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The Adoption of Collaborative Robots toward Ubiquitous Diffusion: A Research Agenda

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Abstract—**This paper proposes a framework to study the adoption of collaborative robots (co-robots or cobots) as an innovation and their diffusion into the larger population. Collaborative robots are only starting to appear in our society, yet challenges such as fear and distrust may impede their further adoption. This paper discusses the foundational work necessary to understand collaborative robot adoption and the core elements to achieve ubiquitous diffusion, with a focus on human users and the communication processes.**

Keywords—collaborative robots, co-robots, diffusion of innovations, technology acceptance, innovation adoption

I. INTRODUCTION

The innovation of collaborative robots (co-robots or cobots) is predicted to spread among the larger population over the next decades, making robots at the workplace as ubiquitous as computer technology is today [1]. Working alongside collaborative robots presents a novel context that has the potential to transform our society and economy. For example, collaborative robots can aid in a rescue mission, where a particular task may be too dangerous for a human rescuer. In manufacturing, collaborative robots can take dangerous and repetitive jobs while human workers teach the robots different ways of performing the task. Such robots offer scalability, flexibility, and the ease of use to accommodate human-robot team complexity [1]. This paper discusses the innovation of collaborative robots and its path to early adoption, systemic diffusion, and ultimate ubiquity.

Despite much enthusiasm, clear challenges remain before collaborative robot ubiquity can be reached. As an innovation, collaborative robots invoke cultural and ethical concerns, related to perhaps due to dramatic portrayals in entertainment media and sensational framing in news stories. Entertainment sources are powerful, such as the classic *Terminator* series, and often instill fear of robots. Headline news stories such as ones about the humanoid robot *Sophia* acquiring Saudi Arabian citizenship in 2017 are intriguing yet provoke feelings of uneasiness to many people.

Despite popular movies and news stories, most users have yet to personally experience a situation where they practically work alongside robots. However, their preconceptions about robots influence many to ideologically reject this innovation before an actual personal experience. More importantly, collaborative robots present a new innovation that requires the adoption of physical technology, behavioral modifications, and ideological adaptation, making it a multi-dimensional challenge [2]. In this paper, we examine the barriers to the ubiquity of collaborative robot and the core elements of its ultimate diffusion, by discussing the foundational work required to achieve such goals, with an emphasis on human users and related communication processes. We seek to answer the research question, '*How can collaborative robots be studied in order to strategically promote their user adoption and systemic diffusion, as long as the benefits outweigh the concerns?*'

II. THEORETICAL BACKGROUND

To provide a comprehensive view of the adoption of collaborative robots, we integrate diffusion of innovations theory and the technology acceptance model, along with social media, persuasion, and message design literature.

A. Diffusion of Innovations

In the widely cited *Diffusion of Innovations* theory (hereafter referred to simply as diffusion theory), Everett Rogers [3] defined *diffusion* as the communication process through which messages about an innovation are passed among the members of a social system over time. Diffusion is a systemic phenomenon that results from organic adoption by individual users [2]. In general, individuals first learn about the existence of an innovation (knowledge stage), then they develop a positive or negative attitude toward the innovation. This attitude is influenced by the degree of uncertainty about the innovation and the information received from others (persuasion stage). Individuals then weigh the advantages and disadvantages of the innovation and decide whether to adopt or reject the innovation (decision stage). Once they make a decision, individuals put the innovation into practice and evaluate its usefulness (implementation stage). Additionally, individuals may seek reinforcement for the decision they have already made or may even revoke the decision (confirmation stage). The focal point of the five stages of the information-decision process is that adoption involves information-seeking and information-processing activities, where individuals are motivated to reduce uncertainty about an innovation. Given that collaborative robots invoke a high degree of uncertainty, understanding this innovation communication process is crucial for adoption.

