Growable Robot with 'Additive-Additive-Manufacturing'

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Abstract

Additive manufacturing, the academic term of 3D-Printing, is the way of fabricating new objects by adding materials layer-by-layer. Our team extended this technology to the next level enabling users to add materials directly onto ready-made (3D-printed) objects. Therefore, we named our technology as 'Additive-Additive-Manufacturing'.

While 'Additive-Additive-Manufacturing' is one of general-purpose technologies, we believe that one of the killer-applications using this technology is to customize and modify body parts of personal pet robots.

In this paper, we report our concept, software and hardware technologies of additive-additive-manufacturing, and prototypes of a growable pet robot and its potentials.

Author Keywords
3d printing; Additive Manufacturing; Robot; communication robot;

ACM Classification Keywords
I.2.9. Robotics;

Introduction

Due to recent advancements of A.I. (for example, deep-learning), computer vision and other kinds of software technologies, personal pet robots could "grow up" in the sense of learning new motions and behaviors (motor control), changing voices and speeches through communicating with humans and environments [1][2]. Needless to say, new software and data would be easily transmitted through wireless networks, with the technology of IoT.

However, it is still difficult to grow physical bodies of personal pet robots. There is a clear distinction between ‘software growth’ and ‘hardware growth’ (Figure.1). While ‘software growth’ is becoming popular, ‘hardware growth’ has not been shown yet.

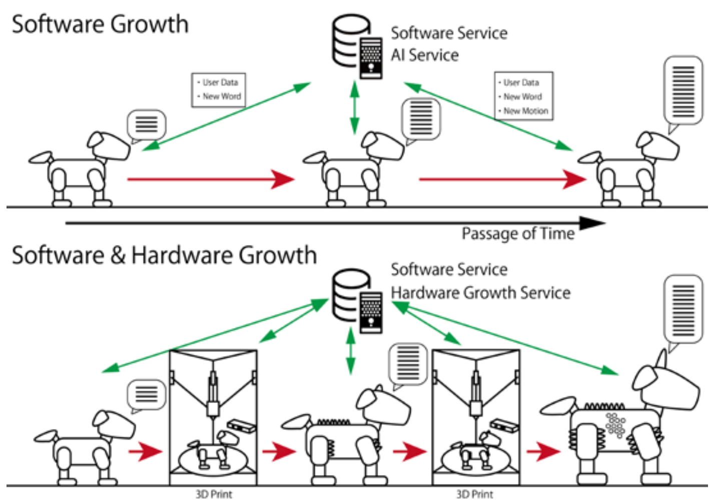

Figure 1: Software Growth and Hardware Growth

Additive manufacturing technology is capable to customize and adjust body parts of pet robots. It is easy to fabricate new customizable parts and attach them to a pet robot by hands. However, it is tedious to print and attach every part manually. So we decided to raise 3D-Printing to another level that would enable us to add materials directly onto ready-made (3D-printed) objects.

We named our technology as ‘Additive-Additive-Manufacturing’.

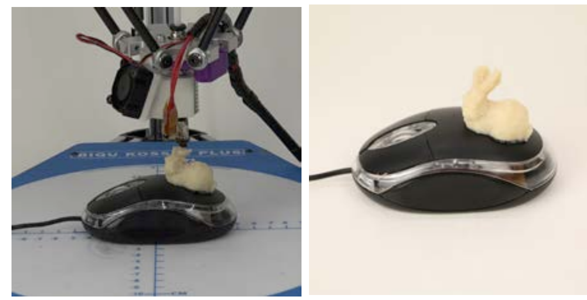

Figure 2: An example of ‘Additive-Additive-Manufacturing’ applied to a Stanford bunny on a mouse.

Figure.2 shows an example of additive-additive-manufacturing applied to a Stanford bunny on a mouse. In this case, we use ABS as an added material, since a mouse is made by ABS. It is known that material adhesion would be quite weak when it comes to sticking different types of materials.

Additive-Aditive-manufacturing is not purely our original method. There are former examples of adding materials onto existing printed objects [3][4][5]. However, there are two limitations pointed out.

Complexity of shapes:
Former researches were applied to simple geometries like cubes and spheres. In general, a pet robot such as dog consists of complex curved shapes. In order to add materials directly onto curved shapes, we have to develop new slicing software and hardware.

