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ROBOTS MORPHOLOGIES AND COMMUNICATION STRATEGIES TRADE-OFF IN A DYNAMIC MULTI-ROBOT COLLABORATIVE ENVIRONMENT

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Many robotic use cases stand in need of robot collaboration. Thus, it is vital to make sure that they collaborate effectively. While various dimensions of robots such as communication skills and morphology were studied independently, to our best knowledge, no anterior research has checked out those dimensions jointly. The aim of this article is to demonstrate the existence of an intrinsic relationship between morphology and communication strategies. In our study, we present collaborative scenario simulation results demonstrating that both morphologies and communication strategies interact in complex ways. The bulk of these results are derived from multiple simulation runs with randomly generated initial conditions. We compared task execution times for different morphologies, using either implicit or explicit communication. Simulation results proved that implicit communication was the most suitable strategy for anthropomorphic robots, whereas explicit communication was the most appropriate for zoomorphic and functional robots. We plan to pursue this research by verifying our approach on real robot platforms, including a larger number of robots, and tackling new types of interaction.

1. INTRODUCTION

At the beginning of robotic technology, robots were mainly considered instruments to be used in industry and warehousing. However, lately, and thanks to improvements in mechanics, design, hardware, software, actuators, and power autonomy which helped build up various robots with different morphologies, that thinking has changed. Current trends in robotics hold tremendous promise for the next decade of research, emphasizing robots' potential to reach into every aspect of life. We witness astonishing advances in dynamic multi-robot systems [1], inter-robot communication, robot morphology, and much more.

Based on the heterogeneous composition of several units [2] (control units, communication interfaces, processing units, actuators, motors, and sensors), different morphologies could take place and become the unique features of robots. Robot morphology was defined by Paul *et al.* [3] as being the structure and mechanical characteristics of the robot body. It also denotes the robot-specific aspect and bodily representation. Robot morphology is crucial because it: 1) influences expectations for interaction, 2) defines the robot differing capabilities, and 3) affects how well the robot fits with the task.

The focus of robotics research was control heretofore. Nevertheless, more and more research provide importance to robot morphologies, focusing on robots' bodies' mechanical properties and shape [4, 5]. Though, few are research methods that tackle robots' morphology in communication space, despite the clear proof that morphology presents a critical role. Indeed, a crucial issue relates to the impact of a specific physical design or morphology on the way collaboration occurs and what will be the best communication strategy to choose [6]. Robots' motion and physical forces are not the only features depicted by the morphology, but morphology also affects the communication strategy required by the interaction. An efficiently chosen morphology could conduct to exceptional diminishments in task completion time specifications. On the other hand, choosing an unsuitable morphology may require complex control algorithms or be simply inadequate for the task. To our best knowledge, though closely related, communication strategies and robot morphologies were treated as rather uncoupled entities; and no research has shown that there is a close relationship between them in dynamic multi-robot systems.

Consequently, the relation between morphology and communication is worth attacking in the field's actual state of the art. Thus, the aim of this research is to open the possibility of systematically studying the role of morphology in collaborative multi-robot interaction and communication development. This paper is chiefly concerned with the impact of robot morphology on collaborative interactions from the perspective of communication science, which encompasses both implicit and explicit strategies.

Increasingly, robots may communicate with speech and movement, replacing traditional interfaces of fundamental communication. This paper presents a unique and challenging opportunity to explore the existing trade-off between morphologies and communication strategies. Thanks to simulations allowing easy, cheap, and fast testing we were able to infer new relationships between anthropomorphic, zoomorphic, and functional morphologies, and communication strategies. We present the outcomes of our study, which explores the trade-off between robot morphology and communication strategy using a simple collaborative task. The results analysis demonstrates that significant correlations exist between those two dimensions that previous studies missed.

Our approach is different since we conduct simulations, which can allow performing experimentations where the body becomes an experimental variable that can be changed. To our knowledge, our research is the only work tackling the impact of robot morphology on task execution in the communication strategies domain for dynamic multi-robot systems. We believe that by understanding the impact

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of morphology, we can expect progress towards more efficient multi-robot interactions.

The remainder of this paper is outlined as follows. First, in section 2, we present a more specific inducement of the two dimensions (communication strategies and robot morphologies). Next, our simulation setup is introduced, presenting the simulation methods and the used robots. These simulations' results are reported and analyzed in section 4. In section 5, we summarize our findings and their implications. Then we conclude with a section presenting the envisioned future work.

