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Effect of the Robot Operating System (ROS) on Startup Agility and Scaling

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Abstract **Original Research Articles**

With the introduction of the Robot Operating System (ROS), the industry has now seen a shift in the way startups are turning to robotics, automation, and the digital innovation to gain agility and scalable expansion. Although it has global applicability, little attention has been paid in comprehending the effect of ROS adoption on startup agility and scaling, especially in the up-and-coming economy like Nigeria. The theoretical frameworks that will be discussed in this conceptual paper to identify the impact of ROS on the startup agility and scalability are the Resource-Based View (RBV) and the Dynamic Capabilities Theory. The research design adopted in the study is a conceptual research design that wholly relies on secondary data that has been obtained through journals, conference proceedings, books, and technical reports. It has been found that ROS increases modularity, interoperability and containerized deployment, promotes agility, scalability and innovation in startup ecosystems. In addition, ROS is a resource that is dynamic and can be reconfigured flexibly and distributed architecture, enhancing operational effectiveness and entrepreneurial performance. Some of the recommendations made in the paper include creation of ROS-based training, creation of industry academia partnerships, and creation of policy frameworks that will guide the open-source robotics use by startups and SMEs. The study concludes by confirming that the strategic execution of ROS can serve as an impetus to agile and scalable start-ups.

Keywords: Robot Operating System (ROS), Scalability, Resource-Based View, Start-up Agility, Dynamic Capabilities.

1.0 Introduction to the Study

1.1 Background of the Study

The open-source implementation of the Robot Operating System (ROS) has completely changed the ecosystem of robotics in the world. The earliest software platform called ROS was created by Willow Garage in 2007 and is a part of the core software platform that enables modular, reusable, and scalable robot programs (Macenski et al., 2022). It provides a middle level that will make interaction between hardware and software components easier, thereby improving the speed of development and reliability of operations (Brouzos et al., 2023). This advancement is particularly essential to the startups themselves, which tend to lack capital and technological workforce, as well as support facilities (Shipei, 2018).

The use of ROS in research laboratories has been extended to an industrial automation, self-driving cars, and intelligent manufacturing across the globe (Tan, 2023; Polzin et al., 2025). The advantage of Startups using ROS is a community of open-source cooperation, resulting in agility by means of quick prototyping, container implementation, and reusable codebases (El-Hariry et al., 2024). Its ability to integrate ROS2, with support of Data Distribution

Service (DDS) and Real-Time Operating System (RTOS) has further supported its applicability to high scale and mission-critical systems. This scalability encourages fast adaptation to changes in the market and enables scaling of operations within the dynamic market, like robotics, logistics, and artificial intelligence (Mora-Sánchez et al., 2020).

The development of robotics, its research, and start up activity are slowly rising in the African context with the help of innovation ecosystems, university laboratories, and cross-continental cooperation. Nevertheless, the continent remains underdeveloped compared to the rest of the world because of the poor attitude toward investment in research infrastructure, poor technology transfer, and the lack of skills in robotics engineering (Aliyu, 2023; Mohammed et al., 2024). A number of African startups started to test the ROS-based applications to automate agriculture, use drone technology, and implement smart city schemes where modularity and scalability are essential (Lawal et al., 2023).

In West Africa, especially Nigeria, the emergence of tech-based entrepreneurship due to innovation hubs in Lagos, Kano and Abuja have created a new robotics ecosystem (Sundararajan and Mohammed, 2023). The use of ROS-enabled automation by African startups is becoming more popular in order to address manufacturing, logistics, and agricultural challenges in Nigeria. Systemic obstacles, such as untrustworthy power supply, insufficiency of funds, and a lack of expertise in the country, impair their potential to embrace scalable robotic solutions, though (Aliyu, 2023; Mohammed and Sundararajan, 2023).

Hence, the paper contextualizes the Robot Operating System (ROS) in the entrepreneurial and technological environment of startups, and it focuses on agility and scalability. This comprehension of the way ROS promotes fast response, modular flexibility, and scalability of growth will give vital insights to enhance the industrial automation and digital transformation agenda of the African continent.

1.2 Problem Statement

Even though global startups have gained significantly in terms of agility and scalability brought about by ROS-enabled frameworks, there is still a lack of studies on ROS application in emerging economies such as Nigeria. The technical architecture of ROS is the topic of most studies (Macenski et al., 2022; Tan, 2023) instead of its managerial and entrepreneurial aspect on startups (Mohammed et al., 2023).

In some places, like Africa, there is the problem of imprinting the open-source robotics platforms in the resource-constrained startup conditions, where the knowledge diffusion, infrastructure and human capital is minimal. This leaves a gap in research information about how adoption of ROS can impact the agility of the startup (adaptive capacity) and scaling (expansion potential). Moreover, the extant empirical research seldom relates the Resource-Based View (RBV) or Dynamic Capabilities Theory with the strategic utilization of ROS in the growth of a start-up (Brouzos et al., 2023; Wang et al., 2020). In turn, this paper discusses the role of ROS as a technological enabler that can empower the performance of the entrepreneurship when applied to the concept of digital transformation and Industry 4.0, and particularly in relation to African and Nigerian startups.

