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Incremental and Radical Innovation: Design in Robotics for Autism. Teo and Riby robots. Evolutionary Development

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Abstract: Present paper analyzes and compares two innovation models in robot design. The first part describes the incremental development process of Teo: a robotic tool for Autistic Spectrum Disorder (ASD) treatment for children. The second part describes the radical innovation model used for Riby: a robotic tool for ASD treatment for adults. At the end of this paper, authors discuss the results of each case and expose the conclusions as a possible new method of product development in social robotics.

Keywords: Learning tool, Autism, ASD, Robot, Human-Robot Interaction, Accessibility, Robot Design

1. Introduction

The adoption of robots has been proven as successful in many cases in developing abilities in subjects affected by Developmental Disabilities (DD), in particular Autistic Spectrum Disorder (ASD). Given the wide range of actual situations, and the specific problems each of these subjects has, there is space for many exploratory experiences to enlarge even more the set of success cases.

In most of the applications so far proposed, the interaction is limited by the nature of the robot: imitation activities, framed touch activities, and in general activities with almost static robots have been explored so far.

The authors of this article believe that rapid progress in the field of robotics offers various possibilities for incremental innovation in treatment for individuals with ASD.

The research is focused on the development of Non-Humanoid mobile Robot with full body interaction. Follows a short description of PoliSocial Krog project for which it was developed.

> "Teo has been designed in partnership with a team of DD specialists, and it is meant to be used as an efficient and easy-to-use tool for caregivers. Teo is integrated with virtual worlds shown on large displays or projections and with external motion sensing devices to support various forms of full-body interaction and to engage DD persons in a variety of play activities that blend the digital and physical world and

can be fully customized by therapists to meet the requirements of each single subject." (Bonarini A., 2016)Our experience in research allowed us to make a radical innovation in the field of ASD treatment and improve it through incremental changes.

We have come a long way through hits and misses, and we want to share our experience in this project.

2. Incremental Innovation: Teo robot case study

Figure 1. Development of Teo Robot, from left to right, version 1, 2, 3 and 4

Starting in 2013, a two years research project, produces as one of the result, Teo Robot. The research project called KROG: Kinect-Robot Interaction and Gaming with children with autism was conducted by a multidisciplinary team of Politecnico di Milano and founded by Polisocial Program.

This research that began with a User Research phase, including on-site observations and expert interview, finished with an interactive system composed by a robot and a large screen game.

The name of the robot was Teo, and his 4th version was the final release at the end of the research program. According to definition given by Norman and Verganti as follows: "Improvements within a given frame of solutions ("doing better what we already do")" (Norman. D.A, 2013), Teo Robot development could be considered "incremental innovation".

In the next paragraph will be described the entire process of development, as well as the main design choices.

2.1 Teo Robot, first version

Since the first version, Teo Robot was composed by an aluminium plate as bottom base, supporting all the electronic hardware, as motors, microcontrollers and batteries, with 3 omnidirectional wheels mounted with 120° angle each other, to allow the holonomic kinematics, and an upper soft body.

Teo1 was a first functional prototype. Easy to make, cheap and useful, it was a perfect structure for the early test and for improving design ideas. We used it as shape and dimensional evaluation mock-up, but also for image recognition experiments using kinect camera. The whole front-end of Teo1 was created in less than 4 hours, including mold making.

We used the main sponge body to fix on-purpose targets, so to test both user-robot interaction while gaming, and also dimensional constraints over targets, distance, game field size and shape. The plastic cover for the base was a unique part, created vacuum-forming a sheet of Polystyrene over a cardboard mold: it was a very easy and fast build, using a cardboard cutting plotter. A 3d model was designed to be sliced in horizontal sections, in order to obtain several contours to be glued together creating a 3D shape. We designed it to snap onto the aluminum plate, that is the core of the base, so to avoid drilling additional holes and adopting additional fasteners.

The choice of main body material made it very lightweight, but it turned out to tear easily along sewing points on the sponge. Preliminary tests shown that dimensions were slightly too big for interaction with kids of target age.