2. **BACKGROUND AND MOTIVATION**

Extensive work has been done in communication within dynamic multi-robot systems. Also, much research has been conducted in the field of robot morphology. A concise review of some of the most recent relevant work in these fields follows.

2.1. COMMUNICATION IN DYNAMIC MULTI-ROBOT SYSTEMS

Merriam-Webster's dictionary [7] provides two language definitions, distinguished by the components forming communication's basis. Compellingly, those definitions conform entirely to the two different communication strategies already known in the multi-robot interaction domain.

- "Language is the suggestion by objects, actions, or conditions of associated ideas or feelings."

This type of communication within dynamic multi-robot systems is becoming very popular. It is another form of language that does not require a concerted lexicon. Robots transmit desires, intentions, emotions, and interests using suggestive actions. It is called *implicit communication*: the unintentional act of passing information. Also called indirect or non-verbal communication, it describes any interaction processes in which information is captured by the observations of the environment and other robots but does not involve an intentional conveyance and is not explicitly transmitted by spoken language. In this strategy, communication takes place either via environment as a medium (proxemics); or via sensing one another (*i.e.*, through robots' sensors) without explicitly communicating (kinesics).

- "Language is a systematic means of communicating ideas or feelings by the use of conventionalized signs, sounds, gestures, or marks having understood meanings."

Much of multi-robot communication research heretofore fits into this second category, as it relies on preset shared vocabulary, signs, or gesticulations use. Those elements explicitly communicate specific meanings, making it possible for complex information to be directly transmitted. It is called *explicit communication*: the intentional act of passing information. Also called direct or verbal communication, it describes any communicative act whose sole aim is to convey information to other team robots. It is realized by sending and receiving voluntarily meaningful explicit messages, such as speech or a radio message transmission relying on some hardware dedicated to signal transfer. In this strategy, communication is directed to a particular receiver; and takes place either in the one-to-one form (local communication) or one-to-many form (global communication).

2.2. ROBOTS AND COMMUNICATION: IMPORTANCE OF ROBOT MORPHOLOGY

A fundamental feature of robots is their embodiment. Appearance is a vital aspect of the robot embodiment, specifically its morphology. Embodiment in 3D form and texture influences how the robot interacts with the environment and communicates to its collaborators.

The shape and structure of a robot: robot morphology serves several purposes. In many multi-robot applications involving interaction, robot morphology combined with behaviors that morphology enables constitute the primary means of communication. Indeed, robot morphology communicates the states and capabilities of the robot relative to the world. To date, however, research in this area has largely overlooked the importance of robot morphology. Nevertheless, none of it dealt with the impact of morphology on communication strategies.

Still, morphological features are communication affordances, perceived as communication channels, and trigger communication strategies. Figure 1 shows that the choice of morphological features grouping: sensors location, effectors and actuators, shape, physical parameters, and the environment, defines the robot morphology and sharply affects the robot team's communicative functions during collaborative tasks. These are settings where robots collaborate to accomplish tasks or affect the environment.

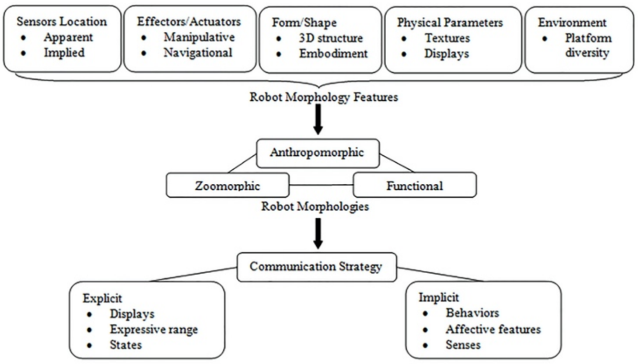

Fig. 1 – Trade-off between Robot Morphology Features and Communication Strategies.

The remainder of this section concentrates on robot morphology. For the sake of brevity, only a sampling of the available literature is presented here.

Robot morphology is what collaborators notice first and foremost, and there are several values associated with it. A general taxonomy was given by Yanco and Drury [8] and Fong et al. [9]; presenting three primary morphologies as shown in Fig. 1, which are:

- Anthropomorphic

Having a human-like appearance, they are also called humanoid robots. As the name implies, they usually have two legs, two arms, and a head. Many examples exist, such as Kaspar [10], HRP robots [11], the SoftBank NAO robot [12], Honda's Asimo robot [13], and most lately, Sophia [14]. Moreover, wheeled self-balancing robots were also developed, such as Ball-bot [15] and iBot [16]. Other robots possess social interfaces such as Kismet [17], Pearl [18], and SPARKY [19].