1.3 Significance of the Study

This conceptual study is significant for several reasons:

1. **Academic Significance:** It adds to the small number of studies that relate open-source robotics (ROS) to entrepreneurial agility and scalability, which endorses the sphere of technical functionality with that of strategic value as a business (Mora-Sánchez et al., 2020; Mohammed et al., 2023).
2. **Practical Significance:** As an example, it is useful to startup founders to understand how ROS can be used as a strategic solution to gain flexibility in operations, reduced time-to-market, and scalability on the fly. The software redundancy and deployment costs are minimized by ROS-based solutions, and, at the same time, they fit startup lean approaches (El-Hariry et al., 2024).

3. **Policy Implication:** To policymakers and innovation agencies in Nigeria and Africa, the results can be used to make investments in robotics incubation centers, open-source learning, and digital infrastructure, which are needed to facilitate the growth of inclusive technological development (Aliyu et al., 2023).
4. **Technological Significance:** The paper demonstrates the benefits of containerization (Docker, ROS2-Compose), RTK-based navigation, and cross-domain collaboration in terms of reliability of the systems, data combination, and collaboration between systems (Tan, 2023).

1.4 Research Objectives

General Objective

To conceptually analyze the impact of the Robot Operating System (ROS) on startup agility and scaling, especially in the case of the new economy Nigeria.

Specific Objectives

1. To examine ROS and its ability to promote agility during startup, based on modularity and reusability.
2. To investigate how ROS provides scalability of startups through containerization and distributed architecture.
3. To determine the relationship between ROS adoption and entrepreneurial performance in Resource-Based View (RBV) concept.
4. To suggest a conceptual model that will combine technological, organizational, and strategic aspects of ROS implementation.

1.5 Research Questions

1. What is the effectiveness of adopting ROS in enhancing the agility of the startup in the dynamic market?
2. How does ROS make the startup operations and business models more scalable?
3. What are the theoretical associations between the ROS-supported agility and business performance within the RBV and Dynamic Capabilities perspectives?
4. Which conceptual framework is most suitable to help understand the relationship between the ROS adoption and agility and scaling in the context of the startup ecosystems?

2.0 Literature Review

The literature review examines background views of the impact of new digital technologies on startup agility and scaling like the Robot Operating System (ROS). This part will start with conceptual foundations of robotics-based entrepreneurship and proceed to give a detailed discussion of the structure, development, and entrepreneurial consequences of ROS.

2.1 Conceptual Review

The theoretical background is based on the technological innovation, entrepreneurial agility, and digital scalability theories and how open-source ecosystems can be used to facilitate adaptive business models. Over the past few years, the digital transformation has progressed beyond the mere automation to the incorporation of cyber-physical system, robotics that are AI-powered, and open-source (Khin and Hamid, 2019; Zhe and Hamid, 2021). The advantages of startups that utilize ROS are the ability to develop and grow collaboratively, have modular flexibility, and deploy in real-time, making it easy to scale in the dynamic markets. The open innovation paradigm focuses on the move of closed R&D to the open collaboration models, where software ecosystems such as ROS fill the technological gaps and minimise barriers to entry (Mohammed, 2023; Lawal, Abdulsalam, Mohammed and Sundararajan, 2023).

The use of ROS can also be seen as a development of the digital entrepreneurship model whereby the technological capability forms a fundamental part of strategic agility. The integration of the open-source robotics and cloud computing enable the startups to access scalable resources, simulation resources, and the innovation networks (Aliyu, 2023; Kumar, Mohammed, Raj and Sundaravadivazhagan, 2024).

2.1.1 Robot Operating System (ROS) Overview

The Robot Operating System (ROS) is a loose system, open-source, system meant to simplify the creation of robot applications. ROS was first released by Willow Garage in 2007, and it is a collection of software libraries and tools to assist developers in creating robot behaviors, spanning between perception and motion control (Macenski, Martín, White and Gerkey, 2022).

Historical Background and Evolution

ROS started as a scientific project to standardize robotic software projects in both academic and industry spheres. As it has developed, it has become a collaborative ecosystem worldwide, sustained by the Open Robotics Foundation, with support of thousands of contributors and a variety of applications in manufacturing, logistics, and autonomous mobility (Quigley, Conley, Gerkey, Faust, Foote, Leibs, Wheeler and Ng, 2009).

Architecture and Modular Features

ROS uses a distributed and modular architecture, which allows heterogeneous robotic sources to be interoperable with each other. The three major elements of it are:

1. **Nodes** - It consists of independent processes that carry out a particular computation.
2. **Topics** - Topics are message buses on which nodes interact.
3. **Services and Actions** - synchronous and asynchronous communication mechanisms (Macenski, et al., 2022).

The design ensures a higher fault tolerance and modularity as well as real-time coordination, which are essential in agile startups that implement robotics at scale.

