

A Multi-Disciplinary Design Process for Affective Robots: Case Study of Survivor Buddy 2.0

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Abstract—Designing and constructing affective robots on schedule and within costs is especially challenging because of the qualitative, artistic nature of affective expressions. Detailed affective design principles do not exist, forcing an iterative design process. This paper describes a three step design process created for the Survivor Buddy project that engages artists in the design process and allows animation to guide physical implementation. The process combines creative design of believable agents unconstrained by costs with traditional design decision matrices. The paper provides a case study comparing the resulting design of the Survivor Buddy 2.0 robot with the original (Survivor Buddy 1.0). The multi-disciplinary methodology produced a more pleasing and expressive robot that was 50% less expensive, 78% lighter, and up to 700% faster within the same amount of design time. This methodology is expected to contribute to reducing risk in designing cost-effective affective robots and robots in general.

I. INTRODUCTION

Design and construction of mobile robots is time-consuming and often leads to an expensive series of functional prototypes converging on an acceptable design. In general, budgets (and time considerations) require that the first design be sufficient for use and that only minor modifications are needed. Essentially, due to costs, the design of robots is an open loop process where the best guess at minimizing the error guides the construction. The design of explicitly affective robots, such as AIDA [1] and Survivor Buddy [2], add more challenges and risks to the design process because affect is often an subjective appraisal by the human user. This subjective appraisal is usually incorporated into design processes by creating functional mock-ups for evaluation by large number of potential users. This type of design feedback is expensive (it requires construction of multiple functional prototypes), time-consuming (requiring human-subject studies), and inconsistent with the need to construct a robot with sufficient capabilities the first time.

This paper describes a three-step method that incorporates artists and animation into the design process in order to produce an affective robot without multiple functional prototypes. The incorporation of artists into the design process replaces feedback from users, allowing appropriate affect to be captured with confidence. Animation serves to provide a mechanism for exploring designs but more importantly provides requirements for key components, such as the range and speed of joint motions.

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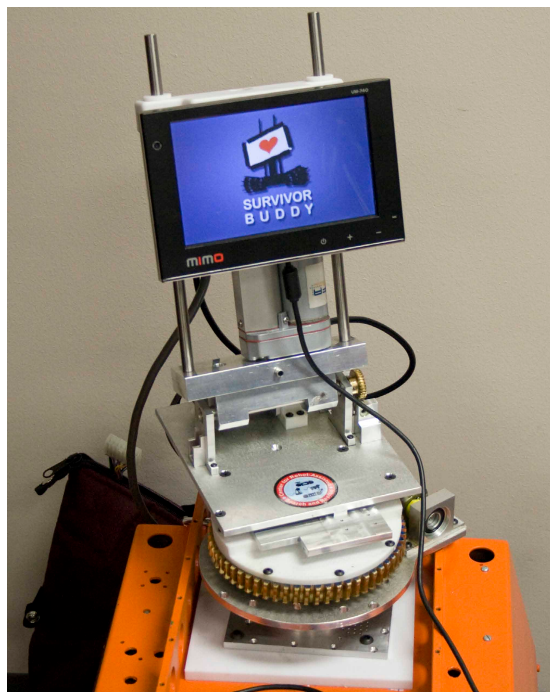


Fig. 1. Survivor Buddy 1.0 mounted on an ATRV-jr robot base (orange).

The Survivor Buddy robot serves as the example for the design process. The Survivor Buddy project is focusing on robots that interact with dependent humans. These robots serve as social mediums that combine attributes of a social actor (fully autonomous, socially consistent robot) with that of a pure medium (a computer screen, music player or other device with no affective expression.) The project assumed a sequence of prototypes would have to be produced; however, the first version of the robot, Survivor Buddy 1.0, came close to exceeding the budget for the entire set of prototypes, illustrating a weakness of relying on iterative refinement. Furthermore, the prototype did not have the right speeds of motions and reliability to be practical. Therefore a more informed design process was needed to ensure that Survivor Buddy 2.0 would be adequate for actual use. The resulting design process is expected to generalize to affective robots in general.

