Self-growing Motion Mechanism for Inspection and Maintenance

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Purpose An inspection and maintenance system is essential to obtain a proper and stable construction. However, internal inspection and maintenance of the inner parts of pipeline are difficult to conduct. Force effects should be eliminated to accurately inspect the state of a pipeline. This paper suggests a self-growing mechanism (SGM) which focuses on a minimization of force effects compared to previous progress maintenance methods. **Method** SGM mimicks the motion of amoeba, a protozoan, as a growing unit. It is shaped like a reversed hose. The SGM represents gelation and isolation of the amoeba; the inside skin is fixed outside and fluid is injected. In this way contact force is minimized so as to be negligible. By passing through injected fluid, the SGM acts as a buffer. Nevertheless, there is a limit to the use of this instrument for maintenance due to the drift of the upper section of the growing unit. To overcome this and expand the field application, the SGM was equipped with auxiliary equipment called install-base, this is composed of three rings. Bundling several units was also considered. This can give SGM direction by differential fluid injection to each unit, and facilitates progress through the curved paths. **Results & Discussion** SGM allows only contact force on the surface, similar to amoeba movement. This can be described as the contact which occurs when a rolled surface unfolds. SGM can help in the maintenance process of highly hazardous or unreachable spots, such as nuclear power plants, pipelines, and so on. It is best suited for highly sensitive environments. SGM is also promising in combination with inspection and maintenance of constructions with field endoscopy; it can provide medical checkups or remedies innovatively. Moreover, it is expected that SGM, unlike previous methods, can more accurately carry out maintenance of gradually downsized applications.

***Keywords**: self-growing, inspection and maintenance, pipeline, minimization of contact force*

INTRODUCTION

Recently, there are increasing infra constructions necessary to human life. Especially, needs of various pipelines such as for urban gas, sewage facility, chemical plants, and nuclear power plant and so on has been increased. According to this situation, importance of inspection and maintenance for pipelines is emerged. However, it is more difficult to carry out internal maintenance for pipelines because of access limit to operation spots than other processes. To overcome this point, a number of motion mechanisms for intelligent inspection and maintenance have been developed.

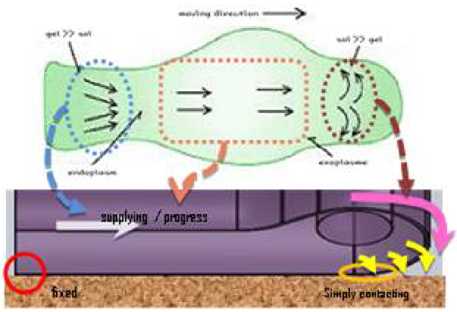

Fig. 1. Concept of the Self-growing unit with respect to a protozoan mimetic

Previous motion mechanisms can be classified into many forms: wheel type, crawler type, legged mobile type, and inchworm type[7].

There was the simply proceeding method to use wheel. More practical design utilizing wheels has been also proposed, one of which is a micro robot driven by the principle of screw. The design is composed of main body and two tires and adopts proceeding along spiral trajectories on the inner wall[8, 9]. Motion mechanism based on inchworm type was suggested, one of mechanism can contribute to remote distance progress of system by friction effect as introducing friction rings[10]. Other design with Shape Memory Alloys (SMA) as an actuator provides stable and accurate locomotion in way to alternate clamping with moving modules[11]. Some researchers have also proposed different motion mechanism designs for inspection and maintenance of pipeline. An example of designs is called as mechanical adaptive in-pipe robot. It can be applied to various size of pipeline due to employing elastic wheeled legs and driving module which feature tri-axis differential velocity mechanism[12]. The other legged type design was also studied: walking micro robot[13].
Although numerous motion mechanisms are developed currently in order to improve efficiency of inspection and maintenance, constructions under inspection and maintenance operation are unable to

avoid a force effect caused by proceeding characteristic and usage of instruments for the task. When conducting inspection and maintenance of pipeline, as to detect the state of line accurately, it is necessary to eliminate force effects. The reason of this fact is that force effect can be the problem in respect to point which the inspection and maintenance is originally aimed at the overall improvement of the system. To satisfy the purpose of inspection and maintenance and take appropriate actions to obtain reasonable state of systems, the conditions obtained from operation should explain the system correctly. Unless getting out of a force effect, operation findings will not the present state but the state result from force effect. Because, at highly hazardous or highly sensitive environments, this can act as critical factor, improvement in inspection and maintenance technique is required.

