GlowBots: Designing and Implementing Engaging Human-Robot Interaction

Mattias Jacobsson, Ylva Fernaeus and Lars Erik Holmquist

***Abstract*—GlowBots are small tangible, communicating and interactive robots that show eye-catching visual patterns on a round LED display. This paper details the development of the GlowBots from the early user-oriented design phase, through hardware and software development and onto preliminary user studies. In the design phase we outlined a robot application based on a study of how owners relate with unusual pets, such as snakes and lizards. This led to an application concept of a set of ”hobby robots” which would communicate with each other and the user through dynamic patterns. Based on these requirements, we developed a LED display called see-Puck, which together with an open robot platform was used for the GlowBots application itself. One particular issue is dealing with energy consumption problems, as resources in embedded systems often limit the potential time for user interaction. We conclude with a report on early user experiences from demonstrating GlowBots and a preliminary user study in a home environment as well as remarks about future directions.**

***Index Terms*—GlowBots, Human Robot Interaction, Tangible Interfaces, Ubiquitous Computing.**

I. INTRODUCTION

THE ROBOTS are coming, but are they here to stay? [1] Human-robot interaction is a rapidly expanding area, with many new journals and workshops appearing in recent years. However, in order for robots to truly become a part of our everyday life they should provide a meaningful and sustainable presence as a result of interaction with other robots, humans, pets or devices. Seen from this perspective, everyday robotics shares a strong synergy with the vision of ubiquitous computing [2], and tangible computing [3], where technology tends to become more and more intimate [4]. The main difference from these emerging interaction paradigms is that robots manifest themselves as mobile embodied units that can affect the world physically.

In the European project *ECAgents – Embodied Communicating Agents,* [5] we have been actively working to expand the boundaries of what interaction with robots might be like in the future. Mundane labor such as vacuuming, cleaning or other practically oriented chores are merely a subset of existing needs where robots could play a role [6]. From a design point of view, it is also important to use ”out of the box thinking”, as we might miss out on important areas and interaction modes that are difficult to imagine before they exist.

As a way to stimulate new ways of thinking about robots, we first gathered researchers in the field for a two days workshop called ”Designing Robots for Everyday Life” to brainstorm about innovative new robotic design spaces [7]. As a direct outcome from this we got a number of robotic mockup scenarios, for instance, robot plants that would re-arrange themselves in order to guide queues in a complicated environment such as an airport, or the listening psychologist, bean-bag shaped robot that would attach itself to a car’s rear mirror. But more interesting than these design suggestions was that we learned that designing robotic applications often results in far-fetched expectations and visions of problem oriented scenarios – even though we did all we could to be as open minded as possible.

To further explore how robotic appliances could be designed, we started to experiment with a new design method, *transfer scenarios* [8]. In this process we sought ways of grounding our designs in existing practices where relationship, autonomy and embodiment were essential [9]. We looked for an existing human practice that could be used as inspiration and guidance for the design of new forms of robots. Eventually, we decided to study owners of unusual pets, such as snakes, spiders and lizards as inspiration for designs. One of the results pointed towards an application where robots are engaging, but not overly personal, similar to a dynamic, mobile and visually appealing trading card game collection.

Fig. 1. Exhibition visitors playing with a swarm of GlowBots.

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a round LED-display that could extend an open educational robot platform, the *e-Puck*. The result was a top mounted extension module that we swiftly named *see-Puck* [10]. We then also needed to make several energy-optimization changes to the e-Puck firmware in order to cope with sustainability and stability problems. The resulting application is called *GlowBots* and consists of the assembled hardware together with software for infrared communication and animated morphing patterns (Fig. 1).

Not only did this project begin with a study, but we will also conclude this report with a preliminary user study conducted in a real home environment. In the discussion we will also compare findings and comment on the overall design process.

II. BACKGROUND AND RELATED WORK

What would be the design requirements for a more subtle robot technology, one which could be found in the intersection between robotics and ubiquitous computing - robots that quietly find their ways into our everyday life and eventually become an integral part of it? Today new robots are appearing almost every day, so first we would like to recapture some historical points and put our standpoint in contextual highlights.

