Autonomous Fishing Vessels Roving the Seas: What Multiagent Systems Have Got to Do with It

Blue Sky Ideas Track

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ABSTRACT

With the advent of autonomous vehicles, (partial or total) autonomy of fishing vessels or operations is seen as a possibility for increased competitiveness among actors of the fishing industry. This study describes the state of art and the possible gradual deployment of autonomous fishing vehicles (AFVs), which may bring unparalleled changes to the fishing industry. Critical challenges related to safety, conservation, economy, law, and ethics of AFVs utilization remain that could be addressed using multiagent approaches. We analyse these possibilities together with the associated difficulties.

KEYWORDS

Innovative agents and multiagent applications; Multi-robot systems; Agents for improving human cooperative activities

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1 INTRODUCTION

Partial or total autonomy is explored as a possibility for maritime operations in domains such as military activities [11], maritime and port security [31], maritime transport / shipping [4], oil and gas exploitation [34], offshore renewable energy [18], marine /coastal monitoring [27], and aquaculture [28]. Following this trend, this study focuses on fishing, a maritime operations domain that has never been explored before from this perspective.

Fishing is defined as any activity that involves the catching, taking, or harvesting of fish [12], and as such is the core activity of fisheries, a concept analysed lately through the lenses of socio-ecological complex adaptive systems [17]. In many respects fishing has not evolved from the primitive forms of hunting, but it is a diversified activity. It relies on the existence of a prey (i.e. the fish) and an operator (i.e. fisher) equipped with some form of fishing gear. Presently, fish is one of the most traded food commodities in a world basis despite wild fish being a limited resource [10]. Where fisheries target valuable species or in industrial fisheries automation may be beneficial: a) it can provide access to otherwise non-reachable areas, due to large distances, harsh conditions, no or unreliable internet coverage; b) it can decrease costs of fishing by reducing labour; c) it can decrease costs associated with ship size and design in the case of unmanned or autonomous vessels; d) it can lead to environmental gains, as small autonomous vessels and smart operations may lead to significant reductions in CO2 emissions; e) it can bring additional possibilities for live-handling of catches (by removing the stage of hauling the fish into a dry environment), thereby reducing stress (and increasing animal welfare) and increasing value of fish; f) it can lead to a reduction in bycatch (i.e. unwanted fish and other marine creatures, such as birds, turtles, dolphins, trapped by fishing gear during fishing for a different species) and discards of unwanted catch (often dead or dying); g) access to difficult, deep-sea resources; h) most of all, it can lead to increase in human safety in a sector where labour-related accidents are frequent due to, for example, harsh weather conditions (e.g. strong winds), which might be exacerbated by climate change effects, and where sometimes the working environment is causing illnesses (e.g. snow-crab fishery in the Barents Sea).

When crossing the domain of fishing with the one of autonomous vehicles, the main research questions rise around transforming a classic fishing vessel into a partial or full autonomous fishing vessel (AFV), operating alone or in an autonomous fishing operation system (FOS), i.e. together with supporting marine autonomous vehicles, be they underwater or surface vehicles, and possibly aerial autonomous vehicles. Besides clearly attainable benefits, due to the technical and social complexity of fishing operations, which go beyond those raised by other domains where autonomous vehicles are used (e.g. navigate, find, catch, store, and transport live animals for human consumption with minimum economic, environmental, and animal welfare costs; presence of self-interested operators, the need to prevent illegalities, the need of cooperation between operators), the autonomous fishing may bring unparalleled changes to the fishing industry (i.e. paradigm shift in the ways the fish are caught, processed, and maintained to the market stage), as well as raise critical challenges related to technology, safety, conservation, law, and ethics. Some of these challenges could be addressed using multiagent approaches. Here we analyse these possibilities together with the associated difficulties.

2 FISHING OPERATIONS AND FISHING VESSELS

A fishing operation is composed of four phases: search/detection, capture, storage, and transport/carry of fish. The capture phase can be performed with fishing vessels or without them (e.g. fishing

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with traps or trap nets), and this phase can be active (e.g. with trawls) or passive (e.g. with gillnets) [32]. A fishing vessel is an odd combination of functions: transport (i.e. navigation, movement), carrier, hospitality (i.e. hosting people on board), and a dedicated fishing function [26]. Often these vessels are built specially for one type of industrial fishing (e.g. tuna fishing), having special equipment (e.g. seines) whose deployment requires very special skills from the crew. As some experienced people put it, there are critical aspects and instants that only a human captain on-board can handle on this kind of vessels (as they are operated today) [35]. These events are related to the critical time to deploy the gear, which can be a costly operation, without jeopardizing the safety of the crew and vessel, while respecting the navigational and fishery regulations. An array of sensors are commercial available to aid with navigation, fish search, and with the environmental and catch variables of the fishing gear.

