Correlation of Qualitative User Experience Feedback and Interface-Generated Quantitative Data during Human-Robot Interaction

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ABSTRACT

My research is on Human-Robot Interaction (HRI) from a User Centered Design (UCD) perspective and values the user's qualitative assessment of their interaction under the concept of User Experience (UX). Traditionally, UX is retrieved in a written questionnaire as a satisfaction survey, nevertheless, with the hike in electronic devices equipped with a diversity of sensors, actuators and processing capabilities (turning everyday appliances into robots) comes an intention to migrate from qualitative to quantitative assessment of the UX; for example, visual recognition of emotional facial expressions. In this regard, what I present as a novelty in the research area is the study of interaction data generated through the robot's interface during its intended use (everyday use), while providing an anonymous experience (no cameras, no mics) to the user.

For the experimental setup, I designed and built a robotic DeskLamp with 5 degrees of freedom (height, brightness, projection angle, sensitivity of the interface and ambient lighting) as test bench, equipped with: an interface instrumented to sense the force delivered by the user while "pushing buttons"; 18 variable datalogging system at 20 SPS (Sample Per Second); high precision and high repeatability electronics and mechanisms; real-time sensing of the user and low-latency operation due to parallel processing. The test bench is designed to be used in multiple experiments with users, varying the robot behavior and interaction procedures to compare the interaction data generated in the interface with a written UX questionnaire.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **HCI design and evaluation methods**; **User studies**;

KEYWORDS

User centered design (UCD), User experience (UX), Design of experiments (DoE)

ACM Reference Format:

Carlos Gilberto Gómez-Monroy. 2021. Correlation of Qualitative User Experience Feedback and Interface-Generated Quantitative Data during Human-Robot Interaction. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '21 Extended Abstracts), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3411763.3443430

CHI '21 Extended Abstracts, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8095-9/21/05.
https://doi.org/10.1145/3411763.3443430

1 CURRENT YEAR OF STUDY AND PROJECTED COMPLETION DATE

I am in the 5th semester (Sept-2020 to Jan-2021) of an 8-semester Ph.D. program, and I plan to obtain the degree in June 2022.

2 RESEARCH CONTEXT AND MOTIVATION

Users of technological devices experience the emotional distress that bad human-device interaction provokes, as well as the satisfaction of being in tune with a tool. It is of interest to me how the same device produces both, positive and negative reactions. It is of my belief that cognitive ergonomics and human factors will play a leading role in technology development. In this regard, my Ph.D. research is on interaction design and interface development. I think of interfaces as objects that allow the interaction between user and robot (or any device, physical or virtual), where the interaction is an exchange of information between them, which could take place in any way and using any human qualities (cognitive, sensorial, and physical) and within all available technological repertoires (not just knobs and buttons).

Robots, bots and intelligent devices are populating human spaces and activities, each with their own customizable characteristics and, in some cases, with overlapping features. With so many variables available to the user, it is understandable to have a sub-optimal performance and experience. Even though, humans are cognitively and sensorially capable of controlling many variables with high accuracy and in real-time; for example, an orchestra director using the baton and gestures to conduct 155 musicians playing multiple notes per second; currently there is a need for a "simple" way to communicate human intentions to robot systems, such as the orchestra director does it with the musicians.

The question on HRI that contains all others I have thought of is:

- "How should the interface be in order to have useful and safe interactions?"

In this respect, my research hypothesis is that interfaces of the devices will be able to capture high-order user's intentionality (what they want or feel) during their intended use (without requiring cameras or microphones) and not only by following direct orders.

3 KEY RELATED WORK THAT FRAMES MY RESEARCH

(1) The ISO 9241-210, 2010,[2] "Ergonomics of human-system interaction: Human-centered design for interactive systems", assesses the concept of UX, giving a general framework of the implementation techniques and strategies.
(2) Ghosh et al., 2017, [1] present their work "Cyber-Empathic Design", a study correlating quantitative data generated while the device is in use (instrumented running shoes) and the qualitative user's evaluation of the device (UX).
(3) Qianli Xu et al., 2011, [6] acknowledge the specific user's characteristics to act in correspondence of their specific needs while the user is immersed in the device or system (in this case a subway station).
(4) Shen et al., 2017, [4] tackle the problem of controlling multiple robotic and automized entities in a shared workspace with humans as regulatory entity and harmonizer.
(5) Laugwitz et al., 2008,[3] present a UX questionnaire, "USAB", to retrieve user's UX in a written survey.
(6) Vitale et al. 2018, [5] address the impact of privacy on the user experience while interacting with a device.