It was a holonomic unit, to be recognised by a kinect-driven interactive video game. On the body, different targets were applied, to detect the orientation in space, position and distance from the screen. It was used for testing purpose in a human-robot interactive game, where both should move accordingly to the game tasks.

The main advantage of this version was that it was easy to move and replace targets on the body. The high contrast with the body (white) allowed to use geometric shapes as well as targets. Being cylindrical, the identification of direction could be done with 3 targets

Targets were sometimes hard to fix due to improper material (sponge) as a background for printed paper. Without IR capabilities of Kinect, it would have been hard to identify the robot by its shape, as the body color was sometime blending with white walls behind, based on actual ambient light.

Teo1 wasn't intended to deeply investigate human-robot interaction. It allowed easy access to the robot's core, thanks to the snap system.

2.2 Teo2

The body of this version was the first try to create a soft fabric body filled by polystyrene microspheres. The outer material chosen was a yellow Pile fabric, with a small set of eyes in the middle of the front describing a face, and a set of small hand-stuffed arms. The main shape was very basic, just to hold the stuffing inside: the final look was an egg-shaped robot. To protect the electronics mounted on robot's base from the stuffing and from user's action, we opted for an hard plastic dome, made by vacuum-forming on a pre-made spherical mold: such solution, allowed to protect electronics and leave enough air to prevent overheating.

The base cover was made by vacuum formed plastic, but this time all 3 wheels were covered singularly by 3 identically shaped smaller covers. This allowed to have a cheaper mold, crafted out of wood. Buttons were fixed on a vacuum formed helmet designed to fit 6 buttons on it. The main body was easily recognised by the kinect system without targets. The little objects located on the robot made it easily recognisable as a small and cute character by users. Buttons were easily reachable. The main soft body was appreciated by users, for caressing, touching, and even punching. As a final touch, a bluetooth speaker was insert and paired with the game controlling computer. Music helped a lot the gameplay, mostly when rewarding the user for the correct answer, or during the welcoming phase.

Figure 2. User playing Teo2 during the welcoming phase.

The front-end weakest point was the base cover: it wasn't very effective in protacting electronics and motors. Wires could be seen from the gaps between the singular parts, and it was too easy to disconnect them. In addition, the externals objects could get stuck underneath the robot and it was not effective in distributing impact force. As per the overall dimensions, it seemed too small during user tests: it encouraged a sit-play session, while we wanted users to play actively in space with it. We also faced problems fixing the body to the base, as it was hard to have it perfectly stable and durable.

Teo2 was still an holonomic robot with implemented autonomous moving capabilities and LED lights on the base. Back-end functions were almost ready for final, and this prototype was sent to preliminary user tests. Some Buttons were implemented on the top of it, so to allow kids to express some choices. All electronics was put under a plastic vacuum formed dome, so to protect them from impacts and usage. In this version, a sound speaker was implemented: it was controlled externally via a bluetooth connection with the computer used to monitor the whole game. The robot was controlled via Xbee wireless connection by the external laptop: a wireless remote joystick was used to control Teo2 remotely.

The robot had an RGB LED strip, which allowed a richer experience, especially for ASD users. Light allowed to enrich the task transmission during color game exercises, as well as to express emotionals. The buttons implemented were almost fail proof and with a nice and wide interaction area. Adopting bluetooth connection with Computer for audio allowed to store a huge number of files and music tracks without additional computing cost on-board. Remote control also allowed an higher freedom and a less "coded" behaviour

Another disadvantage was that RGB did not have a diffuser, so light was hardly perceived, Sound was not clear mostly due to speaker positioning. Powering on the bluetooth speaker was not an easy task and required an educated person to accomplish such task: the problem was again the placement of the speaker, right under the helmet with sensors.