3 LOOKING INTO THE FUTURE

Autonomous fish capturing: vessels and passive gear: For the purpose of demonstrating the core vision about autonomous fishing, we present here possible developments in the phases of search/detection and capture, and for full autonomy, a model that would maximise all the benefits enumerated in Section 1. In addition to AFVs, autonomous fishing could also be implemented via autonomous passive fishing gear (APFG), i.e. traps and nets, or a combination of both AFV and APFG. Passive fishing gear is utilized since ancient times, and it has interesting characteristics, such as low cost of operation and the possibility to keep the fish alive for long periods of time. Their operation is generally devoid of the critical events frequent in operation of active gear, and as such they would be the first candidates to autonomization of fishing. In the case of APFG, the autonomous vehicle component would be related to the movement of the gear to appropriate places (horizontally or vertically) and transport of fish holding structures. Repetitive, low-intensity operations by autonomous passive fishing gear increase the time and opportunity to expose live fish to non-lethal sorting procedures (based on size, behaviour etc.), decreasing bycatch. At the same time, these vehicles could collect and transmit information related to environment (e.g. depth, temperature, light), navigation and hazards, as well as size and type of catch.

Autonomous fishing operation systems: An autonomous fishing operation system (AFOS) can be defined as the multiple interacting autonomous agents (AA) that perform tasks necessary for integrated fishing operations (Figure 1). An integrated fishing operation would link or coordinate the four phases of a fishing operation: search/detection, capture, storage, and transport/carry; in this study, we focus only on the first two of these phases. In addition to the AFVs or APFGs, a variety of supporting autonomous marine vehicles, and even autonomous aerial vehicles, could be deployed in such a system. These vehicles could be seen operating as multiagent systems (MASs). As far as we can predict now, AFOS would have to make use of MASs techniques, because the application domain is intrinsically decentralised. Agents are on different vehicles, which are difficult to connect (e.g. one is on the surface, one is underwater; there is no global Internet far away from shore or in harsh environments, such as strong winds, high waves, extreme cold; there is need for robustness if the Internet connectivity is lost; there is a need for reactivity that prevents to use internet). The specificity of fishing operations requires that each agent acts in autonomy while taking others into consideration, even in the absence of centralized decision-making. Further complexity is added by the fact that that agents might represent different stakeholders (e.g. various fishing companies), thus multiple agents are required to defend multiple private interests (e.g. fishing performed by different companies employing AFOSs in the same area), while stakeholders might have private information they do not want to share with others (e.g. exact location of targeted fish).

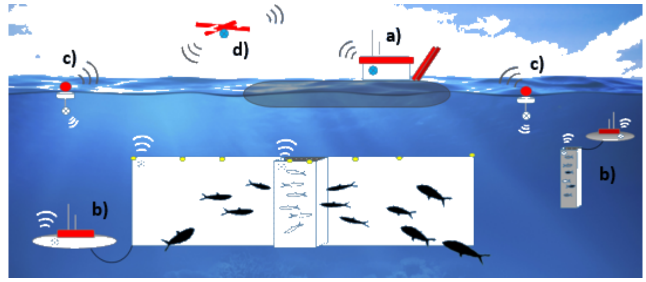

Figure 1: Example of an Autonomous Fishing Operation System (AFOS) performing search/detection and capture phases of a fishing operation. Usually, either a) or b) would perform the fish capturing task, with c) and d) as support vehicles. a) Autonomous Fishing Vessel (coordinating with c) and d) for optimal path planning); b) Autonomous Passive Fishing Gear (trap-net capturing fish); c) Autonomous Surface Vehicle (collecting data about the environment, e.g. light, temperature, concentration of zooplankton, and communicating it to a) and/or b)); d) Autonomous Aerial Vehicle (coordinating with c) in order to reduce by-catch, and with a) for optimal path planning).