People have an underlying assumption that robots are socially capable [11]; hence they are quite biased when it comes to their image of a robot. The word itself (although not the concept) originates from Czech ”robota”, and was popularized through the theatric play by Karel Ĉapek called ”Rossum’s Universal Robots” (R.U.R) in 1921. The word at that time simply meant work or compulsive labor, but a general definition once given in the Merriam-Webster dictionary centuries later still reflected this common perception:

”An automatic apparatus or device that performs functions ordinarily ascribed to human being or operates with what appears to be almost human intelligence”.

It may be a pity that we did not catch up on the Japanese older and more humble notion similar to *automaton*. The profound cultural differences to western attitudes could be seen as in contrast to the Japanese compassion for robotic characters like the *Mighty Atom* (Astro Boy in the US) which is more emotionally oriented rather than labor oriented.

Today, the word robot still represents a governing descriptive purpose, but we also have a flora of words in the subsequent field of robotics that captures more fine tuned distinctions, e.g. android, humanoid, mecha, cyborg, but which all still inherits much of the original anthropomorphic connotations. Another example, the *Robot Fish* [12], is designed to be a copy of a common fish in terms of looks, properties and behavior. This approach is common, especially from a robotic toys perspective as anthropomorphic values are added to the designs as a mean to extend interaction. To mention just a few of these commercial examples of robotic pets we have Aibo, RoboPanda, Furby [13] and now also Pleo [14].

Masahiro Mori’s *uncanny valley* is an example of what happens when more subtle expectations do not correspond to the perceived input in human-robot interaction [15]. Instead of getting relaxed and enjoying the anthropomorphic features the hypothesis states that we unconsciously start to focus on the dissimilarities which in the end results in an uneasy repulsive reaction. In relation to this theory we notice that anthropomorphism and zoomorphism play an important role in setting the levels of expectations, and by being aware, and taking control of these insights would be a key component in taming robotic design.

As a consequence we sometimes instead prefer to use the term ”embodied agents” to describe a more general and open view of robots that moves the focus away from traditionally biased anthropomorphic preconceptions [7]. Other researchers prefer the term ”robotic product” to denote mechanically based interactive applications [16]. Examples of robots intended for labor oriented work include the *Roomba* vacuum cleaner [17], the *Artemis* guard robot [18] or the *Minerva* museum tour guide robot [19].

In a sense our work is the opposite of the above approaches; we have absolutely no intention to make a new dog or cat, or replace work already performed by humans. Several researchers are also pursuing such alternative views of robots. For instance, *The Hug* [20] is an example of a robot that does not look like anything biological, but instead reminiscent of an artifact that can be found in an everyday setting, in this case a pillow. It does not have any sophisticated communication capabilities like speech, or complex behavior like walking. Instead it appeals to our most primitive need of affection. Yet another example of a design that expresses life-like qualities but also integrity is *Tabby* [21] – a simple interactive furniture demonstrator. Our work is thus similar in that we also move our focus away from the ordinary expectancies of robotics and at the same time avoid elevated expectations.

Another relevant study looked at peoples’ relationships with everyday artifacts, such as computers, corkscrews and notebooks [22]. It points out that a notebook will increase in perceived value over time as it is filled with notes and sketches, while e.g. fashionable clothes value actually decreases as it becomes increasingly obsolete. We found such observations inspirational in regards to where we should position ourselves and think about future robot applications.

III. DESIGN METHOD

One of the problems of designing novel forms of robots could be the lack of perspective outside that of the experts and scientist who are already designing robots. We have taken inspiration from the field of human-computer interaction to find methods that infer design implications either directly from studies of users or by extrapolating from known human needs and interests. One such method is to use fictive representative characters called *personas* [23].

