INNOVATIVE DESIGN OF A HEXAPOD SCORPION THROUGH DIGITAL PRODUCTION TECHNIQUES

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INNOVATIVE DESIGN OF A HEXAPOD SCORPION THROUGH DIGITAL PRODUCTION TECHNIQUES

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Abstract—This paper describes the innovative design process and production of a novel scorpion-based hexapod robot. The robotic scorpion was designed to be as reproducible, modular and adaptable as possible, being produced strictly using digital production techniques and off-the-shelf parts. These production techniques ensure that the robot and all its components become easy to reproduce and adapt, making it possible for everybody to build their own hexapod robot or optimize the robot in future work. In addition to our digital production, some innovative, anatomy-based features were integrated in the robot to solve several problems related to other hexapods. The use of elastics in the legs, for example, solves the high energy consumption of the motors and gravitational separation caused by the heavy weight of the hexapod. Furthermore, the scorpion tail is actuated by one single servomotor, simulating antagonistic muscles with ropes. By integrating these nature-inspired solutions, in combination with digitally produced parts, we improve the performance of a previously designed hexapod.

1. Introduction

Thanks to the upswing of digital production techniques, new opportunities have emerged and opened for makers and creative minds in the world of Do-It-Yourself (DIY) robots. A huge amount of web resources, in combination with fabrication labs providing digital production machinery [1-2], makes part of what is called 'the maker movement' [3–6]. Both evolutions extremely lower the entry point for people who want to design, fabricate, assemble and program their own robots [6]. In order to investigate the possibilities, advantages and disadvantages of these digital production techniques in the design of a personal robot, a new hexapod scorpion was designed strictly using 3D printing, laser cutting, CNC-milling, thermoforming and off-the-shelf parts. In addition to our detailed description of the hexapod design process, this paper presents solutions and optimizations for some problematic issues faced in a previously designed demonstrator, i.e., an ant-based hexapod.

2. Related Work

Several recently designed robots have used digital production techniques to produce one or more of their components. Up till now, however, few robots were produced and designed entirely using digital fabrication techniques. Two representative examples are Dmitri, a hexapod robot [7] and Aracna, a quadruped robot platform [8]. The main reason for this limited amount of digitally produced robots is that the effort and required knowledge and skills are too high for the majority of robot makers. Recently, however, Disney Research Zürich, ETH Zürich and Carnegie Mellon University started the creation of a design tool that should lower this effort [9]. Similar trends are observed in other robot categories. In social robotics, for example, several digitally produced DIY social robots have been designed over the last years, such as Ono [10-11], Nelson [12], Romibo [13], SA³M [14], and AlphaBot [15]. Since these robots were designed for reproducibility, it is possible for therapists to make their own low-cost, adaptable robot without the need for an incredible amount of knowledge and skills. We propose a similar approach for hexapod robots.

3. Design methodology of the Scorpion Hexapod

The methodology used in our design process was based on 'Innowiz'[16], which facilitates an iterative process with lots of improvements and redesigns, as described further in this paper. Our previously designed hexapod ant, shown in Figure 1, contained some weaknesses which should be taken into account in the new robot design process. Firstly, a short battery life was encountered by the high energy consumption of the motors in the legs. These motors were carrying a heavy robot body, existing of laser cut MDF-plates. Secondly, the ant had no 'stand-by mode', which leads to an energy waste if nobody is interacting with the robot. By making the robot more autonomous, it would be possible to detect people in its environment and act accordingly. Thirdly, the robot should be designed in a more modular way, allowing easy adaptation, reparation and reprogramming. Digital production techniques and a clear code structure will be key in fulfilling this requirement. In addition to these three main issues, a creative and innovative interaction with the expo visitors is demanded.