4 SPECIFIC RESEARCH OBJECTIVES AND GOALS.

Research Objective: To correlate sensed-based data acquired during HRI and the user's reported UX.

Technical objective: To measure the time and force of each user's push on the robot's interface during the intended use of the robot. Direct measurements: force. Indirect measurements: time and energy of the interaction.

Experiment goal: To build a grid of HRI through changes in the robot's functional characteristics, aiming to harvest UX evaluations from all the survey scale, from "bad" to "good" experiences, as an impulse-response mechanism to validate that there is an actual phenomenon of correspondence between the reported UX and the controlled experimental variables that represent the robot's functional characteristics.

5 RESEARCH APPROACH, METHODS AND RATIONALE

My Ph.D. research revolves around the idea that tools will recognize the user's needs in real-time, considering the instant characteristics of the user, the environment, and the tool itself, and will accordingly adapt on the fly to ensure the best UX while aiming for the best collaborative, energy, and time efficiencies, and at the same time providing anonymous human-device interaction.

5.1 Motivation (thought train).

How to interact with multivariable devices (or environments)?

Statement 1) Interaction takes time, requires mental-effort/data-processing and physical action.

Statement 2) Interaction is a data transfer process between human and device, within a shared protocol (interface).

Statement 3) Humans are closed-loop controlled systems with their own requirements and limitations.

Statement 4) The possible characteristics that a robot interface could have are infinite; on the contrary, the human interface is limited to the human body.

Premise 1) As the robot's functions and capabilities grow, the interaction protocols should approach natural human language and capabilities, to provide faster data transfer between user and robot.

Conclusion) Therefore, the robot's human-feedback assessment of the human-robot interaction should not represent an independent activity for the user (which would require extra time and effort), instead it should be assessed during the main (intended) use of the robot.

5.2 Hypothesis and implication

Hypothesis: The mental effort, time, and energy that a user requires to interact with a robot is related to its reported UX.

Implication: The user's reported UX could be a parallelism of collaborative efficiency in terms of time and energy spent on the robot's interface, enabling the robot's real-time assessment of the UX.

5.3 Experimental approach:

To compare a) the time and energy that a user spends pushing buttons on the robot's interface while it is being used for a daily activity, to b) the user's qualitative evaluation of the interaction in a written questionnaire.

5.4 Experimental scenario (test bench design).

The participants will interact with a robotized desk-lamp in a room with controlled lighting while performing a "real-threat activity" (reading comprehension test). The written experimental instructions for participants include: a) the participant's guide to perform the experiment, b) a short reading comprehension test, and c) the UX assessment question.

The participants will be asked to set up the head of the lamp "height", "luminous flux", and "projection angle" according to their personal preference and through the interface of the Desk-lamp robot, Figure 1, instrumented with four buttons: 1) "On/Off", 2) "Shift", 3) "Up", & 4) "Down". During the experiment, the room lighting will routinely change, alternating from multiple room lighting states: dark, dim, bright, and very bright; as an intent to provoke the user to adjust the Desk-lamp characteristics to the instant room-lighting conditions.

All activity on each button is recorded by the robot as an independent data channel.

- Button (1) "On/off" is a push-button that corresponds to a Boolean variable designed to synchronize the user's mental model of HRI and the data acquired during the interaction with a clear beginning and ending points.
- Button (2) "Shift" (push-button) corresponds to a Boolean variable that toggles between the robot's adjustable characteristics available to the user: "height", "luminous flux", "projection angle", "interface sensitivity", and "interaction mode".