This prototype worked good during tests, allowing the research team to evaluate more deeply how to improve both the game and the robot behaviour, as well as the session frame and organization. Light and music added an extra output that was generally very welcomed by users. To fix faces on the main body, some double sided tape was used, and it allowed users to attach all options available on Teo's body, thus eliminating the sense of facial expressions recognition exercise.

2.3 Teo3

Teo3 was the third version. Improvements concerned mostly the overall shape and the interchangeable face system. The base was covered with a brand new vacuum formed ABS plastic cover, one unit for all the wheels and motors: the mold should have been more expensive, but re-using some discarded wood planks it allowed to save both money and improve final part. As a unique piece, all accesses were closed, and impacts could be absorbed much better than before. Fixing to the aluminum plate was done with some standard fasteners.

Eyes were replaced with some Velcro strips to allow users to stick new faces on it, and only on choosen spots.

On-OFF buttons were put in front of the robot so to have easier access then before, as lifting the robot was required in Teo2 to shut it down or power it up.

This version moved definetly the game towards a true full body interaction due to its increased dimensions. The design of the overall shape helped the identification of a character, with only minor changes to the shape. Helmet was taken from previous robot, but positioned higher from the ground: almost 25cm in height made the game more dynamical forcing kids to stand up. The whole robot seemed harder to lift, even if the weight was almost the same as before: this because of the increase dimensions that communicate a different affordance.

To change expressions it was necessary to place the male velcro exactly on the female velcro, thus making it hard to stick several faces on Teo2, trying to force users to match a correct position. The lack of arms did not make a big difference.

The weakest point of this version were the On-Off buttons: too easy to push, it happened more than once that user, playing with the robot, accidentally shut it off with his feet.

In addition, the new shape moved added a good amount of stuffing far from fixing area. Such distance from the fixing points made it difficult to keep non cohese stuffing exactly in place, where needed and demanded by the shape. During the game, it needed to be adjusted with some shakes, to avoid falling to much.

Regarding the back-end, main changes concerned the electronics and how to fix it to the skeleton. Teo3 was still powered by an Arduino board, but a new layout was adopted: additional shields were moved on one single layer (instead of previous 2 layered layout designed to save space) and fixed to a plastic plate so to isolate electronics from the aluminum base. All connection were still by prototyping connectors and jumpers, but this time using a custom made PCB board, instead of a common breadboard. The plastic dome designed to protect the core was here enlarged to allow more space and help increase the robot's height without increasing too much the quantity of stuffing used. A flex sensor was then added to the robot, on its back, allowing researcher to sense hugs and have the robot react.

Teo3 generally resulted as a more stable prototype, proving better protection and resistance from hits. Although, high stability was still not achieved: having several wired connections, made the prototype messy and complicated to fix when not working for a disconnection or a fake contact.

This prototype was used only for few tests before further improvements in next version. The increased height helped raising the kid from the floor and having him play standing with the robot, as we expected and went for.

2.4 Teo4

When sewing the fabric, designers decided to give the small "potato robot" some more characterization, adding some blue fabric, resembling a pair of trousers. The face got a total new look and a new system, adopting a magnetic sheet on which faces were printed: a bigger area was stitched onto the robot allowing to magnetically attach a set of smiles and eyes in this area only, describing a face. A pocket was then added on the back of the robot to carry all the expressions. The hat was changed with a bought one, and modified to fit the buttons. The base cover was changed to protect the on-off buttons and two Infrared distance sensors.

The newly designed face allowed a much higher freedom in creating facial expressions using the given blocks, still keeping a defined frame. The back pocket came very handy when storing everything. The whole robot, with the added "trousers" and the new hat, was given a whole new characterization, much easier to identify as a game and learning companion. The base, vacuum formed in white plastic, proved to be as functional as required, protecting sensors and buttons from heavy crashes, breaking only when under too strong forces, but still providing protection. One part was changed in 6 months of daily use, due to harsh play sessions.

The new helmet provided only a small area to fit buttons on. So we reduced the number from 6 to 4, as it seemed they were enough. Smaller buttons made possible to see them all at once. With Teo3 it was sometimes needed to walk around the robot to clearly see the option available: the reduced area on the hat allowed a different placement, so to have a unique plane on which all option can be identified.

