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Throwable Tetrahedral Robot with Transformation Capability

Kenjiro Tadakuma1, Riichiro Tadakuma2, Keiji Nagatani3,
Kazuya Yoshida3, Ming Aigo1, Makoto Shimojo1, Karl Iagnemma4

Abstract—
In this paper, a tetrahedral mobile robot with central axis for transformation to the flat vehicle is presented. The throwable robot with the function of going into narrow spaces when its in the flat-vehicle mode is explained in detail. A prototype has been developed to illustrate the concept. Motion experiments confirm the novel properties of this mechanism: mode changing function and omnidirectional motion. Basic Motion experiments, with a test vehicle are also presented.
Keywords: Search and Rescue, Throwable, Tetrahedral Shaped, Omni-Ball, Transformation, Mechanical Design

I. INTRODUCTION

A. Throwable Robot for Access to the Field

Concerning ways to access a disaster area, there are several methods used all around the World. Some of them are as follows.

1) Throwing [1]
2) Air deployment [2]
3) Ladder [3]
4) Base unit [4][5]

There exit as well ways which are combinations of the above methods to access a disaster area.

In this paper, we focus on the first one: Throwing, and the second one: Air deployment, to access such kind of dangerous place for search and rescue robot (e.g. [6]-[10]) as shown in Fig. 1. As a throwable robot with protected body, we propose-, the tetrahedral shape because of the benefit of its symmetric property.

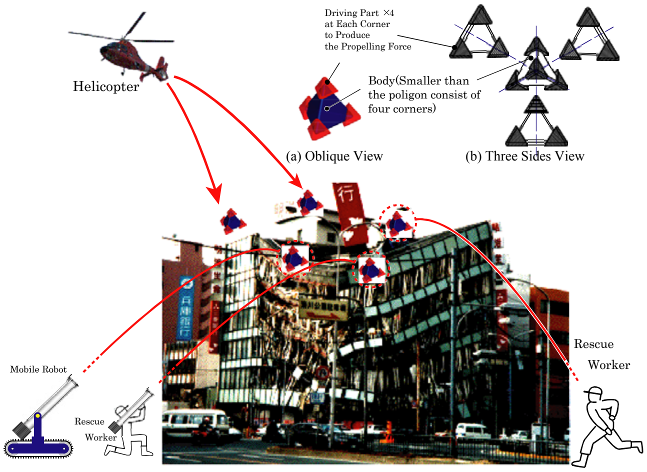
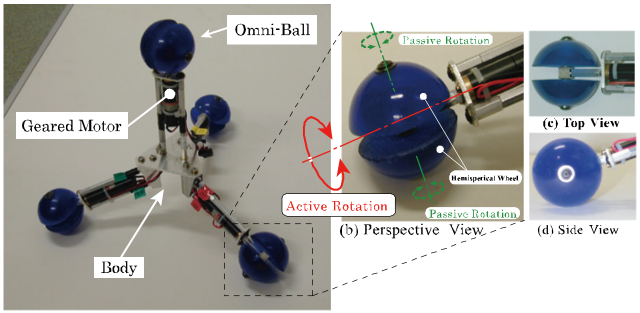


Fig. 1: Concept of Throwable Tetrahedral Mobile Robot



(a) Overview of TMR with Omni-Balls
(b) Perspective View
(c) Top View
(d) Side View

Fig. 2: First Prototype of Tetrahedral Mobile Robot

B. Tetrahedral Mobile Robot

The tetrahedral mobile robot has its body in the center of the whole structure. The driving parts that produce the propelling force are located at each corner. As a driving wheel mechanism, we have developed the "Omni-Ball[11]" with one active and two passive rotational axes as shown in the expanding view in Fig.2. The normal omni-wheel(e.g. [12] [16]) could be used for this robot, but the mobility on a rough terrain is important elements of the field, therefore we adopted this mechanism for a tetrahedral robot. This configuration can protect its own body and prevent taking damages from outsides.

(C-1). Basic Configuration of "Omni-Ball"

The basic mechanical model is shown in Fig.3. In Fig. 3, two hemispheres rotate passively, and the active rotational axis lies in the center of the Omni-Ball. In order to rotate, both the hemispheres are passive.

When the active axis rotates, the Omni-Ball produces a propelling force in a direction perpendicular to the active rotational axis, as shown in Fig.3. At the same time, the wheel does not produce a propelling force in the horizontal direction in Fig.3, so that this mechanism can similarly move in an arbitrary direction by a combination of three propelling forces.