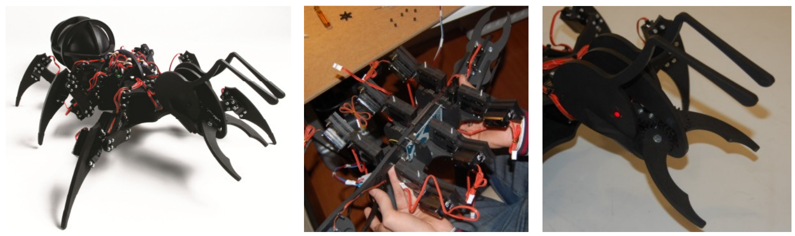

Figure 1. Stigmergic Ant, designed at the Industrial Design Center (IDC) in 2012.

Several ideas were generated through different brainstorm sessions using Innowiz [16], considering the context and the several stakeholders. Inspiring images and projects were gathered, while the main inspiration source was found in the anatomy of different insects and other animals. The selected nature-inspired concept was a scorpion-based hexapod robot, strictly produced using digital production techniques, such as 3D printing, laser cutting and thermoforming on CNC – milled molds. The anatomy of a scorpion, and more specifically its tail, gives us the possibility to study additional interactions with the audience. In our case, the tail holds a marker in its tail, with which he can stab (i.e., stamp) expo visitors when interacting with the robot. Furthermore, the scorpion robot should be partially autonomous, containing some realistic Human Robot Interaction (HRI)-aspects to interact with its environment.

Figure 2 shows the main architecture of the scorpion hexapod. The design iterations, tests and decisions are briefly discussed in the next paragraphs.

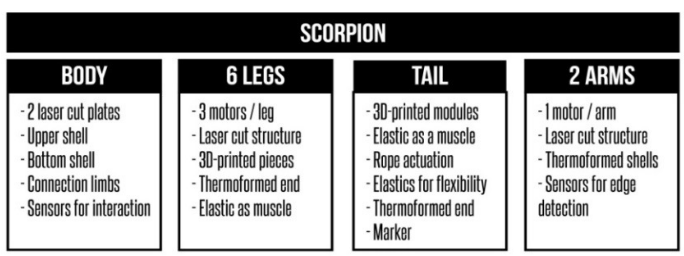

Figure 2. System overview and architecture of the scorpion hexapod

The most challenging innovation is to decrease the continuous load and torque forces on the motors (caused by the robot weight) on the scorpion legs. Of course, a more lightweight design and material choice for all robot components has a major impact on this. However, the motor load can further be reduced by optimizing the mechanical design of the robot. Several concepts and techniques were tested to solve this issue and to select the most practical/simplest solution.

In the previous design, the leg components were simply attached to the axis of the servomotors. This caused a big torque load on the motor axis. To reduce this load, a second axis was created on the other side of the motor case by constructing a framework around the motor. In this way, a more robust leg hinge is achieved. This principle was based on the motor modules used in Ono [10–11]. These Ono-modules were redesigned several times towards a lighter weight and maximum simplicity. Several shape-optimizations were done to decrease the amount of 3D printed parts and their volume, increase strength and allow cable management. Finally, we discovered that we could add an axis by drilling through the servomotor case, which meant that we needed less 3D-printed parts, decreasing the cost, production time and complexity of the hexapod.

A second problem we had to solve was to decrease the continuous motor load caused by the weight of the robot. Instead of using complex gear couplings, an elastic was attached to the bottom side of the legs, continuously pushing the body upwards. This technique, shown in Figure 3, was based on the principle of antagonistic muscles in anatomy [17]. In stationary mode, the measured current asked by the motors with the elastics is about one third of the original setup (i.e., circa 1A instead of 3-4A depending on several parameters, such as the positioning of the legs and the friction of the underground). When the motors are switched off completely, the robot stays upright and the elastics fully carry the weight. In this case the robot consumes almost no energy.

Important to mention is that all parts of the legs can be produced through 3D printing and laser cutting, making it easy to reproduce or repair certain parts. Because of aesthetical reasons, a thermoformed shell was added at the end of each leg, as shown in Figure 4.

