Shape Memory Alloy based Flower Robot

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Abstract—The flower robot, a household service robot, has been main focus of our research. Generally, the flower robot has the appearance of a common flower which consists of the petal, the stem, and the leafage. Besides having the appearance of a flower, the flower robot has the following functions, such as a moving mechanism, a sensing ability, and a home appliance function. Especially, the moving function is very important function among the various function. The moving function of flower robot consists of the bending of stem, the blooming of petal and the stirring of the leafage. In this paper, we focused on the movement of the flower robot structure. As an actuator for flower structure, we adopted coil type Shape Memory Alloy and proposed silicone stem, petal and leafage structure which 6 coil type SMA. Firstly, using SMA actuator, we designed and fabricated the flower structure. Secondly, we derive the kinematic equation such as stem, petal and leafage. Then, through the kinematic equation we can design the control system to drive the flower robot by dSPACE. Finally, through the experiment we prove the feasibility of the system, its performances are evaluated.

Keywords – shape memory alloy (SMA), actuator, flower structure, control system

I. INTRODUCTION

The flower robot, a household service robot, has been the main focus of our research. Generally, the flower robot has the appearance of a common flower which consists of the flower, the stem, and the leafage. Besides having the appearance of a flower, the flower robot has the following functions, such as a moving mechanism, a sensing ability, and a home appliance function.

For the flower robot, the development of the moving function is very important and this paper and patent is focused on the moving mechanism of the flower robot. The motion of the flower robot is divided as the blooming of flower, the swaying of the stem and the stirring of the leafage and petal. Especially, in this paper and patent, we will focuses on the swaying of the stem and propose new moving mechanisms of stem structure for a flower. For the actuation of moving function, coil Shape Memory Alloy is adopted and a silicone rod structure using 4 SMA is proposed.

Shape memory alloy (SMA) is a smart material that has the shape memory effect. After a sample of SMA has been deformed from its original crystallographic configuration, it regains its original geometry by itself during heating. The range of applications for SMA has been increasing in recent years, the major area being industry, medicine, and navigation [1-3]. One major application of SMA is actuator which has the very high power-to-weight ratio. In addition, high possibility of miniaturization and low power consumption are salient properties of SMA actuator. Accordingly, this class of actuators is widely researched and employed to various fields [4]. Pfieffer et al. proposed shape memory alloy robot prostheses such as shoulder and fingers [5], Mascaro and Asada presented a wet shape memory alloy actuators for active vasculated robotic flesh [6] and Byungkyu et al. suggested an earthworm-like micro robot using shape memory alloy actuator [7]. In current existing SMA propel designs such as active palpation sensor [8], biomimetic vehicle [9], and actuated composite beam [10], moulds in industrialized production and mechanical fishes, the control of the movement directions are by all means the least complicated. Most of the designs follow axial movements, especially the classical 3 SMA designs in a typical cylindrical movement sensor. Such mature design somehow hinders the further development and application of the SMA control into other more versatile applications.

Until now, artificial flowers were concerned in patents as follows: illuminated artificial flower ornament [11], temperature sensitive artificial flower [12], scent emitting artificial flower [13], artificial potted flower with plant radio and television antenna [14], and blooming artificial flower device [15]. The proposed artificial flowers can only give ornaments and simple functions, such as sensing, moving and home appliance functions.

Recently, however, the robotic flower was firstly proposed by Carnegie Mellon University researchers [16] and has seven degrees of freedom. One is used to move stem toward right and left, the other six are used to move flower. DC servo motors are used by the actuator. This flower robot has IR sensors on three of its petals so it can track objects moving in front of it. It can also catch a lightweight ball. The robotic flower has moving functions and sensing functions. However, compared with a real flower, the robotic flower has a remarkable difference of the appearance and a limited moving function. In addition, the IR sensing function is also restrictive.

Other flower robot [17] had been successfully designed and had functioned properly before our flower robot, but most of them are powered by small motors, and the robot is controlled by interpreting the rolling motion of the motors into flower movements through means of gear box. Certain defects are reflected in such design as the size of small motors are sometimes extravagantly large, thus resulting the entire robot to be less agile if more than one motor is installed. Also take into the consideration of the complications with wiring and electronic modules required...
to purr the robot. Another imperfection is the noise uncomfortably resided with the motor which is not evadable. Coding sophistications, complications in external electronic control module, relative high pricing and less agreeable smoothness in running the motor also rendered the motors declined to be a first choice.

The SMA provides new dimensions in solving all the flaws or imperfections mentioned above. It magnifies the freedom of movement at the root level, it leveraged the SMA to propel the robot into motion and avoided the defects that may have been brought about by a parallel motor design, rendering the SMA a more applicable choice.