- Zoomorphic

Having animal-like appearances, the robots no longer resemble humans. They are now taking after birds, fishes, snakes, dogs, and insects [20]. Indeed, since animals have special abilities, there is no surprise that researchers and scientists have recently developed robots modeled after creatures from the animal kingdom. For instance, the German robotics company FESTO [21] is known for its animal-inspired robots. One of their robots is AquaJelly which moves similarly to a jellyfish. Engineers at FESTO also developed BionicKangaroo to reproduce the unique way that a kangaroo moves technologically. They also attached attention to flying robots. Thus, they created BionicOpter, a multidirectional flying dragon-like drone that can hover, and SmartBird, which can fly off and fly by using only its wings. A fish-like robot called Robofish was also developed by Faria et al. [22]. Whereas Ramezani et al. [23] developed the Atrias robot, modeled after birds, which are the fastest and most agile two-legged runners globally.

- Functional

Many researchers developed standard functional robot platforms related to the robot's function, having neither anthropomorphic nor zoomorphic morphologies. Most of those robots resemble human vehicles or machine models such as aircraft, cars, and blimps. Indeed, various robot platforms are available such as the robot created by Caprari et al. [24] named Alice. The e-puck is another example of this morphology, designed by Mondada et al. [25]. Whereas Krajník, et al. [26] developed an AR-Drone quadrotor helicopter as a functional robotic platform for education and research.

The present study's objective is to inspect either and how those two dimensions interrelate to foster our comprehension of their possible trade-off. These perceptions will enable us to conceive improved and more intuitive collaborative interactions for dynamic multi-robot systems.

3. **SIMULATION SETUP**

We start by introducing the simulator used throughout this study to analyze robot morphologies and communication strategies. Then, we give detailed information about our collaborative multi-robot scenario. We finally end this section with a description of the shapes and structures of the simulated robots used in this research.

3.1. SIMULATION ENVIRONMENT

All experiments should be tested under the same conditions to have tangible results. Because of different hazards, it is impossible to ensure such a thing in the real environment. To avoid these disadvantages and rapidly design, test, and verify the approach, we conducted simulations in the 3-D physics-based environment, CoppeliaSim: former V-REP (virtual robot experimentation platform), as presented by Rohmer, et al. [27]. CoppeliaSim is a powerful 3D robot simulator targeted to mimic the physics of robotic environments. It allows the creation of scenes filled with diverse scene objects: sensors, obstacles, and robots. It also provides various existing models available for direct use and tools to edit them, adapt their functionalities, or build new ones. It features several versatile calculation modules, distributed control architecture, and extension mechanisms. The latter makes CoppeliaSim flexible and perfect for multi-robot applications and permits designing robotic systems in a way like reality, where control is often distributed. It also provides script functionality and a specific API which allows to integrate and combine a multitude of functionalities easily. V-REP is a suitable tool for remote monitoring, fast prototyping and verification, robotics-related education, simulation of factory automation systems, and fast algorithm development.

3.2. COLLABORATIVE TASK SCENARIO

As outlined in the former section, using the V-REP simulator paves the way for successfully changing the morphologies and testing the communication strategies. However, it was necessary to decide upon an environment in which the robots are to operate before considering their morphologies. Table 1 presents the simulation parameters and their respective values.

Table 1

Simulation parameters

Parameter	Value
Number of robots	5
Game area size	5.5 m x 5.5 m
Number of simulations	50
Time step	50 ms
Simulation time limit	180 s
Number of scoring objects	10
Number of scoring platforms	2
Number of bonus platforms	1

For our work, we used a flat ground plane with gravity. The latter was chosen as a simple environment to implement in our scenario. The multi-robot task consisted of a collaborative game. As depicted in Fig. 2, the playing field is a walled area with no obstacles to prevent interference with the robot's motion, divided into three zones.

