (a) shows typical experimental set up of robot mapping in the field; and (b) shows the result.

The next project, we will propose several disaster robots, namely (i) fire-fighting robot and (ii) unmanned surface vehicle and then we will develop (iii) IoT-based coordination and navigation of the robot (see Fig. 13).

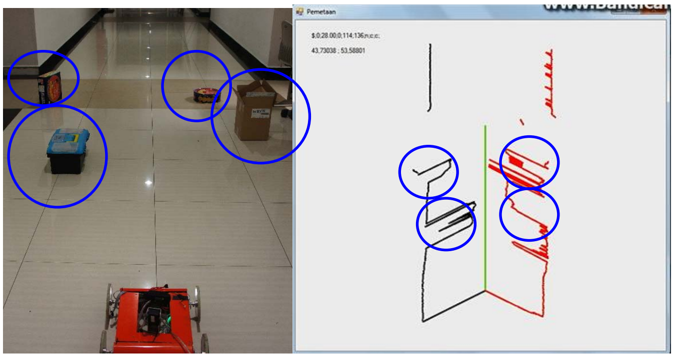


Fig. 12. (a) Experimental set up (b) Typical experimental results

The project was proposed by considerations (i) in every eartquake disaster, there is a chance that fire may happen due to, among others, leak of gas installation and short-circuit of electricity (ii) during tsunami disaster, often the building collapse and submerged in the water.

In this first year, the initial design of the fire extinguisher robot will be made. The robot has a unique mobility capability. First, he has a jagged wheel that easily grips in irregular terrain. In addition, the robot has a hoe-like arm, which will be used when the robot faces obstacles that dimension exceeds the robot. The robot has a unique arm with 4 degrees of freedom, allowing the robot arm to move freely to direct the portable fire extinguisher to the desired fire location, even though the robot body cannot move (e.g. due to its own too narrow field of disaster).

In this second year an Unmanned Surface Vehicle (USV) will be developed in the form of autonomous vessels for the purpose of searching for earthquake and / or tsunami victims when they occur on the coast, in offshore and / or large riverfront buildings. This ship has two movers, so it can be controlled with a simple "differential drive" principle. The system has several sensors both camera and any underwater sensor. Computer systems are made for good use for control, coordination and navigation.

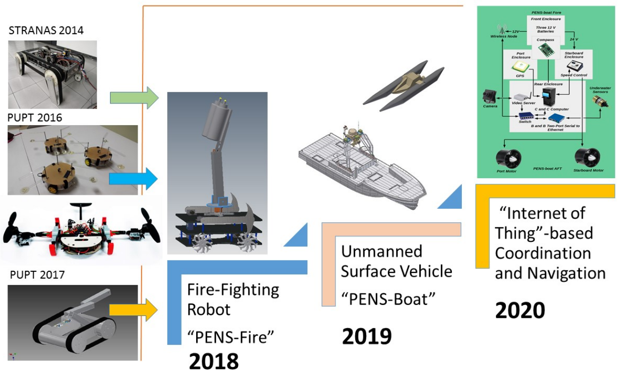


Fig. 13. The next proposal of disaster robot (2018-2020)

V. Conclusions

In this paper, we discussed our on-going project several disaster robot that have been developing by our group. Initially, we develop robot with high degree of freedom that makes the robot rich in mobility and locomotion. Then, our focus shift to the swarm robot and adaptive mobility, by considering the flexibility and mobility of the robot in the disaster field, that mostly uncluttered, unstructured and very narrow.

Since Indonesia prone to the disaster, we have to prepare for every disaster. Disaster robot could not replace human SAR team, but complementary. Robot development need more resources and time consuming. To make the success of the robot in the disaster area, more advanced technology needed, especially on smart sensor, knowledge engineering and reliable communication systems.

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