This paper suggested the motion mechanism focused on the minimization of force effects in comparison with previous mechanisms for inspection and maintenance. As reducing force effect, this mechanism can find state of system accurately. It is named as the Self-Growing Mechanism (the SGM).

This new motion mechanism is based on the characteristic of amoeboid movement and liana's growing. It has a strength applying at most contact force on relative surface. Through this paper, from basic concept of the SGM as new mechanism to ideas for auxiliary equipment required to realize actual progress will be presented. Finally, the experiment of moving forward was carried out by making prototype for the SGM.

FOUNDATION OF THE SELF-GROWING MECHANISM

1. Bio-mimetic

The Self-growing mechanism is based on biomimetic: specifically, a protozoan organism and a liana.

1.1 Protozoan mimetic

The amoeboid movement typically observable in an amoeba as a protozoan organism differs from traditional progress methods. A pseudopodium, an organelle for motion, is temporary processes of cell bodies. The basic components of the amoeboid movement are a gelation and solation phenomenon in amoeba body. Amoeba consists of ectoplasm and endoplasm. Ectoplasm exists as gel state inside thin pellicle called as Plasma lemma, and covers endoplasm in a state of sol. Endoplasm moves forward continuously, getting near the head of body, is

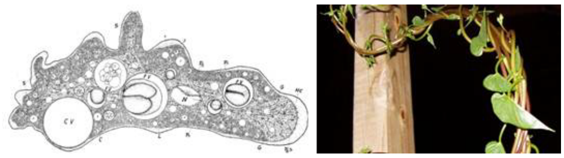

Fig. 2. Amoeba and liana as subject of mimetic

converted into ectoplasm through gelation. Simultaneously, at the rear, ectoplasm is solated and complements endoplasm. That is, gel solates and goes into endoplasm region at the rear part of the body, and sol gelates and goes out to ectoplasm region at the head. These gelation and solation make whole amoeba body proceeding. Actually, amoeboid movement is similar to a spreading phenomenon of oil on water, so that the surface tension of the amoeba-surface interface is less than the water-surface interface when spreading. There are also a number of facts fully established which show conclusively that surface tension applied due to amoeboid movement plays a very insignificant role[5]. The SGM adopts amoeboid movement in order to aim at lowering the force effect on the surface within the framework of protozoan mimetic.

1.2 Plant mimetic

A liana is commonly name to explain various plants which grow along trees as well as other means of vertical supports without standing itself. Its growth has characteristic climbing according to standard surfaces or supports located at core section of progress[6]. Standard supports decide the direction of growth as being a sort of guidelines. The SGM adopts a liana's growth characteristic so as to aim at setting the direction of progress and carrying out the required operations along the given path within the framework of plant mimetic.

2. Correspondence of the SGM to the mimetic objects

2.1 Protozoan mimetic

The SGM as motion mechanism can proceed from core element called growing unit. The relationship between the progress of growing unit and the amoeboid pseudopodium movement is described in fig1. In the SGM, the growing unit playing the role of circulative ectoplasm and endoplasm is fueled by fluid injection. The difference of the SGM with the amoeboid movement at here is that the growing unit is not circulating and fixing external edge arranges the location adjusting proceedings.

2.2 Plant mimetic

The SGM is modeled from a liana's growth characteristic that it can go along the given path under the environment as guidelines.

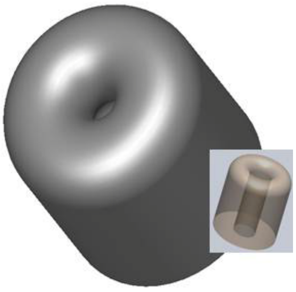

Fig. 3. Concept of growing unit

Designs for the Self-Growing Mechanism

1. Configuration of the SGM

The SGM is composed of several components in order to proceed. Composition of the SGM can be sorted to main and supporting parts.

- Main parts: growing unit, air pump as source for proceeding
- Supporting parts: install-base, Supply and Withdrawal(S/W) module, bundle for steering

There is described each briefly as following.