University of Electro-Communications1, LAAS2, Tohoku University3, Massachusetts Institute of Technolog4 , tadakuma@gmail.com

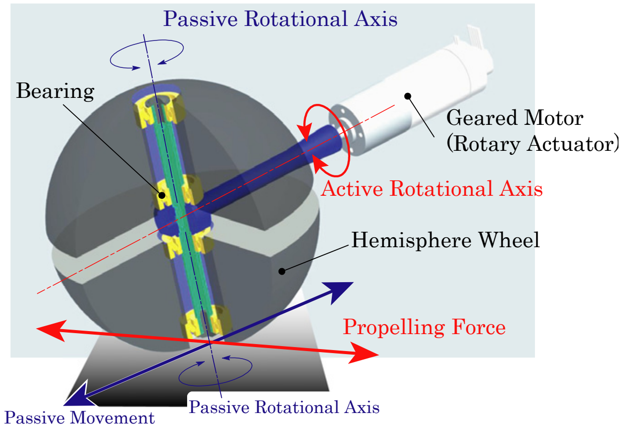


Fig.3: Basic Structure of the "Omni-Ball"

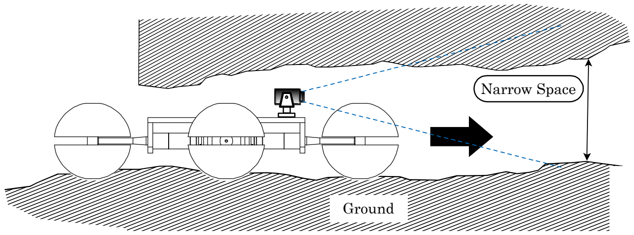


Fig. 4 Flat Vehicle into Narrow Space (Side View)

B. Need of to go into narrow space

On the other hand, there are requirements for search and rescue robots which move in collapsed buildings as shown in Fig.4[18]. After the robot would pass the narrow spaces, there still exists the possibility of the robot becoming trapped by debris or fallen down the suddenly and unexpectedly on rough terrain. Therefore, in such event, it is desirable that the robot has a retractable mechanism in order to protect the core body of it.

In next chapter, the retractable configurations are discussed and developed.

II. Expanding Mechanism for Tetrahedral Mobile Robot

A. Basic Two Expandable Mechanisms

Two different kinds of expanding mechanism are considered as shown in Fig.5. One is the linear expanding type at each of the four arms of the tetrahedral mobile robot, the other is a rotational type at the center of the core-body.

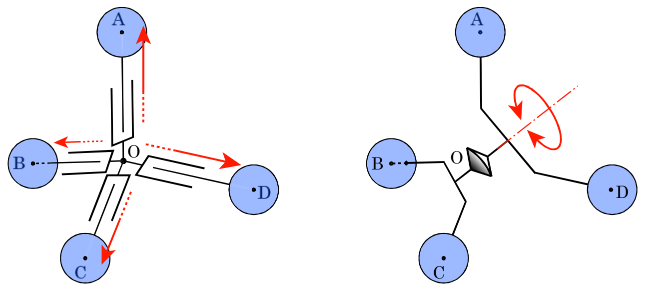
1) Linear Expanding Type

In the linear expanding type, the tetrahedral mobile robot needs one linear expanding mechanism on each leg. Thereof, 4 numbers of actuators are needed for this configuration. Considering the requirements of light weight for the throwing, a small number of actuators is desirable.

2) Rotational Expanding Type

As shown in Fig.6, and the attached video to this paper, the tetrahedral mobile robot can change its whole shape into the flat vehicle mode with just only one rotational axis at the center of that body.

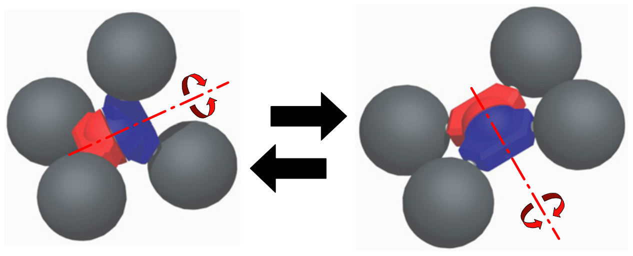
The equations of the geometrical conditions are show in equ.(1), and (2). Because of its symmetric condition, AO=BO=CO=DO in Fig. 7(a) and (b).