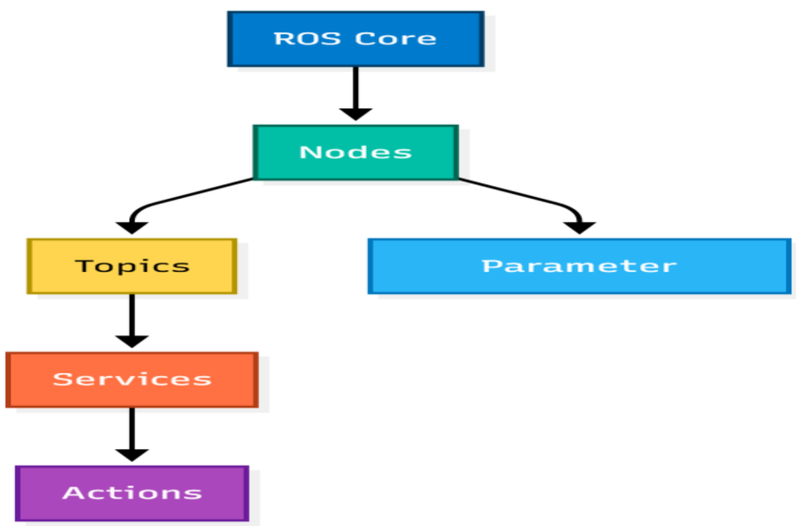

Figure 1: ROS Architecture Overview

Source: Adapted from Macenski, Martín, White & Gerkey (2022).

ROS1 vs. ROS2 Transition

The publication of ROS2 was an important improvement to the initial system, with a Data Distribution Service (DDS) middleware, improved security, and real-time communication capabilities. These developments cater to the needs of all businesses, such as startup scalability, cloud integration, and robotics-as-a-service (RaaS) (Maruyama, Kato and Azumi, 2016).

Table 1: Comparison between ROS1 and ROS2

Feature	ROS1	ROS2
Communication Middleware	Custom TCP/UDP	DDS-based (Real-time)
Platform Support	Linux-only	Multi-platform (Linux, Windows, macOS)
Security	Limited	Built-in authentication and encryption
Real-Time Capability	Experimental	Supported
Scalability	Moderate	High – suitable for distributed startups

Source: Compiled from Maruyama, Kato & Azumi (2016); Macenski, Martín, White & Gerkey (2022).

The open-source of ROS creates an open-collaborative state allowing startups to innovate without high-licensing fees. By using such repositories as GitHub and ROS Discourse, entrepreneurs can learn the codebases, add modules, and solve problems together. It democratizes robotics innovation thereby making robotic startups less capital intensive and providing them more go-to-market plans (Mohammed & Sundararajan, 2023; Mohammed, Shanmugam, Subramani and Pal, 2024).

Besides, the combination of ROS with the AI, IoT and cloud robotics enables entrepreneurs to develop adaptable and information-driven solutions that correspond to the industry 4.0 paradigms (Aliyu, 2023; Sundararajan, Mohammed and Senthil Kumar, 2023). Strategic flexibility, shorter product iteration cycles, and competitiveness in the overall global technological environment are all benefits of startups using ROS.

2.1.2 Startup Agility

Startup agility is the capability of the organization to quickly adjust to the changes in the market, technology, and operations without losing innovation speed or customer value. Agility nowadays is no longer a choice, it is a survival necessity, especially in the current entrepreneurial environment dominated by technological-based businesses operating under an iterative development model, and whose business success relies on a digitally adaptable environment (Mohammed, 2023; Sundararajan, Mohammed & Lawal, 2023).

Agility in robotics area takes the form of the ability to prototype, test, and apply robots in situations of uncertainty in a short time. Open-source platform Robot Operating System (ROS) contributes to it greatly as it includes reusable modules, community support, and is easily integrated with artificial intelligence and automation tools (Macenski, Martín, White and Gerkey, 2022).

Software modularity, cloud-native, and continuous integration/continuous deployment (CI /CD) pipelines are the forces behind technological agility. The startup using ROS can make substitutions of nodes or modules without redesigning the whole system. Organization agility, on the other hand, is a result of flat hierarchies and data-based decisions-making processes that make the time-to-market faster. Operational agility involves the flexibility in the resource allocation, ability to speed up and repeat, and distributed collaboration (Aliyu, 2023; Mohammed and Sundararajan, 2023).

Table 2: Dimensions of Agility in Robotic Startups

Type of Agility	Key Features	ROS-Enabled Mechanisms
Technological Agility	Rapid prototyping, modular integration	Reusable ROS packages, API interoperability

Organizational Agility	Adaptive management, flat hierarchy	Agile collaboration via open-source networks
Operational Agility	Fast iteration, flexible scaling	Simulation tools, distributed testing environments

Source: Compiled from Aliyu (2023); Macenski, Martín, White & Gerkey (2022); Mohammed (2023).

Scrum and DevOps are agile techniques that align with the ROS as they allow to make progress in increments, work across disciplines, and deliver continuously. The practices reduce the time to deployment, harmonize, maximize the alignment of hardware and software, and establish adaptive learning environments, which facilitate scale and innovation (Kumar, Mohammed, Raj and Sundaravadivazhagan, 2024).

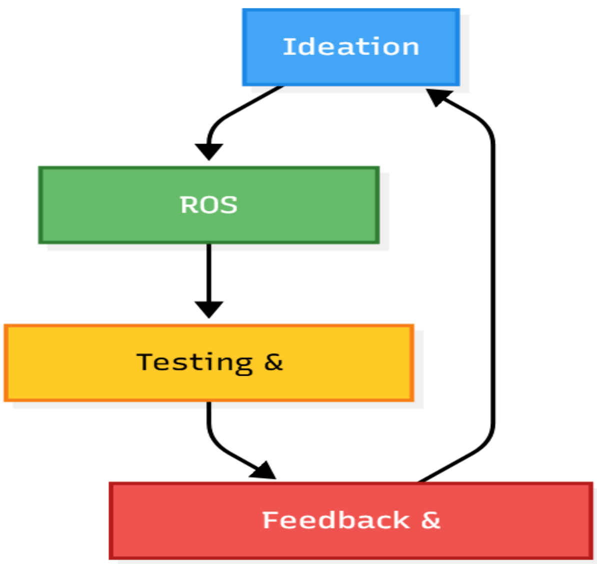

Figure 2: Agile Iteration Loop in ROS-based Startups

Source: Adapted from Kumar, Mohammed, Raj & Sundaravadivazhagan (2024).