Underwater vehicles: Such vehicles could be deployed for water sampling, bathymetric surveys, reduction of bycatch .

Surface vehicles: These vehicles could range from drifting or fixed buoys to hydrodynamic, moving entities. They could perform fishing related tasks: prevent bycatch from getting into the nets; detecting target fish; attracting targeted fish; estimating catch size; reducing catch if necessary; fertilizing plankton, and feeding fish.

Aerial vehicles: One or more autonomous aerial vehicles (AAV) could be integrated in the AFOS, augmenting the overall built-in intelligence. AAVs vehicles can detect the movements of the target fish (e.g. many tuna species move close to the surface), thus contributing to the search/detection phase of the fishing operation. Also, they can detect the movements accompanying other species (e.g. fish, birds, mammals), thus contributing to the bycatch avoidance feature of the AFOS. Further, aerial devices can improve the communication among buoys and the fishing vessels, as well as be critical for satellite communication and warning for passing craft, thus addressing in an easier way for example the path planning problem for autonomous vessels

4 PROBLEMS TO BE SOLVED

Choice of autonomy model: In the present analysis we will focus on the challenges related to fishing operations, as well as the social and ecological issues emerging therein. We thereby neglect other factors associated with shipping in general, such as navigation and transport, which are being handled by other maritime researchers (e.g. [30]). The transition to semi-autonomy or full autonomy of fishing vessels will not be similar in every sector or country. It is very likely that it will take place in industrialized fishing nations such as Japan and Norway first, but that traditional operations will for a period co-exist with autonomous operations. It is likely that autonomous and, particularly, semi-autonomous systems are prone to emerge first in small near-shore operations targeting valuable species. The technological transition raises several questions, particularly as to the potential of full autonomy to achieve all the benefits enumerated in Section 1: should partial autonomy be even considered? But, if not, would it be possible that full autonomy is too complex to achieve in the near future, given the state of the art? If partial autonomy is to be tried first, how should this be done? System requiring support to operators? Operators relying on the system for automating part of their job? Who is (needed to be) embedded on the ship? Only the captain? Fishing crew? Non-fishing crew? Regardless the level of autonomy, should vessels be macro-agents or MASs?

Multi-agent interaction: Even though, as indicated in Section 1, there is already some research about operating autonomous marine vehicles, and sometimes using a MAS approach [21], with fishing operations being such a new application domain there are initial questions that have to be answered, such as: How agents of the system relate to each other and to external systems (e.g. weather forecast)? How should agents cooperate locally to ensure global sustainability? How are decisions taken in an AFOSs (e.g. communication, collaboration, coordination tasks)? It seems that coordination is required in running AFOS. Then, are new coordination mechanisms required (e.g. to avoid overfishing)? Do we need a new type of architecture for agents? Different agent protocols? How would the various combinations of AA be integrated (surface-underwater, surface-aerial, surface-underwater-aerial, underwater-aerial)?

System and human interactions: Moving into this domain, more question arise: Who are the humans involved in autonomous fishing and why are they involved? Does the system needs them for operating? How do these humans interact with the system? How do humans control the system? What is the benefit from their interaction? How would the system interact with humans from outside the MAS itself such as representatives of law enforcement, environmental non-governmental organisations or even human controlled vessels that try to steal the catch of the autonomous fishing system (piracy attacks)? How should the autonomous fishing system interact with the on-land parts of the owner of the fishing system or landing facilities (e.g. transfer of fishing data)?

Ethics: Autonomous fishing is a rich environment for manifestation of multiple ethical concerns. Inside the fishing company, decisions about the command and decision structure, “company rules" for operation, will have to be settled from the onset. Are there sufficient stop buttons placed in the correct places? Further, open access to all the operational information to the legislator or law enforcement is expected to ensure full transparency. In a submerged world, this can be the only way to ensure that companies operate according to desirable standards. To avoid local depletion of stocks, there must be some agreement as to how to explore patches of resource among the operators without compromising individual economic efficiency, that is “rules of the road". In addition, there are ethical aspects connected to the design of the AAs, be them AFVs, APFGs, AFOSs or parts of AFOSs. Should we design AAs that respect ethical principles? Should these agents be given the values of their owners? Should these agents follow social norms? How to design ethical rules for such agents? What would be development of standards of "acceptable" behaviour among multi-robotic agents that exploit shared natural resources? The ethical issues inherent to classic fishing operation will be inherited by the autonomous fishing, such as the question of fishing in waters belonging to developing countries. In addition, new issues will arise, such as: should the MAS be knowledgeable about all the laws applicable in its operational domain or should it just follow the desire / rules of its owner, thus opening for the possibility for the MAS to act illegally? How should agents with different private owners behave with each other (possibly in the case when one of the agents has performed an illegal activity) and towards similar agents owned by state authorities, environmental non-governmental organisations or pirate systems? To what extent should the AFOS defend itself against human controlled pirate attacks?