This version proved to be the most robust, reliable, and efficient among all. A lot of effort was put into stabilizing electronics and wiring, as well as making it the most independent and easy to use as possible. The whole electronic was now developed with an Arduino protoshield, on which all cables were connected. To save space and make everything as compact as possible, instead of fixing the Arduino board to the robot, motor drivers and Xbee communication shield were fixed on the plastic isolated board: the protoshield had connectors to fix to them all and on top the arduino was placed, so to be easy to remove and eliminate the need of wired connections. Before this version, Teo needed a manual battery recharge, removing the LiPo battery each time: in 4th version we decided to place an onboard charger, one for each battery (2 used initially, one 12 V and a 7 V, lately removed), with a single output jack. Final users could easily recharge batteries by themselves.

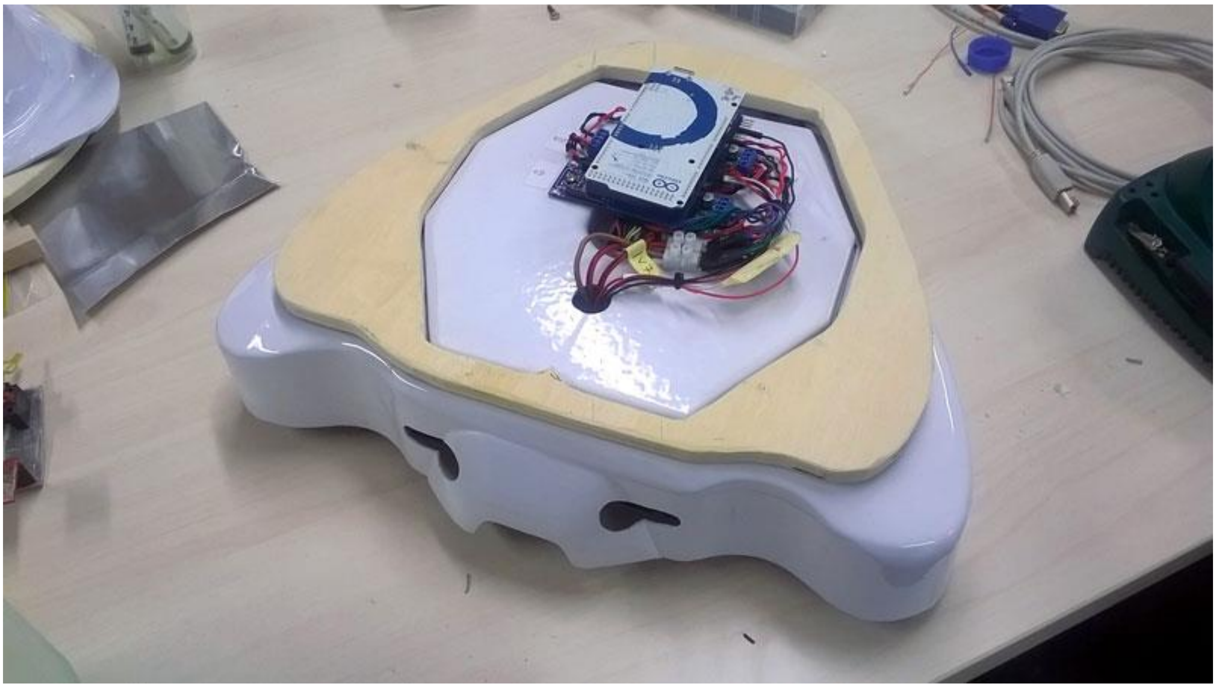

Figure 3. Base and electronics in Teo4.

The stability of this system has been proved by the several months of flawless functioning and harsh testing, with adults and kids. The robot has been reliable, and every small problem could be easily fixed thanks to an easy fit assembling.