II. PREVIOUS AND RELATED WORK

The Survivor Buddy project is one of many in the emerging area of affective robotics. However, affective robots are

typically designed ad hoc and few principles, such as proxemics, are available to guide a design. The design process described in Section III overcomes these limitations and leverages trends in incorporating the animation and theater communities which have a long and rich history of creating believable agents.

A. Survivor Buddy 1.0

The Survivor Buddy project answered the need for an affective robot to study social mediums. The project started in 2007 with funding from Microsoft Research and is currently funded through a National Science Foundation grant. The objective of the project is to explore how trapped victims would use a web-enabled robot to interact with the outside world. The *Computers As Social Actors*, or CASA, model of human-robot interaction [3] suggests that since the robot moves, the dependent will respond to the robot socially. The dependent may become distrustful as well as cognitively confused by a robot that sometimes acts like an intelligent being and sometimes like a stationary TV. Therefore, the hypothesis is that the robot must maintain a consistent affective presence.

The initial Survivor Buddy robot “head” shown in Figure 1 was created to provide a platform that would mount on an existing rescue robot and test the affective research hypothesis. Despite the terminology of “head,” the unit was not expected to be anthropomorphic and indeed had to meet several functional constraints that impacted its form (size, weight, ability to fold up while the rescue robot searched for a survivor, etc.). Given the complexity of the constraints, Survivor Buddy 1.0 was envisioned as a nominal prototype that would be quickly replaced, but it was immediately successful. One set of formal experiments were conducted using the basic design, the robot was used in an episode of the TV science series SciGirls [2], and the Survivor Buddy was cited as a Best of 2009 technology by Popular Science [4].

Survivor Buddy 1.0, as expected with a prototype, was significantly over budget and had significant shortcomings hindering its continued utility for research and necessitated a new version. The joint motions, ranging from 40 to 60 degrees per second, were unacceptably slow, causing human subjects to remark unfavorably on the device. The assembled mechanism was unreliable with gears jamming or separating, producing an excessive number of “re-starts.” Survivor Buddy 1.0 could not be used in conjunction with a typical rescue robot because it weighed too much (7.8kg); this prevented human-robot interaction experiments where the rescue robot was conducting a different set of operations while the Survivor Buddy head maintained an affective, supportive relationship with the victim.

B. Affective Design Principles

The design of affective robots appears to be ad hoc [5]. Bethel et al propose a small set of principles based on proxemics [5] while Mutlu reports on social gaze [6]. Some work has been done in accessing the impact of different

shapes (mechanical-like, animal-like) of a robot on affect [7] but this was too coarse to provide guidance of an affective robot with physical constraints. The robot most similar to Survivor Buddy is the AIDA robot. It is intended for use in cars as an “intelligent navigation system that mimics the friendly expertise of a driving companion who is familiar with both the driver and the city.” [1] However, the current publications and website do not provide details of the design, especially joint motions, or the justification for design decisions.

C. Creating Believable Agents

The animation and theater communities have a long history of creating affect from drawing, puppets, and inanimate objects. Though the process of creation is not quantifiable, it is reasonable to include these artists in design teams. Hanson, creator of numerous humanoid robots, was trained in design rather than robot control [8]. The recent “What do collaborations with the arts have to say about HRI ?” workshop at the 2010 Human-Robot Interaction Conference signifies the movement towards incorporation of artistic sensibilities into robotics.

Animation is routinely used in design of assemblages of moving parts, but is imperfect for affective robots. The CB2 robot used by Movellan et al [9] is frequently cited as the “worlds creepiest robot.” [10], [11] A conversation with Movellan yielded the insight that the design mimicked a toddler and looked good in animation. However, since toddlers have disproportionately large heads, the design did not work as well in the physical world as the robot was built to the size of a 6 year old, causing the head/body size to be perceived as a mismatch.

