MANAGERIAL ROBOTICS: A MODEL OF SOCIALITY AND AUTONOMY FOR ROBOTS MANAGING HUMAN BEINGS AND MACHINES

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Abstract

Background. The development of robots with increasingly sophisticated decision-making and social capacities is opening the door to the possibility of robots carrying out the management functions of planning, organizing, leading, and controlling the work of human beings and other machines.
Research aims. In this paper we study the relationship between two traits that impact a robot's ability to effectively perform management functions: those of autonomy and sociality.
Method. Using an assessment instrument we evaluate the levels of autonomy and sociality of 35 robots that have been created for use in a wide range of industrial, domestic, and governmental contexts, along with several kinds of living organisms with which such robots can share a social space and which may provide templates for some aspects of future robotic design. We then develop a two-dimensional model that classifies the robots into 16 different types, each of which offers unique strengths and weaknesses for the performance of management functions.
Key findings. Our data suggest correlations between autonomy and sociality that could potentially assist organizations in identifying new and more effective management applications for existing robots and aid roboticists in designing new kinds of robots that are capable of succeeding in particular management roles.

Keywords: Social Robotics, Innovation and Technology Management, User Interfaces and Human Computer Interaction, Artificial Intelligence

INTRODUCTION AND BACKGROUND

Currently existing robots possess a wide array of forms and purposes – from robotic welding arms that weld parts in factories, to robotic animals that provide therapeutic benefits for the elderly, to telepresence robots that allow one to offer educational lectures to distant audiences. Such robots are frequently used as tools for human workers; however, one might also ask whether it is possible to design robots that can serve effectively as managers of human workers.

The four key functions that a manager must be able to carry out are planning, organizing, leading, and controlling (Daft, 2011, p. 8). The ability of existing robots to perform these functions is limited. Some telepresence robots can indeed be used effectively to manage the activities of human employees, however these robots are little more than puppets that require the continuous engagement of a human operator. Such a robot is generally

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incapable of processing data, making decisions, and taking actions on its own; thus the 'manager' is not the robot itself but the human supervisor acting through it. Gradually, though, new artificial agent technologies are being developed that will allow robots to act autonomously in performing management functions in overseeing human workers (Nunes & O'Neill, 2012; Kriksciuniene & Strigunaite, 2011; Dai et al., 2013). Our acceptance of such artificial beings as managers will likely be accelerated by the fact that human beings are not only willing but even inclined to create social bonds with computerized systems as though they were human (Rehm, André, & Nakano, 2009; Friedenberg, 2011). In addition to managing human beings, robots are also being developed that can interact socially with human colleagues to receive new tasks and then manage other (nonsocial) machines in carrying out those tasks (Zhang, Ampornaramveth, & Ueno, 2006).

Given the wide variety of forms and capacities found among robots, it seems likely that some robots are better suited than others for performing functions as managers of human beings or other machines. However, significant attention has not yet been given to this question of 'managerial robotics'; we do not yet possess a robust set of models or principles designed to help identify or develop robots that are uniquely qualified to perform particular management roles. In this paper we propose a model that can help us in assessing one such aspect of a robot's potential to successfully carry out management functions.

When analysing and comparing the capacities of different robots, there are many elements that one can potentially consider, such as the robots' size, shape, mobility, sensory capacities, or processing speed and power. Here we have chosen to focus on two factors that we believe will play a key role in a robot's ability to serve as a manager: namely, the robot's levels of autonomy and sociality.

Differing degrees of robotic autonomy are desirable in different situations. If a robot is managing work that involves complex ethical dilemmas or the risk of harm to persons or property, one may wish the robot to be directly and continuously overseen by a human being who bears ultimate responsibility for the robot's actions and can override them at any moment, if needed. On the other hand, if a robot is managing repetitive work that involves no ethical or safety concerns, one may wish the robot to operate without continuous human oversight, thereby allowing the robot to work faster and more efficiently and reducing the human resource demands placed on the organization (Murphy, 2000, p. 31).