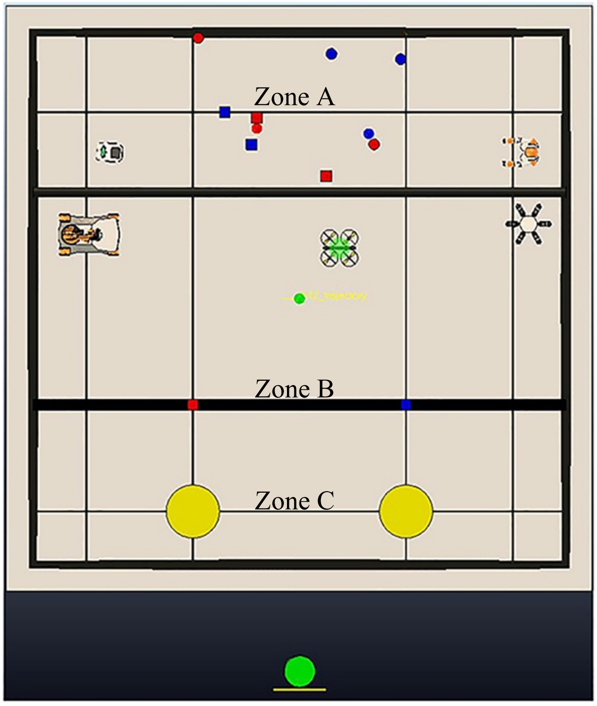

Fig. 2 – Dynamic multi-robot collaborative environment.

Besides some robots, the first zone (Zone A) contains 10 scattered basic and bonus scoring objects. The second zone (Zone B) contains the other robots and 2 scoring platforms (red and blue). The third zone (Zone C) is allocated to a bonus platform. Either using implicit or explicit communication strategies, robots share the same objective. The game's goal is to ensure collaboration between robots to take turns, detect the basic and bonus objects, sort them out according to their colors in the dedicated areas in Zone B or Zone C, and score the maximum number of points before the end of the allotted time. In the beginning, there is at least one robot in each zone, and no robot should leave its given zone, including flying robots. At least 50 % of the robot's volume does not leave the allocated zone. The scoring calculation was based on object layers; for each layer, 1 point was added. Moreover, if the bonus was put into the green basket, 10 points were added.

All robots in our simulations are measurable (distance between them can be calculated), detectable (can be detected by proximity sensors), and viewable (can be looked at and their shape visualized). Each robot's child script accesses other robots programmatically, and the called script functions perform tasks, retrieve data, or send back data to the caller. The algorithm implements implicit communication strategy targeted protocols. Robots share a mutual assessment of implicit cues and assign meanings to implicit cues received from other robots. They perform sensor-based environment mapping, including acquiring a metric model and its semantic interpretation. This semantic mapping process uses AI to model data from exteroceptive sensors mounted onboard the robot to enable collaboration. In explicit communication, custom data blocks are used to communicate.

3.3. ROBOTS

We carried out the simulations considering simple interactions between the robots under the following three conditions, and all robots interacted with each other to accomplish the task under each condition:

- Condition A: Anthropomorphic robots

As shown in Fig. 3, all simulated robots share an anthropomorphic morphology for this condition. We used the model of the humanoid robot named Asti. Asti is the equivalent of the robot ASIMO created by Honda [28]. In our simulations, we also used NAO, an autonomous, programmable humanoid robot constructed by SoftBank Robotics [29].

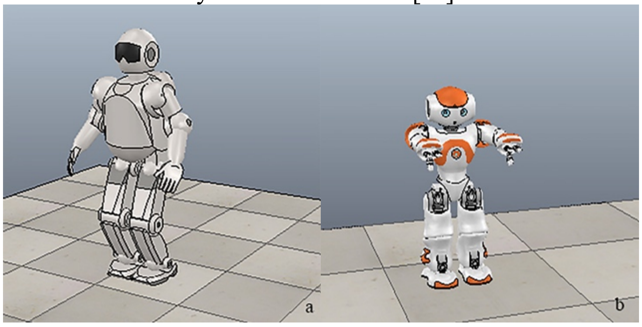

Fig. 3 – From left to right: (a) Asti (b) NAO all sharing anthropomorphic morphology.

- Condition Z: Zoomorphic robots

All simulated robots share a zoomorphic morphology for this condition, as shown in Fig. 4. We used a model of the ACM-R5 [30], a snake-like robot with extra dust sealing, and a rigid structure that allows operation under any severe condition. It comprises several modules with small passive wheels that allow the robot to move smoothly on surfaces. We also integrated a hexapod robot, a type of robot shaped like ants, possessing six legs, and allowing the simulation of insects' behaviors. We also used the Robbie model, which mimics a cat's movements, having a trot based on the movements of a typical house cat.

