TAM Reloaded: A Technology Acceptance Model for Human-Robot Cooperation in Production Systems

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Abstract. The cooperation and collaboration between humans and robots is getting ever closer: While the human body was historically protected by a large safety distance, more and more organizations let robots and humans work hand-in-hand. This means that humans and robots are sharing physical space and are engaging in direct contact with each other. One factor that predicts successful human-robot interaction is the acceptance of the robot by the human. In general, only when a product covers human needs and expectations, it is perceived to be useful and hence accepted. This paper aims at presenting an acceptance model with regard to the cooperation between humans and robots that is based on prior acceptance models while also taking ethical, legal and social implications (ELSI) into account.

Keywords: Acceptance model · Human-robot interaction · Human-machine interaction · ELSI · TAM

1 Introduction

Since the middle of the 20th century the field of robotics has kept on growing and has become a vital part of today's production industry [1]. The latest development of robotics leads away from robots as a component of fully automated manufacturing processes towards processes in which human and robots collaborate. This means that while the human body was protected by large safety margins up to now, there are more and more organizations that are designing collaborative workplaces where human and robot can accomplish a task together and at the same time. However, any erroneous behavior of the robot could result in serious injury of the human so the interaction between human and robot has to be designed ergonomically with regard to both hardware components as well as human cognition. One factor which can predict effective and efficient technology usage is the acceptance of the device in question. Technology acceptance in the context of industrial robots has, to our knowledge, not been explored so far. Therefore, this paper aims at building a model to investigate acceptance of human-robot cooperation in an industrial setting.

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1.1 History in Technology Acceptance Research

In order to measure acceptance there are a number of different models available. The starting point of this research field is commonly seen in Rogers' theory of diffusions of innovations from 1962. This theory proposes a five-step model from knowledge of a new technology to its validation [2]. The next essential step was the Technology Acceptance Model (TAM) proposed by Davis in 1989 [3] which prognosticates the acceptance and corresponding use of information technologies. Specifically, this model builds on the fundamental assumption that behavioral intention leads to an actual behavior. Behavioral intention in turn is dependent on two variables: perceived usefulness and perceived ease of use. Perceived usefulness is "the degree to which a person believes that using a particular system would enhance his or her job performance" whereas perceived ease of use is defined as "the degree to which a person believes that using a particular system would be free from effort [3].

Several researchers have replicated Davis's original study and added further variables to the model such as social influence (subjective norms, voluntariness, image) and cognitive instrumental processes (job relevance, output quality, result demonstrability, perceived ease of use) (TAM 2 by Venkatesh and Davis [5]) which might be of interest when assessing the acceptance of robots. Another noteworthy approach in this area was the Unified Theory of Acceptance and Use of Technology (Tam 3 by Venkatesh and Bala [4]) that aimed at creating a unified model of user acceptance in information technology. Its successor UTAUT 2 by Venkatesh et al. [6] focused on the consumer's technology acceptance by integrating factors such as hedonic motivation.

1.2 The Present Study

The aim of our research was to build an acceptance model with regard to human-robot interaction that builds on already existing knowledge and takes context-specific factors of the interaction between human and robots in an industrial setting into account. Therefore, we went through four developmental stages. First, a research model based on literature was developed and reviewed in a workshop with associates of robot manufacturing companies, associates of companies which make use of industrial robots, employees working with robots and scientists in the domains of psychology, computer science and engineering. This model took variables of the traditional technology acceptance models, such as TAM [3], TAM 2 [7] and TAM 3 [4] into account and was extended with regard to context specific factors which came up during the workshop. Context specific factors integrated in the model are on the one hand variables for adjustment such as perceived enjoyment, perceived safety, ethical, legal and social implications and on the other hand personal characteristics such as self-efficacy, robot anxiety, affinity towards technology (adapted from Karrer et al. [8]), robot-related experiences (adapted from MacDorman et al. [9]) and perceptions of external control, which are considered as variables with uncertain influence on the predictors. As a second step, a survey based on the emerged variables was developed and iteratively validated with experts. Third, the survey was implemented in an online tool and completed by 322 participants, all of them working in production. Lastly, the model was analyzed statistically by correlation analyses in order to draw conclusions with regard to possible predictors concerning the acceptance of robots for cooperation. As robots can adopt an active role (e.g. handing over heavy components) or a passive role (e.g. hold a component so that the human can work on that component) we built two scenarios for the survey in order to make predictions concerning both ways of interacting. Participants were instructed to base their response behavior on the scenario including the robot as an active partner for interaction or a passive partner for interaction respectively.