III. MULTI-DISCIPLINARY DESIGN METHODOLOGY

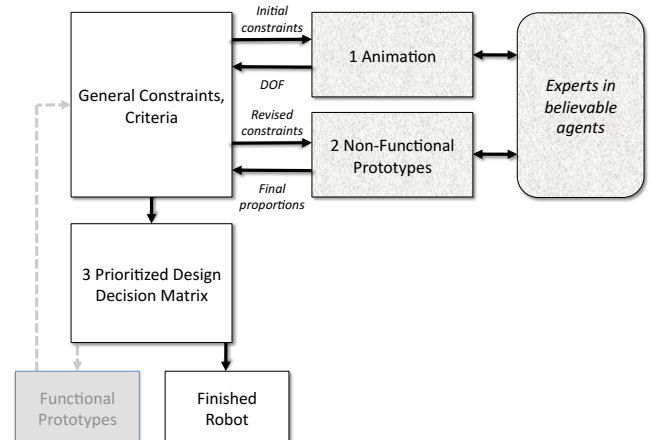


Fig. 2. Multi-disciplinary design methodology. Traditional rapid prototyping shown in dark gray, addition of artists in textured gray.

The creation of Survivor Buddy 2.0 sought to overcome the lack of affective design principles by incorporating artists into the traditional engineering design process and

to reduce the risk of animation/reality gaps by creating non-functional mock-ups. The “traditional” engineering and multi-disciplinary components of the design methodology are shown in Figure 2. The traditional engineering design process is to generate a set of high level goals, translate those goals into criteria or requirements based on inexpensive parts (e.g., motors can provide a minimum joint rotation of X deg/s), and then build a functional prototype, with the expectation that a second (or third) prototype will be needed to capture the qualitative aspect of expressiveness. This can be considered a form of rapid prototyping where the key risk component is the affective expression. An alternative is to generate multiple designs on paper, evaluate how well they meet the criteria using some type of scoring (also called a priority matrix [12]), build the version with the highest score, and see if it sufficiently expressive. Both variants fail to capture the overall aesthetics of the design or expressiveness, in part because affect and expressive are generate through motions.

A different approach is to embrace experts in creating believable agents. These experts have internalized design principles and often work in animation, which can quickly show if the combined range or velocities of joint motion is appropriate. The disadvantage is that designs may not be reflect budgets, physical constraints, or manufacturability. A balance is needed between the artistic and engineering disciplines.

The resulting design process consists of three phases. First, the mechanical designers work with artists exploring designs through animation to achieve an acceptable look and feel, which specifies the degrees of freedom, the general size of the linkages, and the range of motion, velocity, and accelerations for each joint. In the SB2.0 process, the team included believable agent experts Doug Dooley, an animator with Pixar, and Autumn Casey, a professor in performance studies at Texas A&M. As seen with CB2, problems with a design in animation may not be seen due to scale. Therefore the second step is to create non-functional, full scale mock-ups out of wood, plastic pipe or other material to simulate linkages and hinges or other hardware to simulate the joints. The non-functional prototypes support checking the overall designs and checking scales and does not require additional expertise. The third step is to use robotics expertise to translate the prototypes into tangible physical designs with actual costs, weights, etc., and then compare designs. In this case, David Hanson of Hanson Robotics complemented the team’s existing robotics expertise. This last step guides the creation of an affordable and appropriately constructed device.

A. Animation

In this phase, the team works with animation to iteratively create a pleasing design then use that animation to extract the suitable joint ranges and speeds from the animation. See Figure 3 for a snapshot from an animation video.