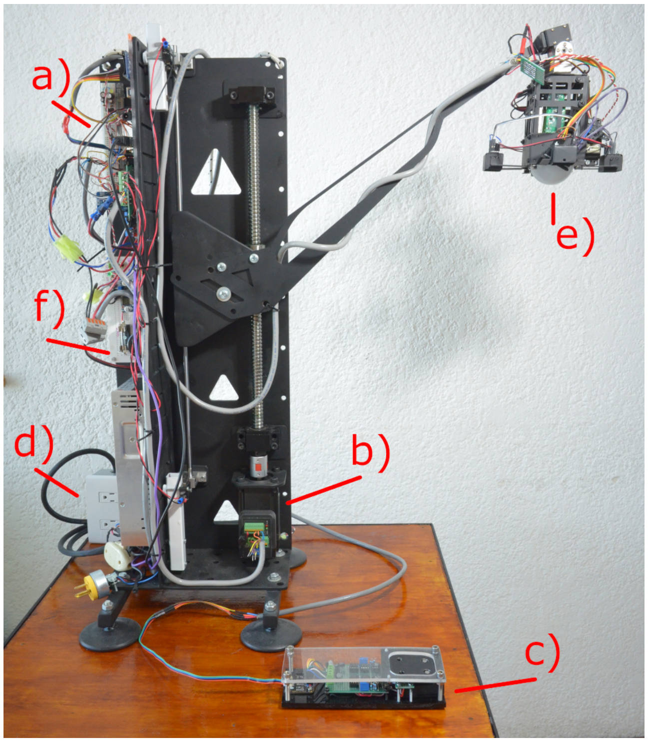

Figure 1: Photograph of the Desk-Lamp robot, showing its six modules: a) processing, b) chassis, c) interface, d) ambient lighting, e) the head of the lamp, and f) power supply.

- Buttons (3) and (4) are high-precision force sensors (Honeywell FSG15) and correspond to digital discretization of the continuous analogous variable that represents the ramp wave of the force exerted by human users while pushing a button. The force sensor acts as a variable-force-trigger device and a measurement instrument: the robot's interface sensitivity is programmed to trigger a response at different-force thresholds, thus providing the feeling that the button is "lighter" or "harder" to activate. All force applied to buttons (3) and (4) is sensed and saved in the interaction data, whether or not the force reaches specific trigger thresholds.

5.5 Experimental design

In order to correlate qualitative and quantitative data during a multivariable-experience, a complete factorial experimental design was chosen to assess 4 experimental variables in the same experiment (Table 1), using the purposefully build test bench (Desk-lamp robot, Figure 1), to measure and save a data-string of 18 variables in its data logging system, accounting for information from the environment, the user, and the robot itself (Table 2). Such data string represents the quantitative data of the experiment while the qualitative assessment of the user is retrieved in a written questionnaire.

Some details of the user trials planning are shown next:

- Experimental groups: 72.
- Participants per group: 5.
- Total number of participants: 360.
- Total time per participant: 15 minutes.
- Total time of experiment: 90 hrs. (25 days at 4 hrs./day).
- Participants' profile: University population (students, faculty members, and other workers).
- Scientific rigor: Accurate measurements (error < 0.5 %), double-blind experiment with randomized variables.
- Complete factorial design: 4x3x3x2 that results in 72 combinations or experimental-groups/robot-states.

Quantitative data: The Desk-lamp robot generates and saves a list of an 18-variable data-string at 20 samples per second, accounting for sensed-based data of: 1) the robot state, containing experimental initial-state values and instant robot-states (completely defining the robot's behavior to ensure repeatability and to establish a common database structure for all upcoming experiments), 2) the user (interface buttons), and 3) the environment.

Qualitative data (written questionnaire): The written questionnaire includes questions to retrieve: 1) personal info: height, weight, age, and gender (open questions), 2) personal affinity to gadgets and robots, "do you like tech devices and robots?" (5-point Likert scale), & 3) user's reported UX, "how was your experience?" (5-point Likert scale). The qualitative data of the written questionnaires is transferred to the digital database by hand after the tests have finished.

5.6 Experimental data statistical procedures:

(1) Calculation of the standard deviation of the reported UX per experimental group (5 DF) to establish a confidence interval in the qualitative experimental results (to evaluate the quality of the data before further correlations).
(2) Null hypothesis test by correlating with environmental variables.
(3) Correlation 1) "Reported UX" / "Total time of buttons being pushed."
(4) Correlation 2) "Reported UX" / "Total energy of the pushes."