We started by seeking out possible sources where established interaction and engagement are essential properties and autonomy plays a significant role. From earlier studies we knew that looking at practices that lies down the long tail of practices, so called *marginal practices*, tend to turn our minds away from the established discourse [8]. When looking for a suitable practice to engage with, we were interested in people who were interacting with living things – but not necessarily commonplace pets, such as cats and dogs, since such an interaction has already been proven hard to capture in a robot. We decided to study and interview owners of pets with fairly low cognitive capabilities and unusual affordances for interaction, e.g. spiders, lizards and snakes (Fig. 2). In total we conducted ten interviews with six male and four female participants. Three of the interviews were made face-to-face and the rest by phone due to logistic restrictions. Typical questions during the interviews would be about why they were interested in a particular pet, what the pet does, what they do together and how they could tell the mood of their pet.

Fig. 3. When designing the GlowBots we took inspiration from the relationship people develop with unusual pets such as spiders.

We then transcribed the answers from the interviews and cut up quotes and wrote them down onto Post-its. From the scrambled Post-its we then tinkered and linked together different properties and intrinsic characteristics in various constellations. After iterating this process several times four distinct clusters started to emerge representing the rough outline for the four personas (Fig. 3). In one of the affinity clusters we could then read several statements without any apparent contradiction e.g.:

- *He does not pet his pets, nor is he interested in different personalities of the pets.*
- *He is interested in breeding his pets in order to create nice patterns.*
- *He enjoys reading about his pets and often meets up with people that have similar pets, to look at or even exchange pets.*

The next step was to create the personas from these clusters, which are descriptive scenarios of imagined users. The complete scenario was then created by filling in general fictive ”glue data”, connecting such different quotes into meaningful coherent descriptions. In total we created four such personas [9] but in this case we will focus only on the persona that is relevant in the context of GlowBots.

We then named the persona, which is a powerful way of building a mental image around a common reference. This particular persona goes by the name Nadim. At this stage the scenario would still refer to a relationship with pets; however, by simply changing the word ”pet” to ”agent”, we *transferred* the scenarios to our target domain [8]:

Fig. 2. a.) Selected data was taken out as notes from the transcribed data. b.) The notes where clustered, each being a starting-point for one persona.

Nadim is 32-years old and works as a network engineer, living alone in a two-bedroom flat in a small town. He has always had a great interest in collecting and exploring various things, and as he got older he became fascinated in having ***agents*** *as a hobby. Nadim finds it exciting to try to understand their behavior and sees them as a research area where there is always something more to learn. He enjoys watching them communicating to each other and changing their patterns. Every single* ***agent*** *has its own specific colour pattern, and when it is put close to another* ***agent*** *they both start to change their individual patterns. The surrounding light, sounds and movement etc, also affects their patterns. The changes are slow, and sometimes it takes several days until it Nadim can see how an* ***agent*** *is reacting. The challenge is to avoid results that are bland or unattractive. Nadim is quite good in developing* ***agents*** *with unique interesting patterns, and he puts pictures of the* ***agents*** *on his website. The number of* ***agents*** *Nadim owns varies, and he has never bothered to give them any names. He likes to read everything that crosses his path; Internet pages and magazines. He also frequently visits other sites to compare patterns and sometimes he writes in a forum for people with the same type of* ***agents****. They sometimes also meet to let their* ***agents*** *affect each other’s patterns.*

This scenario now expresses what a potential user of an autonomous agent would look like. The final step in this process includes matching technology with the scenarios to sketch out real designs:

The agents can evolve interesting patterns over time, but it is a lengthy process and might not always succeed. Agents will be equipped with a color display on their back and have one or more sensors for light, movement and sound. The sensing can be different for different agents. Each agent will have a unique color pattern, developed from meetings with other agents the environment it is in. By touching the agent in a particular way makes it possible to temporarily freeze a pattern. Achieving a nice pattern requires several agent-agent interactions and an attention to timing.

Based on this description we could then proceed with sketching and implement a rough first prototype.

IV. SEEPUCK DEVELOPMENT

Our design pointed towards some kind of visual interface as one of the central components. We also decided to base the project on an educational robot platform, the e-Puck, developed by Ecole Polytechnique Fédérale de Lausanne [24]. We looked for an existing display but found that all currently available displays had a rectangular shape, often needed backlight to be visible from a distance and prioritized resolution and color depth over cost. We decided to design a new display that fit our needs, and in particular one that had a shape that would fit on the round, roughly coffee-cup sized e-Puck. When designing the new platform, much effort was put into hardware and software design, keeping it simple, modular, obvious, cheap, energy efficient and robust.

