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-3rd Report: Many tiny robots with a single sensor and launcher system -

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14. ABSTRACT
This reports research on producing cheap (<\$10) micro robots for locating victims within collapsed buildings. The approach is to use many small robots that search downward (using gravity, rather than a power source) as the best means of locating victims.

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1. Introduction

<Background>

Collapsed buildings due to earthquake or terrorist attack typically result in a rubble pile with access holes less than 1 foot in diameter. The necessity of producing smaller robots which can locate survivors quickly is evident in light of recent disasters and attacks. In the reported research, instead of developing one or two expensive robots, the proposed concept is to manufacture thousands of less expensive micro robots (< $10/micro robot) which can access small openings in the rubble pile. Therefore, the probability of locating survivors increases exponentially due to the exponential increase in the number of robots and because these smaller micro robots can move through small openings which larger robots are not be able to access. Key to the approach is to place the micro robots at the top of the rubble heap so that little energy is consumed as the micro robots search downward (carried by gravity) when not utilizing their own power source.

In this report, small hopping robots which have a simple locomotion mechanism and IR sensory elements have been developed to detect survivors under collapsed buildings. This small robot includes micro eccentric motors for generating lift and thrust forces, and IR sensors for detecting the thermal signal of survivors. Therefore, the micro robot can crawl without any wheels or legs even on small, rough terrain with the help of eccentric mechanical vibration. This tiny robot also has the ability of self-righting to allow it to keep moving to the target even if it falls and lands in any position. Weight balance as well as resonance parameters are very important to achieve good mobility. Automatic navigation to the target is achieved with simple on-off motor switching. The simple design layout results in not only lightweight robots but also low cost allowing employment of a large number of robots in the dangerous rubble field.

Initially, a small robot utilizing off-the-shelf components (i.e. micro motors, button batteries, sensors and electronics) was designed and assembled to verify feasibility for rescue operations. In the initial experiments, many small robots with optical and IR sensors have been developed and movement toward a human body under zero light conditions has been successfully demonstrated. The aim of this project is to design and to development of micro robots system to find out the survivors rapidly under the rubbles as shown in Fig.1. There are many small robots can walk into the complex and search the alive survivors autonomously, then provide the appropriate signal to identify the location.

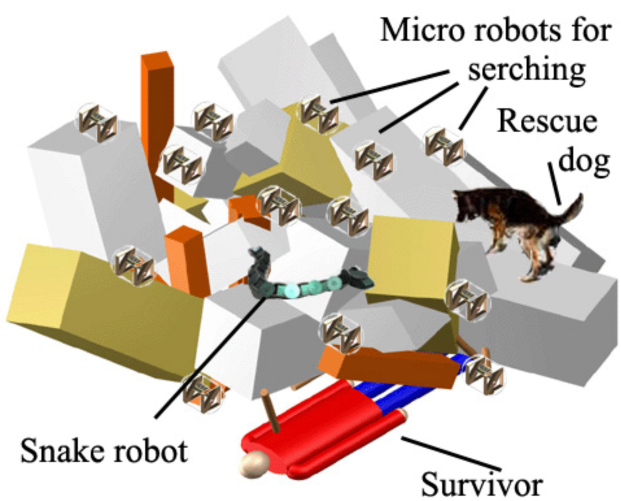


Fig.1 Rescue operation at disaster location with collaboration the dogs, the rescue robots as well as many micro robots

In this report, the micro hopping robots which have a simple locomotion mechanism and sensory elements have been developed to dispatch into the craves of rubble to detect the alive human. This small robot consists of micro eccentric motor for hopping and thrusting with the help of resonating vibration, as well as micro sensory element, button battery and electronics for detecting the signal source. Moreover as an unique performance, this tiny robot has the ability of the self-righting to keep moving to the target even if it drops from the step. The principle of this locomotion is based on the vibration excited by micro motor so that it can keep moving on the non-finished surface such as floor and small rough terrain. In the primary experiment, many small robots with thermal micro sensors are designed and developed and it is demonstrated that they can move toward to the human body based on the thermal signal, and the performances such as mechanical robustness and durability are discussed. The aim of this project is the design and the developement of less than 1 cubic inch size robot which can be composed of the off-the-shelf components. This strategy can give us the benefit of reduction of cost, large-scale employment as well as disposable use. By large-scale employment of many tiny robots a widespread search and rescue operation can occur over the disaster field at minimal risk to rescuers and maximizing probability of survivor location and rescue.

<Previous works from Jan. 2003 to Jun. 2005>

In the previous work, we succesfully developed the prototypes based on hopping locomotion manner. To check the basic performances such as mobility and durability, the prototype (I) in Fig.2 was designed and constructed by using many off-the-shelf componets. Then it was confirmed that this simple mechanism could move at the speed of 65mm/sec. And it was verified experimentally that this small hopping locomotion mechanism had the durability of 350 minutes with the battery of LR44, 100 minutes with CR1616 button battery as shown in Fig.3

Alternative style in which the sensory device and some electronics as well as the wire frame guard was implemented was also designed and developed to check the automatic navigation to the target and the self-righting performance as shown in Fig.4. Two small eccentric motors were incorporated at the center of the body and this layout allowed the small mechanism to take the turn to the left and right when one of each was activated, although the elastic resonator was not built in yet. In the primary experiment, three micro robots with the optical sensors succeeded in tracking the light source as the target in the dark after falling from the top of table approximately 50cm in height as shown in Fig.5

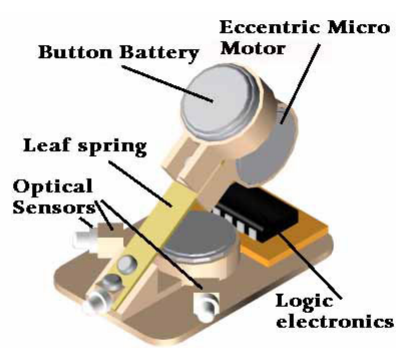


Fig.2 Micro hoppoing locomotion mechanism driven by the resonating cantilever with micro eccentric coin DC motor.