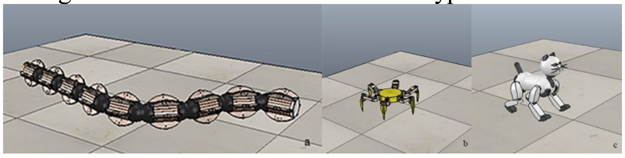

Fig. 4 – From Left to Right: (a) ACM-R5 (b) Hexapod (c) Robbie all Sharing Zoomorphic Morphology.

- Condition F: Functional robots

All simulated robots share a functional morphology for this condition, as shown in Fig. 5. In fact, from the V-REP model collection, we used the dr12 robot (courtesy of Cubictek co. ltd.). We also integrated the KUKA youBot [31] into our simulations, a powerful robot specially designed for mobile manipulation. It consists of an omnidirectional platform, a five-degree-of-freedom robot arm, and a two-finger gripper. Our simulations also used a quadcopter model; a flying robotic platform elevated and impelled by four hooked rotors.

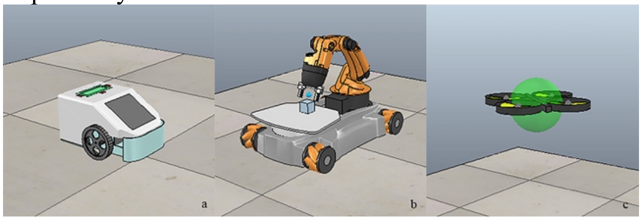

Fig. 5 – From left to right: (a) dr12 (b) KUKA youBot (c) quadcopter all sharing functional morphology.

In simulations, communication strategies controllers were written in a scripting syntax using Lua programming language and were performed on a Dual Core 2.40 GHz machine running Windows with 4 GB of RAM. Time is calculated in steps, considering that every step is a program iteration calculating robots' upcoming positions. Data collection and analysis were subsequently done after every simulation experiment. The task accomplishment time in every simulation trial was recorded. In all our simulations, robots' morphologies were closed to evolution, and no robot changed its morphology during the simulation. Moreover, all simulations engaged 5 collaborating robots that moved within the same starting positions and kept the same velocity. We used a signal processing approach; the visual stimulus (gesture, posture, sign) is repeatedly tested in each simulation step. This approach allows the acquisition and understanding of collaboration potential and helps the robots make the right decision in real-time.

4. SIMULATION RESULTS

This section describes the performed simulation and the accomplished results. We executed 50 different simulations for each case to evaluate the morphology impact, either by (i) switching the robots' morphologies or (ii) changing the communication strategies. The robot system performance was evaluated by how much time it took for robots of different morphologies to complete the task using implicit and explicit communication strategies.

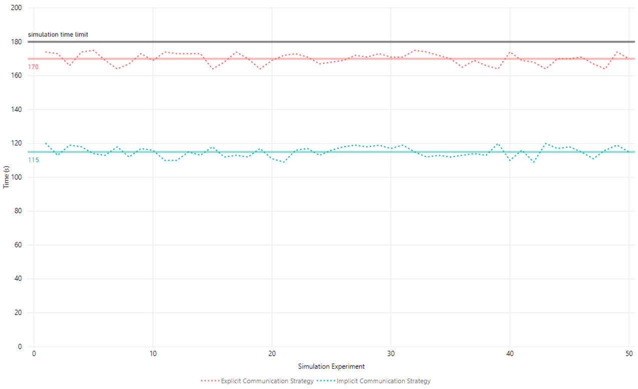

Fig. 6 – Task execution time for the anthropomorphic morphology using implicit and explicit communication strategies.

Figure 6 shows the results obtained in these simulations while using anthropomorphic robots. In this condition, simulations were conducted for both communication strategies already discussed, with robots collaborating to solve the prior mentioned task. It took robots respectively an execution mean time of 115 and 170 seconds for implicit and explicit communications to accomplish the task.

Figure 7 shows results obtained in these simulations using zoomorphic robots. This condition took robots respectively an execution mean time of 100 and 90 seconds for implicit and explicit communications to accomplish the task.