Society: Large scale utilization of autonomous fishing practices would lead to reorganisation of society in different respects. Displacement of labour from the operational fishing sector can be beneficial from, for instance, the perspectives of human safety, health or well-being (e.g. more time with family). However, the history of Norwegian coastal regions in the last 30 years shows that with increasing efficiency of the fishing sector at sea there has been a flight from coastal regions where normally fishers and family dwelled, to the cities [2]. Nevertheless, a focus on the catch and transport of fresh, live fish has the potential to create new jobs in other sectors downstream along the coast that could compensate for that loss. From an organisational perspective, it might be possible that fishing companies would re-organise and new forms of organisations will be formed to operate the various elements of AFOSs, for example. For various reasons, such as distance from law enforcement, unclear regulatory regime, increased public sensitivity, these re-organised fishing companies and new forms of organisations might operate in a different way than those operating on land, and there might be clear winners and losers in these circumstances.As inferred from other areas where robots were introduced [13, 36], society might have a low level of acceptance of autonomous fishing operations, and this might reflect on, for example, seafood consumption patterns. Thus, it would be recommended to implement societal preparedness initiatives before and in parallel with the autonomisation process.If the change to autonomous fishing is going to happen, how should this be implemented (incremental or mass-replacements)? Would the autonomous system render obsolete fishing crew skills (would “the captain’s nose" (i.e. human skill considered absolutely necessary for fishing [35]) become history?)?

Legal aspects: Autonomous fishing systems as those presented in Figure 1 are in principle not limited by area or depth of operation, which is to say that they can operate in the high-seas, and capture pelagic, demersal or sedentary species. This means that, seen or unseen, these systems may transverse easily different national and international jurisdictions. It is at this stage difficult to judge whether international law can accommodate this kind of activities and autonomous systems. But, judging from the number of conflicts that have been fully or partially resolved by international law with regard to conventional vessels [23] one may suspect that international laws would need an update.Moreover, there is the question of legal responsibility for the AFVs actions, AFOSs as wholes or parts of these AFOSs. If they do something considered illegal, who has to respond in front of the law? The experts informing the MAS design, the MAS designer / engineer, the owner of the AA (and in this case complexity would increase if various agents that are part of the same MAS have different owners with different views on legal compliance, sustainability, profits, discards, by-catch, illegal fishing, and all these agents participated in taking the decision to perform the illegal action)?

5 APPLICABILITY OF MULTIAGENT SYSTEMS

Coordination techniques for optimizing AFOS performance: Considering AFVs and AFOSs MAS, there are different ways to optimize system performance. Multiple autonomous systems, which cooperate when belonging to the same owner and compete when belonging to different owners, require a minimum amount of coordination. For instance, they should avoid local patch depletion, even if the system belongs to different owners, a problem usually dealt with by optimum foraging theory. Furthermore, AFOSs should be capable of coordinating the use of the various devices they rely on (e.g. fishing nets, operations with of traps) jointly with ship operations (e.g. speed, orientation). In addition, advances in cybersecurity could play a role here [33]. Numerous techniques have been proposed for coordinating such heterogeneous and large-scale MASs. Norms [5] and protocols [19] constitute classical tools for setting rules on behaviours interactions of possibly conflicting agents. Norms, in particular, can embed legal norms, offering a strong step towards designing agents that comply with laws. Automated negotiation [8] can help reaching satisfactory outcomes between competing agents. Organizations [1, 14, 15] offer a usual tool for defining roles and duties between collaborating agents.