Similarly, different degrees of robotic sociality are desirable in different situations. If a robot's work will involve managing very simple machines in the performance of repetitive, predetermined tasks, it would likely be a waste of time and resources to design a robot that possesses advanced capacities for natural language processing, cultural competence, or emotional display; it would be simpler and cheaper to select a robot with very limited sociality. On the other hand, if the robot's work will involve negotiating project goals with human subordinates and motivating and instructing them in their tasks, the robot would benefit from possessing a form of sociality that is as sophisticated as possible.

The particular question that we are exploring here is whether a robot's level of sociality is independent from its level of autonomy. We hypothesize that the two traits are not independent but interrelated. If there is a strong positive correlation between autonomy and sociality, then designers of future managerial robots may not easily be able to implement one of these attributes without taking the other into consideration.

METHOD

An Instrument for Assessing Robotic Autonomy and Sociality

In order to evaluate the autonomy and sociality of existing robots, we have utilized the newly developed version 1.1 of our assessment instrument IOPAIRE, the Inventory of Ontological Properties of Artificially Intelligent and Robotic Entities. This inventory encompasses eight aspects such as Identity, Temporality and Change, Physicality, and Cognition, which together comprise 75 general characteristics and a wide range of particular properties.

Autonomy and sociality are multifaceted composite traits that reflect the possession of a wide range of more basic capacities. For example, for robots, 'autonomy' consists of being "capable of operating in the real-world environment without any form of external control for extended periods of time" (Bekey, 2005, p. 1). In its full sense, autonomy thus means that robots can not only perform cognitive tasks such as setting goals and making decisions but can also successfully perform physical activities such as obtaining energy sources and carrying out mechanical self-repair without human intervention. In the IOPAIRE framework there are 34 assessed properties that contribute to an entity's score for Autonomy and 36 properties that contribute its score for Sociality, with the completed inventory yielding a score ranging from 0-100 for each of these traits. Drawing on conventional classifications of robotic autonomy (Murphy, 2000, pp. 31-34), the score generated for Autonomy by the IOPAIRE instrument is normalized so that a score of 0-25 represents a robot that is Nonautonomous (e.g., a telepresence robot that is fully controlled by its human operator), 26-50 represents one that is Semiautonomous (e.g., that requires 'continuous assistance' or 'shared control'), and 51-75 represents one that is Autonomous (e.g., that requires no human guidance or intervention in fulfilling its intended purpose). We have also introduced the category of Superautonomous' (represented by a score of 76-100) to describe theoretically possible but not yet extant robots whose degree of autonomy significantly exceeds that displayed by human beings – e.g., because the robot contains an energy source that can power it throughout its anticipated lifespan or because its ability to independently acquire new skills and knowledge frees it from any need to seek guidance from with human subject-matter experts.

Similarly, drawing on established classifications of robotic social behaviour, social interactions, and social relations (Vinciarelli et al., 2012), the score for Sociality yielded by IOPAIRE is normalized so that a value of 0-25 reflects a robot that is Nonsocial (e.g., that might display basic social behaviours but cannot engage in social interaction), 26-50 reflects one that is Semisocial (i.e., that can engage in social interactions but not full-fledged social relations), and 51-75 reflects one that is fully Social (e.g., that can participate in social relations that evolve over time and are governed by the expectations of a particular society). We have also introduced the category of Supersocial' to describe theoretically possible but not yet extant robots whose degree of sociality significantly exceeds that displayed by human beings—e.g., because they can fluently converse in all known human languages or, through the use of multiple communication interfaces, can engage in separate social interactions with thousands of human beings simultaneously.