1.1 Growing unit
This paper suggests the new concept of a method of progress from protozoan and plant mimetic. The purpose of this study is to develop and apply the motion mechanism differentiated from previous ways. To achieve the goal, it employs the growing unit as key technology. Growing unit which shape is like reversed hose represents progress as growing gradually by fluid injection (fig3).

1.2 Install-base
The growing unit is gradually lengthened during proceeding and its upper section is continuously shifted. However, there should be space for taking the instrument needed to particular task. For that reason, the SGM equips the auxiliary equipment called install-base, composed of three rings to overcome the drift of upper of unit and obtain stably fixed position independently of drift.

1.3 S/W(Supply and Withdrawal) module
A capability of going forward/backward is essential for operation. Therefore, to add to going forward by growth of unit, S/W module is introduced for going backward.

1.4 Bundle for steering
The solution improving progress along the given path is to set up the direction of growing unit towards destination. Realization of steering utilizes the set of several growing unit. After making a bundle, each unit is supplied with differential fluid source.

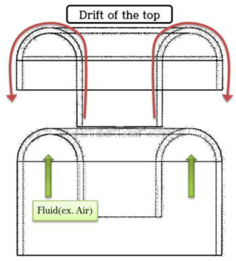

Fig. 4. Top drifts as limitation of growing unit

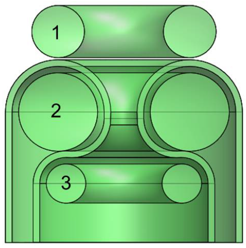

Fig. 5. Structure of install-base composed of three rings

2. Strength of the SGM

Even if many studies of motion mechanism for improving efficiency of maintenance have been conducted, they are not able to overcome inevitable force effect as proceeding. On the other hand, the SGM is superior with respect to minimization of force effect on the relative surface. Additionally, due to fluidic resource for growth, the SGM has buffer effect in itself. Because it is able to minimize friction factors, the suggested mechanism is termed the self-growing method distinguished from the previous.

3. Auxiliary equipment for installing instrument

Realization of the SGM only based on protozoan and plant mimetic has some limitations. Maintenance system can load instrument for operation so as to apply the SGM in many industries, go forward or backward, and alter direction for progress. Thus, auxiliary equipment was considered.

3.1 Install-base
Progress of the SGM is possible when outer edge of the growing unit is fixed and there is injection of fluidic source inside the unit, as if amoeboid movement. The feature of progress is so similar with circulated amoeboid body that there is at most contact force on relative surface. Although the SGM has the minimized force effect as strength, there are limitations for applications in fields due to drift of the upper section of unit. That is, it is not able for the SGM itself to equip the instrument. Therefore, Install-base is considered as auxiliary equipment making up for the functional defect. It is required to be located on the upper surface of unit, not drifting away.

- Structure of the install-base

The idea about Install-base starts from simple constraint structure. Install-base has 3-rings as components. The degree of constraint between each ring adjusts appropriate positions and function of install-base. The fig5 shows the arrangement of 3-rings. From up of growing unit, the rings are numbered as 1-, 2-, and 3-ring. The 2-ring is inside the growing unit, and is bound by 1- and 3-rings. Restriction is built by making the outside diameter of 3-ring bigger than the inside diameter of 2-ring and connecting 1- and 3-rings. The upper section which 1-ring is located offers the base space for equipping the device needed in operations.

4. Auxiliary equipment for forward/backward and steering motion

4.1 Supply and Withdrawal module

Above all, forward moving is accomplished already. However, proper measures for backward moving are not made yet. For this reason, additional supplement is added. Forward/backward movements are matched to supply and withdrawal of the growing unit. It is located on the top of unit and does not interfere with the function of install-base. Its name is Supply and Withdrawal module.

4.2 Bundle for steering

System has to move smoothly along the given path to approach the destination. Therefore, the condition which the SGM has to possess is setting up direction of proceeding.

To steer, a bundle is composed of several units. Differential fluid injection to each unit is the key for direction of the SGM. A change of direction happens as much as difference of injected fluid. The more important thing is stable composition of bundle because unit-set is separable when proceeding. Especially, because there can be amplification of gap between units in matter of a long distance progress, it is necessary to maintain consistent bundle of units.