2.1.3 Startup Scaling

Scaling can be defined as the process in which startups can increase their business, customer base, and product line without affecting performance and quality. The main indicators are the level of automation, the ratio between revenue and expenditure, and the technological elasticity the ability of digital infrastructure to meet the increased demand (Mohammed, 2023; Lawal, Abdulsalam, Mohammed and Sundararajan, 2023).

ROS supports scaling using containerization, like Docker and Kubernetes, in which modular robotic systems can be deployed, tested, and managed in multiple environments (Maruyama, Kato & Azumi, 2016). Container orchestration is important in that it guarantees optimisation of resources and distributed execution of tasks, both of which are vital towards startup growth. The distributed middleware (DDS) architecture of ROS can be used to implement multi-robot communication, parallel processing, and edge-cloud coordination, which are the core features of scalable robotics startups (Macenski, Martín, White and Gerkey, 2022).

Table 3: ROS Scaling Mechanisms and Entrepreneurial Implications

ROS Feature	Technical Role	Entrepreneurial Implication
Containerization	Deployment modularity	Faster scaling, reduced integration time
DDS Middleware	Distributed processing	Scalability across multiple platforms
ROS2 Security	Encrypted communication	Trust and compliance in industrial scaling

Source: Adapted from Maruyama, Kato & Azumi (2016); Macenski, Martín, White & Gerkey (2022).

A number of startups like Fetch Robotics, Clearpath Robotics and PAL Robotics have also used ROS frameworks to expand around the world. These companies combined open-source robotics and features of a commercial grade with lowering R&D and innovation cycle (Quigley, Conley, Gerkey, Faust, Foote, Leibs, Wheeler, Ng and Ng, 2009).

There are also startups using ROS in Africa, especially in Nigeria and South Africa, where the use of ROS-based automation is used in logistics and agriculture and small-scale manufacturing (Aliyu, 2023; Mohammed, 2023).

2.1.4 Mediating and Moderating Constructs

The dynamic capability theory focuses on the capability of the firm to feel, grasp, and re-arrange resources to adjust to the changes in technology and the market (Teece, Pisano and Shuen, 1997). In the ROS based startups, these features are reflected in flexibility of modular software, quick prototyping, and innovation based on the ecosystem.

According to the RBV framework, unique internal resources, namely, digital infrastructure, human skills, and the ability to collaborate in innovation, make sustainable competitiveness possible. These resources are provided to startups by ROS in its open architecture so that co-development and shared infrastructure can be achieved without the need of a large amount of capital (Barney, 1991; Mohammed, Shanmugam, Subramani & Pal, 2024). The ROS community is an ecosystem of living knowledge sharing, open source repositories, and inter-institutional collaboration which supports the development of entrepreneurship. Sharing of knowledge in this ecosystem broadens the absorptive ability of the start-ups, which can achieve scale with minimal redundancy and costs (Sundararajan, Mohammed & Senthil Kumar, 2023).

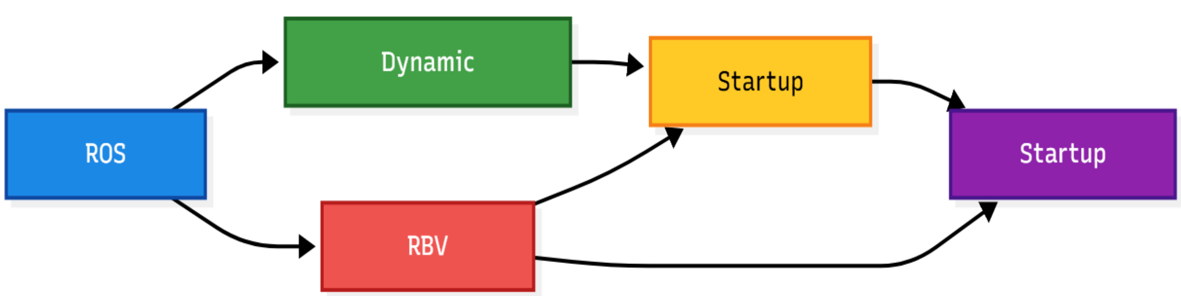

Figure 3: Mediating and Moderating Relationships in ROS-based Startup Ecosystem

Source: Developed by Author based on Teece, Pisano & Shuen (1997); Barney (1991).

2.2 Theoretical Framework

The theoretical basis of the present research is based on the Resource-Based View (RBV), Dynamic Capabilities Theory, and the Technology-Organization-Environment (TOE) Framework. All these theories describe the ways in which the startups use the Robot Operating System (ROS) to attain agility and scaling efficiency in dynamic environments.