2 Method

2.1 Participants

Altogether, 322 subjects participated in the study, recruited via a panel survey. All of them were working in production companies. Thereby, 34.8 % were working in production companies that already deploy robots and 65.2 % were working in companies that do not yet deploy robots. Gender was not well balanced but representative for employees in production: 80 survey participants were female and 242 were male. Age ranged from 21 to 64 years (mean = 46.32, SD = 10.35 yrs).

2.2 Procedure

The survey was structured into explanatory parts, such as the description of the project and questionnaire parts, e.g. for the variables of the model (see Table 1). The mean time to complete the survey was 14.7 min. The software used for the online survey was Unipark, the academic program of Questback. The two scenarios were described as follows:

Table 1. Structure of the online survey

Part	Factors/information
Introduction	Project aim and funding Call for participation
Anchor variables	*Self-efficacy, robot anxiety, robot-related experiences, perceptions of external control*
Scenario 1	Active robot (permuted with scenario 2)
Adjustment variables	*Perceived enjoyment, social implication, legal implications, ethical implications, perceived safety*
Other variables	*Subjective norm, image, job relevance, output quality, result demonstrability, perceived usefulness, perceived ease of use, behavioral intention, use behavior*
Scenario 2	Passive robot (permuted with scenario 1)
Adjustment variables	Same as in scenario 1
Other variables	Same as in scenario 1
Demographical data	Gender, *age*, education
Conclusion	Possibility for final comments on human-robot cooperation and comments on the survey

Active robot: "You are an order picker, working with a robot arm at a shared workstation. Your job is to take a case and the corresponding snap lid and hold these components compatible between you and the robot arm onto the working plate. The robot takes the corresponding screws one after the other and fastens the snap lids to the housing. After mounting the components the robot puts the constructed part in the order picking area next to the workstation and a new process begins."

Passive robot: "You are an order picker, working with a stationary robot arm at a shared workstation. The robot takes an automobile door from the reserve storage and holds it in front of you. You then take individual car components from a shelf and mount these components on the automobile door. After the car components are mounted, the robot puts the door in the order picking area next to the workstation and a new process begins."

2.3 Instruments

The specific items of the survey are presented in Table 2. All items were developed in German to be adequate for the survey participants. The participants rated the degree of consent with the statements on a 7-point likert-scale. In case participants of the survey quoted that they do not deploy robots, items were formulated subjunctively for this group.

Table 2. Items of the survey

Factor	Items
Subjective norm	In general, the organization supports the use of the robot (TAM 2/3)
Image	People in my organization who use the robot have more prestige than those who do not (TAM 2/3)
Job relevance	The use of the robot is pertinent to my various job-related tasks (TAM 2/3)
Output quality	The quality of the output I get from the robot is high (TAM 2/3)
Result demonstrability	I have no difficulty telling others about the results of using the robot (TAM 2/3)
Perceived enjoyment	I find using the robot to be enjoyable (TAM 3/3)
Social implication	I fear that I lose the contact to my colleagues because of the robot
Legal implication (occupational safety)	I do not mind if the robot works with me at a shared workstation
Legal implication (data protection)	I do not mind, if the robot records personal information about me
Ethical implication	I fear that I will lose my job because of the robot
Perceived safety	I feel safe while using the robot
Self-efficacy	I can use the robot, if someone shows me how to do it first (TAM 3/3)

(*Continued*)

Table 2. (*Continued*)

Factor	Items
Robot anxiety	Robots make me feel uncomfortable (TAM 3/3)
Robot-related Experience	How many times in the past year have you read or watched robot-related news articles, movies or materials on the internet? How many times in the past ten years have you had physical contact with a robot? (MacDorman et al. [9])
Perceived usefulness	Using the robot improves my performance in my job (TAM).
Perceived ease of use	My interaction with the robot is easy (TAM).
Behavioral intention	If I could choose, whether the robot supports me at work, I would appreciate working with the robot
Use behavior	I prefer the robot to other machines in the industrial environment
Technology affinity	I like to visit shops for electronic devices. (TA-EG, Karrer et al. [8]) Electronic devices lead to intellectual impoverishment Electronic devices make things cumbersome. (TA-EG) I inform myself about electronic devices, even if I do not have the intention to purchase them. (TA-EG) Electronic devices make people independent. (TA-EG) Trying new electronic devices is fun. (TA-EG) I know most of the functions of the devices I own. (TA-EG) I am enthusiastic when a new electronic device is launched. (TA-EG) Electronic devices cause stress. (TA-EG) I know a lot about electronic devices. (TA-EG) I find it easy to learn how a new electronic device is working. (TA-EG)

3 Results and Discussion

Correlation coefficients were used to determine the relationships in our model and were calculated by using Spearman's rho. According to Cohen and Cohen (2013), effect sizes can be classified into low (r = .10), medium (r = .30) and large (r = 0.50). The level of significance was set to $\alpha = 0.05$. The complete model is presented in Fig. 1.