A. *Hardware*

The see-Puck is designed to fit on top of the *e-Puck* robot and connect through a serial interface. We use the version 2.0 of the e-Puck, which features a number of sensors and actuators including infrared (IR) proximity sensors, one camera, three microphones, a 3-axis accelerometer, loudspeaker, stepper motors, Bluetooth interface, a number of LEDs, a PIC microcontroller, and a twelve step mode-selector.

Fig. 4. The two printed circuit boards of the see-Puck module are mounted on top on an e-Puck.

The see-Puck display module (Fig. 4) consists of two printed circuit boards, one *controller board* and one *matrix board*, sandwiched together by two perpendicular connectors. This design ensures that the matrix board that holds all the LEDs can only be fitted in one way. The controller board (Fig. 5) holds its own microcontroller (Atmel ATmega8L) and firmware to handle higher level instructions from the e-Puck through a RS232 serial interface.

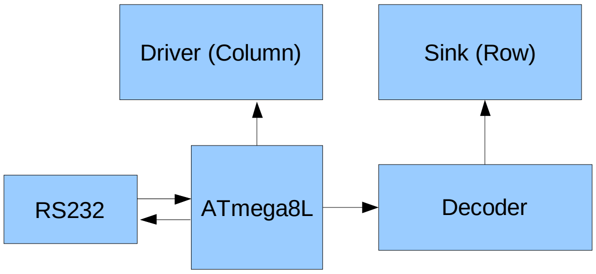

Fig. 5. Controller board overview with arrows indicating the flow of information. The driver sets a column high while the sink grounds one of the rows given by the decoder.

The matrix board holds 148 LEDs in a rounded 14 by 14 matrix. To keep the energy consumption down and also maximize light intensity we exploit a known, but often overlooked feature of the LEDs – the possibility to light them up using short rapid pulses of higher current. To the human eye the quickly flashing the LEDs will appear as a constant light. The gain is significantly lower total energy consumption, which is one of the most important factors when designing for devices that rely on batteries. Furthermore, flashing the LEDs is a perfect fit with the electronic design, since only one LED per column can be lit at a time.

B. *Software*

The software has two parts, one *library* for the e-Puck consisting of the higher level commands that are sent to the see-Puck module from the e-Puck and one *firmware* part for the microcontroller on the see-Puck controller board. The range of graphical commands available in the library represents the most basic ones e.g. *set a pixel, draw a line, draw a circle, shift screen,* etc. These commands often take arguments in form of coordinates and LED brightness. We also decided to make graphics double buffered, i.e. the actual drawing is done to one buffer while the other is shown, so that flickering in animations is kept at minimum.

The firmware consists of two interrupt-driven subsystems - the communication and the graphical subsystems, which run side by side parallel to a continuous main loop (Fig. 6**¡Error! No se encuentra el origen de la referencia.**).

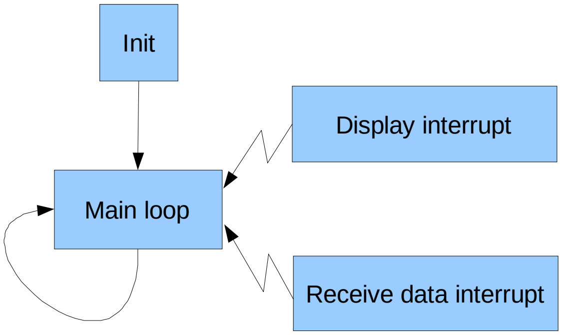

Fig. 6. See-Puck firmware schematic overview with two simple interrupts.

When the communication subsystem receives a byte over the UART (the serial interface on the microcontroller side), it calls the receive data interrupt. After checking the integrity of the message it gets stored into a ten level sized software implemented FIFO buffer shared with the graphics subsystem. At the end the receive interrupt is reset.