A communication channel is the means by which messages about innovations are transmitted between individuals. The diffusion literature emphasizes the importance of interpersonal communication (e.g., naturally occurring conversations among friends) over traditional mass media (e.g., news stories, TV advertisements, etc.). Although mass media channels are both fast and efficient means of informing potential adopters about the existence of innovations, interpersonal channels are more effective in persuading individuals to adopt the innovations. In the case of collaborative robots, the mass media coverage about robots may increase the awareness and interest of potential adopters. However, their decision to adopt robots will depend more on the subjective evaluations of robots by near peers, such as their friends, neighbors, colleagues, or business partners who have an opinion (or a recycled opinion) about robots.

The interpersonal communication channels are not limited to face-to-face (FTF) interactions. Research [4] shows that online word-of-mouth can effectively facilitate diffusion throughout communities. As online communication channels such as social media allow individuals to easily reach a vast number of audiences quickly and at scale, the online word-of-mouth will be increasingly important for the diffusion of collaborative robots. For instance, our study [5] demonstrated that user-generated content such as online customer reviews has the potential to enhance trust and interaction outcomes in human-robot teams. Studying these reviews will yield critical insights.

Diffusion via both FTF communication and social media messages occurs within a social system, where various factors such as social structure, social norms, and social networks matter. For example, Valente [6] showed that the individual adoption of innovations is heavily influenced by the structure and quality of their social networks and that networks can be used as a basis for the aforementioned adopter categorization. More recent research focuses on online social networks because it is a communication channel which possesses unprecedented speed and scalability. In addition, unlike FTF interactions, online channels allow messages to be sent and received at different points in time (i.e., asynchronous communication). For instance, Li and Du [7] suggested that opinion leaders in online communities have higher degrees of centrality and prestige in social networks and become influential through the relationships that they build. Considering the increasing importance of online communication channels, identifying opinion leaders in online social networks will help accelerate the speed of diffusion and reach the maximum cumulative number of adopters [8].

B. Technology Acceptance Model

Diffusion theory has been widely adopted to study various innovations ranging from agricultural practices and contraception usage to the adoption of workplace personal computers [9], personal digital assistants [10], and surgical robots [11]. The theory has been refined to enhance its relevance to the domain of information technology [12]. Diffusion theory has also been integrated with other related theoretical paradigms, including the technology acceptance model [13]. Although originally developed in management information systems literature, the technology acceptance model shares commonalities with diffusion theory. First, both theories share the view that the adoption of an innovation is determined by its perceived attributes. Second, the main constructs in the technology acceptance model are essentially a subset of the perceived innovation characteristics of diffusion theory: perceived usefulness is similar to relative advantage, perceived ease of use is the opposite of complexity. The literature suggests that the findings from diffusion theory and the technology acceptance model usually corroborate and that the integration of these two theories could provide more powerful explanations [2] [9] [10] [14]. Therefore, in this paper, we discuss the main constructs of the technology acceptance model (i.e., perceived usefulness and perceived ease of use) in relation to diffusion theory.

III. PROPOSED RESEARCH QUESTIONS

Grounded in diffusion theory, we propose three central questions for future research. These research questions encompass the relevant theoretical perspectives provided by diffusion theory, supplemented by persuasion. We argue that in order to overcome challenges to collaborative robot adoption, research needs to examine (a) adopter characteristics, (b) collaborative robots' attributes, and (c) communication channels and processes.

A. What Are the Characteristics of Adopters of Collaborative Robots?

Adopter characteristics depend on the innovativeness of adopters, which in turn determines their timing of adoption. Rogers defined innovativeness as "the degree to which an individual or other units of adoption is relatively earlier in adopting new ideas than the other members of a system" [3, p. 22]. Based on their innovativeness and relative timing of adoption, Rogers classified adopters into five categories. First, *innovators* actively seek information about new ideas and are willing to take risks. Applied to collaborative robots, innovators are the first users to work with robots voluntarily. Next, *early adopters* come onboard and are usually the opinion leaders who influence others to adopt the innovation. *Early majority* deliberate an innovation but they adopt before the mid-point. *Late majority* are skeptical about the innovation and wait until most others adopt it. Finally, *laggards* actively resist an innovation and are often isolated in the social networks. Rogers defined the five adopter categories using normal distribution, and the adoption/penetration rate follows an *S*-curve (Fig. 1). Innovators are rare, but they lead the adoption; laggards are the last to adopt an innovation.