Overall, results regarding the robot as an active cooperator compared to the robot in a passive role did not differ significantly, either showing that the area of operation of robots can be ignored when modelling acceptance or that our scenarios did not differ sufficiently. Regarding *perceived usefulness* the most important predictor in our model is *job relevance*, followed by *subjective norm* and *output quality*, which might be caused by the industrial context of the model. Regarding the anchor variables, we found the highest correlation coefficients for the variables of the traditional TAM 3 model *perceptions of external control*, *self-efficacy* and *robot anxiety*. Against our

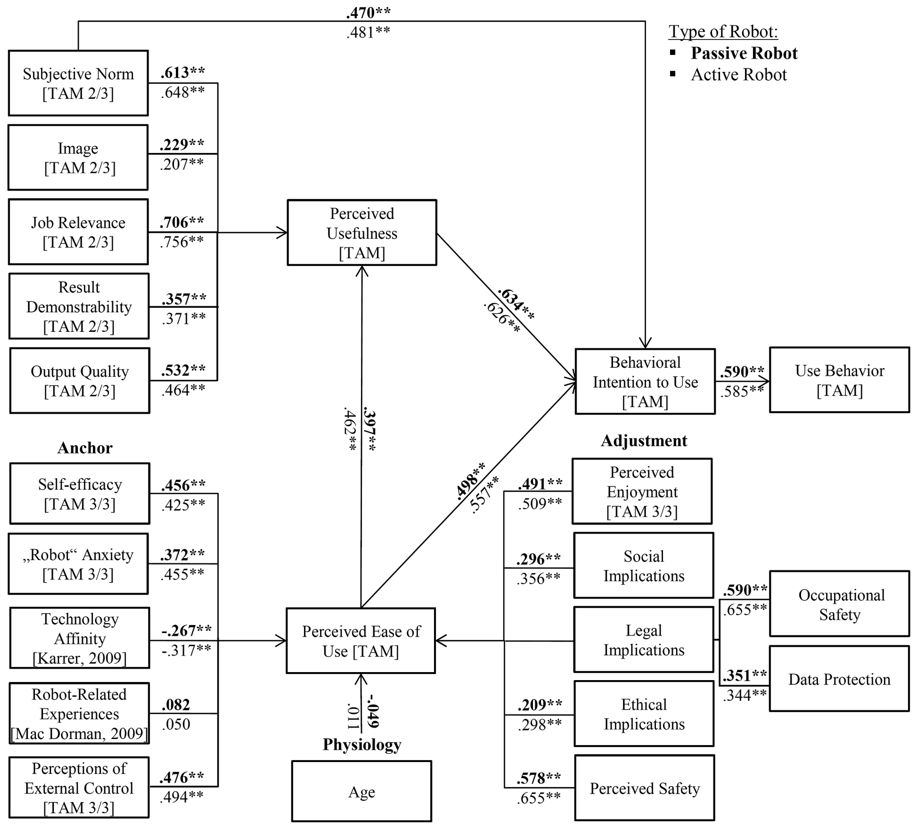

Fig. 1. Robot acceptance model with correlation coefficients as strength of associations between person-specific anchor variables, context-specific adjustment variables, age and the target variable use behavior, *p < .05, **p < .001

expectations, *technological affinity* was negatively correlated with perceived ease of use, maybe because people who have an affinity regarding technology are better informed and may have more prejudices compared to those that shy away from it. Regarding the variables for adjustment we found that *perceived safety* and *occupational safety* are the best predictors for *perceived ease of use* showing high effect-sizes, whereas *social* and *ethical implications* are less important as they show effect sizes which can be classified as medium. With regard to *age,* correlation coefficients showed no significant effect. Therefore, *age* can be ignored in the model. Overall, correlation coefficients between *perceived usefulness*, *perceived ease of use*, *behavioral intention* and *use behavior* reached medium to high levels showing that the original model is transferrable to the domain of human-robot interaction.

The paper presented is a work in progress. As a next step, the model will be analyzed using ordinal regression in order examine the explanatory power of the context-specific variables for the target variable *intention to use* more closely. Furthermore, the model will be evaluated by discriminating between participants who already work with robots on a day to day basis, participants who work with robots sporadically and participants who do not work with robots at all.

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