(a) Linear Type (b) Rotational Type

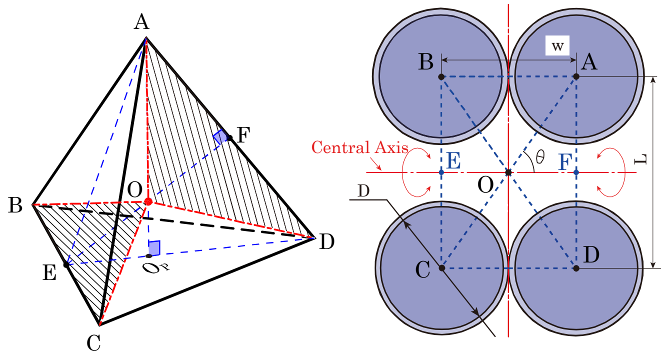
Fig. 5: Two Basic Configuration of the Expandable Mechanism for the Tetrahedral Mobile Robot

[Geometrical Condition]



(a) Tetrahedral Mode (b) 4-Wheeled Vehicle Mode

Fig. 6: Mode Changing by the Rotational Mechanism



(a) Geometrical Configuration (b) Geometrical Condition

Fig. 7: Geometrical Condition of Tetrahedral Mobile Robot with Central Rotational Axis

$$D < W = L / \tan\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

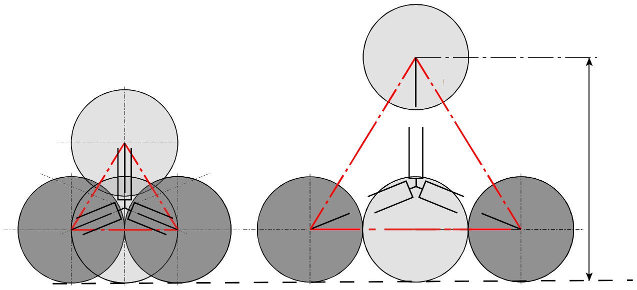
$$\theta = \sin^{-1}[\,(2/3)^{1/2}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The proportion of the actual prototype model shown afterwards meets these conditions.

A. Comparison between Two Expandable Mechanism

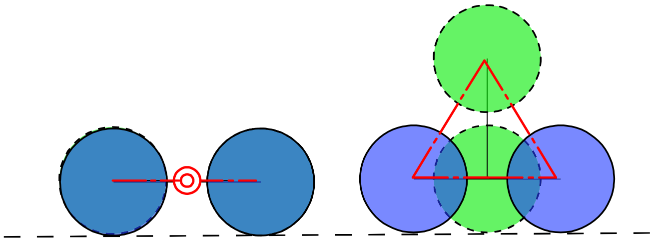
The height on the retracting mode, height of the camera as the device for searching disaster victims and the volume of the core-body are compared between these two expanding mechanism.

When the tetrahedral robot take the maximum filling factor, the proportion of the position of each wheel take the as shown in Fig 13(left one).The equations and geometrical conditions are shown in Fig.13 (right one).



(a-1) Linear (Retracting Mode) (a-2) Linear (Expanding Mode)

Fig. 8: Two Mode of Linear Expanding Type



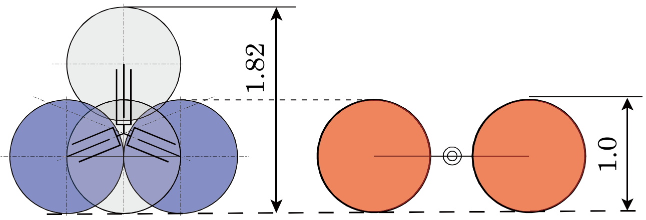
(b-1) Rotational (Retracting Mode) (b-2) Rotational (Expanding Mode)

Fig. 9: Two Mode of Rotational Expanding Type

1) Size on the retracting mode (smaller is better)

The height of the robot when it is in the retracting mode, the The result of the comparisons is shown in Fig.11. The height of the vehicle on retracting mode in lenear expanding type is 1.82 compared with the 1.0 of the rotational type as shown in Fig12. This means that, on the retracting mode, rotational expanding type can go into much narrow spaces in up-down direction in disaster areas.

As a result, rotational expanding type is better than the linear expanding type (Smaller is better).



(a) Linear (Retracting Mode) (b) Rotational (Retracting Mode)

Fig. 10: Height on Retracting Mode (Linear Type and Rotational Type)

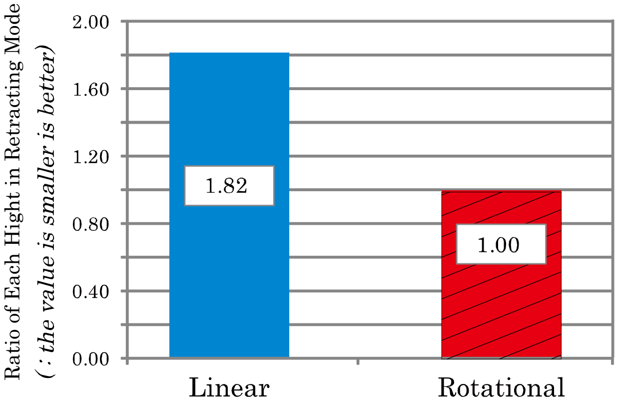


Fig. 11: Comparison of the Height on Retracting Mode

2) Height of the Camera (higher is better)