Scan and Print:
Former researches did not focus on scanning technology[6], because the premise they worked on was

that the system has already known the shape of an existing object. Our premise is different. So, we have to consider about new 3D printer structure embedded with several scanners.

Our research motivations are to overcome those two limitations and show the prototype of additive-additive-manufacturing applied to a robot.

Additive-Additive-Manufacturing Technologies

Hardware

There are three major types of basic mechanics of desktop 3D printer- gantry box structure, r-theta round structure and parallel link structure. Figure.3 shows comparisons of 3 different types. In this research, we adopted a parallel link structure [7][8][9], because it is suitable for us to attach new devices (like scanners) to frames. More importantly, it is a good point that a build plate is fixed on the floor. If a build plate moves, an existing object set on a plate is also moved up and down while adding materials. That would reduce the stability and quality of our method.

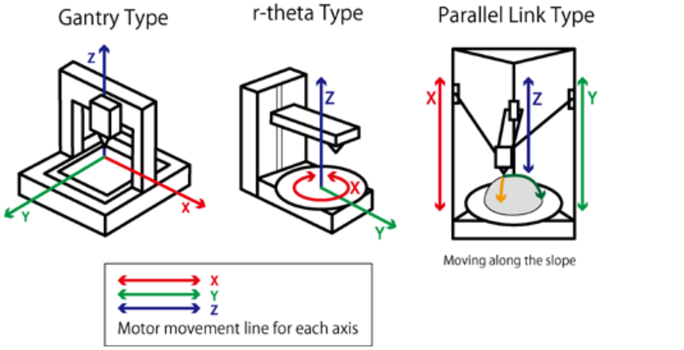

Figure 3: Comparisons between gantry box structure, r-theta round structure and parallel link structure.

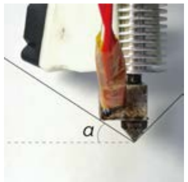

Figure 4: a critical angle of a hot-end part

A critical parameter of 3D printer applied to our method is an angle of a hot-end part (Figure.4). This angle limits the shape on which additional materials would be placed without any physical collisions. This angle will be used in our software as one of important parameters.

Software

In 3D Printing, slicing software generates 'G-Code' [10], which is the data to control 3D-printing machines, including a trajectory of how a hot-end moves. While most of popular slicers generate horizontal trajectories on X-Y plane layer-by-layer, our method requires curved-slicing for adding materials onto a curved surfaces (Figure.5).

Figure 5: Conceptual image of Curved slicing

In this project, we developed our new slicing software as a plugin of a popular 3D-CAD 'Rhinoceros'. Users can apply our slicing algorithm just by clicking any 3D objects including scanned surfaces (Figure 6). G-Code including curved trajectories will be automatically outputted (Figure.7).

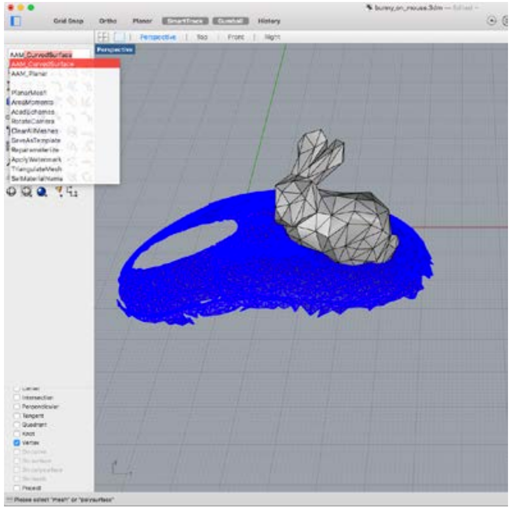

Figure 6: Screenshot of our slicing software on Rhinoceros

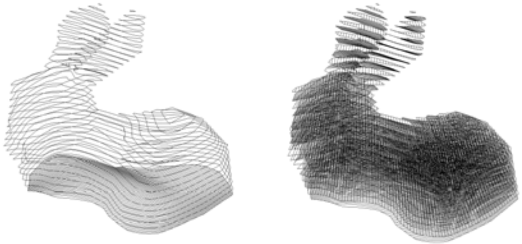

Figure.7: curved tool paths created by our slicer

A common area between a scanned object and a new object is recognized as a basic curved layer (Figure.8). Slicing algorithm will proceed according to this surface. Our algorithm can check all the curvatures of selected surfaces, and confirm that those are less than the limit angle described in Figure.4.

