Systems Overview of Ono

A DIY Reproducible Open Source Social Robot

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Abstract. One of the major obstacles in the study of HRI (human-robot interaction) with social robots is the lack of multiple identical robots that allow testing with large user groups. Often, the price of these robots prohibits using more than a handful. A lot of the commercial robots do not possess all the necessary features to perform specific HRI experiments and due to the closed nature of the platform, large modifications are nearly impossible. While open source social robots do exist, they often use high-end components and expensive manufacturing techniques, making them unsuitable for easy reproduction. To address this problem, a new social robotics platform, named Ono, was developed. The design is based on the DIY mindset of the maker movement, using off-the-shelf components and more accessible rapid prototyping and manufacturing techniques. The modular structure of the robot makes it easy to adapt to the needs of the experiment and by embracing the open source mentality, the robot can be easily reproduced or further developed by a community of users. The low cost, open nature and DIY friendliness of the robot make it an ideal candidate for HRI studies that require a large user group.

Keywords. Do-It-Yourself, emotions, facial expressions, human-robot interaction, maker movement, open hardware, open source, rapid prototyping, robotic user interface, social robot

1 Introduction

To study human-robot interaction (HRI), one needs appropriate systems with social capabilities. Multiple studies and applications in HRI make use of facial expressions since people rely on face-to-face communication in daily life. The face plays a very important role in the expression of character, emotion and/or identity [1]. Mehrabian [2] showed that only 7% of affective information is transferred by spoken language, that 38% is transferred by paralanguage and 55% of transfer is due to facial expressions. Facial expressions are therefore a major modality in human face-to-face communication, especially in fields such as robot-assisted therapy (RAT), where emotions play a crucial role in the communication process.

A major problem in HRI studies is that many HRI platforms are very expensive: Kobian [3], HRP-4C [4], Waseda Emotion Expression Humanoid Robot WE-4RII [5], iCub [6], Kismet [7], Probo [8], … are very high performing social robots, but with a high degree of complexity, hence the high cost. For many studies such performance is not always required and the ability to have many robots for a broader scale of experiments can have benefits. Cheap social robots that are potentially usable for HRI studies are platforms like My Keepon (a toy based on the more expensive Keepon platform) [9], KASPAR [10], or Furby (Tiger Electronics), but their hardware and software is not open-source, giving little possibilities to adapt the platform to the specific needs of the research. Therefore a novel design of a social robot named Ono is presented (figure 1), with the aim to obtain a DIY reproducible open source social robot. Ono is built with the following requirements in mind:

1. Open source hardware and software
2. Do-It-Yourself
3. Modular
4. Reproducible
5. Social expressiveness

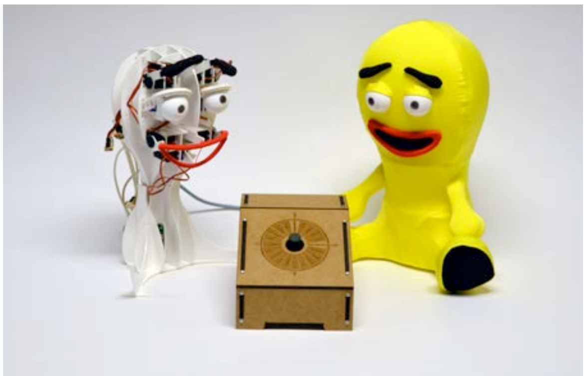

Fig. 1. The Ono prototype with control unit

1.1 Open source hardware and software

One well-known open source platform is the European humanoid robot iCub [6]. Other projects are the Dora Opensource Robot Assistant [11] and the successful e-puck educational robot [12]. The open source community has made new technologies accessible not only to professionals, but also to many hobbyists. Examples include 3D printers such as Fab@Home [13] and RepRap [14] and microcontroller platforms such as Arduino [15]. A lot of initiatives focus on the development and distribution of open source software for robot systems, popular systems are ROS [16], the Player/Stage project [17], the Orocus project [18], and the Urbi project [19]. The aim for Ono is to distribute both the open hardware and the open software. The source files of the robot can be found in a public Github repository [20], however because the design is still being worked on, no final assembly instructions have been made available yet .