The graphics subsystem interrupt is timer-based and called about 60 times a second. When called it starts with getting a pointer to the current front buffer. It then cycles through each row sending a PWM (Pulse-Width Modulation) signal with a four bit resolution for each LED, representing the specified brightness.

The firmware starts with an initialization of the graphics subsystem. It then turns on all the LEDs for about a second before it initializes the communications subsystem and enters the main loop. The interruptable main loop then continuously checks the FIFO for new commands and executes them, preparing the back graphic buffer.

```
#include ”e_see_puck_lib.h”

int main(void){
  int x = 7, y = 7, r = 4, c = BRIGHT;
  e_see_puck_init();
  e_see_puck_draw_circle(x,y,r,c);
  while(1){
    e_see_puck_swap_buffers();
    e_see_puck_copy_buffers(FRONT_TO_BACK);
    e_see_puck_hscroll(-1);
    //Waste some cycles here
  }
}
```

Fig. 7. An example program for the e-Puck using the standard graphics library developed for the see-Puck.

In the illustrative C-code example (Fig. 7) a circle is first drawn at the center of the back buffer. It then enters the main loop executing a buffer swap to make it visible. The front buffer is now copied onto the back buffer and scrolled one step horizontally (to the left) before next iteration. The final result is a circle that scrolls over the screen.

C. *Energy Optimizations*

When the see-Puck modules arrived from factory we measured the average power consumption for it to be in the range of 20 mA. During initial tests it all seemed fine until we started using more and more sensors and actuators. After deeper investigation we found out that the biggest issue was the stepper motors that at the time ran in the range of 200 mA. During power peaks such as sudden friction events e.g. running into an obstacle or another robot this would cause instability problems for the display or even the e-Puck. This forced us to soft-optimize some portions of the e-Puck libraries and to use PWM where possible. This trick worked out very efficiently for the stepper motors, which landed on an average of about 30 mA afterwards (no load). Similarly, all LED’s on the e-Puck were also pulsed to save even more power.

V. GLOWBOTS DEVELOPMENT

Based on the see-Puck hardware, we then constructed an interactive application inspired by the Nadim persona. We had a total of 20 complete robots (e-Puck platform plus see-Puck display) which would allow for large groups of interacting robots. Here we will outline the steps involved creating the GlowBots demonstrator application from based on the design proposal and readied platform.

A. *Visualizations*

The idea with GlowBots was to let the users interact with an ever-changing set of robots, which would express themselves with dynamic patterns on the LED display. In the early proof-of-concept prototype we started out with Conway’s Game of Life, a well known cellular automata example, to produce interesting dynamics on the display when the robots interact. Although it was relatively open-ended, it did not satisfactory convey the intended interaction. We then sought a way of displaying interesting shapes that could be semantically interpreted and that somehow would morph more intuitively as interaction took place. After a great deal of investigation we came to use analytical curves based on the super-formula equation [25], chosen for its richness of simple shapes. The resulting shapes can be anything from star, square, circle, egg, flower and any intermediate state in between (Fig. 8).

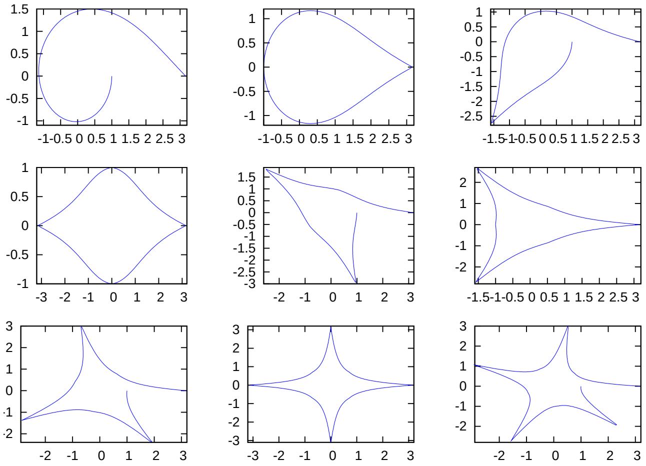

Fig. 8. Examples of shapes generated by the super-formula that would typically occur in the GlowBots application.