Althought, the new charging method proved to work just fine the first weeks and in laboratory tests. When given to the final users, batteries inflated. The problem was caused by users: they were told to keep Teo4 charged, and so they did. Chargers filled batteries to the maximum capacity at every charging session, even if they were more than half-charged: this behaviour inflated them rapidly. During six months of test more than 4 batteries were changed because of this problem. But still, the users could use it with a minor daily check. For the first time, users could manage the robot by themselves. Except minor battery problems, the system has proven to be fully autonomous. New hat forced the user to use it standing behind the robot.

2.5 Comparing the basic parameters

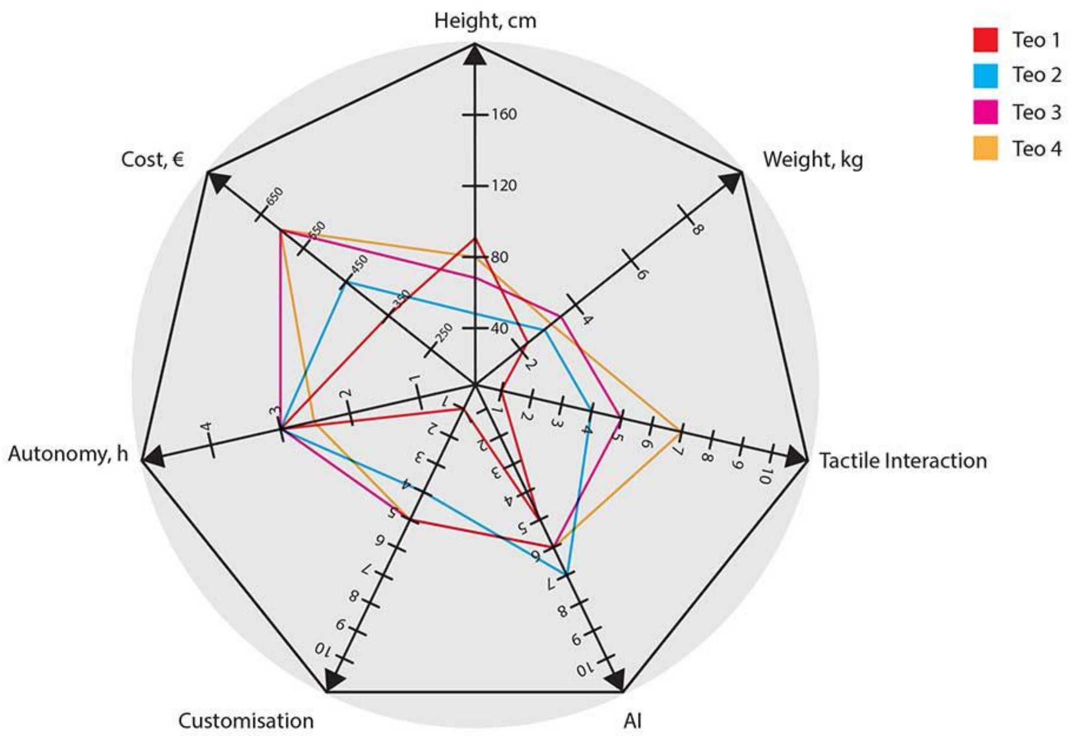

Figure 4. Comparative diagram

The following seven parameters are shown in comparative diagram (Figure 4):

1. Height
2. Cost of robot's components and material
3. Autonomy of battery
4. Possibility of customisation
5. AI
6. Possibility of tactile interaction
7. Weight

We aimed to keep prototyping costs (both components and materials) to low-cost segment. This helps researchers to continously improve prototypes with minor financial investments.

The diagram and table show that the amount of tactile interaction is increasing with each prototype. For us, this factor is one of the most important, because it allows us to vary the scenario of interaction with the robot.

We ranked AI based on autonomus level of therapy management. Customisation concerns mostly the physical aspect of the robot, that allows also to adjust therapies.

Table 1.