II. DESIGN AND FABRICATION OF FLOWER STRUCTURE

Firstly, we propose a new stem structure for flower robot as shown in Fig. 1. There are 3 coil type SMA actuators embedded in a silica gel rod. Each SMA is connected to the power supply. When we control the input powers to each SMA actuator, the shape memory effect appears and the coil type SMA actuator shrinks. And then, the silica gel rod will bend. To obtain the arbitrary bending displacement, the input powers to each SMA actuator are adjusted. Because we initially designated the elongated length of SMA to be 50mm, the length of the silicone is also 50mm. This design contains three open spaces which are the stem’s surrounding area, and take the SMA enchase it. The angle of every hole is multiplied by 120, allowing the entire stem to posses a 360 degree azimuth angle. The hole in the center of the silicone rod is used to gate through the other SMA wire and make the adscititious equipments into the stem of the flower robot.

We used silicone (Sylgard 184A, SeWang Hitech Co., Ltd) and thinner (DC-184B, SeWang Hitech Co., Ltd) to fabricate the silicone rod. Because silicone is liquid, we must design a model to make silicone reach our desired measurement and standard.

This model contains three parts, the container, the cap, and the base. After the model is complete, we start constructing the silicone rod. First we connect the container with the base and transfer the liquid silicone what has been diluted into a container. The silicone’s ratio of dilution is 10:1. Affuse the liquid silicone before we need to be left still for a hours to prevent the formation of gas bubbles.

Finally use the cap and base to secure and stabilize the whole structure. After 48 hours the silicone rod can be obtained. The process of assembly and extraction is shown in Fig. 2.

The motion of petal is show in Fig. 3. We can see there have three parts of the structure: silicone, new cap and localizer. In the center hole of the silicone rod we connect a spring and wire with one side of SMA which to drive the petal of the flower robot then fixed the other side of the SMA. When we applied voltage on the SMA, it will be constricted and take the wire have a motion that downwards. In this time, the petal which connects with the other side of the wire, it will be motioned downwards with the tension what from in SMA. At the same time, the petal will be constricted with the localizer.

Base on the structure of stem, in the design of leafage we just need to adhesion the SMA with one surface of the flower robot.
leafage and fixed the two side of it. The fashion of motion in leafage is same with the stem structure, we do not to introduce any more, the motion of leafage as shown in Fig. 4.

![Fig.4 The motion of leafage in flower robot](image)

When we have been designed the parts of flower robot such as stem, petal and leafage, then we will design the smart flower robot whose sketch is shown in Fig. 5.

![Fig.5 The structure of flower robot](image)

In this robot, three SMA wires are used for control the action of leafages and petals, respectively. The petals are connected to connector of petals and the assembled in base of petals. When the SMA wire which connects to connector is electrified, the petals will be drawn along the incline of base of petals and close. When the current is switched off, the petals will reconvert because of the spring. For the leafage, the SMA wire also can control it to wind and unwind. Combining these parts and stem actuator, the flower robot can perform some simple actions.

III. CONTROL SYSTEM

We’ve already derived a Kinematic Equation [18] for the stem, which described the relationship of Load $P$ and Displacement, and now we’re trying to determine the relationship between Load $P$ and Voltages. The Load here would be acting as a converter linking up the inputs (Voltages) to the outputs (Displacement); a fitting curve is built by correlating the Voltages to the Loads, see the fitting chart below in Fig. 6.

![Fig.6 Fitting curve](image)

The horizontal axis is the inputting Voltages while the vertical axis displays the corresponding Loads per each input. From this correlation we’ve been able to built up the Equation (1).

$$P = 904.6v^3 - 1268v^2 + 1312v + 6E - 0E$$

(1)

which describes the relationship of Voltages and Loads; the $P$ is the Load of SMA, while the $V$ represents the Voltages we apply on the wire. By combining the Equation (1) with the Equation [18] (6), we can come finally to an Equation (2) for stem of flower robot.

$$\theta_s = \sigma \left[ \sec \left( \frac{1240v^3 - 1268v^2 + 1312v + 6E - 0E}{EI} \right) \right] - 1$$

(2)

In the same way, through the bending moment equation [19] with equation (1) we can obtain the kinematic equation (3), (4) of petal and leafage.

$$\phi_P = -\frac{\frac{1240v^3 - 1268v^2 + 1312v + 6E - 0E}{EI}}{2EI} \left[ \frac{6E - 12v^2 + x^2}{2EI} \right]$$

(3)

where $\phi_P$ is the displacement of the flower petal, $x$ is the half length of petal about $6mm$, $EI$ is the bending stiffness of the section, $E$ is the young’s modulus and $I$ is the Poisson ratio of the materials of the flower petal.

$$\phi_L = \frac{6E - 12v^2 + x^2}{2EI}$$

(4)

Where $\phi_L$ is the maximal displacement of the flower leafage. The $v$ is the voltage what is output in the control system. Where $EI$ is the bending stiffness of the section, $E$ is the young’s modulus and $I$ is the Poisson ratio of the materials of the flower leafage.