Selecting the Population for Assessment

To generate our data set, we applied the IOPAIRE instrument to 38 different kinds of entities. Through a review of scholarly, industrial, and popular robotics literature we identified 35 models of existing robots that display a great variety of forms and have been designed for a wide array of industrial, domestic, entertainment, educational, and governmental purposes, and we then researched, documented, and analysed their design specifications and performance characteristics. We have also evaluated three types of living organisms (i.e., a typical human being, dog, and mouse) to reflect the fact that human beings, domestic animals, and robots can be understood as members of a single, shared social space – a phenomenon that is perhaps most clearly visible in the case of therapeutic robots like PARO, which explicitly fills a role of relating to human beings that might otherwise be filled by a dog or cat (Inada & Tergesen, 2010).

Developing a Two-dimensional Model for Classifying Entities

We have created a two-dimensional model in which the X-axis represents Autonomy and the Y-axis Sociality. Because the scores for Autonomy and Sociality are each divided into four groups, this model organizes entities into sixteen different types. We would suggest that each of these types will possess a unique set of capacities and limitations for use in managing human employees and other robots and computerized systems that can be identified through further research.

RESULTS

Mapping of Scores onto the Two-dimensional Model

Figure 1 depicts the results for the 38 robotic and organic entities that we assessed. Each of the 35 grey circular dots represents a particular robot.

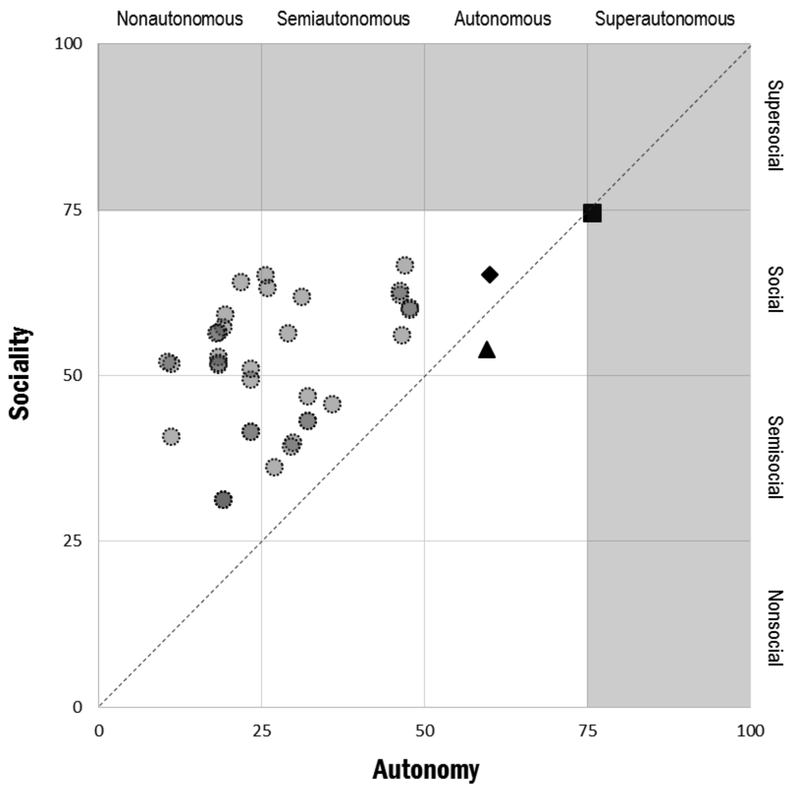

Figure 1. Thirty-five robots and three kinds of organic life-forms categorized according to their degrees of Autonomy and Sociality.

Source: Own data and design.

The three kinds of organic beings that we assessed are represented by a black triangle (a common mouse), a black diamond (a typical dog), and a black square (a typical human being). The seven subquadrants that would include any Superautonomous or Supersocial entities are shaded in grey to note that while these categories might someday include advanced robots or cybernetically or genetically altered human beings, it is not anticipated that any currently extant entities would fall into these categories.

As shown in Table 1, the values for the inventoried robots' Autonomy score ranged from a minimum of 10.6 (for the telepresence robot Hugvie) to a maximum of 47.7 (for PARO and the industrial robot Baxter) with a mean score of 27.0. The robots' values for the Sociality score varied from a minimum of 31.4 (for Looj) to a maximum of 66.7 (for Pepper) with a mean score of 50.9.