Supporting human-to-human business: MASs offer numerous solutions for supporting human-to-human interactions (for example, in our case, interaction between companies active in the seafood supply chain). Due to the increasing amount of automation, the system becomes well-informed on the status of the business or the vessel as a whole. Therefore, MAS can be applied for supporting decision-making and for automating processes. Automated argumentation, automated negotiation, and agreement technologies [16, 22, 25] are solutions for facilitating decision-making in general and during company-to-company competitive interactions. Another classical benefit that MASs can offer to business lies in their capability for automating processes that were usually performed by humans [24], such as recording information (e.g. filling in the log-book for each fishing operation), triggering certain tasks (e.g. start the process of issuing catch certificates for the catch), and then warn impacted entities (e.g. informing about reaching the fishing quota allocated to that specific AFV).

Relevant agent decision architectures: Agents to be deployed in autonomous fishing operations are expected to possess high cognitive capabilities, such as belief-desire-intention (BDI) agents [29] or beyond [9]. Agents operating autonomous vessels have to be capable of committing to long-term goals (e.g. commit early to specific gear and area). They should be capable of reasoning for reaching these goals, revising their plans and goals, based on beliefs of the state of the world (e.g. weather forecast, fish stocks, potential technical failure). Furthermore, these agents need capabilities for reasoning about coordination and thus adapt on the fly. As ethical issues are highly relevant in the context of autonomous fishing of common societal resources, most probably agents would need to be given capabilities for making ethical decisions. They would need to be given values to comply to, as well as logics for complying to ethical rules [6]. Likewise, the respect of humans needs and values should be taken into consideration in the context of autonomous fishing operations. MAS offer decision architectures for reasoning about human values that could be relevant here [7].

Simulation-based modelling: The transition to AFVs, APFG, and AFOS is highly consequential on the society as a whole as well as on how fishing will be performed in the future. In this regards, designing models for predicting the consequences of the evolution of fishing techniques and fishing activities organization is very important for avoiding dramatic outcomes of this shift. Social simulation offers a strong approach for evaluating the consequences of this transition on societies [20]. In addition, fishing operations are temporally extended activities, and as the state of fishing environment and conditions change in response to the fishing activity and contingencies, it is necessary to incorporate on the fly new (real-time) information in the models based on which the AFOSs and/or elements of these systems operate. How to incorporate a variety of types of data, e.g. oceanographic, biological, legal, into simulations and other models represents a significant research direction. Moreover, the major paradigm shift that the transition to autonomous fishing activities requires empowering stakeholders with an understanding of the changes the society will go through. Social simulation, serious gaming, and participative modelling provides a solution for facilitating this transition [3].

Interaction with humans: The domain of semi-autonomy is highly relevant for designing AFOS. In the short run, the problem of designing AFVs, APFG, and AFOSs might be technically too complex (and/or socially to sensitive) for being handled by fully-autonomous agents. Therefore, approaches for designing semi-autonomous systems proposed by the MAS community [37] are of high relevance for designing these fishing systems (e.g. which part of decision is left to humans? How to connect the system and humans? How do humans help the system?).

6 CONCLUSION

For various reasons, notably cultural [26], autonomous fishing vessels might not be roving the seas in the very near future. However, it is not difficult to imagine that various autonomous marine vehicles providing support to classic fishing vessels will be more and more deployed in fishing operations in this very close future. Developments in multiagent systems techniques can make a crucial contribution to solving some of the challenges raised by such operations and, in a more distant time to come, of the challenges raised by the fishing operating systems that include fully autonomous fishing vessels.

REFERENCES

[1] Huib Aldewereld and Virginia Dignum. 2010. OperettA: Organization-Oriented Development Environment. In *Languages, Methodologies, and Development Tools for Multi-Agent Systems*. 1–18.

[2] Helene Amundsen. 2015. Place attachment as a driver of adaptation in coastal communities in Northern Norway. *Local Environment* 20, 3 (2015), 257–276. https://doi.org/10.1080/13549839.2013.838751

[3] O Barreteau, F Bousquet, and J M Attonaty. 2001. Role-playing games for opening the black box of multi-agent systems: method and lessons of its application to Senegal River Valley irrigated systems. *Journal of Artificial Societies and Social Simulation* 4, 2 (2001), 5.