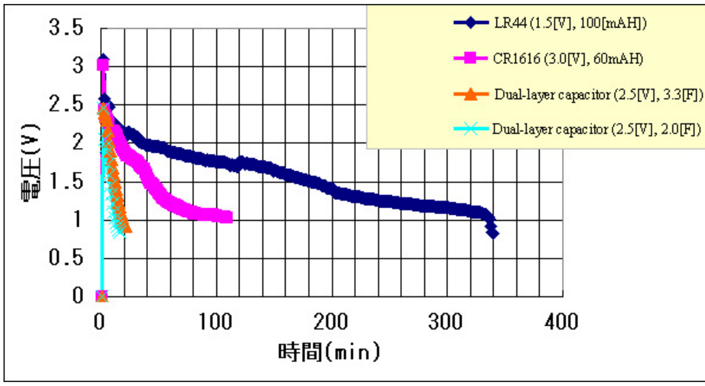


Fig.3 Durability of coin batteries to supply the current to the motor

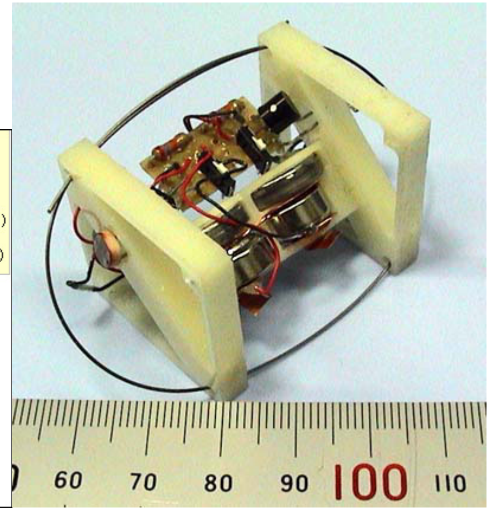


Fig. 4 Two motors and batteries are implemented into the body with wired frame for self-righting

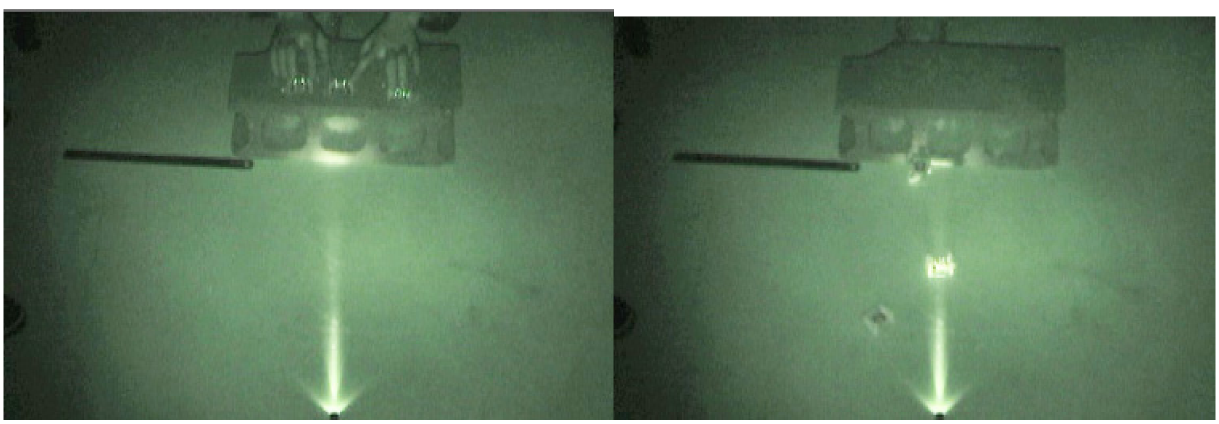


Fig.5 Small hopping robots with optical sensors can keep moving toward the light source automatically after dropping from the top of the block