Animation was an attractive alternative to a functional prototype as Survivor Buddy 1.0, despite undergoing a princi-

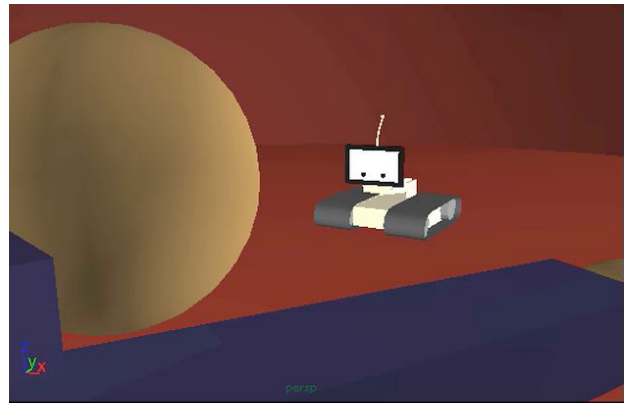


Fig. 3. Snapshot of an animation by Doug Dooley.

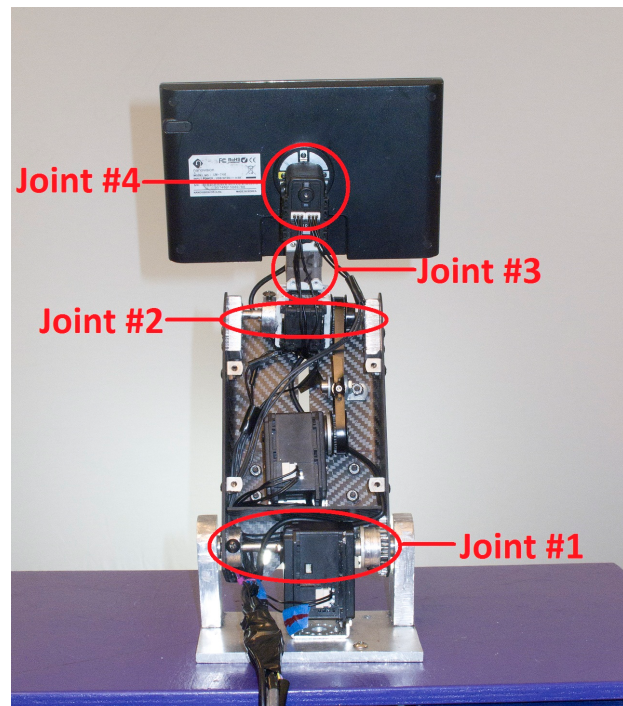


Fig. 4. Rear view of Survivor Buddy 2.0 with joints labeled.

pled engineering design process, was a disappointment. The prototype served its purpose in that it highlighted problems with the degrees of freedom, joint velocities, range of motion, and appearance. But Survivor Buddy 1.0 offered no insight into how to improve the design and exceeded the budget for both the prototype and the final version. Animation allowed the contribution of joints, linkages, and motions to affective functions to be easily and rapidly visualized.

The animation produced a design with 4 degrees of freedom, not 3, and with different linkages, which significantly increased the overall coverage of motions (Table I). The design went from a modified “clamshell” approach, with a panning neck with a “face” that translated and rolled (Figure 1), to a more anthropomorphic “head” with a panning, tilting, and rolling “face” mounted on a tilting “torso” (Figure 4) In retrospect, translational or prismatic joints are

not associated with biological motion. While the Survivor Buddy 1.0 design had eschewed biological similarities in order to avoid making the robot “too cute,” the obvious mechanical flavor of the design was both unappealing and produced limited motions.

Design	SB 1.0	SB 2.0
number of joints	3	4
translational DOF	1	0
rotational DOF	2	4
joint velocities	40-60 deg/s	300-400 deg/s

TABLE I

COMPARISON BETWEEN SB1.0 AND SB2.0 REQUIREMENT

B. Non-Functional Prototyping

The purpose of the non-functional prototyping phase is to prevent mistakes due to scale and proportions that might go undetected in animation. In this phase, several different models of designs capturing the joint motions and dimensions are produced and evaluated. The impact of practical constraints, such as mounts for motors and gears which would produce the desired speeds, also became evident at this stage. So while the general goals and constraints informed the animation, both the animation and the criteria informed the prototypes.