It is defined that the position of the camera is put on the center of the one of the Omni-Ball. To compare the two type, the expandable ratio is depends on the stroke of the linear actuator in linear expanding type, so we estimated the height of the camera on each stroke of the linear actuator as shown in Fig. 12. The value"1.0" in the vertical axis in Fig. 12 shows the height of the camera in rotational expanding mode as a criteria. The dots in this figure show the value of the ratio of the height of the camera between linear one and rotational one. In short, the height of the camera of the linear one is lower than rotational one when its ration of the stroke is smaller than 0.4. Basically it is difficult build the linear expanding mechanism larger than 0.4 in practical, so that the height of the camera could be lower than the rotational type in practical.

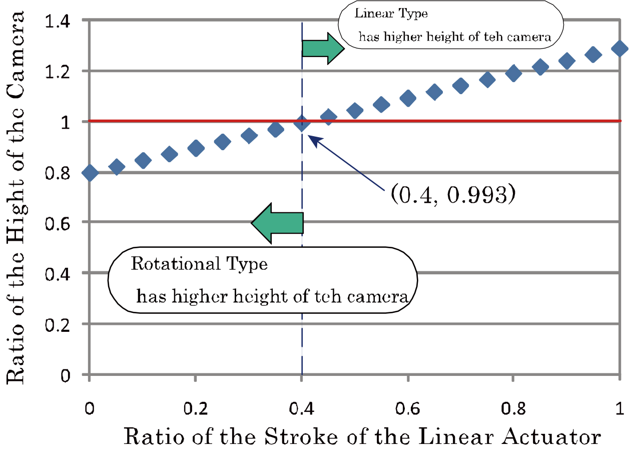


Fig. 12: Comparison of the Height of Camera in the Each Tetrahedral Mode

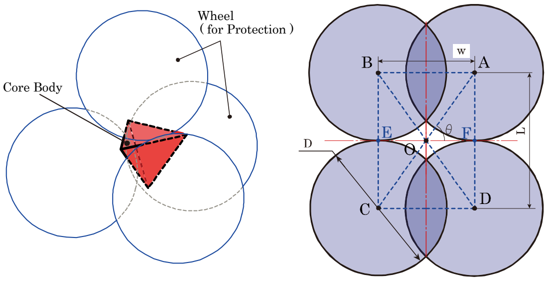


Fig. 13: Highest Filling Factor in Tetrahedral Mode

(C) Volume of the core body

The body is defined as the tetrahedral shaped covered by each wheel as shown in Fig. 13. By the calculation(with each proportion as shown in Fig.10), the value of the volume of the core body is 1.27 times larger than linear one as shown in Fig.14. The body in the linear mode can protects the body better, but the amount of the devices on the body is also drawback. The amount of the devices to set on the body is one of the important elements as a search and rescue robot.

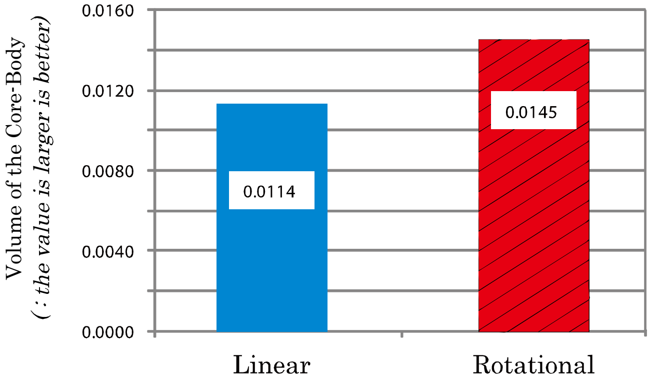


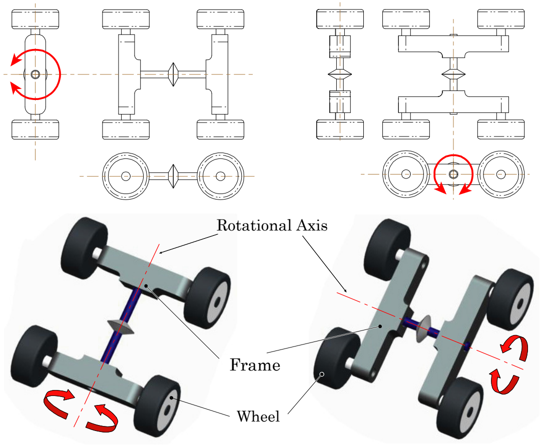
Fig. 14: Comparison of the Volume of the Core Body

As shown here, the rotational type one is not only simpler in the structure from the view of the numbers of the degrees of the freedom: it is easy to put dust or water proofing mechanism, but also the space for the sensors amounted in the core body of the robot.