6 RESULTS AND CONTRIBUTIONS TO DATE

The tangible results of the research are three papers (2 published and 1 recently submitted) related to the experimental process on HRI, using the concept of UX and the empirical experience of developing a test bench (Desk-lamp robot), Figure 1.

6.1 Tech specs of Test bench: Desk-lamp robot.

- Designed and built for accuracy and repeatability.
- Parallel processing (Arduino based).
- Real-time sensing of the user.
- Measures and stores 18 variables at 20 SPS with low-drifting and low-latency (50 ms).
- Standalone unit (including room lighting control of 2 independent lamps).
- Modular Design with Closed-loop control.

Table 1: Closed-loop controlled experimental variables (the robot's functional characteristics) with their possible values.

Robot functional characteristics	Description	Possible value	Degrees of Freedom (DF)
1) Height steps.	Subdivisions of the head-lamp height available for the user.	3, 9, 27 & 81 subdivisions.	4
2) Projection angle.	Angular speed at which the head of the lamp turns. Measured as servo-motor steps per second.	1, 5 & 10 steps/sec.	3
3) Interface sensitivity.	Sensitivity on the force-sensors buttons to trigger robot response action.	1, 2.5 & 8 N.	3
4) Interaction mode.	Discrete: The user is required to push and release the button to trigger a robot response. Continuous: The robot will repeat the response while the button is pressed.	Discrete & continuous.	2

Table 2: List of 18 variables being logged at 20 SPS by the Desk-Lamp robot during use: 9 robot variables, 4 user variables and 5 environmental variables.

Robot variables	User variables	Environment variables
r1: Height (stepper motor)	u1: "Up" button (Force sensor)	e1: Time (Real time module)
r2: Room lighting 1	u2: "Down" button (Force sensor)	e2: Date
r3: Room lighting 2	u3: "On/Off" button (push-button)	e3: Room temperature
r4: Desk-lamp robot lighting 1	u4: "Shift" button (push-button)	e4: Room humidity
r5: Desk-lamp robot lighting 2		e5: Room lighting
r6: Servomotor 1 (mechanical dimmer)		
r7: Servomotor 2 (projection angle)		
r8: Internal logic 1		
r9: Internal logic 2		

6.2 Resolution and error per controlled variable:

- Height: resolution 3.1 μm/microstep, error < 0.1 %, range from 18 cm to 68 cm.
- Luminous Flux: Resolution 20 luxe, error < 1.1 %, range from 200 luxe to 1500 luxe (at 30 cm).
- Projection angle: Resolution 1°, error < 0.6 %, range from 240° to 20°.
- Interface sensitivity: 0.26 gr./dig.count, error < 0.1 %, range from 0.1 N to 15 N.

7 EXPECTED NEXT STEPS

This research is a first step toward building a big data corpus of multiple human-robot interaction experiments for future work on artificial intelligence and database analysis, due to the fact that experimental results will share the data structure and the physical reference of the Desk-lamp robot, taking advantage of a simple user interface and a multivariable robot for a variety of experiments.

8 DISSERTATION STATUS AND LONG-TERM GOALS

The robotized test bench (Desk-lamp robot) has been finished. Nevertheless, the experiment with users is on hold due to the Covid-19 pandemic. Until the pandemic deescalates, I am locked on deskwork. My personal goal is to work on design, research, and innovation, where I can keep on working out of conviction and desire, using logic and imagination to feed curiosity. I think that technology should highlight human capabilities and qualities. Even though users will be subjects of adaptive ergonomics and cognitive ergonomics through ubiquitous, haptic, and affective technologies, devices will not be designed to look engaging, innovative or robotic (with human characteristics such as face, voice or gestures), but instead they will be lean and non-distractive for the user.

ACKNOWLEDGMENTS

A special remark for my thesis advisor Vicente Borja PhD. for his guidance and vital contribution to this research.

This research is funded by Universidad Nacional Autónoma de México through the projects: DGAPA-PAPIIT IT-103320 and IT-101718.

This research is possible thanks to the fully-funded fellowship program for Ph.D. students by Consejo Nacional de Ciencia y Tecnología (CONACYT), Mexico.

Thanks to the proofreaders for their time and help: Maria del Pilar Corona-Lira, Alejandro C. Ramirez-Reivich, Carlos E.G. Sotomayor, and Angelvs Gutierrez Carrillo.

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