Fig. 5. Non-functional prototypes of SB1.2 and SB1.3

Figure 5 shows the two mockups (SB 1.2 and SB1.3) created for SB2.0, each representing a slightly different set of sizes of the components and methods of achieving the desired degrees of freedom determined through animation. SB1.2 and SB1.3 were constructed with wood or plastic pipe based on availability because those materials allowed inexpensive rapid prototyping. SB1.2 was immediately favored due to its height/width ratio which was close to the Golden Ratio of 1.618. The wide arm design in SB1.3 emerged because it would allow a motor and gearbox to be mounted horizontally in between the arms. This modification was due to the selection of Dynamixel Robot Actuators as the only viable motors that could produce the correct range and speeds of

motions for the expected weight. The smaller profile of the Dynamixels allowed the arm struts to be closer together and the direction connection of motors to form joints created a shorter distance between the arm and the monitor.

The mockups were sufficient to generate a third design, SB1.4, a hybrid of 1.2 and 1.3. SB1.4 maintains the same eye pleasing height to width ratio of SB1.2 while using the rectangular arms of SB1.3 which are much easier to construct and maintain. SB 1.4 also utilized the larger distance in SB1.2 between joints 3 and 4 in order to gain a greater range of motion for joint 4. Because of the similarity to SB1.2 and SB1.3, a mockup of SB1.4 was not needed to visualize the design.

C. Prioritized Design Decision Matrix

The third phase is to determine which of the possible physical designs best captures the animated design but is also affordable, programmable, and can be constructed and maintained. This is a multi-criteria decision which can be captured by decision matrix methods which list criteria and apply a prioritization scheme.[12]

Criteria	Weight	SB1.2	SB1.3	SB1.4
		Score	Score	Score
Mechanical		215	210	225
Max lengthXwidth (stowed): 42.7 X 27.7 cm	5	4	5	5
Max height (stowed): 14 cm	5	5	5	5
Mounting plate dimensions: 9.2 X 9.8 cm	3	5	5	5
Weight: At or under 4.5 kg	5	4	5	5
Able to carry MIMO	5	5	5	5
Joint precision +/- 1 degree	5	5	5	5
Mountable on multiple platforms	5	5	5	5
Screen visibility	5	5	5	5
Joint accessibility	1	5	5	5
Basic toolbox serviceability	1	5	5	5
HeightXwidth ratio 1.618	5	5	2	5
Motor Speeds		100	100	100
Joint #1 9.6 d/sec	5	5	5	5
Joint #2 9.6 d/sec	5	5	5	5
Joint #3 48 d/sec	5	5	5	5
Joint #4 20 d/sec	5	5	5	5
Range of Motion		100	95	100
Joint #1 90 degrees	5	5	5	5
Joint #2 90 degrees	5	5	5	5
Joint #3 180 degrees	5	5	4	5
Joint #4 60 degrees	5	5	5	5
Interface to Computer		85	85	85
Powered by tether	5	4	4	4
Controlled by tether	5	4	4	4
Plug and play	3	5	5	5
Single motor control	3	3	3	3
Single motor control protocol	3	2	2	2
Network controllable	3	5	5	5
Safety		75	75	75
Running temperature < 45° C	5	5	5	5
Not susceptible to inductance	5	5	5	5
Does not create significant inductance	5	5	5	5
Cost		75	75	75
Mechanical and safety: 1500\$	5	5	5	5
Computer interface: 500\$	5	5	5	5
Appearance: 300\$	5	5	5	5
Time to Build		45	50	50
Mechanical and interface: 2 weeks	5	4	5	5
Appearance and safety: 1 week	5	5	5	5
Total		695	690	710

Fig. 6. Design decision matrix for Survivor Buddy 2.0.