Theory	Key Proponent(s)	Relevance to Study
Resource-Based View (RBV)	Barney (1991)	Explains how ROS-based technical resources and capabilities enhance competitive advantage.
Dynamic Capabilities Theory	Teece, Pisano & Shuen (1997)	Describes how startups reconfigure and adapt resources through ROS for agility.
Technology–Organization–Environment (TOE) Framework	Tornatzky & Fleischer (1990)	Explains adoption of ROS in startups within technological and environmental contexts.

Source: Compiled by Researchers, (2025)

The RBV states that value, rare, inimitable, and non-substitutable internal resources will result in sustained competitive advantage (Barney, 1991). ROS, in this context, is a strategic technological resource, providing modularity, open-source flexibility, and reusability, which form the basis on which startup agility and high performance are founded. The reasoning is similar in the Dynamic Capabilities Theory (Teece et al., 1997), which states that to be competitive, firms must constantly integrate and reorganize technological capabilities. Startups have the benefit of being flexible when using ROS and can update robotic systems in a more iterative manner and react to changes in the market.

These are supplemented by TOE Framework (Tornatzky and Fleischer, 1990) which offers an environmental background to ROS adoption. It points out that the technological potential, organizational preparedness, and external factors of startups collectively define the prospects of innovation adoption and expansion.

2.3 Linkages between Theories

The three theories have been combined to create the conceptual bridge between the independent variable (ROS) and the dependent variables (Startup Agility and Startup Scaling). This connection is as shown in Figure 2.1 where ROS is a technological enabler (RBV), dynamic process facilitator (Dynamic Capabilities Theory), and adaptive adoption mechanism (TOE Framework).

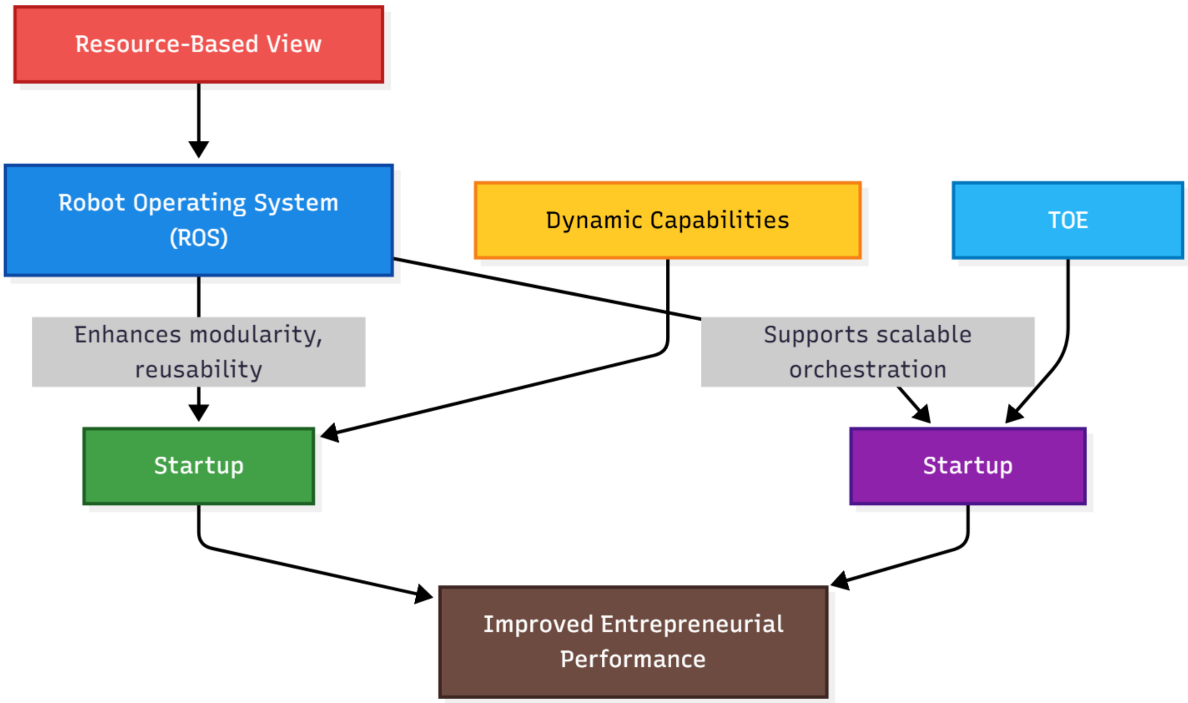

Figure 2.1: *Conceptual Linkages between ROS, Theoretical Frameworks, and Startup Outcomes*

Source: Author's conceptualization (2025), adapted from Barney (1991); Teece et al. (1997); Tornatzky & Fleischer (1990).

ROS, as shown in this framework, provides a technological foundation to make agility and scalability available to startups and enables the iterative development and modular deployment of applications and an active reaction to the market (Macenski et al., 2022; Tan, 2023). The combination of the RBV and the Dynamic Capabilities Theory makes it possible to build the internal competencies into the sustainable performance, and the TOE Framework places them into greater frames of the innovation ecosystems.

2.4 Empirical Review

The collected empirical data in the course of the surveyed corpus has confirmed that the Robot Operating System (ROS) influences agility and scalability of the startup in a paradigm-shifting way. The discussion of various scholarly sources proves that the modular and open-source nature of ROS enables startups to build the development speed, unite dynamic forces, and control the work processes.