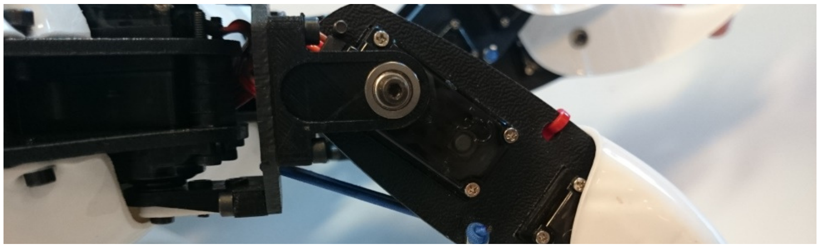

Figure 3. Elastics attached to the bottom of the legs, lowering the continuous load on the motors

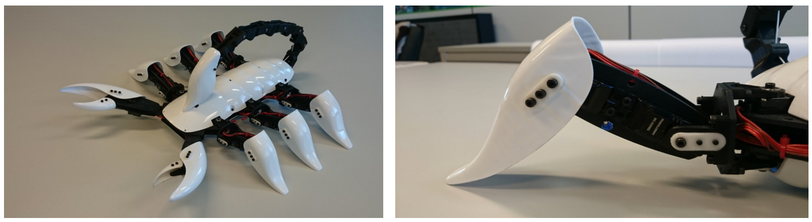

Figure 4. Finished scorpion hexapod robot (left) and detail picture of the leg design (right)

Because of the enormous size and the required movement of the scorpion's tail, it was designed to be as lightweight, simple and modular as possible. Several tests, shown in Figure 5, were done to compare different elastics and ropes, connections, dimensions, and mechanisms. Firstly, initial prototypes were made out of cardboard and PU-foam, allowing us to optimize the shape very easy. Different elastics and ropes, such as bicycle tires, standard rubber bands, textile elastics, and springs, were tested to achieve a realistic movement. Once the quick & dirty phase was finished, different three dimensional (3D) models were made in Siemens NX CAD-software to be 3D printed afterwards. The 3D tail modules, shown in Figure 6, were optimized multiple times to decrease the printing time and make them more functional. In other production methods, this would be a very expensive, time consuming and difficult task. However, digital production techniques and CAD-software allow us to easily do these optimizations.

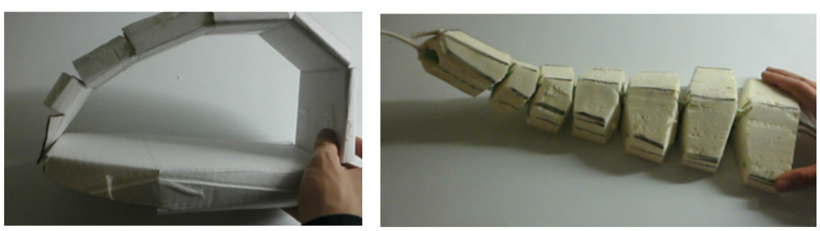

Figure 5. Quick & dirty prototypes made of cardboard and foam to test mechanisms and shapes.

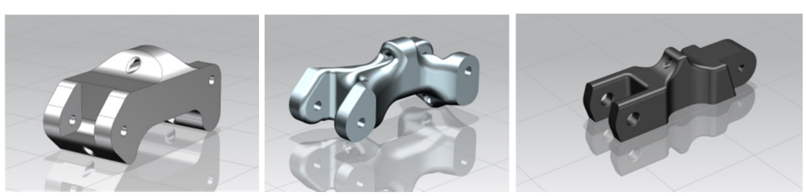

Figure 6. Digital redesign phases of the tail modules through CAD software Siemens NX

In the final tail model, a rope on the bottom side of the tail and a rope on the top side of the tail are both connected with a single servomotor actuated wheel. Rotating the wheel in the one direction stretches the tail, while rotating it in the other direction causes a curled shape. This concept is based on the antagonistic muscles [17], imitating the biceps and the triceps to respectively roll up or stretch the tail. By adding an elastic part to the ropes, the movement becomes very natural, like a scorpion stinging his victim.