1) *Overall Matrix:* The resulting design decision matrix for Survivor Buddy 2.0 is shown in Fig. 6, leading to the conclusion that the hybrid SB1.4 design was superior. The

generation of the criteria C and the priority or weight of a criterion W_C to the overall design D was ranked by three experts, two in believable agents (animation and theater) and one in robotics. Column 1 in Figure 6 is the criteria C with column 2 containing the weight W_C which is an integer over [1,5]. The value of W_C was a consensus rating of importance on a Likert scale of 1 to 5. Columns 3-5 are the three designs, D_i being considered. Each element in normal typeface is the expert consensus score s , again over [1,5] of how well the design meets the criterion in that row k and is represented as $s_{C_k}^{D-i}$. The weighted score appears in boldface and is calculated as $W_{C_k} \times s_{C_k}^{D-i}$. The overall score for a design D_1 is $\sum W_{C_k} \times s_{C_k}^{D-i}$ and the best design is the $\max(D_1, D_2, \dots, D_n)$.

2) *Discussion of Criteria*: Figure 6 groups criteria into eight categories: mechanical attributes, motor speeds, range of motion, interface to the computer, safety, cost, and time to build. It is useful to see how the animation and non-functional prototypes complemented the subject matter expertise in generating these needs.

The *mechanical attributes* represent the general physical properties of Survivor Buddy. The maximum dimensions, mounting, and weight restrictions were driven by the constraints of the Inuktun Extreme robot, the smallest and most commonly used rescue robot [13], though the Survivor Buddy should be usable with all types of rescue robots. SB had to be transportable in a stowed configuration that did not exceed the raised height of the Extreme so as to reuse navigation algorithms which allowed the Extreme to be at its highest position. SB itself had to be capable of carrying the MIMO monitor (the smallest multi-media monitor available) and the range of motion should allow a prone survivor could view the screen when SB is on an Inuktun for all distances less than 3.6 meters (the extent of the range of proxemics for interaction [14]). One mechanical attribute was determined from the animation phase: each joint needed to be controlled within $\pm 1^\circ$ to have sufficient motion resolution. Practical robotics experience dictated the need for joint accessibility and serviceability. Joint accessibility meant that with the proper tools a person with some mechanical training should be able to have access to any of the robots joints within 10 minutes. This is closely related to the basic toolbox serviceability requirements which meant that a relatively basic toolbox (small enough to carry into the field), should be able to repair all but the most serious breakdowns that the robot could run into in the field. The height to width ratio attribute of the design matrix reflected that the Golden Ratio of 1.618 had become a criteria during feedback from the non-functional prototypes phase; the ratio was so clearly appealing that it became a criteria.

The *motor speeds* were the minimum velocities the actuators needed to achieve in order to simulate human and animal like movement. These were determined from the animation phase. The simulations indicated was speeds for each joint were needed to produce an overall look and smoothness of movement.

The *range of motion* of each joint impacted both the

ability to “face” the victim independently of the robot base’s position and to create affective movements to interact with the victim. These criteria were derived from the animation phase, which generated the number of joints and the expected range of motion, and from the non-functional prototype phase, which tested to see that those joints and ranges could maintain a steady position of the monitor as the robot base moved around.

The *interface to computer* criteria address the electronics that power and control Survivor Buddy. These were generated based on robotics expertise. As the majority of deployed rescue robots use a tether, a tether was a permissible aspect of the design. A plug and play philosophy was desirable, although the experts assumed that anyone using this system would be adept enough at computer setup to install complicated devices. The single motor control attribute meant that a single motor controller would be able to run all of the joints on Survivor Buddy, simplifying coding and modifications. The network controllable attribute referred to the ability for the joints to be controlled over a network connection.