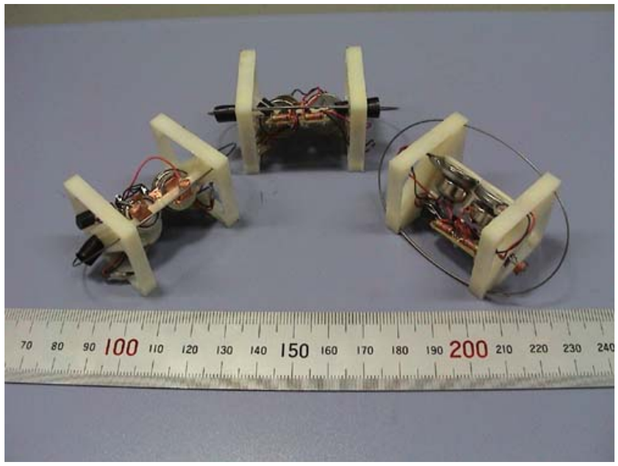
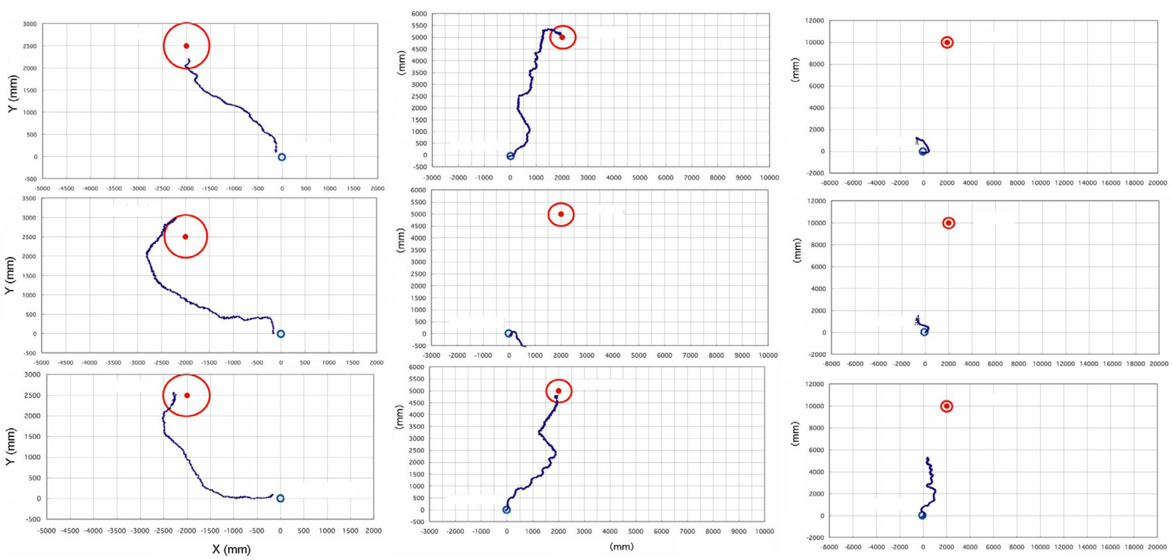


Fig.6 Developmental micro hopping mechanism with flat micro DC motor, sensors, button battery, electronics and the wired frame for self-righting property

To determine typical micro robot performance such as velocity, durability and sensor sensitivity, the following experiments were carried out with threre small robots as shown in Fig.6



(a) 2.5m (b) 5m (c) 10m

Fig.7 Experimental results of micro hopping robot for tracking the target based on the thermal signal from human body

The experimental results are shown in Fig.7. Here the tracking trajectory as measured by a CCD camera is depicted. When the target is located at 2.5m away from the starting point, the micro robot successfully maneuvers to the human subject. When the subject was located 5m from the micro robot, the micro robot was successful in maneuvering to the target 2 out of 3 trials.

However, the micro robot fails to maneuver to the target when the target is located at ≥10m away, because the target is out of detection range. By distributing a large number of micro robots in the rescue field, some of the micro robots will certainly succeed in maneuvering to the target.

<New proposals in this report>

-Technical Issues-

In order to improve the peformance of this unique micro locomotion mechanism which is applicable to the resque operation. Some technical issues and challenges as mentioned below should be considered.

(1) Many tiny robots with a single sensor

In the previous works, it was confirmed that the small robots with a sensor can detect the signal from such optical and thermal source and navigate itself to approach the target with a simple sequencial action. Since it would be better to keep the robot small and consume less power, it might be effective to implement a sensor to one robot and to employ many tiny robots with a single sensor with the integration of swarm technology.

(2) Implementation of visual/audio transmiter and thermal signal for communicating and tracking to the human body

(3) Transport and launch many tiny robots

In order to expand the workable range, several small robots can be transported to the location and then they can be launched by the spring mechanism far and wide. This mother-ship style can also provide the good mobility as well as the extention into the narrow area.

(4)Experiment of large-scale employment based on swarm intelligence

In the actual application, the large number of micro robots should be employed. The number of more than 20 micro robots will be fabricated and it is investigated that the coverage and the rate of success to find out the victim will be checked in the experiments.

-Innovation-

(1)Low Power: 3.0V x 0.05A= 0.15(W)
--->durable over 2 hours by bottun battery

(2)Low Cost: less than 1,000 Jpn yen(=$7.7)
Massive commitment and disposable robots

(3)Wireless motion system based on on board small battery

(4)High mechanical robustness to keep working after falling from the building.

(5)Implementation of several detector such visual/audio transmiter and thermal signal sensor to comminicate with human in the field.

(6)Large scale employment for cover the wider search range with the help of transporting and launching mechanisms.

<Technical challenges>

(1)Packaging a single sensor and electronics into micro robot body.

To get the higher mobility and the ability of automatic tracking to the target, the motion engine and other electroncis should be packaged into the small capacity of robot by using accurate machining process.

(2) Many small robots with a single sensor and swarm technology

To get the information from many small robots with a signle sensor such thermal, visual, audio and chemical sensor, some technical strategy based on swarm technology can give us the location of the target.

(3) Small vehicle as the mother-ship to transport and launch many tiny robots: To get the wider workable range, the combination of the mini-vehicle and many tiny robots can be practical.

<Project Schedule with Milestones>

Proposed Duration: 18 months

September/2005. Project Start
- -Implementation of IR sensor and simple logic electronics
- -Desing and assemble the launcer mechanism

March/2006
- -Many small robots production
- -Examine the sensing performance of IR detector withj thermopile and micro camera visual image.