4.3 Establishment of forward/backward and steering motion

- Rail-embedded growing unit

For S/W module and bundle for steering, rail-embedded growing unit is used. This is made from original plane unit by installing rails internal/external surface of unit. Its shape can be confirmed in fig6. External rails are utilized to compose bundle and become path for 3- and 1-rings of install-base, while internal rails conduct a role of guide for 2-ring.

- Connection for bundle

Since one independent unit only cannot set up direction, special method for connecting several units is needed. For this aspect, rail-embedded growing unit as well as wheel-set used for connection of units is introduced.

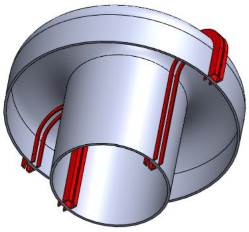

Fig. 6. Rail-embedded growing unit

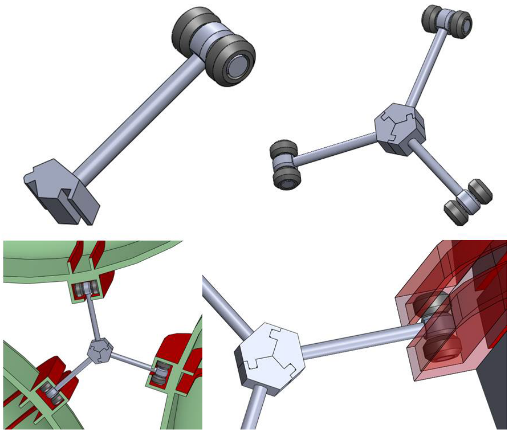

Fig. 7. Connection for bundle

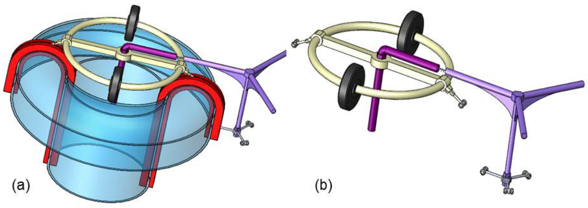

Fig. 8. (a) Conceptual auxiliary equipment, (b) Conceptual auxiliary equipment without growing unit

The wheel-set can not only move along the rail, but also prevent breaking away from rail, owing to a pair of two wheels. A pair of wheels per a growing unit is element for a bundle, which establishes the one bundle-set by combining other pairs.

- Concept diagrams of auxiliary equipment

The fig. 8 is concept diagram of installed auxiliary equipment. In order to explain equipment easily, the configuration of one unit connected with bundle-set and independent auxiliary equipment except unit are described in fig9 (a), (b).

The 1-ring is connected with 3-ring by centrally passed rod and 1- and 3-rings together restricts 2-ring's separation. Moreover, as giving the wheel more play on the external rail of the unit, minimizations of position change as well as jam of unit in equipment are facilitated during the 1-ring is on the unit surface.

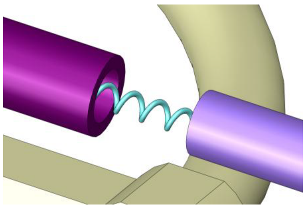

Fig. 9. Elasticity assigned to the connection between unit and bundle

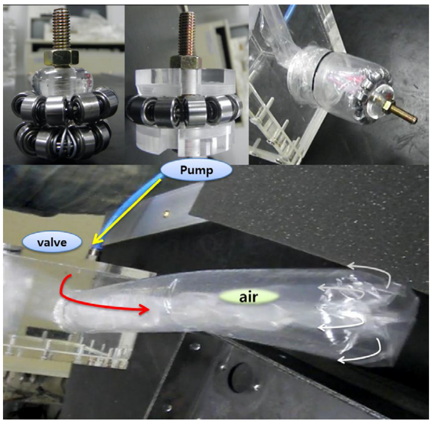

Fig. 10. Experiment for going forward

Bundle of 3-units set up direction of progress by provision of fluidic source. At that time, if connection is completely solid, it can cause inefficiency of setting up direction and hindrance to progress. The solution for these problems is to assign elasticity to the connection between unit and bundle.