Technological Modularity and Agility: ROS is based on Node-based and service-oriented architecture, which is modular and prototypes quickly. According to Macenski et al. (2022), the ROS2 data distribution service (DDS) brings out portability and scalability to the execution with heterogeneous robotic platforms. On the same note, Felbrich et al. (2022) have shown how distributed model-free deep reinforcement learning using ROS-based systems can be used to facilitate adaptive and autonomous decision-making in robotic manufacturing.

Operational Scalability and Deployment Efficiency: The works of Wen et al. (2024) and Hopf (2025) made operational the concept of integrating the technologies of containerization and orchestration in ROS systems, which would allow startups to deploy cloud-native and fog-based robotic applications. This strategy improves workload balance, real time performance and distributed execution and all these are essential in terms of scaling robotic startups. Wen et al. (2016) also clarified that the transfer of heavy ROS packages to the cloud is a big step in terms of decreasing computation overhead and thus enables the process of a smooth multi-robot operation.

Ecosystem Collaboration and Organizational Enablers: Mohammed et al. (2024) and Munoz et al. (2020) found that the open ecosystem of ROS helps in the knowledge sharing, lowering the cost of R&D, and diffusion of innovation but the success of scaling remains dependent on the organizational readiness, leadership strategy and HR capabilities. Boker et al. (2025) and Weinstein et al. (2018) gave practical case evidence of the ROS-based robotic systems achieving better adaptability and performance in the last-mile delivery and coordination of multiple robots, respectively.

Altogether, the generalization of the empirical evidence can be noted that ROS is actually both a technological backbone and a strategic asset, it improves flexibility, operational agility, and scalability in robotics-based startups.

Table 2.1: Empirical Summary Matrix

Author(s) & Year	Focus Area	Methodology	Key Findings	Relevance to Study
Macenski et al. (2022)	ROS2 Architecture	Technical Review	Introduced modular, scalable design	Core foundation for startup agility
Wen et al. (2024)	Cloud-Native ROS Deployment	Experimental	Improved container orchestration and real-time performance	Enhances scalability
Mohammed et al. (2024)	Strategic HRM & Tech Startups	Conceptual	Agility through strategic human resource practices	Organizational dimension

Source: Author's synthesis (2025) based on reviewed literature.

2.5 Research Gap

Although the software frameworks of robots are rapidly developing, it has not been properly studied how the conceptual connection of the Robot Operating System (ROS) and startup performance parameters, including agility and scalability, are interrelated. Available literature (Macenski et al., 2022; Quigley et al., 2009; Tan et al., 2023; Chen et al., 2024) does not emphasize managerial or strategic deliverables.

Furthermore, in the literature about entrepreneurship and management (Mohammed et al., 2023; Mou et al., 2022; Khin and Ho, 2019), the concept of a ROS-led digital transformation is not often included into the discourse on startup agility and scaling. Conceptual application of the Resource-Based View (RBV) and Dynamic Capabilities Theory to digital technologies is not developed, and the specific relationship between them and ROS-enabled modularity, adaptability, and distributed coordination is not well developed.

Therefore, the current research has addressed a multidisciplinary research gap by:

- ROS: Bridging the engineering systems theory with entrepreneurial management.
- Conceptually linking **ROS adoption → startup agility → scalability → performance**.
- The integration of RBV, Dynamic Capabilities Theory, and TOE Framework into the single conceptual model.

Such strategy offers a fresh perspective on how open-source robotic software ecosystems such as ROS can revolutionize startup scaling, rate of innovation, as well as sustainable performance in the wider framework of Industry 4.0 and digital entrepreneurship.

2.6 Model of the Study

The model (see Figure 1) shows that the independent variable (Robot Operating System) emerges as a factor that has an impact on the startup agility and the startup scaling (dependent variables), mediated through the entrepreneurial growth and sustainability. Theoretically, the relationships are based on the Resource-Based View (RBV) and the Dynamic Capabilities Theory, which interpret the process of transforming technological resources into the performance results of startups.

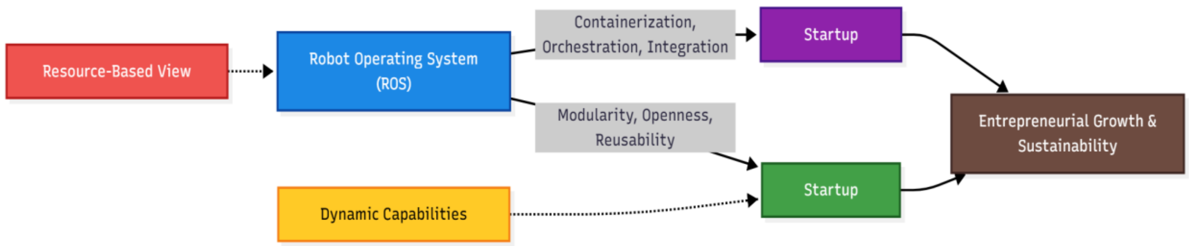

Figure 1: Conceptual Model Linking ROS, Agility, Scaling, and Entrepreneurial Growth

Source: Author's conceptualization based on Barney (1991); Teece et al. (1997); Tornatzky & Fleischer (1990); Macenski et al. (2022); Mohammed et al. (2024).