Fig. 7 gives an overview of how the control system as an organic body would work. It is strictly based on the Kinematic equations we’ve covered in earlier paragraphs, and it is maneuvered by the dSPACE system. The whole
process works as follows: we give datum quantity to the control panel (automatically converted and displayed into the desired results, i.e., degree of displacement, angles in space), the control panel reads and translates the datum quantity into simulation signals through the processing of Matlab/Simulink, thus in turn translate the input to the robot through voltages, and eventually the robot incorporates these inputs and interprets them into the desired results we’d started with.

Fig.7 The process of control system

The first step in control stage is to simulate all the input signals in Matlab/Simulink; since the movement of the stem is the most complicated part in the entire system, we’ll start to elaborate the mechanism behind the stem control first. Fig.8 illustrates briefly the flow of process in stem motion control:

Fig.8 The simulink in Matlab of stem

In this chart, constant 1 represents the angle inputs which extends from 0 to 360 degrees; Matlab Function works as a logic control module which analyzes the input angle and thus translate such inputs into the voltages placed on tri-SMA wires incorporated on the stem which in turn controls the movement of the stem; Product, Product 1 and Product 2 are the voltages placed on the tri-SMA wires; constant 1 is the displacement factor input into the stem motion, which ranges from 0 to 83; Fcn is the Kinematic Equation (18) for stem we’d derived in earlier chapter; the Fcn function works as the core of the entire control phase as it defines the degree of displacement and turning angle in the stem movement. Scope, Scope 1, Scope 2 are the monitoring session enabling handlers to observe the actual voltages placed on each of the 3 SMA-wires.

After the elaboration of stem control we’ll move on to the control of leafage and petal. We follow an identical procedure of simulating the movements in Matlab/Simulink and then control the movement through dSPACE; however the flow of information is quite different. It is illustrated in the Fig. 9.

Fig.9 The control system by dSPACE

Constant 1 is the variable for angle input, ranges from 0 to 360 degrees; If module is the logic control of directions, which is open to 6 sets of valves with 60 degrees applied to each set of valve, i.e., the valve set which represent the degree 330 to 30 is shown in a string (1, 0, 0), which controls the open/close motion of the 3 voltage inputs that control the stem, where 1 means open and 0 close. For further references degree 30 to 90 is shown as (1, 1, 0) and degree 90 to 150 (0, 1, 0); the default string for any degrees larger than 360 degrees or less than 0 degrees is (0, 0, 0). We can accurately control the movement direction of the stem by employing this definition.

Ds1103DAC_C5 and Ds1103DAC_C7 are output ports of the 3 voltage inputs. Constant 14 and Constant 15 are the logic control of the 2 leafages maneuvering their open and close motions; Ds1103DAC_C8 and Ds1103DAC_C9 are output ports for SMA wire voltages controlling the leafage;
Constant 12 and DS1103DAC_C10 are logic control and SMA wire voltages for petals working in similar mechanism. The entire system works as we input the space angle and displacement for the stem which interprets the signals to its degree of bending, direction and exact position. The same method is applied to leafage and petal as well.

IV. EXPERIMENT

Due to the limitation of power output of dSPACE, (its power output will dwindle even when the voltages hold), we’ve employed opamp to magnify its power output in this experiment, which magnifies and enhances the electric current of output port for dSPACE. The equipments for the experiment are shown in Fig. 10, the input DC of opamp is 5v in the system.

![Fig. 10 The equipment of experiment](image1)

The entire flow would work like this as we’d added opamp into the process: user give out inputs through PC control interface, dSPACE analyzes the inputs and translates them into voltages, the opamp magnifies the electric currents and thus electric signals, and eventually the control voltages reach the flower robot and controls the motion of the robot. The results documenting the results of such control are illustrated in Fig. 11 and Fig. 12.

![Fig. 11 The movement of stem in different azimuth angle](image2)

In the Fig. 13, the experimental results are very similar with those of mathematical analysis. The bending displacement is directly proportional to the input voltage. The differences of the three results are caused by the error of assumption in mathematical analysis and experimental
analysis. In addition, the measurement error in experiment can be one reason of the difference.

V. CONCLUSION

In this paper, we proposed the stem, petal and leafage structure for flower robot. As an actuator for stem structure, we adopted coil type SMA and then proposed silicone stem structure with 3 coil type SMA. Using SMA actuator, we designed and fabricated the stem structure with 8mm of diameter and 50mm of length. We calculated the displacement of the flower robot structure through mathematical analysis. And design the control system by dSPACE. Finally, through the experiment of the fabricated flower robot structure, the displacements can be measured. In addition, the results from the mathematical analysis and the experiment are compared. Through the various experiments of the flower structure, its performances for robot are evaluated.

REFERENCES