August/2006
- - Interim Project Report

December./2006
- -Field experiements
- -Summarize

February./2007
- - Delivery Document of Technical Final Report

2. Development of Micro Hopping Self-Contain Micro Robot with Sensor and Camera

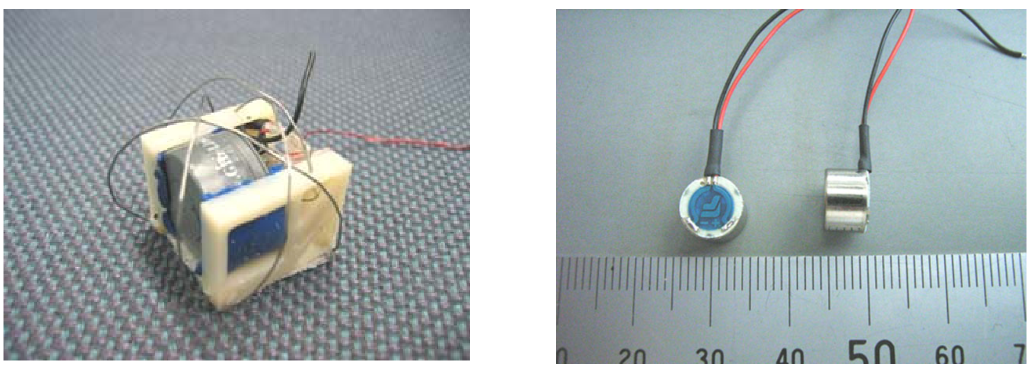
In our previous works, several small hopping robots with such optical and IR sensors have been developed. [1] [2] [3] However, they have still many problems to apply them into the actual situation because the lack of mobility of small robots causes that they can be stuck before the obstacles. Thus, it is required to make the assisting system to help such many small robots with human detectors. Here there are several plans to be considered to develop the assisting mechanism,

1) Easy transportation and maintenance as well as low cost to employ.
2) Convey many small robots near to the front end of the dangerous location and launch to deliver them over the obstacle under the visual remotely control by the operator.

So it can be possible to use many small robots with detectors for a useful rescue work when large scale disaster that needs wide field of search and a lot of numbers of searchers.

2.1 Locomotion principle and design

Small vibration motor (FMIU-004 (Fig.8 (b)) was used as an actuator in the small locomotion mechanism. Locomotion principle of robot that uses this motor is illustrated in Fig.8. This locomotion mechanism is driven by the unbalanced force generated by cyclic force of the vibration motor. Alternative force can thrust up and forward the body, while the reversed force



(a) (b)

Fig.8 Small simple micro robot and micro vibration motor

Fig.9 Micro CCD camera implemented on small robot to get the visual image around it

can push it down on the floor. So, the vibration motors are fixed at certain angles with ground. With this layout, the body can be driven to the one direction based on the differential force of the friction and the centrifugal force. In order to allow the micro robot to turn, a pair of micro motors are included and the current to each motors can be alternated. Then either of two motors provides the momentum force required to turn the micro robot. Two of these motors are built onto the micro robot as illustrated in Fig.8 (a).

2.2 Basic specification

In the previous works, optical sensor and IR sensor were mounted on the micro robot to allow to approach the illuminant and thermal source like a human. However, there was the problem that the thermal source could not be distinguished between human and another thermal source in actual disaster area. In this report, a small CCD camera (The ME as shown in Fig.9) is implemented on the small robot and the visual image can be transmitted to the operator although the electric power is still supplied by the cables. However the real image from the camera is displayed on the screen and then the micro robot can be navigated to the point is interested to check out. Control of the robot can be done to use a simple jog controller that switches the current to each motor and the motion direction can be easily changed. The typical speed of 50 to 60 mm/s can be achieved on the smooth flat surface while it is still not enough to employ them in the practical applications.

3. Design and fabricate of launching mechanism

It is most important for such small robots to move over the rubbles in the practical field. Here we are proposing the launching mechanism for many small robots. It's also possible to reduce the operation time to search of survivors by using this device.

3.1 Catapult-assisted launch mechanism

Several devices can be considered for the launching mechanism

1. A blast that used explosive etc.
2. Acceleration by electromagnetic force
3. Elastic energy of rubber and spring etc.

When a lot of energy should be given to the micro robot after catapult, the way of 1 or 2 is applied for the launcher. However these mechanisms become more complicated and small force can be enough to push up the small robot as the mass of that is approximately 14[g]. Other most important issue is that the launching mechanism can never provide such spark or fire, because it is expected that some gas can be leaked around the launching mechanism and be exploded in the practical situation. A simple mechanism is better for the point of maintenance and cost. Thus the actuator of the rubber and the spring can be used for our launcher. To gain energy enough to launch the small robot, it is necessary to extend the rubber or spring. Catapult-assisted launch mechanism with the leaf spring is designed and fabricated as shown in (Fig.10).

3.2 Mechanism description

Each part of this catapult-assisted launch mechanism is discussed in the next sections.