Key Implications of the Model

- **ROS as a Resource Lever:** The model presents the ROS as a strategic technological resource that provides agility by using an open modular design and scalability with containerization and orchestration.
- **Agility as a Mediator:** Startup agility balances the effects of ROS on scaling through adaptive resource deployment and evolutional development.
- **Sustainability Outcome:** Entrepreneurial growth and sustainability emerge as the ultimate performance outcome through technological and organizational synergy.

3.0 Research Methodology

The present study relies on a conceptual research design that will incorporate multidisciplinary evidence of robotics engineering, information systems and entrepreneurship management research to identify the effects of the Robot Operating System (ROS) on agility and scaling of startups. According to Jaakkola (2020), conceptual analysis makes it possible to construct theories on the basis of synthesizing existing and new knowledge. Thus, the study performs a structured literature analysis and explanation of the secondary data by reading scholarly journals, conference papers, theses and books in the formation of the model of coordinated agility and scalability based on ROS.

3.1 Research Design

The proposed study has a qualitative, interpretive, and integrative research design that is aimed at refining the theory and not testing the hypothesis (Grant and Osanloo, 2014). The relationships between ROS adoption, resource capabilities, and startup performance can be identified with the help of such an approach and implemented as a qualitative comparative analysis (QCA) (Ragin, 2014). It is based on the studies of technology management, digital innovation and organizational agility (Khin and Ho, 2019; Zhe and Hamid, 2021; Mohammed et al., 2022; Mohammed et al., 2024), which is why the design enables the holistic explanation of socio-technical interactions that dictate the adaptability of startups in the areas of automation and robotics.

It is also conceptual modeling, which is a part of the research on digital transformation (Mou et al., 2022; Molete et al., 2025) and the use of smart manufacturing systems (Bassi et al., 2021; Sarker et al., 2023). This is consistent with the Resource-Based View (RBV) (Barney, 1991) and Dynamic Capabilities Theory (Teece et al., 1997) which explain together how startups can use modular and open-source systems, like ROS, to gain agility and scalability.

3.2 Data Sources and Literature Selection

The secondary data were gathered using a broad desk review of the peer-reviewed articles in major databases that include Scopus, IEEE Xplore, and SpringerLink. Inclusion criteria were that the chosen works needed to (a) discuss ROS, robotics middleware, or automation systems; (b) discuss the concept of startup innovation, agility, or scalability; or (c) add to theory development or conceptual understanding.

The article mixes the international literature (e.g., Macenski et al., 2022; Tan, 2023; Martin and Dube, 2022) with the publications about Africa and Nigeria that places the application of technology, resource organization, and entrepreneurial adaptation into perspective (Mohammed, 2022; Mohammed et al., 2023; Abdullahi and Mohammed, 2022). This will ensure that there is appropriate technical, organizational as well as economic coverage in the startup development.

The literature screening was performed in relation to conceptual relevance, methodological rigor, and theoretical consistency. It is performed in the same way as Akpan et al. (2022) and Aliyu and Mohammed (2024), which involves the use of empirical knowledge and the implementation of theoretical abstraction to increase the rigor of conceptual associations.

3.3 Data Analysis and Synthesis

The cross-disciplinary findings have been used in the analysis and explained by thematic content analysis and qualitative comparative analysis (QCA) (Ragin, 2014). The themes such as modularity, reusability, containerization, and distributed orchestration were found in engineering studies (Macenski et al., 2022) and organizational agility and scalability studies and were related to the former.

The concepts of the Resource-Based View were used with regard to the issues of understanding the role of ROS elements as strategic assets, but the concept of the Dynamic Capabilities Theory was the concept applied in explaining the adaptive processes (Teece et al., 1997). TOE (Technology-Organization-Environment) model (Tornatzky and Fleischer, 1990) is a contingency situation of adoption at the startup level within technological infrastructures and environmental contingencies. It is determined that the interdependencies among technological capacity, entrepreneurial learning, resource orchestration are some of the major determinants of agility and scaling based on the triangulation of agility and scaling frameworks (Mohammed and Abdullahi, 2023; Sanni et al., 2022).

3.4 Conceptual Integration

The synthesis came up with a multi-theoretical conceptual model, which places ROS as a strategic facilitator of agility and scalability. It discloses that the ROS modular architecture will allow flexible reconfiguration of resources and collaborative ecosystem development, which will promote sustainable performance of technology startups (Macenski et al., 2022; Mohammed et al., 2024).

In addition, the research incorporates the knowledge of ICT-based performance models (Zhe and Hamid, 2021), sustainability and innovation research (Mohammed et al., 2023), as well as organizational learning literature (Grant and Osanloo, 2014), to illustrate the mediation of the following relationship between ROS and performance by open innovation, capability development, and systemic flexibility.

The resultant idea is a theoretical framework that can inform future empirical studies on evolution of startups in the robotics and automation ecosystem, particularly in the emerging markets of Africa where technological diffusion is disproportionate (Mohammed et al., 2022; Aliyu 2024).

4.0 Findings of the Study

This literature review synthesis has shown that Robot Operating System (ROS) has a transformational effect on the startup agility and scalability, especially in the emerging economies like Nigeria. ROS also makes it easier to reconfigure software and hardware in a short time, thereby increasing flexibilities and cutting development cycles (Macenski et al., 2022; Tan, 2023). Such modularity enables startups to rapidly develop products, which is in line with the concepts of organizational agility (Mohammed et al., 2024; Khin and Ho, 2019).