B. *User Interaction*

The user interaction stems from the developed persona description from the design step. Users interact with the robots directly, either by moving them around on the surface (to place a robot next to another with an interesting pattern) or by gently shaking them. If the user shakes the robot up and down this will encourage the pattern that the robot is currently displaying to become more dominant. If the user shakes the robot side to side, this will instead have the effect of making the robot more susceptible to be influenced by other patterns. Thus, while the users cannot directly create new patterns, they can indirectly influence the visuals by encouraging certain patterns and discouraging other. As two robots stand next to each other, they will start communicating and slowly converge to showing the same pattern, which will be a mix of both the original patterns. The effect is that of a slowly evolving, constantly surprising collection of a tangible autonomous robotic display.

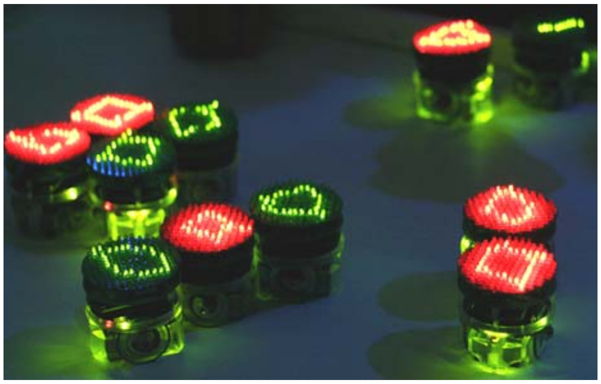

Fig. 9. A group of interacting robots that uses their patterns to attract users to play and interact with them.

From an application point of view, each GlowBot will communicate their respective parameterized internal states, including current motion and the shape visualized on the display. The robot-robot communication uses the infrared proximity sensors for broadcasting and receiving data. There are two important reasons for choosing IR over e.g. Bluetooth. First, since there are eight IR-sensors distributed around the robot, we can get a sense of directionality. Second and most important is the situatedness of the communication. The communication radius of IR is typically 10-15 cm, which means that only robots that are close to each other will communicate (Fig. 9).

VI. DEMONSTRATION EVALUATION

GlowBots have been shown at several major venues such as SIGGRAPH Emerging Technologies [26] and WIRED NextFest, with a combined audience of over 60.000 people. At these settings, we had the opportunity to observe how the GlowBots demonstration was received by ordinary people. Rather than only having them for show, we encouraged people to come up and play with the GlowBots. Literally thousands of people have thus gotten hands-on experience, many of them school children from the Los Angeles area. Having this kind of demo was possible only due to the efforts made in energy consumption optimizations and carefully planned continuous maintenance during the exhibitions. It also helps to have a swarm of units so that the demo does not rely on a single unit.

As with big exhibitions like SIGGRAPH people come to see the latest news in technology, listen and ask questions about the presented material. In the end they usually end up with a flyer or brochure to take home and reflect upon. The one thing we really could expect in this type of setting is the brief experience based on very first contact that the visitors would have with our GlowBots as they stumbled into our presentation booth.

Based on informal observations of how users interact with the GlowBots in exhibition settings we noted that many users spontaneously thought that the display would react by touch, similar to a large press button. Since this had not yet been conceived of as a possible use, we soon realized that the robots were not robust enough for such treatment. We thus had to stabilize the robot platform so that even though the robots still did not work as push buttons, they would not break in case someone tried to use them as such.

At SIGGRAPH, we recorded several hours video of the demonstration as people stopped by and interacted with our GlowBots. When reviewing this material we saw that the complexity of the setting involving many moving glowing tangible artifacts, crude and developing use of speech and gesture made it an analysis problem. Also, the level of noise from surrounding demonstrators and the fact that we had used a hand camera resulted unfortunately in very poor sound coverage.