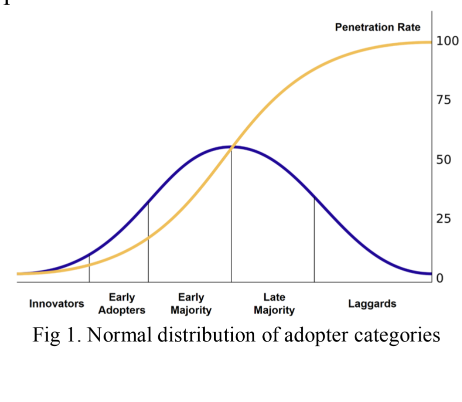

Fig 1. Normal distribution of adopter categories

innovators (the first group of adopters), change agents should target early adopters (the second group of adopters, who possesses the highest degree of opinion leadership due to their relatability with the rest of the population) as their primary audience. If the innovation is overly associated with the first group of adopters who tend to be characteristically different from the majority, the adoption of robots can be impeded by its association with a niche group of users or a geek market.

By contrast, it is important to understand why late majority and laggards are skeptical, distrustful, or even fearful of collaborative robots. We note this because one of our recent studies [5] with nationally representative data revealed that 26% of the U.S. population reported a moderate or severe level of fear toward robots and artificial intelligence. The level of fear depended on participant characteristics: females, ethnic minorities, and people with low socioeconomic status and low education levels were more likely to report a heightened level of fear. Late majority and laggards often have a low socioeconomic status. Understanding this pattern is important in order to share the benefits of collaborative robots equally among the members of society and prevent another form of digital divide.

Diffusion theory specifies that adopters have traits that affect their likelihood to adopt an innovation. It is important to understand such traits as adopters are often the basic unit of analysis in diffusion research. We suggest that future research should focus on at least the following four aspects regarding adopters:

Adopter Characteristics: Rogers [3] defined characteristics that relate to the adopter's (or potential users') categorization as an innovator, early adopter, early majority, late majority, and laggards (Fig. 1). For example, innovators are venturesome, while laggards are risk-aversive. Future studies are needed to examine the full profiles of these characteristics and their demographic distribution among robot adopters' population.

Adopter Personality Traits: Currently, little research has examined the connection between user psychological profiles and robot users' adoption. The established standards for personality involves the Big Five dimensions, which includes extraversion, agreeableness, openness, conscientiousness, and neuroticism [15]. An individual can be categorized according to these five psychological dimensions. Future research may explore the connection between users' personality and how they correspond to robot diffusion, such as the categories in Fig. 1.

Adopter Anxiety, Fear, and Distrust: People experience a high level of anxiety when they expect to communicate with robots because they do not hold mental representations or schemas that guide their understanding of and interaction with robots [16]. In other words, uncertainty in human-robot interaction produces increased anxiety. The heightened level of anxiety may lead to fear [5]. Given that fear likely produce robot avoidance, fear is clearly an important user characteristic that impedes robot adoption. Another important, related concept is trust. Successful coupling between human users and robots requires a trusting relationship. Trust is important across different collaborative tasks with robots and various levels of risks [17]. Trust building can be challenging, especially for a diverse population [18]. Addressing those negative psychological states should be a focus for future research.

Adopter Ability and Motivation: User ability and motivation refer to the cognitive aspects that affect the persuasion process. Dual-process models such as the elaboration likelihood model [19] and the heuristic-systematic model [20] are well-established in persuasion and communication literature. These models specify that an individual's ability (e.g., need for cognition) and motivation (e.g., issue involvement) affect how that person evaluates persuasive messages. Persuasive messages originating from Internet sources (e.g., online reviews, social media), marketers (e.g., advertisement), or mass media (e.g., news) may involve persuasive attempts to convince (or deter) users to adopt collaborative robots. Dual-process models explain that individuals with the high message-processing ability and high motivation will evaluate messages according to the message's argument strength. On the other hand, heuristic appeals (e.g., credibility, emotional content) affect individuals with lower ability and motivation. Future research may examine the extent to which people are able and motivated to process such persuasive messages. It will reveal the type of messages that best addresses the cognitive demands of potential co-robot users.