[4] Bjorn-Morten Batalden, Per Leikanger, and Peter Wide. 2017. Towards autonomous maritime operations. In *2017 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA)*. IEEE, 1–6. https://doi.org/10.1109/CIVEMSA.2017.7995339

[5] Cristiano Castelfranchi. 2003. Formalising the informal? Dynamic social order, bottom-up social control, and spontaneous normative relations. (2003), 47–92 pages. https://doi.org/10.1016/S1570-8683(03)00004-1

[6] Nicolas Cointe, Grégory Bonnet, and Olivier Boissier. 2016. Ethical Judgment of Agents' Behaviors in Multi-Agent Systems. In *Proceedings of the 2016 International Conference on Autonomous Agents & Multiagent Systems (AAMAS '16)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 1106–1114. http://dl.acm.org/citation.cfm?id=2936924.2937086

[7] Stephen Cranefield, Michael Winikoff, Virginia Dignum, and Frank Dignum. 2017. Cranefield, Stephen, et al. "No Pizza for You: Value-based Plan Selection in BDI Agents. *IJCAI* (2017), pp. 178—-184.

[8] Eugenio de Oliveira, Jose Manuel Fonseca, and Adolfo Steiger-Garcäo. 1999. Multi-criteria negotiation in multi-agent systems. *CEEMAS'99* (1999), 190.

[9] Frank Dignum, Rui Prada, and Gert Jan Hofstede. 2014. From autistic to social agents. In *Proceedings of the 2014 international conference on Autonomous agents and multi-agent systems*. International Foundation for Autonomous Agents and Multiagent Systems, 1161–1164.

[10] Praveen Duddu. 2014. The ten most traded food and beverage commodities. (2014). http://www.foodprocessing-technology.com/features/featurethe-10-most-traded-food-and-beverage-commodities-4181217/

[11] D B Edwards, T A Bean, D L Odell, and M J Anderson. 2004. A leader-follower algorithm for multiple AUV formations. In *2004 IEEE/OES Autonomous Underwater Vehicles*. IEEE, 40–46. https://doi.org/10.1109/AUV.2004.1431191

[12] FAO. 2017. FAO Fisheries Glossary. (2017). http://www.fao.org/faoterm/viewentry/en/?entryId=98375

[13] Leopoldina Fortunati, Anna Esposito, and Giuseppe Lugano. 2015. Introduction to the Special Issue âĂIJBeyond Industrial Robotics: Social Robots Entering Public and Domestic SpheresâĂİ. *The Information Society* 31, 3 (2015), 229–236. https://doi.org/10.1080/01972243.2015.1020195

[14] Marcel Hiel, Huib Aldewereld, and Frank Dignum. 2011. Modeling Warehouse Logistics Using Agent Organizations. *Collaborative agents-research and development* (2011), 14–30.

[15] Bryan Horling and Victor Lesser. 2005. A survey of multi-agent organizational paradigms. *The Knowledge Engineering Review* 19, 04 (2005), 281. https://doi.org/10.1017/S0269888905000317

[16] Catholijn M. Jonker, Valentin Robu, and Jan Treur. 2007. An agent architecture for multi-attribute negotiation using incomplete preference information. *Autonomous Agents and Multi-Agent Systems* 15, 2 (2007), 221–252. https://doi.org/10.1007/s10458-006-9009-y

[17] Simon Levin, Tasos Xepapadeas, Anne-Sophie Crépin, Jon Norberg, Aart De Zeeuw, Carl Folke, Terry Hughes, Kenneth Arrow, Scott Barrett, Gretchen Daily, and Others. 2013. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics* 18, 2 (2013), 111–132.

[18] Antoine Y Martin. 2013. Unmanned Maritime Vehicles: Technology Evolution and Implications. *Marine Technology Society Journal* 47, 5 (2013), 72–83. https://doi.org/10.4031/MTSJ.47.5.12

[19] Borhen Marzougui and K Barkaoui. 2013. Interaction Protocols in Multi-Agent Systems based on Agent Petri Nets Model. *International Journal of Advanced Computer Science and Applications* 4, 7 (2013), 166–173.