3.2.1 Adjustment of the leaf spring of the catapult mechanism

In order to launch the small robot to take over the rubbles, the injecting force and the launching angle are dominant to determine the distance for arrival and the top height of jumping. These conditions depend on the situation and then the range of launcher should be adjustable

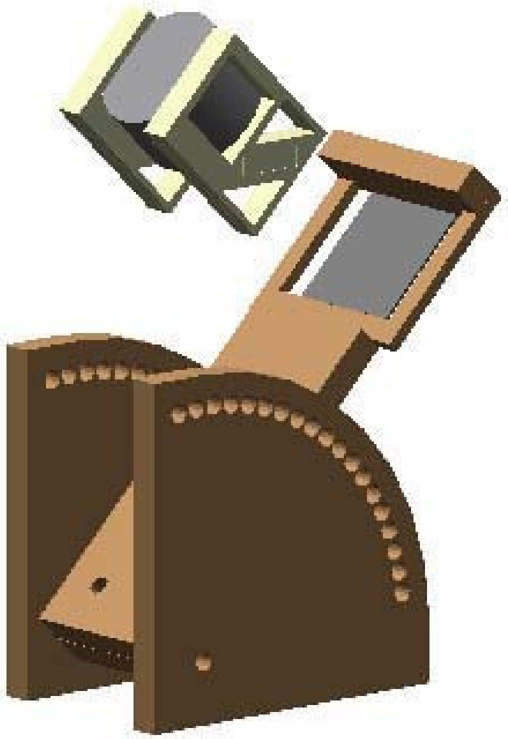


Fig.10 Isometric view of the leaf spring assisted catapult launching mechanism

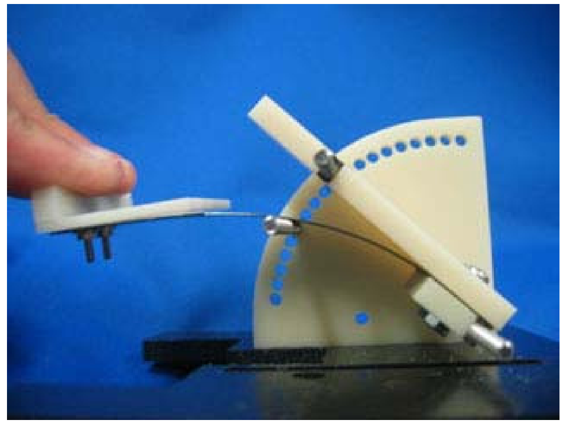


Fig.11 Spring bend can be adjusted at the intervals of 5mm

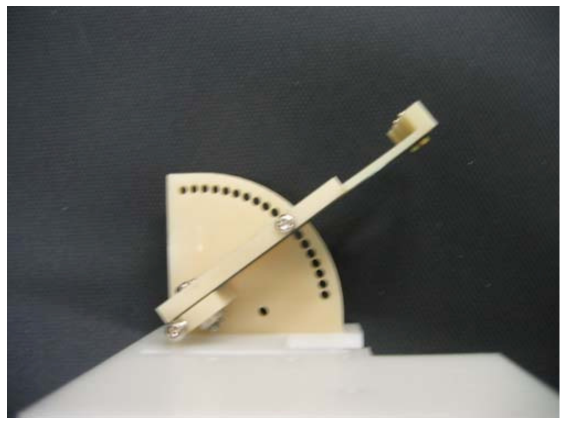


Fig.12 Angle of ejection is controlled with pin stopper of leaf spring

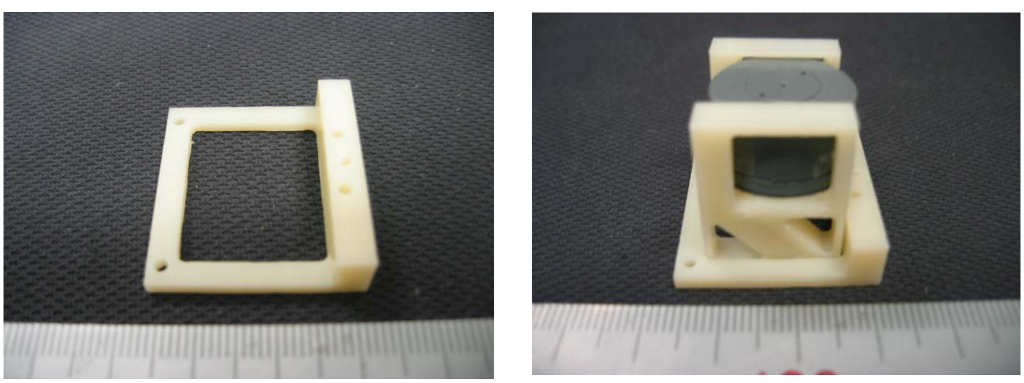


Fig.13 Mechanical holder for small robot at the end of the spring launcher

with the control of preset. Thus the expansion of the leaf spring and the catapult angle of launching lever are designed and fabricated to be adjustable with several steps of preset. In this mechanism, we can preset both the leaf spring expansion and the angle of ejection as mentioned below. The expansion amount of the leaf spring in the launcher can be read out with the wire winding drum and it can be estimated the force of ejection as shown in Fig.11 As shown in Fig.12, the angle of catapult can be adjusted with the pit stopper which is preset and thus the top height can be estimated by using the simple motion equation.The small robot can be set into the holder that is fixed at the end of the leaf spring to prevent from unexpected slipping and falling down(Fig.13).