B. *What Are the Innovation Attributes or Characteristics that Drive Diffusion?*

Diffusion theory specifies five attributes/characteristics of innovations that drive diffusion: relative advantage, compatibility, complexity, trialability, and observability. We discuss how to adapt these exclusive attributes to collaborative robots, while focusing on the aspects of collaborative robots as an innovation, rather than the aspects of individual robot technology. We also integrate ideas from the technology acceptance model [13].

Relative Advantage: Rogers defines relative advantage as "the degree to which an innovation is perceived as being better than the idea it supersedes" [3, p. 213]. He further explained, "The nature of the innovation largely determines what specific type of relative advantage is important to adoption, although the characteristics of the potential adopters also affect which dimensions of relative advantage are most important." This suggests that relative advantage needs to be conceptualized from user perspectives, not simply a technical feature. According to the technology acceptance model, one of the driving factors for adoption is the user perceptions of a new technology's usefulness within the work context. Therefore, relative advantage conceptualization should cover if users believe that collaborating with robots is more useful than working with only humans, or with non-intelligent and non-autonomous robots.

Compatibility: Compatibility refers to how consistent an innovation is with (a) user values, (b) experiences, and (c) needs. This characteristic presents a unique challenge to collaborative robots since the only alternative would be the default of working with human teams. Interfacing with this novelty may immediately violate user perceptions of compatibility. Future studies need to focus on how collaborative robots are in fact compatible with the cultures and norms of the current workplace, in order to capture each of the three types of compatibility above.

Complexity: Complexity is the extent to which an innovation is perceived as easy or difficult to use. The central conception here is that complexity is perceptual, not actual. Therefore, the more collaborative robots are perceived by users as easy to use, the more their diffusion process should positively correspond to this ease. the technology acceptance model specifies ease of use as a key mediator of new technology adoption.

Trialability: This concept refers to how much the innovation can be experimented with prior to adoption. According to diffusion theory, innovations that can be tried on and deployed over time will be adopted more effectively than innovations that are immediately deployed. If research focuses only on the initial diffusion and adoption of collaborative robots, trialability may remain outside of the research boundaries.

Observability: Observability refers to how the innovation results can be seen by others. This typically occurs when people exchange or share information through word-of-mouth or online reviews [21] [22]. To differentiate this innovation characteristic from communication channels (discussed later), this research involves the perception to which users believe they have actually collaborative robots in action, perhaps from other co-workers or peers. In the communication channel section, the focus differs in that the research examines the actual communication and channels that people employ regarding collaborative robots.

C. How Do Messages about Collaborative Robots Diffuse via Communication Channels and Social Networks?

Diffusion theory views diffusion as a communication process where individuals exchange messages about the innovation. As Rogers describes, diffusion is "a very social process that involves interpersonal communication relationships" [3, p. 19]. Through interpersonal communication, individuals seek information about an innovation and influence others to adopt or reject the innovation. Given such, it is crucial to understand how individuals exchange messages about collaborative robots. The messages exchanged over social networks is especially pertinent, as this channel allows the creation, access, and exchange of user-generated content that is ubiquitously accessible [23]. Individuals reach a wide audience rapidly and conveniently using web-based and mobile-based Internet applications. For instance, the hashtag *#robochef* gained instant popularity among Twitter users when new media covered a pizzeria in Silicon Valley where robots work with human employees to prepare pizzas [24]. A number of users posted comments on this new co-robot application and some of them were relayed (i.e., retweeted) rapidly.

An interesting avenue for future research is to examine how messages about collaborative robots as an innovation spread via social media, especially over an extended period of time. The research needs to document (a) what kind of messages are transmitted, (b) who relays those messages, and (c) what those messages convey. This documentation of current diffusion processes will yield predictive data regarding future diffusions.