[20] James G McCarthy, Tony Sabbadini, and Sonia R Sachs. 2007. Multi-agent Model of Technological Shifts. In *Multi-Agent-Based Simulation VIII*. Springer Berlin Heidelberg, Berlin, Heidelberg, 112–127. https://doi.org/10.1007/978-3-540-70916-9_9

[21] P McGillivary, J Borges De Sousa, R Martins, K Rajan, and F Leroy. 2012. Integrating autonomous underwater vessels, surface vessels and aircraft as persistent surveillance components of ocean observing studies. In *2012 IEEE/OES Autonomous Underwater Vehicles, AUV 2012*. IEEE, 1–5. https://doi.org/10.1109/AUV.2012.6380734

[22] S. Modgil and T. J. M. Bench-Capon. 2010. Metalevel argumentation. *Journal of Logic and Computation* 21, 6 (sep 2010), 959–1003. https://doi.org/10.1093/logcom/exq054

[23] Stephen C Nemeth, Sara McLaughlin Mitchell, Elizabeth A Nyman, and Paul R Hensel. 2014. Ruling the Sea: Managing Maritime Conflicts through UNCLOS and Exclusive Economic Zones. *International Interactions* 40, 5 (2014), 711–736. https://doi.org/10.1080/03050629.2014.897233

[24] Steven Okamoto, Katia Sycara, and Paul Scerri. 2009. Personal Assistants for Human Organizations. In *Handbook of Research on Multi-Agent Systems: Semantics and Dynamics of Organizational Models*. 514–540.

[25] Sascha Ossowski. 2012. *Agreement technologies*. Vol. 8. Springer Science & Business Media.

[26] Kees Pieters. 2017. The Near Future of Unmanned Vessels. A Complexity-Informed Perspective. (2017).

[27] Benny Poedjono, Sudhir Pai, Stefan Maus, Chandrashekaran Manoj, Ryan Paynter, and Others. 2015. Using Autonomous Marine Vehicles to Enable Accurate Wellbore Placement in the Arctic. In *OTC Arctic Technology Conference*. Offshore Technology Conference.

[28] R R Price and S G Hall. 2012. Design, development, and testing of an autonomous boat to reduce predatory birds on aquaculture ponds. *Biological Engineering Transactions* 5, 2 (2012), 61–70. https://doi.org/10.13031/2013.41399

[29] Anand S Rao and Michael P Georgeff. 1995. BDI Agents: From Theory to Practice. In *ICMAS*. 312–319. https://doi.org/10.1.1.51.9247

[30] Ørnulf Jan Rødseth and Åsmund Tjora. 2014. A system architecture for an unmanned ship. In *Proceedings of the 13th International Conference on Computer and IT Applications in the Maritime Industries (COMPIT)*.

[31] Adam Salamon, Drew Housten, and Peter Drewes. 2008. Increasing situational awareness through the use of uxv teams while reducing operator workload. *Journal of Field Robotics* 25, 9 (2008), 598–614.

[32] J Scharfe (Ed.). 1972. *FAO Catalogue of fishing gear designs*. Wiley. 160 pages. https://doi.org/10.1007/978-3-642-77411-9

[33] Munindar P Singh. 2015. Cybersecurity as an application domain for multiagent systems. In *Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems*. International Foundation for Autonomous Agents and Multiagent Systems, 1207–1212.

[34] Lavinia Suberg, Russell B Wynn, Jeroen Van Der Kooij, Liam Fernand, Sophie Fielding, Damien Guihen, Douglas Gillespie, Mark Johnson, Kalliopi C Gkikopoulou, Ian J Allan, Branislav Vrana, Peter I Miller, David Smeed, and Alice R Jones. 2014. Assessing the potential of autonomous submarine gliders for ecosystem monitoring across multiple trophic levels (plankton to cetaceans) and pollutants in shallow shelf seas. *Methods in Oceanography* 10 (2014), 70–89. https://doi.org/10.1016/j.mio.2014.06.002

[35] Andres von Brandt and Others. 1984. *Fish catching methods of the world*. Fishing News Books.

[36] Kristian Wasen. 2010. Replacement of Highly Educated Surgical Assistants by Robot Technology in Working Life: Paradigm Shift in the Service Sector. *International Journal of Social Robotics* 2, 4 (2010), 431–438. https://doi.org/10.1007/s12369-010-0062-y

[37] Shlomo Zilberstein. 2015. Building Strong Semi-Autonomous Systems. In *Proceedings of the Twenty-Ninth Conference on Artificial Intelligence*. Austin, Texas, 4088–4092. http://rbr.cs.umass.edu/shlomo/papers/Zaaai15.html