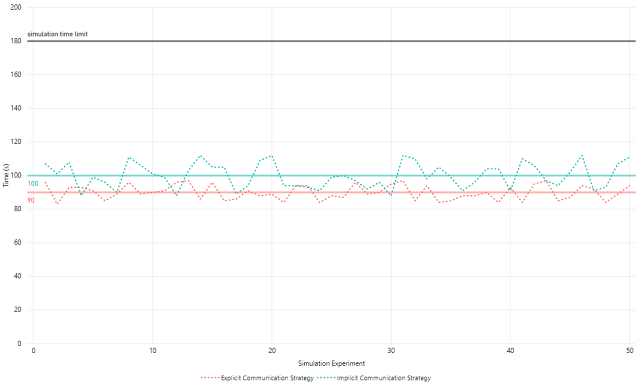

Fig. 7 – Task execution time for the zoomorphic morphology using implicit and explicit communication strategies.

Figure 8 shows results obtained in these simulations using functional robots. This condition took robots respectively an execution mean time of 90 and 75 seconds for implicit and explicit communications to accomplish the task.

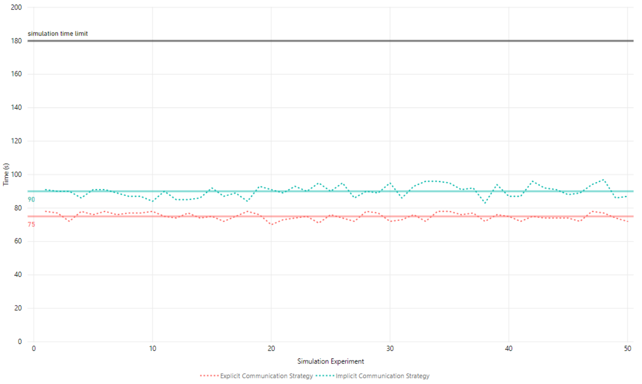

Fig. 8 – Task execution time for the functional morphology using implicit and explicit communication strategies.

Statistical analysis of the conducted simulations, as depicted in Table 2, shows that robot morphologies greatly influence collaboration. Thus, the conducted simulations to detect the trade-off between the communication strategy and the robot morphology demonstrated that implicit communication was suitable for accomplishing tasks involving anthropomorphic robots. In contrast, explicit communication is suited better when robots have either zoomorphic or functional morphologies.

Table 2

Statistical analysis of the conducted simulations

	Communication strategy					
	Implicit			Explicit		
Statistical measures	A	Z	F	A	Z	F
min	109	88	83	164	83	70
max	120	112	97	175	97	78
range	11	24	14	11	14	8
mode	113	99	91	174	84	78
median	115	99	90	170	89,5	75
$\bar{X}$	115	100	90	170	90	75
V	10.04	57.39	13.22	11.43	19.43	5.18
σ	3.14	7.50	3.60	3.35	4.36	2.25

Central tendency measures showed that comparing the different scenarios', the overall trend revealed that the best scenario was to use explicit communication with functional robots to solve the task. Moreover, implicit communication with functional robots was as efficient as explicit communication with zoomorphic robots. Comparing implicit and explicit communication strategies used within the A condition, we found that implicit communication had an average execution time of 115 s compared to explicit communication, which was 170 s. We concluded that implicit communication worked better with anthropomorphic morphology. Regarding the Z condition, the average execution time was 100 s and 90 s, respectively, using implicit and explicit communication. As the difference was insignificant, we could conclude that both communication strategies were adequate for zoomorphic morphology, with a marked improvement while using explicit communication. Finally, in the F condition, we found that implicit communication had an average execution time of 90 s compared to explicit communication, which was 75 s. We concluded that explicit communication worked better with functional morphology.

5. DISCUSSION

In this paper, we demonstrate that robot morphology is a fundamental point influencing the choice of communication strategies. We also show that the performance of any collaborative task is enhanced while choosing the appropriate communication strategy and the suitable robot morphologies. We tested different robot morphologies against both communication strategies for the game collaborative task in a physically settled simulation environment, to evaluate the most suitable communication strategy. Further, we set up the task by changing the robots' morphologies and comparing these conditions' results. We analyzed the difference in task completion time during interactions for both communication strategies.