3.2.2 Melt-down wire cut for ejection

It is well known that one of reason that robots are used to rescue work in disaster area is the replacement of human operation even in such dangerous situation. Thus it is necessary to operate the catapult-assisted launch mechanism by remotely control manner. In the proposed mechanism, the leaf spring can be bended by the wire that is winded up the drum in order to keep the energy enough to eject the small robot. In order to cut off the wire, the thermal heater is set close the wire and the current causes the wire to be melt down as shown in Fig.14. Then the small object can be push away from the catapult. This simple and classic manner is enough to operate with the good reliability.

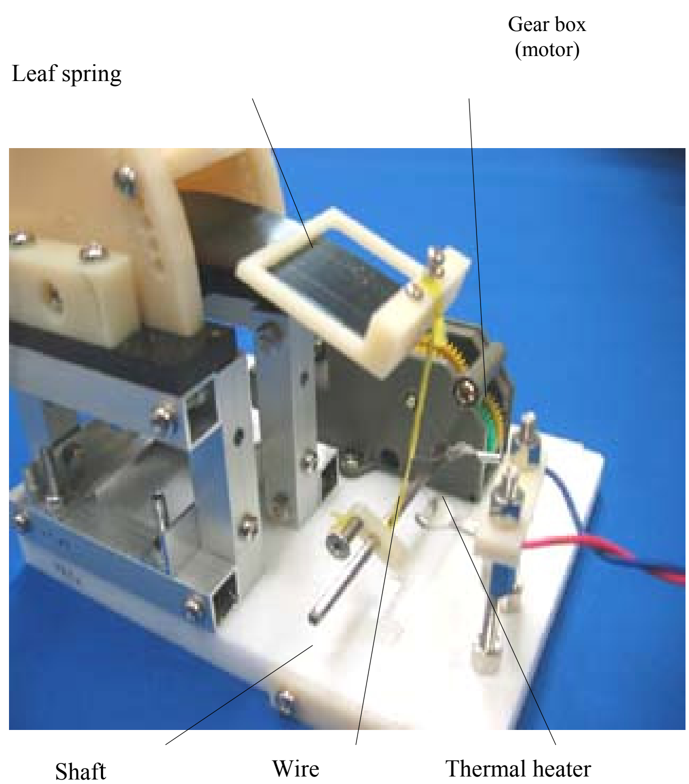


Fig.14 Ejection device with the wire
to melted down and cut off

4.Experiments

In order to check the basic performance, some experiments were carried out in terms of such the arrival distance with the spring bend and the ejecting angle of the catapult. The field experiment to examine the relation between the arrival distance and the launching parameter such the spring bend and the ejecting angle as shown in Fig.15. It should be also investigated whether the wire of small robot can be negligible or not. The comparison between the experimental results and the simple simulation will be discussed in the next section in 4.1 and 4.2, here the simple motion equation is applied for simulation while there is still more consideration.

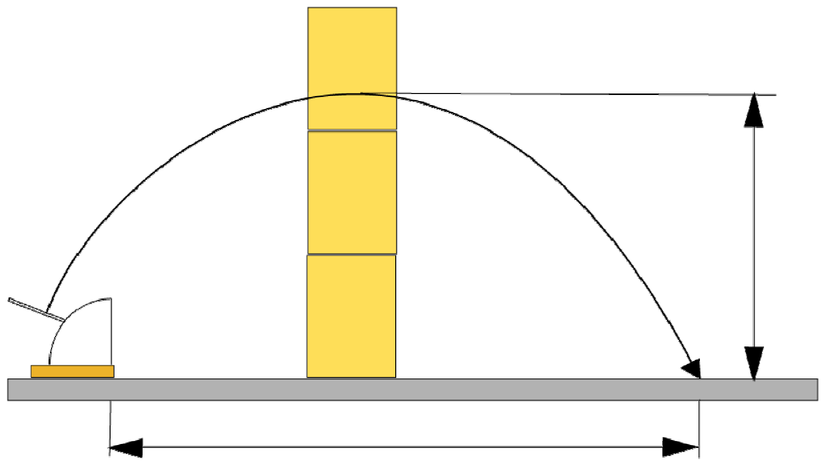


Fig.15 Experimental setup to check the arrival distance of small robot from the launching mechanism

4.1 Angle of ejection

The top height and the arrival distance are examined in order to check the appropriate ejecting angle of the catapult mechanism.The experiment results are shown in Fig.16 and here it is found that the range of arrival distance and the top height of this launch mechanism can be easily controlled so that the small robot can take over the obstacles.As the result, the ejecting angle is available between 20 to 60 deg to launch the target over the range of 4m. As the result of this experiment, the arrival distance and the top height can be controlled with the spring change and the distribution range of small robots can be also estimated. The tolerance of the arrival distance and the top height are less than 2m and this performance might be good enough to distribute several small robots near the target location.

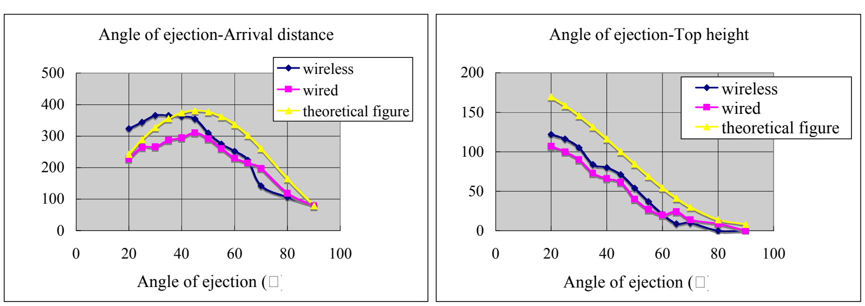


Fig.16 Flying distance and maximum height to the ejecting angle

4.2 Spring bend

Also the arrival distance and the top height are checked when the spring bend is incrementally changed with 5mm separation in the condition of the 20 deg initial catapult angle. The experimental result are shown Fig.17(20 deg). As the result of this experiment, the arrival distance and the top height can be controlled with the spring change and the distribution range of small robots can be also estimated. The tolerance of the arrival distance and the top height are less than 2m and this performance might be good enough to distribute several small robots near the target location.