By promoting the free redistribution and access to hardware and software, other researchers have the opportunity to easily extend the capabilities of the robots and make the platform suitable for their particular applications.

1.2 Do-It-Yourself

In contrast with iCub [6], which is complex and expensive to build, our goal is that Ono can be built without the aid of paid experts or professionals. The goal is that the robot can be built using easy to understand instructions, in an Ikea-wise manner. The interest and wider adoption of DIY is facilitated by (1) easy access to and affordability of tools and (2) the emergence of new sharing mechanisms, which plays a major role in motivating and sustaining communities of builders, crafters and makers [21].

1.3 Modular

By dividing the robot into small, independent modules, each containing a set of related sensors and/or actuators, newer versions can be developed and distributed easily. If a module is damaged or broken, it can be replaced without needing to disassemble the entire robot. Also, the development of independent modules makes it easy to reuse these modules within other social robots. This means that different types and forms of social robots can be developed more quickly and that the improvements made to modules by other research groups can be reincorporated into the Ono project. Another advantage is that a degree of customization will be possible. Not all research requires the same degree of complexity of the social robot used; some applications may only require a smaller subset of modules while others may need a camera and additional sensors. By allowing this customization, the Ono social robot can become accessible to a larger group of users.

1.4 Reproducible

Another important factor of this new platform is the ease of making or reproduction. Developing this new prototype with low volume manufacturing techniques in mind has several consequences.

The advantage over traditional methods is that more and more rapid prototyping machines, such as laser cutters and 3D plastic printers, are available in different labs or at low cost over the internet. Low-cost 3-D printers could very well be the next big trend in home robots [22]. These machines can be operated by non-skilled users, which in contrast with e.g. CNC milling machines, where specialized technicians are required.

1.5 Social expressiveness

Bartneck and Forlizzi propose the following definition of a social robot [23]: "*A social robot is an autonomous or semi-autonomous robot that interacts and com-*

municates with humans by following the behavioral norms expected by the people with whom the robot is intended to interact." Communication and interaction with humans is a critical point in this definition. This definition also implies that a social robot requires a physical embodiment and a social interface. For Ono we concentrated on the facial expressions and gaze as social interface. For the display of the emotions most of the DOFs in the face are based on the Action Units (AU) defined by the Facial Action Coding System (FACS) developed by Ekman and Friesen [24]. AU express a motion of mimic muscles as 44 kinds of basic operation, with 14 AU to express the emotions of anger, disgust, fear, joy, sadness, and surprise, which are often supported as being the 6 basic emotions from evolutionary, developmental, and cross-cultural studies [25]. Several other robots rely on this principle, such as Kismet [7], Probo [26] and EDDIE [27].

2 Structural Makeup

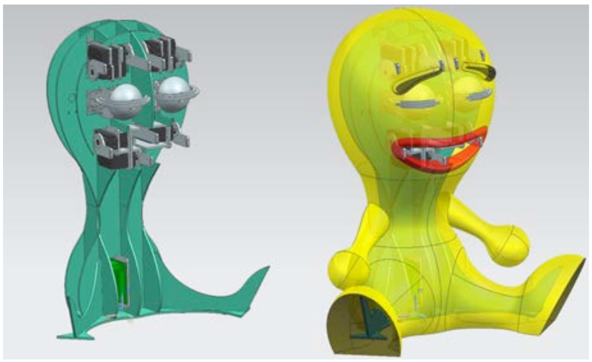

Fig. 2. Skeletal structure and modules

The Ono robot consists of 5 main groups:

2.1 Skeletal frame

A 3D model of the intended appearance of the robot was used as a starting point. After accounting for the thickness of the foam covering, this model was sliced into multiple cross-sections. These sections were then used as the basis for the skeletal structure of the robot. The sections of the frame are connected to each other using interlocking slots and tabs. The frame also has 5 openings in order to accommodate they eye-, eyebrow- and mouth-modules (figure 2). Finally, mounting holes and slots were made so that the electronics and cables could be connected to the frame. We chose a sitting pose for Ono to improve the robot's stability. The robot head is made disproportionally large in order to make facial expressions easier to see and to make it easier to integrate the modules into the head.