Accordingly, this case study brings compelling data on how different robot morphologies influence task completion time using implicit or explicit communication. The found differences are not so enormous. Nevertheless, since it relies on robot morphologies and the size of the dynamic multi-robot system, we believe that the simulation brought corroboration for deciding whether a specific morphology should be envisioned for a particular usage of each communication strategy. The result shows that communication strategies performance differs between the three morphologies. This finding provides clues for choosing a communication strategy based on the robot morphology. The accomplished simulations are tested into a CoppeliaSim virtual environment and demonstrate that implicit communication is suitable for anthropomorphic robots. In contrast, explicit communication is suitable for zoomorphic and functional robots.

This research study is part of an ongoing project that aims to specify when each communication strategy is to be used in a collaborative multi-robot environment. We introduce results from the first large study exploring the impacts of switches in robots' morphologies and communication strategies on collaborative multi-robot tasks accomplishment. The results demonstrate that any mono-dimensional study that solely explores one of the two dimensions is foreseeably going to skip valuable results that are only uncovered when both dimensions are considered together. The findings of this exploratory study contribute to research on robot morphology and communication strategies. This work provides researchers with a new insight by which they can choose the suitable robot morphology and build meaningful multi-robot interactions.

However, since our comparisons are derived from a case study involving the available CoppeliaSim robot models, robot's extrapolation is restrained. Indeed, we do not assert whether simulations results are relevant to further robots. Nevertheless, we trust that the setting is accurate enough and is a promising kick-off for research on the influence of robot morphologies on communication strategies.

6. CONCLUSION AND FUTURE WORK

Our research on morphology's impact on communication is still in its infancy; thus, many issues remain to be explored. The first phase simulation shows promising results in achieving multi-robot interaction, changing robot morphologies, and communication strategies. Further investigations are on the way with a larger scale of implementation to verify the proposed principle.

Future work will include evolving robots' morphologies during simulations, mixing robots having different morphologies, and experiencing real hardware. As the simulated robots have static morphologies, the possibility of evolving robots' morphologies is exciting and will be explored later as a possibility for future work. We also aspire to test the results on actual robots operating in a physical environment to determine how reliably simulation results transpose to the real world. Another exciting course for future work is a more extensive investigation of the morphology dimension to detail the causes of the morphology outcomes we perceived in this study.