Name	Height, cm	Weight, kg	Cost, Euro	Tactile Interaction Hight/Low 1-10	AI manual/prediction 1-10	Customisation Full/None 1-10	Battery Capacity	Autonomy, h	Color
Teo 1	90	kg 2.30	350	1	5	1	7V 4Ah 12V 5Ah	3	White
Teo 2	50	kg 2.90	450	4	7	4	7V 4Ah 12V 5Ah	3	Yellow
Teo 3	70	kg 3.50	600	5	6	5	7V 4Ah 12V 5Ah	3	Yellow
Teo 4	80	kg 3.40	600	7	6	5	12V 5Ah	2,5	Yellow+Blue

3. Riby. Future development steps

3.1 Front-end particularity

Figure 5.

After experience with Teo we decided to design new robot trying to further improve therapists with adults, such need shown up while testing Teo4 with adults: all the inperfections in adult robot interaction came clear, giving the developing team a good amout of dates to work with. Analizing tests results the following requirements we established:

1. Targeted exercises: possibility to set up ad hoc exercises, according to ABA logic. Contact with robot is deemed as fundamental.
2. Natural and unconstrained interaction: touchable and huggable body, encouraging caressing actions.
3. Visual communication channel needs to attract user's attention and keep person's eye contact.
4. Expression is a must to help expressing robot status quickly. Earnings per exercise.

5. Audio: needed for reinforcement sounds
6. Therapist control: support a wireless connection for remote control from a smartphone application / controller.
7. External design of Riby is realized with different materials, to suit production methods. In particular, suitable materials have been chosen to absorb weak or strong impacts and shocks as well.

We successively worked on resistance and shapes of the main structure to reduce weight and keep high performances.

3.2 Front-end and Back-end

External design of Riby is realized with little different materials, to suit production methods. In particular, suitable materials have been chosen to absorb weak or strong impacts and shocks as well. We successively worked on resistance and shapes of the main structure to reduce weight and keep high performances.

The external skin of Riby is the most important part for interaction with final user. From the previous practice, we understood that a robot which allows and encourages a full-body interaction is needed. Another important fact is robot resistance and reliability because it will be stroked and pampered heavily. The solution chosen is to use a soft body filled with non-coherent lightweight material. It was implemented using three parts: outer fabric, inner lining, internal filling.

The pair of sonar sensors are the only elements that need to come out from the fabric. They are used to identify possible big obstacles in the robot travel, just,to avoid damage of the furniture or overheating the drive-unit: given its softness, kinematics,and operational speed, Riby is intrinsically safe.