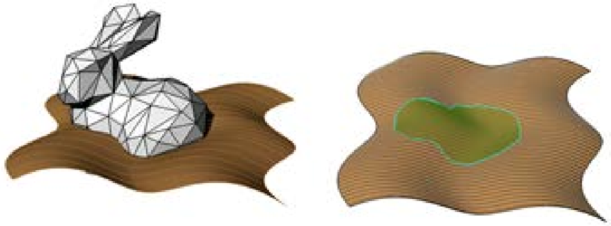

Figure.8: Curved base layer for additive additive manufacturing

Working Prototypes

As a proof-of-concept of new possibilities on physical robot growing with additive-additive-manufacturing, we adopted an obsolete dog-like robot (SONY AIBO ERS-210), and applied our method.

Figure 9: a dog-Like Robot (SONY AIBO ERS-210)

Followings are the processes: Scanning the existing parts (I), checking the curvatures of scanned surface to avoid physical collisions (II), adding new shape on it (III), slicing and generating g-codes (IV). Our workflow is shown in Figure. 10. Our printing time was roughly 1 hour for one part. Eventually, we made two different bodies from one dog-like robot (Figure.11).

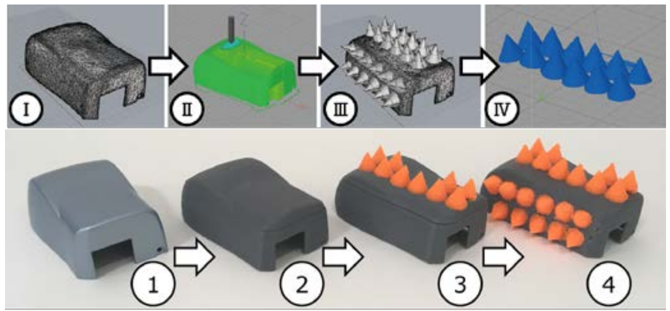

Figure.10: Workflow using our software and hardware

Figure 11: Two different types of a dog-like robot

Conclusions

We introduced our basic concept and technologies of Additive-Additive-Manufacturing, and show our first prototypes and experiments. Our future work includes three of new trials:

3D-Printed Hair:

It was reported that hair-like texture can be realized with 3D printer [11][12]. This kind of animal-like effect is one of attractive directions especially applied to pet-robot customization.

Adding different materials:

In our example, we add the same material to an existing object (ABS to ABS). According to material science, it's not easy to adhere two different materials. However, Bi-Matrix Structure (Figure.12) which was invented by Mutoh-Engineering has potentials to combine two different materials using 2 heads 3D-Printer with special tool-paths. It's possible to add soft materials to a hard robot by using this method.

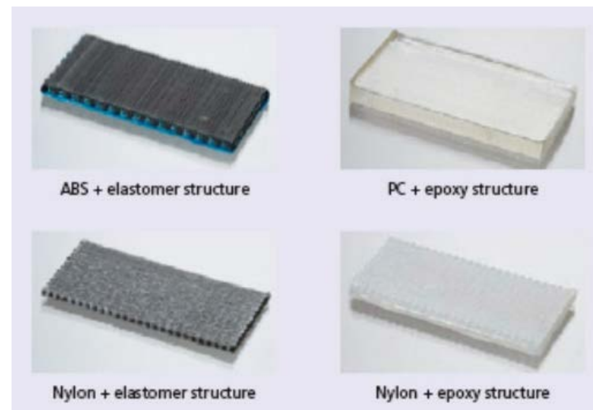

Figure.12 Bi-Matrix Modelling (Mutoh-Engineering)

Designing new movements and behaviors by combining software and hardware:

As we described in chapter.1, our expectation is personal pet robots will be 'grown up' both in software and hardware. By using software technology, a pet robot can get new motions and behaviors (motor control), while our method can change a physical part of a robot. By combining software and hardware, we can realize new evolution of movements and behaviors.

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