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REFERENCES

1. B.F. Florea, O. Grigore, M. Datcu, *Multi-agent exploration based on constraints imposed with graph search algorithms*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **62**, *1*, pp. 87–92 (2017).
2. M. Zohaib, J. Iqbal, S.M. Pasha, *A novel goal-oriented strategy for mobile robot navigation without sub-goals constraint*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **63**, *1*, pp. 106–111 (2018).
3. C. Paul, M. Lungarella, F. Lidia, *Morphology, control, and passive dynamics*, Robotics and Autonomous Systems, **54**, pp. 617–618 (2006).
4. A.I. Gal, L. Vladareanu, R.I. Munteanu, *Sliding motion control with bond graph modeling applied on a robot leg*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **60**, *2*, pp. 215–224 (2015).
5. R.H. Elhachemi Amar, L. Benchikh, H. Dermeche, O. Bachir, Z. Ahmed-Faitih, *Efficient trajectory reconstruction for robot programming by demonstration*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **65**, *1–2*, pp. 117–121 (2020).
6. B.S. Wood, *Children and Communication: Verbal and Nonverbal Language Development*, Prentice-Hall, Inc., Englewood Cliffs – New Jersey (1981).
7. *"Language"*, https://www.merriam-webster.com/dictionary/language, Nov. 17. 2020.
8. H.A. Yanco, J.L. Drury: *Classifying human-robot interaction: An updated taxonomy*, Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics, pp. 2841-2846, Los Alamitos, CA, 2004.
9. T. Fong, I. Nourbakhsh, K. Dautenhahn, *A survey of socially interactive robots: Concepts, design, and applications*, Technical Report CMU-RI-TR-02-29, Robotics Institute, Carnegie Mellon University, Pittsburg, p. 1–56, 2002.
10. L.J. Wood, A. Zaraki, B. Robins, K. Dautenhahn, *Developing Kaspar: a humanoid robot for children with autism,* International Journal of Social Robotics, pp. 1–18 (2019).
11. K. Akachi, K. Kaneko, N. Kanehira, S. Ota, G. Miyamori, M. Hirata, S. Kajita, F. Kanehiro: *Development of humanoid robot HRP-3P*, 5th IEEE-RAS International Conference on Humanoid Robots, pp. 50–55, Tsukuba, Japan (2005).
12. D. Gouaillier, V. Hugel, P. Blazevic, C. Kilner, J. Monceaux, P. Lafourcade, B. Marnier, J. Serre, B. Maisonnier: *The NAO humanoid: a combination of performance and affordability,* ArXiv e-prints (2008).
13. S. Shigemi, *ASIMO and humanoid robot research at Honda*. Humanoid Robotics: A Reference, Springer, Dordrecht, 2019.
14. J. Retto, *Sophia, first citizen robot of the world*, ResearchGate https://www.researchgate.net, pp. 2–9 (2017).
15. T.B. Lauwers, G.A. Kantor, R.L. Hollis: *A dynamically stable single-wheeled mobile robot with inverse mouse-ball drive*, Proceedings of the IEEE IEEE International Conference on Robotics and Automation, pp. 2884–2889, Orlando, FL, 2006.
16. D. Ding, R.A. Cooper, S. Terashima, Y. Yang, R. Cooper, *A study on the balance function of the IBOT™ transporter*, RESNA 27th International Annual Conference, Orlando (2004).
17. C. Breazeal, *Towards sociable robots*, Robots, and Autonomous Systems, **42**, pp. 167–175 (2003).
18. J. Pineau, M. Montemerlo, M. Pollack, N. Roy, S. Thrun, *Towards robotic assistants in nursing homes: Challenges and Results*, Robots and Autonomous Systems, **42**, pp. 271–281 (2003).
19. M. Scheeff, J. Pinto, K. Rahardja, S. Snibbe, R. Tow: *Experiences with Sparky, a social robot*, Socially Intelligent Agents, Multiagent Systems, Artificial Societies, and Simulated Organizations Series, pp. 173–180, Springer US (2002).
20. L. Vladareanu, A. Curaj, R. I. Munteanu, *Complex walking robot kinematics analysis and PLC multi-tasking control*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **57**, *1*, pp. 90–99 (2012).
21. *Innovation and technology – Festo Corporate*, https://www.festo.com/group/en/cms/9999.htm, Dec. 9. 2020.
22. J.J. Faria, J.R.G. Dyer, R.O. Clément, I.D. Couzin, N. Holt, A.J.W. Ward, D. Waters, J. Krause, *A novel method for investigating the collective behavior of fish: introducing 'Robofish'*, Behavioral Ecology and Sociobiology, **64**, *8*, pp. 1211–1218 (2010).
23. A. Ramezani, J.W. Hurst, J.W. Grizzle, *Performance analysis and feedback control of ATRIAS, A Three-dimensional bipedal robot*, J. of Dynamic Systems, Measurement, and Control, **136**, *2*, pp. 021012–021012-12 (2013).
24. G. Caprari, T. Estier, R. Siegwart, *Fascination of downscaling–Alice the sugar cube robot*, J. of Micro-Mechatronics, **1**, pp. 177–189 (2002).
25. F. Mondada, M. Bonani, X. Raemy, J. Pugh, C. Cianci, A. Klaptocz, S. Magnenat, J.-C. Zufferey, D. Floreano, A. Martinoli, *The e-puck, a Robot Designed for Education in Engineering*, Proceedings of the 9th Conference on Autonomous Robot Systems and Competitions, pp. 59-65, Castelo Branco, Portugal (2009).
26. T. Krajník, V. Vonásek, D. Fiser, J. Faigl, *AR-drone as a platform for robotic research and education*, Research and Education in Robotics, Communications in Computer and Information Science, pp. 172-186, Springer Berlin Heidelberg (2011).
27. E. Rohmer, S.P.N. Singh, M. Freese: *V-REP: A versatile and scalable robot simulation framework*, IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 1321-1326, Tokyo, Japan (2013).
28. K. Hirai, M. Hirose, Y. Haikawa, T. Takenaka, *The development of Honda humanoid robot*, Proc. of the IEEE International Conference on Robotics and Automation, pp. 1321-1326, Leuven, Belgium (1998).
29. *NAO the humanoid and programmable robot – SoftBank Robotics*, https://www.softbankrobotics.com/emea/en/nao, Oct. 24. 2020.
30. *ACM-R5H - Robotic Infrastructure & Services Provider - Robot Center*, https://www.robotcenter.co.uk/products/acm-r5h, Aug. 18. 2020.
31. *KUKA Industrial Robots – KUKA youBot*, http://www.kukarobotics.com/en/products/education/youbot/, May. 05, 2019.