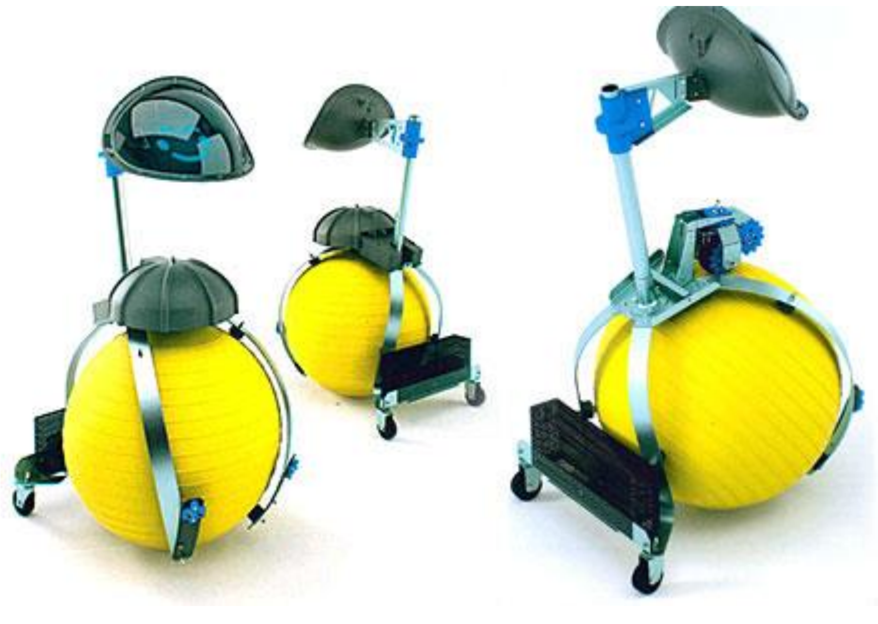

Figure 6. The inner shape of Riby

Last parts of the structure are the vertical pipe and the mounting arm of the face: to rise from a height of approximately 60 cm to 130 cm, it was necessary to adopt a 40mm diameter standard aluminum tube, angled at 25 degrees with the perpendicular to the main plate: it holds the support of the face.

3.3 Basic parameters

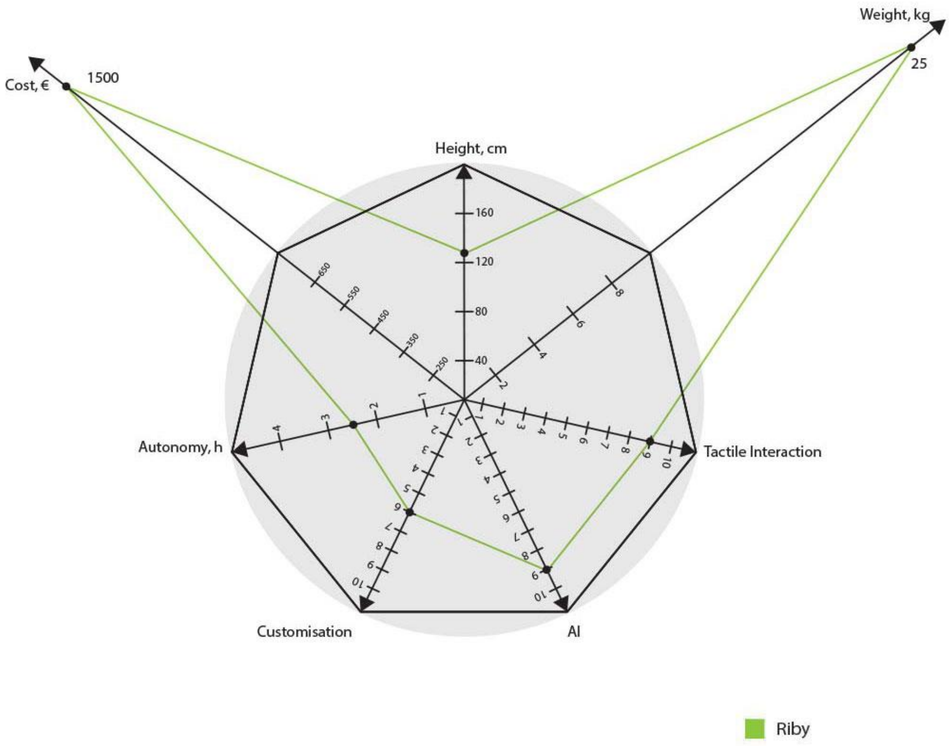

Figure 7.

Table 2.

Name	Height, cm	Weight, kg	Cost, Euro	Tactile Interaction Hight/Low 1-10	AI manual/prediction 1-10	Customisation Full/None 1-10	Battery Capacity	Autonomy, h	Color
Riby	130	25	1500	9	9	6	14 A h	2,5	White+Blue

As in Teo's development process first technical and functional prototype has been created for validating the new concept. It has proven to fulfill the new brief directionals and is ready for the second developmental stage.

Height has for now being setted at 130 cm considering ergonomics parameters of adults. The same is for weight, batteries have been chosen in order to disallow users to lift the robot, a problem that was often noticed when testing Teo4 with adults.

For the AI we decided to set an higher level of robot self-management, in order to allow therapist to focus mainly on the patient.

As for cost, we did not set a price limit, so it is just a components and labour sum.

