New Folding and Gluing Robot for Automatic Assemble of 3D Shapes

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1 Research goal

Origami, the ancient art of folding a flat-piece of flexible material such as paper into a three-dimensional shape, has attracted the attention of the scientific community because it can be used to create interesting-looking objects and mechanical structures with a vast number of applications. One of the most interesting applications of origami into science is in robotics. However, a proper solution in this matter has not been found, due to limitations in paper manipulation and the lack of possibilities to apply the robot systems into different applications. Some of these robots use complex mechanisms and require several sensors to work properly. These make it difficult for robot to be developed and its prices are increasing.

This study centers its attention in origami robotics, especially in folding-performing robots, and methodologies to create folding patterns for it. In this dissertation, an automatic folding robot is proposed and developed. This robot uses a crease pattern that combines simple folding patterns with small gluing areas to reduce the number of manipulations. Two methodologies for creasing pattern development are also proposed here. These methodologies are created to be applied into the proposed robot, and used to create vast number of three-dimensional shapes.

2 Summary of the chapters

Chapter 1 Introduction

This chapter describes the background of this thesis. The purpose and research contents of this thesis are described.

Different types of objects have been created inspired in origami such as boxes for protecting goods safely, satellite antennas able to unfold in space to provide the system with solar energy. The sector of science that studies the paper folding behavior, its properties and applications is called “Origami engineering”. There are two types of objects in which origami-goods could be divided: Objects or products that take inspiration from origami and objects that use origami properties to work. Among the second category, is the "origami robotics". In origami robotics, two on-going researches have been the center of attention in the recent years: the first is called "Self-Folding Robots", and the other one is called "Origami performing robots (Folding robots)". This work centers its attention in the folding robot category. Thus, several works related with this type of robots are studied.

Chapter 2 Kansei applied into Origami Engineering

The main idea of this chapter is to quantify the appreciations of persons to different geometrical shapes in origami. Origami is an art, and an important part in analyzing the final shape is the attractiveness. The idea here is to use our previous works in kansei engineering to create a quantitative model of perceptions. We compare this model, with a quantitative model that analyzes the quality of the final shape using the expected area and the resulting area to obtain a deformation rate value. This could help us to understand which type of figures are more visually attractive to most people, and what characterize this attractiveness. These results are then applied to the shapes created with the proposed robot to evaluate the attractiveness and the quality of the results.

Chapter 3 Origami-performing robot design

Previous works in origami-performing robots have shown that the required manipulations in paper-folding could be a challenge. The robots with these works use complex robot systems, or adjust standard robot manipulators that exist in the market to fold paper sheets. However, these existing robot devices have complex mechanisms and are expensive. To reduce the number of manipulations in the folding process, the use of simple folding procedure combined with gluing areas is proposed in this chapter. The use of LEGO MINDSTORMS NXT is also proposed to reduce the price of the system, and gives us an easy way to analyze and test different concepts (e.g. kinematic and dynamic models, control scheme, and applicability) during the development process. In this chapter, the trajectories calculations are exposed, this includes, the kinematic model, and some trajectory considerations to implement the proposed robot into mass-production procedures. Then, several algorithms related with the paper properties such as: spring-back and stacking effects, are included to improve the accuracy of the movements.

Chapter 4 Control scheme applied to the proposed robot

It is extremely difficult to introduce automation in robots to handle shape-changing objects such as sheets of paper. There are two main problems associated with paper handling. One of them is controlling deformation of objects that has infinite degrees of freedom using a finite number of manipulated variables. The other problem is how to handle fragile material such as paper without exerting excessive stress. In this chapter, a new method that uses feedback error learning (FEL) to control the robot is proposed. Adaptive learning algorithms are implemented and compared using several artificial neural networks (NN) to perform precise and smooth manipulations of paper sheets. Several feed-forward controllers based on artificial neural networks are tested and compared with other types of classic controllers. Adaptive algorithms are evaluated, to improve the convergence of the tested NN and ensure stability of the controlled system. These results show a clear superiority in the performance of systems using Holographic Neural networks . Such superiority is due to the simplicity of the HNN and the small of data required for convergence.

Chapter 5 Methodology for designing crease patterns for the proposed robot

The methodology applied to create crease patterns with the proposed robot is based on shapes of surface of revolution. The origami pattern developed with previous software, is intended to be assembled by hand, and has folds that are very difficult to execute with a robot due to handling problems. In this new methodology, a modified version of the surface of revolution (SOR), created by Jun Mitani in 2009 is proposed. This new methodology, uses a combination of simple folding patterns with gluing areas to reduce the number of manipulations required by the robot to execute a 3D shape. Some modifications are made to add the gluing areas into the folding process, and some extra additions are included to allow the final shape to be opened correctly. Several examples are exposed and assembled using the proposed robot to demonstrate the applicability of this methodology.

Chapter 6 Improved methodology for designing complex 3D shapes by robots

The methodology explained in chapter 5, can be used to create 3D shapes that are based on SOR, able to be built by the proposed robot. Though this methodology expands the applicability of the proposed robot, there are figures that are not based on SOR, because they have irregular shapes. Several software and methodologies have been made to create crease patterns of irregular shapes. However, the resulting 2D crease pattern for these complex shapes is even more complicated to build than the SOR counterparts, having inside folds that required multiple manipulations at the same time, making extremely difficult to assemble these 3D shapes automatically using a robot. To solve irregular 3D shapes using a slightly modified version of our already existing robot, a novel methodology extracted from the previous SOR methodology is proposed and explained in this chapter. This new methodology can be applied to figures with star-shaped-projected polyhedrons. A star-shaped-projected polyhedron is a shape that is composed and contains an infinite number of star-shaped-polygons. A star-shaped-polygon is an irregular 2D polygon that contains a point, from which the entire boundary of the polygon is reachable.

Chapter 7 Applications of the proposed methodologies and robot

In this chapter, different applications of the proposed methodologies and robot into several areas are exposed. These applications include many things such as guard protection for sweet fruits in growths, medicine and architecture, etc.

The first application is on guard protection for sweet fruits in growths. The main idea in this application is to create a recycle-paper sag to cover the fruits during this period of ripening. The second application is on packaging, where using the proposed robot and methodology, interesting looking boxes or envelops can be assembled. The third application is in the creation of scaled-house models. In house design the option to observe the result through a scale model is essential to analyze and make decisions about the structure, and appearance of the building. The final application is on medicine, where the proposed methodology can be used to create shape-shifting mechanisms to execute several tasks. These tasks go from non-invasive surgeries to open-close mechanisms to deliver medicine directly to an affected area.

Chapter 8 Conclusions and Future works

This chapter summarizes the contributions of the current work into the research area. Some general conclusions are exposed, and some future works are included.

There are several contributions in this dissertation:

- An automatic paper folding robot is designed. We show that using simple folds in combination with gluing areas, good-looking 3D shapes can be achieved with this robot.
- Simulations and experimental results with the proposed robot show a clear superiority of the learning algorithms developed with HNN.
- Proper modifications are made to the SOR methodology to include gluing areas into the crease pattern.
- Additions to the crease pattern from SOR are made to allow free movement of the flaps, reducing the degrees of freedom and the complexity in the folding process.
- An enhanced version of the SOR methodology is proposed to create crease patterns with irregular shapes, which later can be folded the proposed robot.
- Several real-world applications are exposed to demonstrate the applicability of the robot and methodologies.