A. Additional Feature of the Rotational Motion

Additional function of the central axis to change the mode of the robot, it can be used for the equalizer on rough terrain, it means that, the axis works not only as the mode changing mechanism but also as the equalizer. The roll axis type and pitch axis type are shown in Fig. 15 respectively.

Thanks to the Omni-Ball: spherical omnidirectional wheel, the tetrahedral robot with center rotational axis can move not only forward-backward way but also sideways, therefore the proposed model with the omnidirectional wheel can take both of the types as the case may be.



(a) Roll Axis Type (b) Pitch Axis Type

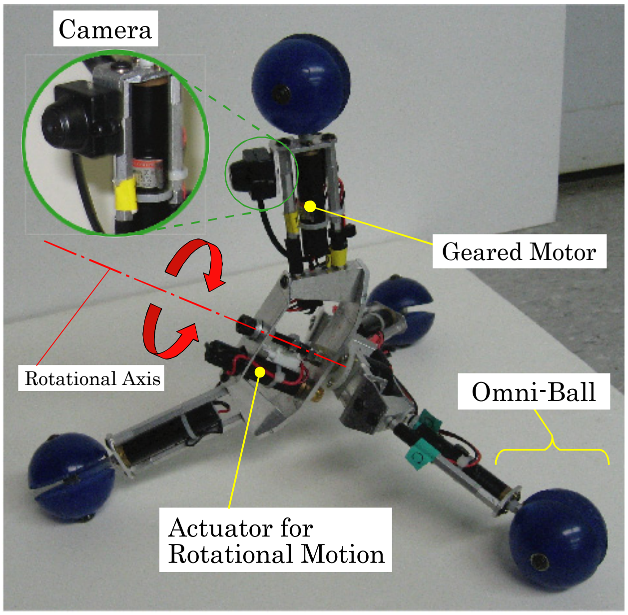
Fig.15: Central Axis to Enlarge the Running Ability on Rough Terrain

III. Basic Configurations of Prototype Model

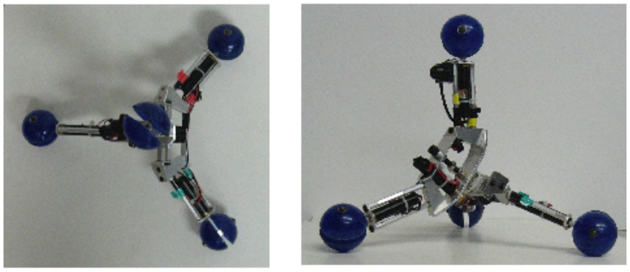
In this section, the basic configuration of the proposed tetrahedral mobile robot with transformation capability is described.

The first mechanical prototype model has been developed based on the geometrical condition shown in Fig.7. The overview of the tetrahedral mobile robot with transformation capability on tetrahedral mode and 4-wheeled flat vehicle mode is shown in Fig.16 and Fig.17 respectively. In addition, the specification of the prototype on each mode is shown in table1.

As a application for the search and rescue robot, there is the camera mounted on one arm of the robot. As the first prototype model, for the ease to make in low cost, the size of the Omni-Ball is set smaller than that of the demanded one to protect the core-body as shown in Fig.16, so that there is not enough space to include the camera or other sensing devices into the inside of the Omni-Ball. Therefore, the camera is positioned below the Omni-Ball for the first prototype model, but the mechanical model with the camera inside of Omni-Ball will be considered.