4. Discussion

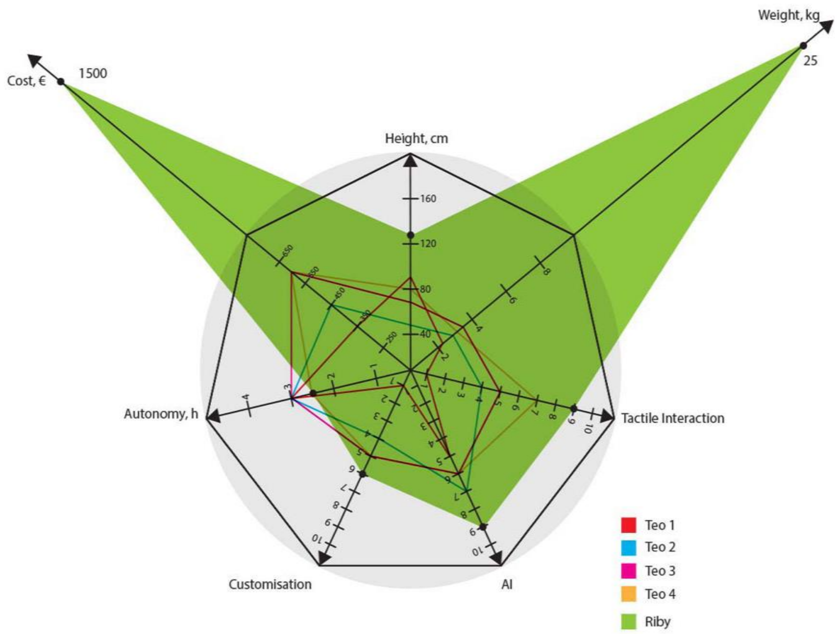

Figure 8.

In Figure 8, the diagram shows that many parameters have changed radically.

Riby's dimensions have been also adapted to keep a correct interaction with adults: all tests were made with Teo, focusing on a standing interaction to increase the amount of daily physical activity for patients, and keeping this key in human-robot interaction is, for us and therapists, very important.

Riby is a completely new robot in pretty much all aspects, but mainly in its core structure. It is designed to solve all small issues found in Teo's experiences, leading hopefully to a better tool for therapists: the way to achieve a decisive change is to cut the rope with the old prototyping board, create something new. And this step is possible only thanks to the massive knowledge acquired during Teo tests and experiences, and all the incremental improvements lead to a radical improvement and a completely new product.

5. Conclusion:

For the first time we applied a trial and error design method typical of product design to a social robot. Including several strictly managed user-tests. This method allowed us to evaluate our concepts, refine better and better user interaction, usability and reliability of our robot, as well as identify critical points to improve as much as possible with incremental development of the same structure. After few versions, it came clear that we could improve even more small problems it would have been much harder, time consuming and expensive, to solve some of critical point identified: radical innovation came to be the only solution to overcome in smarter way those aspects, designing whole new product, with critical points leading the new concept, driving the brief of the new concept, enriched by the previous experience.

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Andrea Brivio Graduated in 2013 in Product design at Politecnico di Milano, in 2016 he finished his academics with a master's degree in Design&Engineering at Politecnico di Milano with a Thesis concerning robots for autism. He has been working in academic robotic field from 2013, being unofficial and then official tutor of Robotics&Design master's degree course in Politecnico. He has also been involved in Krog project, both in development and testing of a small holonomic robot to support therapy for kids with Autism. Few months after graduation he became Research Fellow at Politecnico di Milano, focused on robotic toys and social robotics.

Ksenia Rogacheva Graduated in 2011 in Product design at MIET (National Research University of Electronic Technology), Moscow, Russia. In 2012 won Silver Scholarship and started to study in Politecnico di Milano. From 2014 to 2015 intership in NuZoo Robotics, developing project Kobra, a video surveillance robot. In december 2015 she achieved Master's degree, Product design for innovation, in Politecnico di Milano in December 2015. Since September 2016 work like collaborator in Politecnico di Milano, focused on robotic toys and social robotics.

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