As a first step in the analysis we published a small video-clip, showing how a little girl, five to six years old, plays with GlowBots for several minutes, before her dad wants to leave [27]. From the look of her face and posture she is totally immersed with the interaction and very hesitant about leaving the newly found little friends. We will also use the video material as a testbed for applying analysis tools for video encoding. For example, only transcribing the user side of the interaction would result in encoding only part of the story, leaving out important aspects related to the multitude of interactions.

Our experience from the demonstrations suggests that even though the design was initially based on a scenario of an adult persona, in its current state there is even more potential of GlowBots as used by children.

VII. PRELIMINARY USER EVALUATION

During demo sessions, most focus was on the hardware platform, and the actual and intended implementation of the software could be discussed with the presenters as part of the demonstration. More recently, we have also explored more long term use in a home environment. Leaving the robots ”on their own” with users, and allowing users to make their own interpretations of what the robots should do and what they should be good for could then potentially give much valuable input to the design process, apart from also being a more realistic case for testing the robustness of the hardware platform. In HCI research, this approach to user studies is sometimes referred to as *Technology Probes* [28], which is an increasingly popular method for user-inspired interaction design. The goal with our user studies were thereby not primarily to *evaluate* the technology, i.e., to say if it works or not, but to explore *how* the robots are used, what intended and unintended usages that may arise, and to feedback into what directions to further develop the designs.

With the initial development primarily focusing on the hardware and internal infrastructure of the robots, we needed to perform a pilot to investigate both the robustness of the hardware platform, as well as to gain more input to the details of how the software to run on the robots should be take shape. The interaction pace that had been developed was at this point geared towards exhibition settings where people typically only have a few minutes for every demonstration, which we assumed was rather different from the interaction in the intended home environment. To be able to learn how the robots could be used, and how to further develop the technology at the application level, we therefore complemented or experiences from demo and lab studies with a long-term study of how the robots were taken into use in a domestic setting.

A collection of 10 GlowBots were placed in the home of a 34 year old man with two children, (a girl of six and a boy of four years old), for a period of six weeks. The children were staying with their mother every other week, so their father was left alone with the GlowBots during half of the study period. From our previous demo sessions, we knew that the robots would need quite some maintenance with exchange of batteries, which was taken care of by the father in the family. Below we report on some initial findings based on video recordings and interviews.

The fact that the robots *glow*, meant that they became quite specifically experienced as to be used in darkness. This could be observed for instance in how a natural part in 'staging' the play session with the GlowBots was to switch off the ordinary light in the room. The displays then worked as decorative toys that could be played with in the dark, at the same time placing attention on themselves as the focus in the play activity.

The first spontaneous comments that we got on the GlowBots functionality were concerned with how the robots *moved*. It was repeatedly pointed out by the children that they moved too slowly, especially since after a period of active play, the robots usually stopped moving due to low battery levels. Moreover, the robots were at this stage programmed to keep going until they reached a wall, and then stayed there, which made them appear 'stupid'. Although it became part of the play to go collecting the robots that were on escape towards the wall, this soon became rather uninteresting as an activity on its own. The users suggested that instead of moving in a straight line in one direction, the robots should be able to wander about in a more complex manner. This would make the robots feel more unpredictable and interesting to play with. They were also interested in being able to in some way control how the robots moved, e.g. by waving or putting something in front of the robots.

As soon as the robots stopped moving, they did seem to get transformed into a kind of static mechanic sculptures, bringing back the glowing LED surface into attention. These were clearly attractive for the children and were used in a variety of ways in their play. Surprisingly though, the children did not initially seem to pay much attention towards the actual patterns that were on display (Fig.10).

Fig. 10. Using a GlowBot as a vehicle, podium or stage for other toys (left), and stacking the GlowBots into a tower (right).

The users were clearly attracted by the looks of the dynamic and glowing patterns, but they did not seem to reflect as much as one could expect on how the patterns arouse and how these were communicated between the robots. Instead, more focus was placed on the behaviour of how the robots moved, expressed for instance in discussions on what made them move in a certain direction and whether or not their movement could be controlled somehow. This suggests that physical robotic movement possibly overrides patterns on a visual display in terms of users' direct experience. Although this needs to be further investigated, it could be valuable aspects to consider in the development of new interactive technologies that make use of a combination of motion and visual display technologies.