Table 1. Summary of the Autonomy and Sociality scores for 35 inventoried robots

Trait	Min. score	Mean score	Max. score
Autonomy	10.6	27.0	47.7
Sociality	31.4	50.9	66.7

Source: Own data.

When we categorize the 35 robots according to subquadrants, we see that:

1. Seven robots can be described as Nonautonomous Semisocial, including the Looj 330 gutter-cleaning robot and MQ-1 Predator unmanned aerial vehicle.
2. Seven robots are Semiautonomous Semisocial, including the KR Quantec Pro industrial manipulator arm, the Curiosity Mars rover, and the Roomba 500 series of vacuum-cleaning robots.
3. Eleven robots are Nonautonomous Social, including the Geminoid HI-4, Telenoid R2, and PackBot Explorer.
4. Ten robots are Semiautonomous Social, including PARO, the therapeutic robot resembling a baby seal; the Care-Providing Robot FRIEND wheelchair; and the 'emotional robot' Pepper.

The grid's remaining 12 subquadrants contained no robots at all.

Analyzing the Relationship of Scores for Autonomy and Sociality

One may note that all of the inventoried robots are mapped to a position above the line defined by the equation $y = x$. In other words, all of the robots possessed a Sociality score greater than their score for Autonomy; in no case does a robot's Autonomy exceed its Sociality. In order to better understand the relationship between autonomy and sociality, we calculated the Pearson product-moment correlation coefficient (r), Spearman's rank correlation coefficient (ρ), and the p-value for our data set, as shown in Table 2.

Table 2. Overview of correlation coefficients and *p*-value for the evaluated entities

Population	*r*	ρ	*p*-value
35 robots	0.36	0.26	0.13
35 robots plus 3 organic beings	0.50	0.37	0.02

Source: Own data.

If only the 35 inventoried robots are considered, the *p*-value of 0.13 does not allow us to presume with great confidence that there is a correlation between the value of the entities' Autonomy and Sociality scores; it is not inconceivable that an apparent relationship similar to that visible in Figure 1 could be obtained by random chance. However, when we consider the population of inventoried entities that includes both the 35 robots and three kinds of organic beings, the *p*-value of 0.02 allows us to conclude with a high degree of confidence that an entity's level of Sociality has a significant correlation with its level of Autonomy.

DISCUSSION AND CONCLUSIONS

It is perhaps not surprising that no robots were classified as Superautonomous or Supersocial: these categories represent abilities significantly beyond those of which human beings are capable, and artificial intelligence technologies are not yet sufficiently advanced to grant robots synthetic emotion, cultural competence, or ethical judgment that can matches human capacities, let alone significantly surpass them. The Autonomous Social subquadrant also contains no assessed robots, although a number of them fell just outside it, possessing adequate Sociality but insufficient Autonomy. Our data would suggest that developing autonomous robots may be a greater challenge than developing social ones: while telepresence robots such as Hiroshi Ishiguro's Geminoid models demonstrate a level of sociality that exceeds that of a mouse, rivals that of a dog, and even approaches that of a human being, when it comes to manifesting autonomy the robots that we have studied still fall short of common mice – entities which are, after all, able to go about their regular activities, survive, thrive in the most difficult environments and with no human assistance (or indeed even in the face of active human opposition).

Also noteworthy is the fact that the quadrants representing Nonautonomous and Semiautonomous Nonsocial robots were empty; none of the robots that we evaluated could be described as truly 'nonsocial' entities. We would hypothesize that this may reflect the fact that at present, it is not possible for robots to be designed and created solely by other machines without the involvement of human beings. Every existing contemporary robot has been designed by human beings; it has been 'born' into a human society in which it will be operated and maintained by human beings to fulfil a purpose that has been chosen by human beings and is intended to benefit certain human beings. While it might be possible for a rock or a flower or a distant star to be classified as 'nonsocial,' it is not surprising that robotic artefacts created to serve the ends of human society possess at least a weak form of semisociality, since sociality depends not just on the inherent qualities of an object itself but also on the ways in which it is viewed and treated by the human beings who interact with it.