2.2 Modules

Sets of related sensors and/or actuators are grouped into modules. The current prototype has 3 distinct types of modules: an eye module, an eyebrow module and a mouth module. Each module uses a set of cantilever snaps to connect the module to the frame. In addition, cross-shaped mounting holes allow the modules to be connected to Lego Technic bricks, so that new robots can be built and tested rapidly. For the current prototype each eye module was given 3 DOFs, each eyebrow was given 2 and the mouth was given 3. These DOFs allow Ono to express the 6 basic emotions [25] and additionally move the eyes both horizontally and vertically, which allows the robot to gaze.

2.3 Foam and skin covering

The skeletal frame is wrapped in a protective cover made from polyurethane foam. This gives the robot a soft exterior for interaction with children and protects the inner components from potential damage. The foam covering is made from flat pieces of laser-cut foam. This technique requires that the shape of the robot is smooth and continuous, so that the body can easily be split in two-dimensional patterns. The soft foam covering is in turn covered by a sewn lycra suit. This covers up the inner components and provides a visually pleasant appearance. The color yellow was chosen because of the association between yellow and positive emotions, as described by N. Kaya et al. [28]. We chose to give Ono an exaggerated, cartoon appearance, so as to avoid the effects of the uncanny valley [29].

2.4 Electronics & interface

The main power supply, logic processing and interface are contained within a separate unit. This unit provides power and movement instructions through a cable to a servo controller inside the robot, which in turn powers and controls the servos individually. A joystick interface allows the operator to select the correct emotion and intensity from Russell's circumplex model of affect [30] or alternatively, the robot can be controlled through a USB interface.

3 Production Techniques

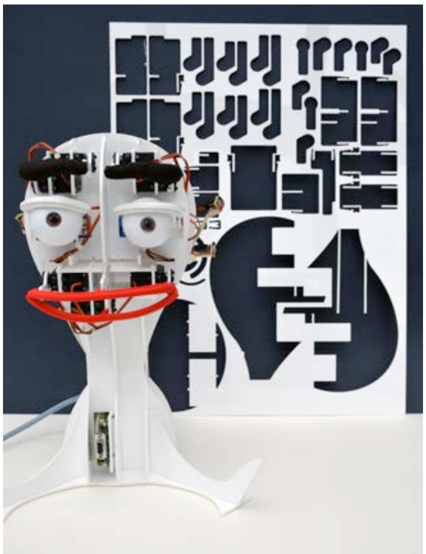

Fig. 3. Prototype with one of 2 laser-cut sheets in the background

The construction of the robot relies heavily upon the use of laser cutting. The main advantages of laser cutting are that (1) it is fast, (2) the files can be edited easily, (3) it is well suited for larger components and (4) the machine is easy to operate.
Both the hard, mechanical parts and the soft, protective foam covering are cut using a laser cutter. The structural parts are made from 3 mm thick ABS plastic (figure 3). This material was chosen because it is a readily available, low cost material and because it is flexible, making the robot more resistant to damage and allowing design features such as snap connectors. To give the robot a soft, huggable appearance, a protective foam cover is placed over the skeletal structure. In early prototypes, this foam cover was made by casting a flexible PU resin in a mold. The main disadvantage of this approach is that a mold is required, which makes producing the parts from digital files much more labor intensive. We solved this problem by recreating the 3D foam shell using 2D laser cut pieces of foam. The cost of materials to build one robot is around €310. This cost may vary depending on location and on what components the user already owns. Table 1 provides a rough breakdown of the costs.