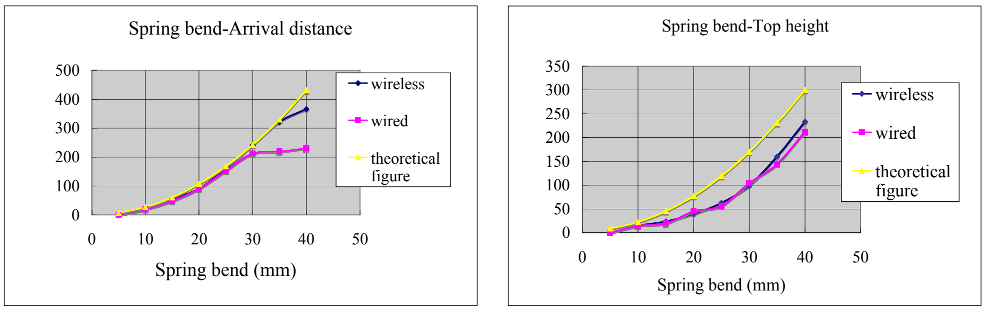
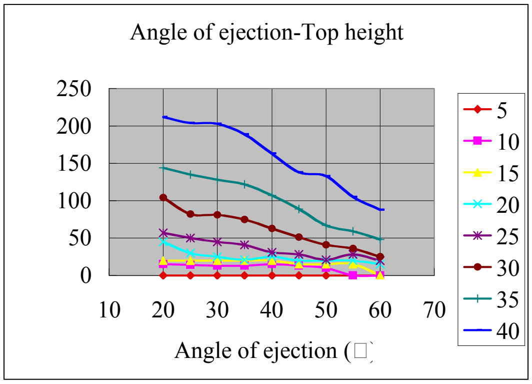


Fig.17 Flying distance and maximum height to the spring bend

4.3 Range of launching mechanism

The arrival distance and the top height are summarised as shown in Fig.18 and here we can determine the workable range of the launching mechanism. After investigation of the previous basic performance, the practical experiment is carried out by using the field as shown in Fig.19. According to Fig.18, the experiment was carried out when the ejecting angles of 20 deg and 60 deg are preset because the maximum arrival distance and the highest top height are achieved at these ejection angles. And the possibility was also checked when the obstacle is set at the middle point between the mother-ship and the target position. The height of the obstacle is a little smaller than the highest top height.

There it is found that both of the arrival distance and the top height were measured as smaller than that of the values in the Fig.18. So the launching mechanism can not eject the small robot to move over the obstacle that should be overcome. Since the tention wire of the spring is cut off by its melt down, the wire can not be cut quickly and then the acceralation for launching can be smaller than the estimated value. However it had good repeatability and thus it was possible to take over a little smaller obstacle. Thus it might be approval to dispatch the small robots into the narrow and the dangerous location with the consideration of such performance tolerance.



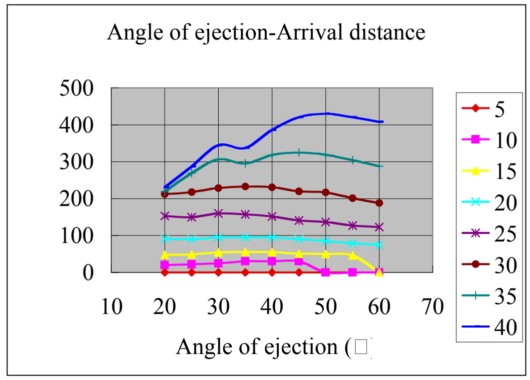


Fig.18 Performance of the lauching mechanism for the arrival distance and top attitude

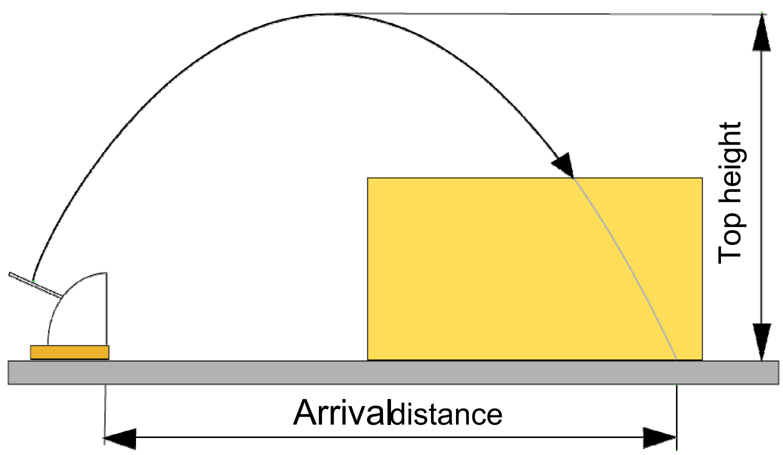


Fig.19 Layout of the launching mechanism and the obstacle in the field experiment

4.4 Search of human body

In order to use the catapult assisted launch mechanism in such the practical field, the wheel vehicle that can hold several launching mechanism is developed as a mother -ship. The second experiment with several small robot with nd when it can not move anymore due to some obstacles, then these small robots can be launched to take over the obstacle.