While the data obtained from the 35 robots does not by itself provide conclusive evidence that there is a correlation between the robots' levels of autonomy and sociality, the additional data obtained from the three kinds of living organisms suggests strongly that such a correlation exists, if one views robots and living organisms as fellow members of the single population of entities that are capable of possessing some degree of autonomy and sociality. If a correlation between robotic autonomy and sociality exists, there remains a question of whether a direct causal connection exists between the two traits, or whether some third factor produces them both. Our data suggest that increasing a robot's degree of sociality does not, in itself, enhance the robot's autonomy, as we identified a number of robots with quite high scores for Sociality but low scores for Autonomy. On the other hand, every robot that possessed a high score for Autonomy (i.e., nearing 50) also possessed a high score for Sociality. This leads us to formulate a working hypothesis that enhanced robotic autonomy contributes to a higher level of robotic sociality.

This supposition will require further research in order to be confirmed. We plan to expand our data set to include a larger quantity and variety of evaluated robots, and we also hope to employ the IOPAIRE instrument to develop an expanded multidimensional model that can identify correlations between robotic traits other than those of autonomy and sociality. Even in the absence of further data and analysis, though, the results described here seem to warrant suggesting a piece of practical advice to any engineers who are attempting to design an Autonomous Social managerial robot that is capable of carrying out all four management functions: if they should encounter obstacles while attempting to directly increase their robot's level of sociality, they might instead try focusing on enhancing their robot's level of autonomy, and then see whether this increased autonomy is accompanied by growth in the robot's social capacities. We anticipate that further future study in this area of managerial robotics will not only aid organizations in identifying existing robots that can effectively perform particular management functions, but will also aid engineers to develop new robots and artificial intelligence systems that are optimally suited to filling particular managerial roles.

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ROBOTYKA MENADŻERSKA: MODEL SOCJALIZACJI I AUTONOMII DLA ROBOTÓW ZARZĄDZAJĄCYCH LUDŹMI I MASZYNAMI

Abstrakt

Tło badań. Rozwój robotów z coraz bardziej wyrafinowanymi zdolnościami do podejmowania decyzji i zachowaniami społecznymi otwiera robotom drzwi do możliwości wykonywania zarządczych funkcji planowania, organizowania, prowadzenia i kontrolowania pracy ludzi oraz innych maszyn.

Cel badań. W tej pracy badamy relację pomiędzy dwiema cechami, które mają wpływ na zdolność robota do skutecznego wykonywania funkcji zarządzania: związanych z autonomią i socjalizacją.

Metodyka. Korzystając z instrumentów oceny oszacowaliśmy poziom autonomii i socjalizacji 35 robotów, które zostały stworzone do szeroko pojętego użytku przemysłowego, domowego i rządowego wraz z kilkoma gatunkami organizmów żywych, z którymi wspomniane roboty mogą dzielić sferę socjalną i które mogą w przyszłości zapewnić wzorce niektórych aspektów projektowania robotów. Następnie rozwijamy dwuwymiarowy model, który klasyfikuje roboty na 16 różnych typów, z których każdy oferuje niepowtarzalne mocne i słabe strony wykonywania funkcji zarządczych.
Kluczowe wnioski. Nasze dane wskazują na związek pomiędzy autonomią a socjalizacją, która mogłaby potencjalnie pomagać organizacjom w identyfikowaniu nowych i bardziej skutecznych aplikacji zarządzania dla już istniejących robotów i robotyki pomocniczej w projektowaniu nowych rodzajów robotów, które byłyby zdolne odnieść sukces w poszczególnych w rolach zarządczych.

Słowa kluczowe: robotyka społeczna, zarządzanie innowacją i technologią, interfejsy użytkownika i interakcja człowiek-komputer, sztuczna inteligencja