Table 1. Cost Overview

3mm polystyrene sheets	€20
20mm polyurethane foam	€5
Arduino Uno microcontroller	€25
SSC-32 servo controller	€40
PC power supply	€25

RC servos	€80
Nuts, bolts, cable ties	€10
Connectors and electric components	€30
Textile supplies	€30
Laser cutting cost	€45
Total	**€310**

4 User tests

Fig. 4. Child interacting with Ono during user tests

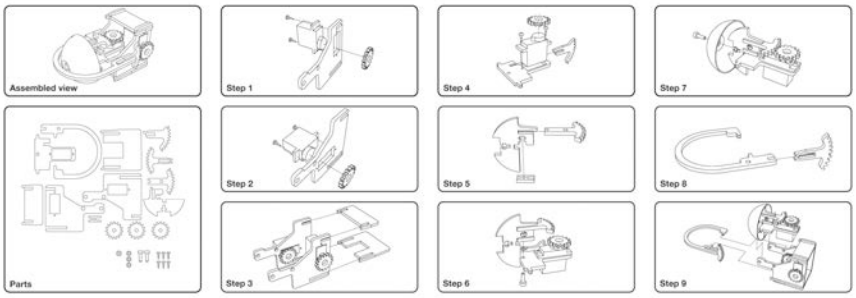

Fig. 5. Assembly instructions for an eye module

An important aspect during the development of Ono was that building the robot has to be as easy as possible so that even users with little technical skill can complete the project successfully. A small-scale user test with 5 users (aged 18-55) was done to identify possible roadblocks during the assembly. The tests showed that the visual instructions work well to guide inexperienced users through the assembly process. Users noted that while the drawing of the finished module looks very complex, the actual assembly process is greatly simplified by the step-by-step instructions. One user compared the module kit to a set of Lego bricks and that completing the assembly of the eye module gave him a sense of satisfaction. These tests also revealed a number of pitfalls for both the instructions and the parts themselves. The instructions should include more color to identify new or dissimilar components. Each component should also be labeled with an identifying number and required tools – if applicable – should be shown in each step. Problems with the laser-cut components include snap cantilevers being too rigid or soft, distinct parts being too similar to one another and parts being used in mirror position. Another problem was that nut & bolt connections were hard to make due to the inability to properly grip the nut while fastening the bolt. Changes to solve these problems were then reincorporated into the newer versions of those modules: parts were reduced and simplified, bolts are screwed directly into the ABS sheet and the snap cantilevers were readjusted.

Additionally, a pilot study was performed with 5 autistic children (aged 3-10), without the presence of the engineers and without explicit training of the operator, to test the overall interaction of the children with the robot and to test the recognition of emotions. Children were asked to identify the emotion expressed by the robot, they were then asked to mimic the robot's facial expressions and were finally allowed some time to freely interact with Ono. These tests show that Ono has an overall inviting appearance that elicits interaction, but that there are still several issues that need to be solved. During testing happiness and sadness were recognized correctly 15 times out of 16, while anger was only recognized only 3 times out of 16 and surprise only 6 times out of 16. The facial expressions for these emotions need to be adjusted. Additionally, the control box interface proved to be suboptimal: the joystick distracts the children and the (short) cable means that the whole setup can be unwieldy at times. Another required feature is the addition of idle animations, to make the robot seem more lifelike when the operator is not actively controlling it.

5 Conclusion

This paper has presented the first steps toward the development of a DIY reproducible social robot. By splitting the robot up in several independent modules, development can take place more rapidly and modules may be reused in other projects. By translating facial actuation systems found in other social robots to systems that can be produced with hobbyist-level tools and services, an affordable HRI platform was developed. By taking advantage of the benefits laser cutting technology offers, a large degree of flexibility can be obtained while still offering a quick means of production. The ultralow cost and open source nature compared to existing platforms makes Ono an ideal tool to use in larger scale HRI studies.

The next steps include the further development of the robot’s electronics. Tests have shown that the current control box setup needs improvement. One option is to integrate all the electronics within the body of Ono and to make the control of the robot wireless. Newer, more advanced modules will also be developed to accommodate a wider range of possible applications. The eye module in particular needs to be improved further; the current one is difficult to assemble and is not robust enough. Current modules can be connected to Lego bricks using cross-shaped axle holes, however this interfacing system should be extended to electronic Lego bricks. This should allow fast prototyping of social robots using Lego Mindstorms. For example, the eye modules of Ono can be connected to the Tribot robot of Mindstorms NXT in order to create a rudimental social robot. With further development these modules may complement Lego Mindstorms, providing an inexpensive and easy to use platform for HRI studies. This would solve the lack of sufficient HRI capabilities of the Mindstorms platform, as noted by Murphy et al. [31].

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