The *safety* attributes were used to ensure the safety of Survivor Buddy and victims and was determined by robotics expertise. The running temperature of the system needed to be less than $45^\circ C$ so that it would not burn victims if touched, prior experience encountered robots which had very hot power converters. Inductance was another issue based on experience. The first criteria was to ensure that SB would not be vulnerable to inductance from powerful motors on a robot base. The second was to make sure that SB motors did not produce enough inductance to interfere with other electronic devices, either on SB or the robot base.

The *cost* category captured the traditional budget constraints, while *time to build* captured the need to meet grant deadlines. Both sets of criteria came from general management constraints.

IV. SURVIVOR BUDDY 2.0

Figure 7 shows the constructed Survivor Buddy 2.0 next to the Survivor Buddy 1.0. As can be seen, 2.0 is smaller and less mechanical looking. The table below (Table II) compares the two versions.

sample attribute	SB1.0	SB2.0
weight	7.8kg	1.72kg
footprint	21cm X 25cm	14cm X 9.5 cm
joint velocities	40-60 deg/s	85-500 deg/s
cost	\$3,600USD	\$1,800USD
time to design	6 months	6 months

TABLE II

COMPARISON OF SB1.0 AND SB2.0 AFTER CONSTRUCTION

Both weight and footprint were dramatically reduced in the 2.0 version. Additionally, the joint velocities were greatly increased, allowing the achievement of more natural and fluid motions. The animation produced the acceptable lower bound, but motors and gearing were found on the recommendation of our expert, David Hanson (Hanson Robotics) which exceeded the minimum without sacrificing resolution (1/1023 of the maximum velocity). While the design times were

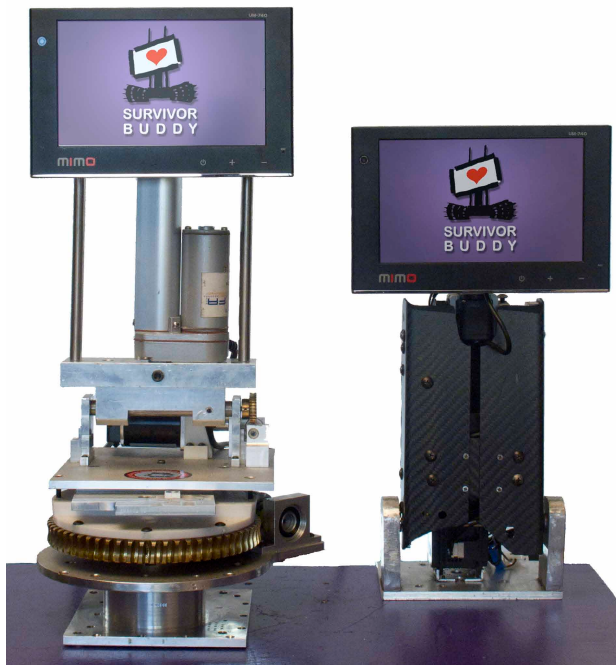


Fig. 7. Survivor Buddy 1.0 and 2.0.

essentially the same for both versions, the parts costs were lower for SB2.0, did not require any additional manufacturing or assembly skills than for SB1.0, and the suitability of the SB2.0 design was much higher.

V. CONCLUSION

This project has shown that the technical and economic risks associated with the design of affective robots may be ameliorated by the inclusion of artists, especially animators and theater experts who work with the design of believable agents. While this finding is not particularly surprising, the three step method for engaging and incorporating artistic contributions is expected to expand traditional design methodologies used by roboticists to include affect, while the restatement of formal design methods should help guide interaction specialists who have little understanding of robot construction. The multi-disciplinary method consists of three phases, animation, non-functional prototyping, and evaluation of competing designs through a priority matrix, versus an iterative functional prototyping process. As seen with the case study of the design of the Survivor Buddy 2.0 robot, the first phase allowed the incorporation of artistic sensibilities with non-functional prototyping phase acting as a sanity check on scalability and physicality of the robot. A traditional design matrix populated the prototypes with functional attributes (motor, controls, etc.) and their costs, then scored were scored using robotics measures. This design methodology produced a more affective robot; applying this method to the Survivor Buddy improved the overall affective expressiveness of the robot through a different set of joints and motions, produced a robot with a pleasing 1.618 height/width ratio (Golden Ratio) and was

more cost-effective (50% lighter) and mechanically elegant (78% lighter and up to 700% faster for some motions). Without the incorporation of artists, the alternative would have been to refine the Survivor Buddy 1.0 prototype and missed the selection of a more appealing set of joints and useful motions.