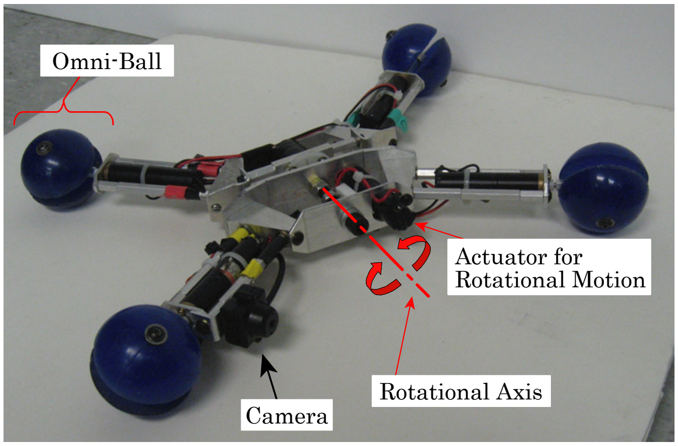


(a) Oblique View

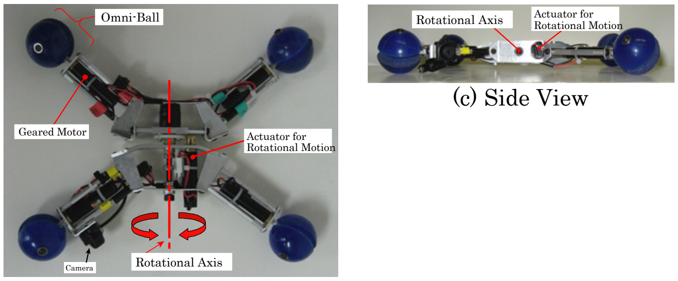


(b) Top View (c) Side View

Fig.16: Overview of the Mechanical Prototype Model on Tetrahedral Shaped Mode



(a) Oblique View



(b) Top View

(c) Side View

Fig.17: Overview of the Mechanical Prototype Model on 4-Wheeled Flat Vehicle Mode

Tab.1: Specification of the Tetrahedral Mobile Robot with Transformation Capability

Length on Side in Tetrahedral Mode	294.4[mm]
Height in Tetrahedral Mode	248.6[mm]
Short Width in 4-Wheeled Mode	234.4[mm]
Long Width in 4-Wheeled Mode	294.4[mm]
Height in 4-Wheeled Mode	45[mm]
Weight	467[g]
Diameter of the Wheel	45[mm]
Motor (Rotary Actuator)	2.5W
Battery(Out of the Body)	12[V]5[Ah]
Height of the Camera	192[mm]

V. Basic Experiments of the Prototype Model

In this section, we describe a set of experiments conducted to confirm the performance of a prototype of this tetrahedral mobile robot with transformation capability.

A. Omnidirectional Motion

Being a basic feature of this robot, the omnidirectional motion should be confirmed. One example of such motion is shown in Fig.18. In this figure, the length of the square on the floor is 300mm. It was observed that this prototype robot has the ability to move in arbitrary direction. Considering that the mobile robot is to be used in somewhat rough terrain, and that precision is not be paramount in a disaster area, the ability of omnidirecional motion of this robot is considered sufficient through this experiments.

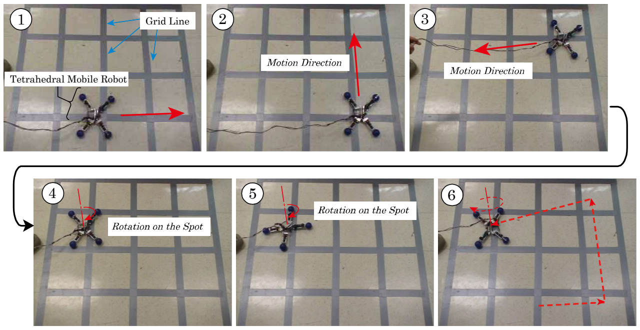


Fig.18: Omnidirectional Motion on Floor

B. Mode Changing Function

The ability of change the mode of vehicle was also confirmed as shown in Fig.19. In the present prototype model, the center of the gravity of this robot is not at the precise center of this robot, so the posture of the robot is depends on the which way that C.O.G. exist at that moment. As a next model, by putting just only one simple arm, it will be able to change its center of gravity actively and able to choose the posture it takes.

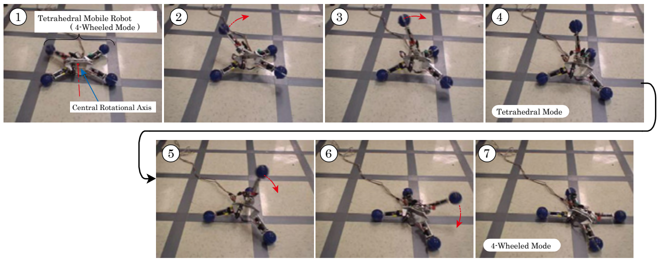


Fig.19: Motion of Mode Changing

C. Mode into the Narrow Space

The ability of getting into the narrow space by the flat vehicle mode has been confirmed as shown in Fig. 20. The height of the space under the desk is about 139.7mm. It is shorter than the height of the tetrahedral mode. The tetrahedral mode is useful for protecting the core body from a sudden tumbling and wide search by the camera at the top wheel of the tetrahedral robot. On the other hand, the 4-wheeled mode is useful for going into the narrow space as shown in this experiment. The tetrahedral robot with the central axis can change these two modes.