The degree of going forward or backward of the SGM is determined by the degree of supplying or withdrawing growing unit. Therefore, when making system including the SGM, it has case for storing growing unit. Adjusting growing unit will be carried out by motor actually.

While, as moving forward, fluid injection produces the growth of growing unit, as moving backward, limited fluid injection maintains the shape of unit and withdrawal of unit is conducted.

Experiment for the Self-Growing Mechanism

For the SGM based on features of amoeboid movement and liana's growth, prototype was made. Using the prototype, experiment for forward going performance was carried out. The information about experiment can be categorized as following.

- Experiment about forward going performance of one growing unit, providing fluidic source by pump
- Experiment about forward going performance of one growing unit with install-base
- Later planned experiment about forward/backward and steering motion

1. Hardware requirements for the prototype of the SGM

- Air pump: the power source for proceeding of growing unit
- Material for growing unit: in order to maximize growth performance of unit according to its material, ad-balloon is selected finally. For experiment, vinyl unit was used.
- Case: assign the space of fixing and storing growing unit and fluid path
- Install base: by using prototype, experiment was conducted
- Valve: determine the degree of going forward as the degree of opening or shutting

2. Experimental plan and result of forward moving performance

2.1 Experimental plan

- Progress of growing unit by adjusting air pump and valve
- Find forward going performance after equipping install-base
- *Fig. 10. Elasticity assigned to the connection between unit and bundle*

The ultimate purpose of this experiment is to grasp the SGM's performance of going forward.

2.2 Experimental result

Fluid (at here, air) as power source is transfer to internal growing unit through case by adjusting valve. Continuous growth is derived by provided unit stored inside case by fluidic push. Fig.10 shows prototype of install-base and experiment of forward going performance.

This leads to confirmation of basic forward going of the SGM. If additional experiments about forward/backward and steering motion are made, the SGM can be developed as more complete moving mechanism.

Conclusion

This paper introduces the Self-Growing Mechanism which is the method minimizing the force effect on the surface in order to conduct inspection and maintenance operation effectively by finding the current state of subject accurately.

The SGM is motion mechanism based on protozoan and plant mimetic. Due to using fluid as resources, the SGM has buffer effect in itself. Furthermore, progress by the growth of growing unit generates at most contact force as if a rolled surface is getting unfolded. In previous motility mechanism, force effect is inevitable element. This point can be problems especially in sensitive environment because the inspection results may has highly deviated distribution according to effect from exterior conditions. Therefore, the SGM can be superior mechanism which reduces damage/deformation of surface and conducts tasks in sensitive environment. The SGM can equip the instrument for inspection and maintenance by install-base and can not only move forward/backward but also set up direction of progress through S/W module and bundle connection. With this, the SGM becomes the great means of inspection and maintenance to apply various industries.

Concretely, the SGM has sufficient potentials to enter tunnel-, pipe-maintenance, and endoscopy field. Although inspection and maintenance inside tunnels is essential for traffic safety, it is in poor conditions. That is, workers in tunnel are exposed to respiratory problems and related industries become job which most people avoid getting into. Moreover, perhaps the vicious circle of this fact brings about a manpower shortage or aging of manpower. The SGM can be utilized here for inspection and maintenance by adjusting the system at outside. Another example is pipe-maintenance similar to tunnel-. Because, for circulation of regional heated-water, double insulating pipe is laid under the ground, it is difficult to check damage of grid after construction of line. The SGM is expected as alternative plan for detect damage or aging of line effectively and easily. In the other words, the system can be improved by appointing representative sectional spot and governing the line based on the SGM. As the era entered modern times, the attack rate of colorectal cancer has increased sharply due to westernized eating patterns. The miniaturization of the SGM can improve newly conceptual endoscopy which supplements previous endoscopy. According to previous method, since medical staff handles examination tool manually, unskillful operator may manipulate the tip of endoscopy so poorly that intestinal canal of patient can hurt and examination can be conducted difficultly. If there is convenient method, medical staff can offer more comfortable examination. It is the SGM that does not apply force to intestinal canal and carry out safe endoscopic examination. As a result, the SGM will contribute greatly to an early diagnosis and effective treatment. Besides, convergence with nano- and macro-technology being highlighted recently can accelerate improvement thoroughly.

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