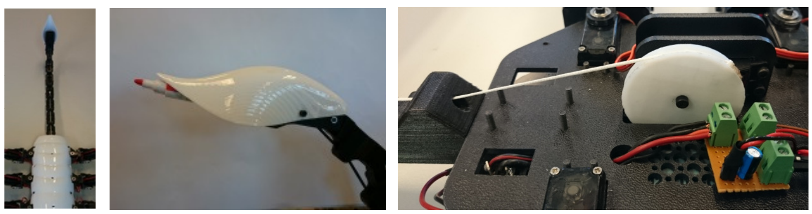

Figure 7. Final tail mechanism based on antagonistic muscles,
almost entirely built of 3D printed modules.

The scorpion arms and claws were designed to be actuated by one single servomotor. More motors would again increase the weight, cost and complexity. A realistic movement was perceived using only one motor by making the small, inner part of the claw fixed, and let the bigger shell move over it. Since this part was meant to be less complex than the tail and the legs, less iterations were needed to make this part functioning as desired. A laser cut skeleton was designed to be attached to the body afterwards. In the laser cut plate, holes for the motor and cable management were integrated towards an easy assembly and a stiff construction with few materials needed. Again, thermoformed shells were designed to create a smooth streamlined design.

Once all limbs were designed, produced and functioning properly, the scorpion body was designed to keep all these parts together. The body exists of two laser cut ABS-sheets with a gap in between them to increase the stiffness. All electronic and mechanical components were attached to these two plates. The plates contain holes for snap fits, cooling, and cable management, i.e., to achieve an easy assembly. For aesthetical reasons, two polystyrene shells were thermoformed to cover the electronic parts.

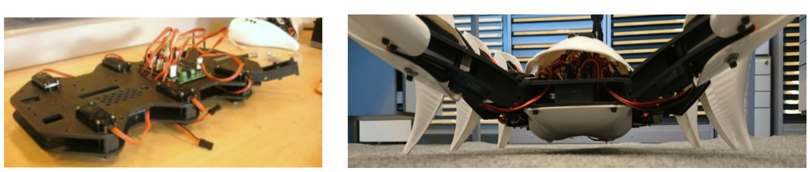

Figure 10. Final scorpion body, existing of two laser cut ABS- plates and thermoformed PS shells

4. Designing and Programming the Human-Robot Interaction (HRI)

A robot wouldn't be a robot without electronics and software to make it walk, move and interact. An Arduino Nano takes care of all the calculations and decision making, functioning as the brain of the scorpion, while an SSC-32 takes care of driving the servos. A set of infrared sensors were installed to provide the necessary input for the robot to interact with its environment. To control all the motors and combine their movements to achieve a coordinated move, Inverse Kinematics (IK) were used. The robot is assigned global coordinates based on its dimensions, while each leg has its local coordinates. In this way, the individual angles of each servo are automatically calculated by the inverse kinematics calculations, by simply writing global coordinates. This way, it's a lot easier to program complex movements. The code has been upgraded to provide body movements too. In this case, the legs stay in the same position, but the body position and angles can be changed. The combination of leg IK and body IK provides a lot of possibilities for moves. For efficient programming, a graphical user interface (GUI) was created, which allows easy calibration, debugging and combining moves.

5. Conclusions

This paper presents a detailed description of the design, the production and features of our novel hexapod scorpion. Thanks to the use of digital production techniques and an Arduino-programmed human robot interaction, the scorpion hexapod can easily be modified, optimized, reproduced, adapted or extended. Furthermore, thanks to the modular design, the tail and claws can easily be replaced by other limb modules to design other types of hexapods, e.g., based on another insect or animal. Several solutions, based on nature and the anatomy of different animals, have proven their worth in the construction and performances of the nature-inspired robot. Future work will focus on a thorough system evaluation (i.e. to test the ease of reproduction), HRI user tests and extending the sensor-based interactions and autonomous behavior. Furthermore, we plan to share our code at a GitHub repository and document it with a wiki/Instructable.

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