Hashtags: A Twitter hashtag is a unique convention where a user creates labels or metadata tags about an event or a context using a prefix symbol #. Searching for a specific hashtag yields a collection of messages that have been tagged with the same keyword. The analysis of hashtags allows examining how they are diffused over the social networks and evaluate the message life cycles [25]. Future research may utilize hashtags related to collaborative robots to identify relevant messages from vast amounts of user-generated text and messages.

Retweets: When Twitter users find an interesting message (i.e., tweet) posted by others, they may share it with their followers, by relaying the message with a prefix *RT* and addressing the original poster with a sign @. This behavior of retweeting has become a prevalent practice among Twitter users. This information allows researchers to identify how the message is spread and by whom. This information also allows researchers to measure the speed, scale, and range, which are the three major properties of information diffusion [26].

Sentiment: Sentiment analysis is an application of text analytics techniques for the identification of subjective opinions in text data. It allows analyzing how positive, negative or neutral the tone of each message (sentiment subjectivity analysis), as well as how strong, weak or mild the opinion in the text. This information will be important for inferring users' attitude toward collaborative robots.

IV. Conclusion

In this paper, we explore key areas of research opportunities through which early adoption, systemic diffusion, and ultimate ubiquity of collaborative robots can be achieved. Essentially, we laid out a research agenda for future research to understand the diffusion of collaborative robots, especially the idea of working with robots in a collaborative context. We accomplish this through integrating diffusion theory and the technology acceptance model, along with literature on persuasion, social media, and message design. Below we will briefly summarize the key arguments. These arguments are also visually represented in Figure 2.

First, in terms of adopter characteristics, individual users vary in how they react to new innovations [3]. Some users may experience initial excitement toward working with collaborative robots or a novelty effect. However, certain segments of the population can also experience fear that limits how they respond to collaborative robots. As previously noted, in our study [5], the fear of autonomous robots and artificial intelligence was more pronounced among female, older, less educated, and low-income participants. Understanding such characteristics of all the different categories of adopters (from early to late) is important for widespread adoption and ubiquitous diffusion of collaborative robots.

Second, in regard to collaborative robots' attributes, the usefulness and other attributes of collaborative robots depend on how users view the robots. For example, human trust in robots is crucial to the partnership with collaborative robots [27]. A meta-analysis on human-robot interaction showed that robot performance plays a vital role in how much people trust the robot [28]. Yet, early diffusion cycles rely on users' initial perception of trust toward the robot, before they actually work alongside collaborative robots. In other words, if users do not believe robots are useful, they may voluntarily choose to omit or avoid robots, making robot performance a moot point.

Third, in terms of communication processes, people exchange messages about robots, and those messages affect how they perceive and then work with robots. Our study [29] showed that word-of-mouth information about robots could modify the trust and perception of robots. Beyond FTF channels, such information spreads via social media. Research [21] [22] has documented a strong effect of messages on social media channels on user perceptions. Given such, the channels to which people exchange communication regarding collaborative robots also warrant important attention and presents a unique challenge to understanding the diffusion process.

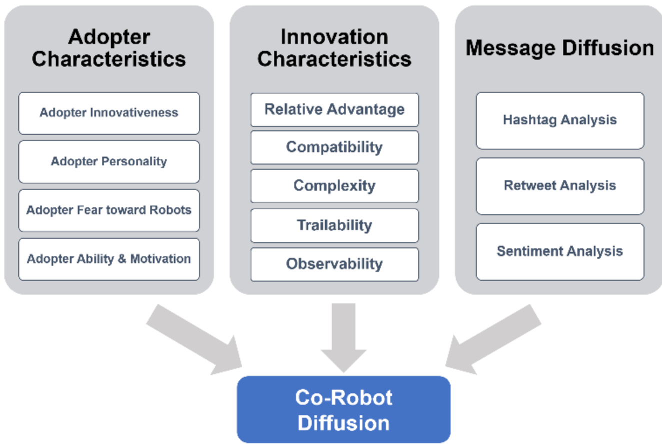

Fig 2. The co-robot diffusion model

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