VI. ACKNOWLEDGEMENTS

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REFERENCES

- [1] AIDA: Affective Intelligent Driving Agent <http://senseable.mit.edu/aida/>, 2010.
- [2] R. R. Murphy, V. Groom, T. Zourmos, C. Nass, V. Srinivasan, Z. Henkel, B. Duncan, R. Daneshvar, N. Rashidi, M. Garza, L. Wear, and A. Rice, "Survivor buddy and scigirls: Affect, outreach, and questions," in *IEEE/ACM Conference on Human-Robot Interaction*, Japan, 2010.
- [3] C. Nass, J. Steuer, and E. Tauber, "Computers as social actors," *Proc. CHI 1994*, pp. 72–78, 1994.
- [4] M. Jannot, "Survivor buddy: A rescue 'bot you can trust," *Popular Science*, Dec. 2009.
- [5] C. L. Bethel and R. R. Murphy, "Survey of non-facial/non-verbal affective expressions for appearance-constrained robots," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 38, no. 1, pp. 83–92, 2008.
- [6] B. Mutlu, T. Shiwa, T. Kanda, H. Ishiguro, and N. Hagita, "Footing in human-robot conversations: how robots might shape participant roles using gaze cues," in *HRI '09: Proceedings of the 4th ACM/IEEE international conference on Human robot interaction*. New York, NY, USA: ACM, 2009, pp. 61–68.
- [7] M. Walters, K. Koay, D. Syrdal, K. Dautenhahn, and R. Te Boekhorst, "Preferences and perceptions of robot appearance and embodiment in human-robot interaction trials," in *Proceedings New Frontiers in Human-Robot Interaction, symposium at the AISB09 convention*, 2009, pp. 136–143.
- [8] J.-H. Oh, D. Hanson, W.-S. Kim, Y. Han, J.-Y. Kim, and I.-W. Park, "Design of android type humanoid robot albert hubo," in *Intelligent Robots and Systems, 2006 IEEE/RSJ International Conference on*, 2006, pp. 1428–1433.
- [9] T. Minato, Y. Yoshikawa, T. Noda, S. Ikemoto, H. Ishiguro, and M. Asada, "Cb2: A child robot with biomimetic body for cognitive developmental robotics," in *2007 7th IEEE-RAS International Conference on Humanoid Robots*, 2007, pp. 557–562.
- [10] D. Melanson, "Cb2 child robot returns: smarter, creepier than ever," <http://www.engadget.com/2009/04/06/cb2-child-robot-returns-smarter-creepier-than-ever/>, 2009.
- [11] M. Kanaujia, "Cb2 world's creepiest robot," <http://www.robotster.org/entry/cb2-worlds-creepiest-robot/>, 2007.
- [12] D. Ullman, *The Mechanical Design Process*. McGraw Hill, 1992.
- [13] R. Murphy, S. Tadokoro, D. Nardi, A. Jacoff, P. Fiorini, and A. Erkmen, "Rescue robotics (chapter)," in *Handbook of Robotics*, B. Sciliano and O. Khatib, Eds. Springer-Verlag, 2008, pp. 1151–1174.
- [14] C. Bethel, C. Bringes, and R. Murphy, "Non-facial and non-verbal affective expression in appearance-constrained robots for use in victim management (video and abstract)," in *IEEE/ACM Conference on Human-Robot Interaction*, San Diego, CA, 2009.