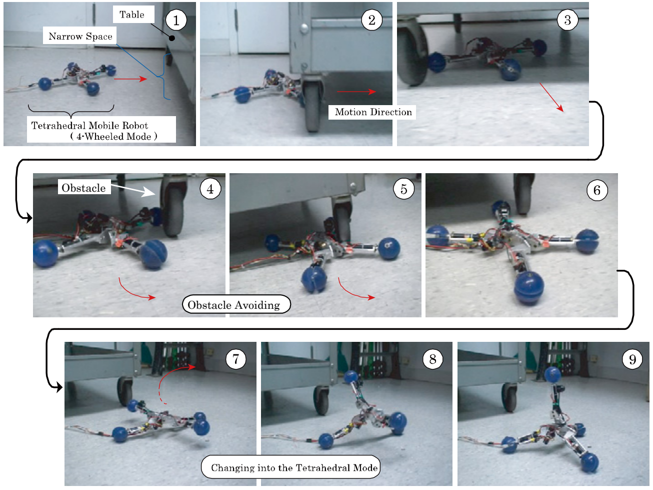


Fig.20: Motion into the Narrow Space

D. Function of Central Axis

The function of central axis of this robot was also confirmed as shown in Fig.21. The height of the step is 52mm. It was observed that a prototype can make use of the function of central axis and make the C.O.G of the robot lower and then can keep the higher stability.

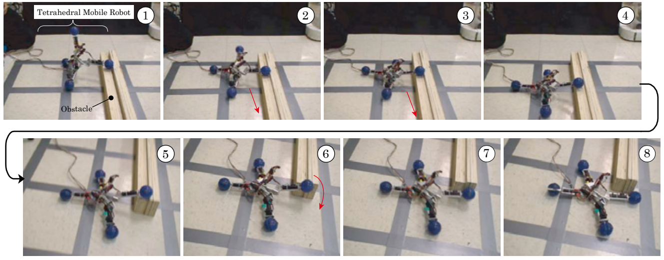


Fig.21: Function of the Central Axis

E. Walking Motion

As one of the advanced mobility criteria of this robot, the ability to produce walking motion has been confirmed. One example of such a motion is shown in Fig.22, and the height of the rock is about 15.5cm. It was observed that this prototype model has the ability to climb the higher rock compared with the wheeled mode.

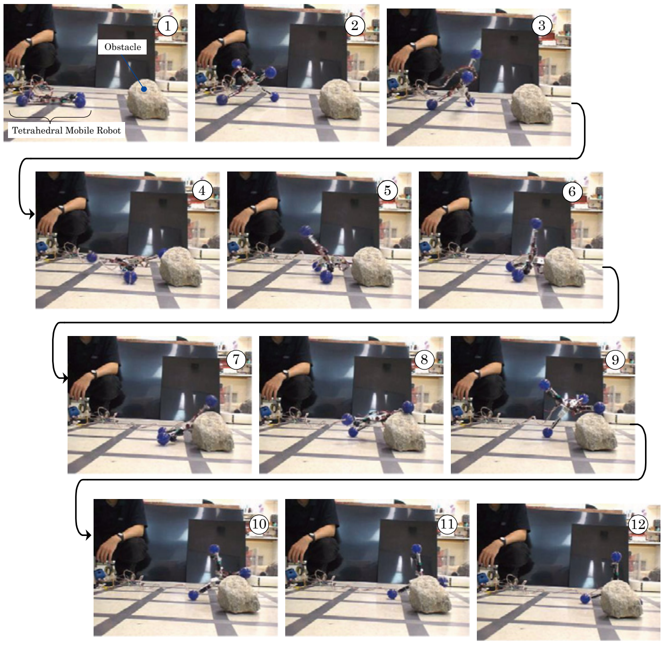


Fig.22: Walking Motion (Obstacle-Climbing Motion)

VI. Stability Margin

In this section, in order to show the increasing of the stability in 4-wheeled mode of the tetrahedral mobile robot with the central axis, S_{NE} : Normalized Energy Stability Margin[19] is calculated in two modes. The "S_{NE}" is defined as follows,

$$S_{NE} = h_{max} - h_0$$

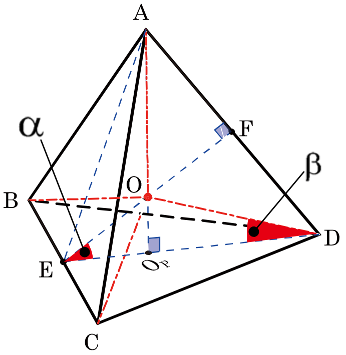


Fig.23: Definition of α and β

The angle OED is defined as "α" and angle ODE is defined as "β" in Fig.23. Based on the definition of S_{NE}, and as shown I n Fig.24(b-1), the minimum S_{NE} in the tetrahedral mode is calculated as follows.

$$S_{NE} = OE\{1-\sin(\alpha+\gamma)\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

"γ" is defined as the angle of the slope which the robot stays.