In Fig.20, the sequential photo that the micro robot is conveyed by the mother -ship vehicle in the front of the obstacle and then the small robot with the micro CCD camera is launched to take over the obstacle. After landing the field, it can be remotely controlled to survey the survivors with the CCD camera image. It is expected that it might be possible to assist the survey process in the rescue operation by using the micro robots with the image camera that are conveyed and launched to the dangerous location.

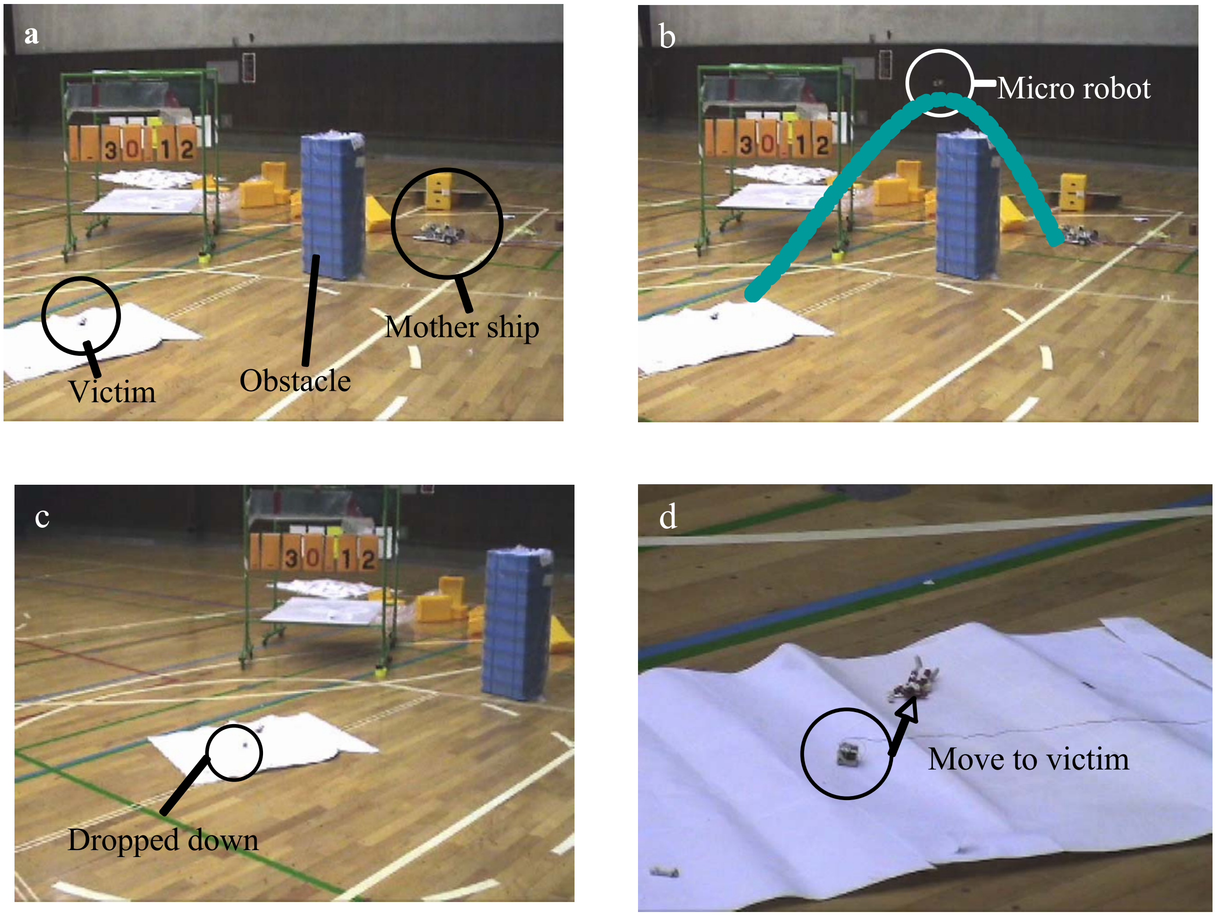


Fig 20 Succesful Result that automatic navigation of micro robot to approach the victim after flying over the obstacle by the lauching mechanism

5. Conclusion

In this report, it was described that an unique micro hopping locomotion mechanism, that it was drove by a micro eccentric motor, was
this locomotion mechanism is neither wheels nor legs. For the second phase of this research a mini cam and control electrics were integrated onto the micro robot to permit the micro robot to approach a victim. And as support device of micro robot, catapult-assisted launch equipment is developed. And the launching mechanism that can eject many small robots with the simple leaf spring was also developed. Some typical performances were checked in the field experiments.

In field experiment, this catapult-assisted launch mechanism succeeded in conveying the small robots and in launching them to take over the obstacle to get the visual image from the small robots distributed around the situation. In the future works, a microphone and a micro speaker can be mounted for detecting the sound signal and providing some sound information on the mother ship from the small robots.

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List of Publications:

(1)Katsuya Mugishima, Hisayuki Aoyama, Misaki Daigo and Theodore Sumrall; Development of micro robots and launching mechanism for suvivors survey in rescue operation; Proc. of 2nd Asia International Symp on Mechatronics, pp.230-235(2006)