VIII. DISCUSSION

Looking back onto the original design-proposal that came out from the Nadim persona, we believe that the governing idea is still on track, while minor changes have been introduced to allow for a more seamless interaction. For instance the software does not impose heterogeneous sensing capabilities, but instead small and big differences in hardware settings contribute to individuality. Infrared sensors are bent, batteries end up having different mileage causing robustness problems and there are different manufactures of IC-circuits between hardware revisions. All this contributes to making even the most mass-produced robot more individual and characteristic, something that in the end would benefit personalized, although subtle, interaction between man and robots.

It is interesting to observe how natural it looks when people interact with embodied, tangible and communicating digital artifacts, like the GlowBots. It not only becomes a bonding experience, but it also lets the users explore communication through observing cause and effect. It is also important to notice that embodiment and communication are closely entangled, which becomes very important when another type of embodied element, as for instance another user, enters the picture. We noticed that for humans to be a part of an ongoing communication we observed that the setting benefitted from being truly situated. For instance, if the range of GlowBots communication would have been in e.g. the Bluetooth reach, the perception of the swarm would have been very different and more resembling a simulation running on a computer.

Our design process illustrates how sensitivity to changes in the technology, and experiences of user interaction sometimes result in essentially new use settings which was not envisioned. For instance there became much more hands on and petting activity than envisioned in the original design descriptions.

IX. CONCLUSIONS AND FUTURE WORK

We have detailed the work on a novel robotic prototype, GlowBots, that was the result of a design effort developed to open up new perspectives on the future role of everyday robots. We ended up creating a form of robot that would entice an aesthetic experience outside the domains of the zoomorphic pet robots previously seen in research and products. Although the initial design came from a specific scenario [9] the see-Puck platform is not limited to the GlowBots application. We hope that the detailed development of the see-Puck could work as inspiration for how to construct simple displays with rather unconventional shapes. All see-Puck hardware and software is released under a GPLcompatible license so that anyone can use, revise, extend upon and improve it.

Fig. 11. When demonstrating the GlowBots we encouraged people to come forward and get the hands-on experience.

At SIGGRAPH and NextFest, we demonstrated the GlowBots continuously for several days at a stretch to thousands of users (Fig. 11), but this required almost constant battery changes and continuous maintenance of the robots. We have observed that energy consumption in this type of setting can vary greatly, not only because not two robots are perfectly identical, but also because they are both autonomous and tangible. We would also like to note that our efforts in optimizing energy consumption resulted not only in improved mean runtime, but more importantly contributed to an overall increased robustness.

We wanted to encourage a long-term relationship with the robots, inspired by how people interact with artifacts and creatures in everyday settings. One aspect that crystallized in this process is the need of open ended play – an important factor to sustain interest over time. We believe this work shows that it is possible to change how we think about new robotic products and how we can rethink their roles in our everyday environment. By grounding the design in existing needs, they will have the potential to last considerably longer and have a much more rewarding interaction than what in most cases is being offered today.

In the future, see several possible improvements for the see-Puck. One example would be to make the display touch sensitive by also using the LEDs as sensors [29]. This would allow users to point at and directly influence what is seen on the display, for instance to ”paint” patterns directly on the display. Another important improvement would be to continue the work on software optimization on the e-Puck in order to increase battery life and overall robustness even further.

From the preliminary user evaluation we found several interesting observations that requires further investigation, but also implications guiding further development. The more immediate step will then be to tune our pilot application and once more place it in an everyday setting to study it in more depth. In this case we will slow down the interaction, which is currently geared towards exhibition settings where people typically only have a few minutes for every demonstration. We will also take more consideration to motion behavior due to the much larger spaces that home environments offers. For a truly long-lasting relationship to develop between robots and humans, it is necessary to sustain the interest level over weeks, months and hopefully years. Achieving this sustained level of interest is an important challenge for future human-robot interaction applications.

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