As shown in Fig. 25 (b-1), he minimum S_{NE} in the 4-wheeled mode is calculated as follows.

$$S_{NE} = OE(1-\sin\gamma) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

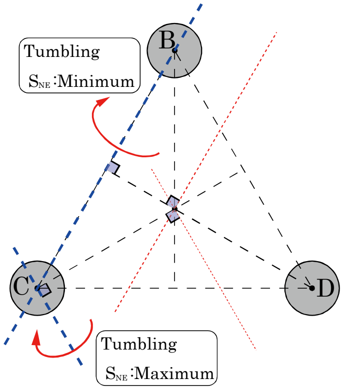
As shown in Fig.24 (b-2), the maximum N_{SE} in the tetrahedral mode is calculated as follows.

$$S_{NE} = OC\{1-\sin(\beta+\gamma)\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

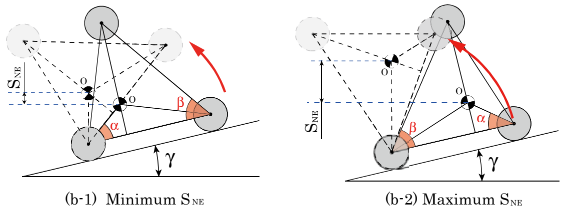
As shown in Fig. 25(a) and (b-2), the maximum N_{SE} in the 4-wheeled mode is calculated as follows.

$$S_{NE} = OC(1-\sin\gamma) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Based on these equations, each S_{NE} line is shown and compared in Fig. 26.

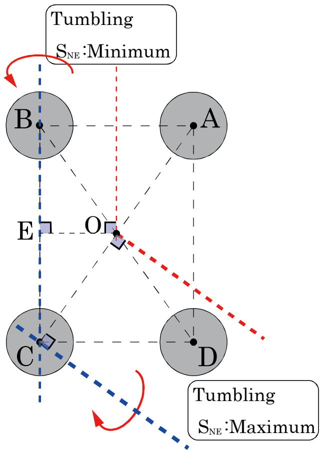


(a) Tumbling in the Tetrahedral Mode

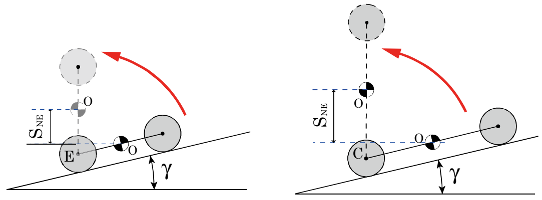


(b-1) Minimum S_{NE} (b-2) Maximum S_{NE}

Fig.24: Normalized Energy Stability Margin in the Tetrahedral Modes



(a) Tumbling in the 4-Wheeled Mode



(b-1) Minimum S_{NE} (b-2) Maximum S_{NE}

Fig.25: Normalized Energy Stability Margin in the 4-wheeled Modes

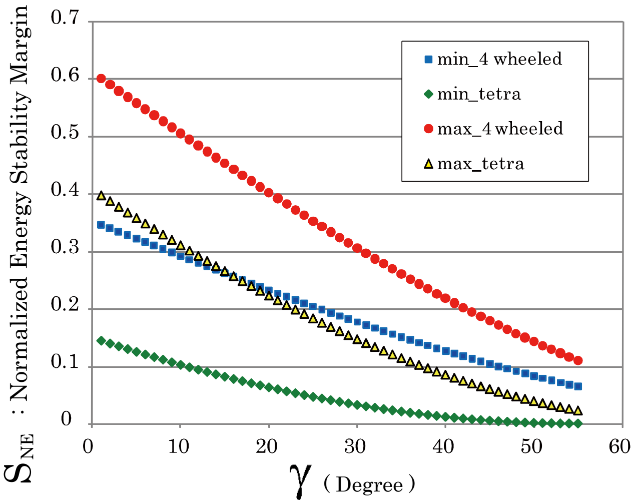


Fig.26: Comparison of Normalized Energy Stability Margin

As shown in Fig. 25, the 4-wheeled mode is higher than normal tetrahedral mode. Therefore, It can be said that the tetrahedral mobile robot with the central axis can make the stability much higher than the normal tetrahedral one.

VII. Conclusion

In this paper, we showed the tetrahedral mobile robot with central rotational axis to realize the compact retracting mode in order to go into narrow spaces. The linear the tetrahedral mobile robot was also presented. We confirmed the basic characteristics of the tetrahedral mobile robot with central rotational axis and the motions of the robot through experiments.

In future works, we plan to optimize the mechanism of the driving mechanism: omni-ball, bumping mechanism of each arm as well as the sensors in the core body for search and rescue missions.

Acknowledgment

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