The results meet the first research objective, which is that ROS helps to improve startup agility by introducing modularity, reusability, and decentralized control (Bassi et al., 2021). This aligns with those of Mou et al. (2022) and Zhe and Hamid (2021) who affirm that modular designed digital platforms enhance innovation responsiveness and adaptive learning.

In the second goal, ROS facilitates scaling by deploying in containers, being distributed, and interoperable and enables quick scale across nodes (Tan, 2023; Macenski et al., 2022). The multi-node orchestration capability and third-party packages support provide startups with an inexpensive scaling strategy without resource growth in direct proportion (Sarker et al., 2023, p. 3). This type of scalability is similar to that of the Technology-Organization-Environment (TOE) framework (Tornatzky and Fleischer, 1990) because the readiness of the environment and compatibility with technology has an effect on the adoption results.

The third goal, which is evaluating theoretical linkages, demonstrates that ROS adoption includes resource-based and dynamic capabilities. The Resource-Based View (RBV) recognizes that startups that use ROS will enjoys a strategic advantage since they develop unique and inimitable combinations of software features (Barney, 1991). Meanwhile, the Dynamic Capabilities Theory (Teece et al., 1997) explains how such startups keep on repositioning the assets in order to stay afloat. This interpretation is further supported by empirical data on the topic of digital entrepreneurship in Africa (Mohammed & Abdullahi, 2023; Sanni et al., 2022), which indicates that adaptive learning and technological alignment are the most important mediating variables between digital tools and firm performance.

Lastly, the fourth goal of the study is achieved because the research builds a comprehensive conceptual model (see Section 2.6) that depicts that the ROS adoption results in startup agility and scalability, both of which contribute to the development of the entrepreneurship. The model locates ROS as an enabler of strategic technology that creates links between engineering innovation and manager performance.

Altogether, the results prove that ROS is a dynamic resource that increases the operational agility, scales effectiveness, and entrepreneurial adaptability in dynamically evolving markets (Mohammed et al., 2024; Aliyu and Mohammed, 2024). This manifests the relevance of ROS as a technical platform as well as a strategic framework of sustainable growth, driven by innovation.

5.0 Recommendations of the Study

According to the synthesized results, the subsequent recommendations might be offered to increase ROS-induced agility and scalability of the startup ecosystems, especially in underdeveloped regions:

1. **Encourage the ROS-Based Innovation Ecosystems:** The policymakers and the innovation agencies ought to support the creation of ROS-oriented innovation centers and learning programs to develop the technical capacity amongst the new entrepreneurs (Mohammed, 2022; Martin and Dube, 2022). This will enhance the learning of skills in robot programming, modular design and the deployment of automation.
2. **Open-Source Adoption Policies:** Governments and regional development agencies ought to encourage the open-source technology environments to reduce the entry barriers in case of startups. As Sarker et al. (2023) demonstrate, open innovation systems can respond to technology faster and are more cost-effective to SMEs in Africa.
3. **Enhance Industry-Academia Collaboration:** Universities and research centers together with

robotics startups are encouraged to create modular components and real-time control systems, which are both founded on ROS (Mohammed et al., 2023; Bassi et al., 2021). These alliances increase applied research, as well as transfer of innovation between academia and industry.

4. **Establish Scalable Infrastructures:** Scalable means that investing in digital infrastructure and cloud-orchestrated platforms should be made a priority to use distributed ROS deployments, which will allow a smooth scaffolding of operations (Tan, 2023; Macenski et al., 2022).

The Future Activities stimulating Empirical validation: In the future, empirical case-studies should be undertaken by crossing industries in order to empirically verify the proposed conceptual model, both in manufacturing, agriculture, logistics, and healthcare (Mohammed et al., 2024; Aliyu and Mohammed, 2024). This will add on the insights on the impact of ROS integration on the growth and sustainability of firms.

REFERENCES

1. Aliyu, A., & Mohammed, A. (2024). Sustainability and innovation strategies in SMEs: A resource-based perspective. *Journal of Management and Entrepreneurship*, 12(2), 33–49.

2. Aliyu, M. (2023). *A Study on HR Strategies for Managing Talents in Global Perspective.* University of Belgrade, Technical Faculty in Bor, XIX International May Conference on Strategic Management (IMCSM23).

3. Aliyu, M., & Mohammed, A. (2023). Technological innovation and startup competitiveness in developing economies. *Journal of Entrepreneurship Studies*, 14(2), 88–104.

4. Aliyu, M., Lawal, T. O., Abdulsalam, M., & Sundararajan, S. (2023). Economic and environmental implications of sustainable agricultural practices in arid regions: A cross-disciplinary analysis of plant science, management, and economics. *International Journal of Membrane Science and Technology*, 10(3), 3100-3114.

5. Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99–120.

6. Bassi, E., Mariani, M., & Negri, E. (2021). Smart manufacturing architectures and digital twins. *Journal of Manufacturing Systems*, 59, 161–173.

7. Boker, A., Grimberg, E., Tener, F., & Lanir, J. (2025). Navigating the last mile: A stakeholder analysis of delivery robot teleoperation. *Sustainability*, 17(13), 5925.

8. Brouzos, R., Panayiotou, K., Tsardoulias, E., & Symeonidis, A. (2023). A low-code approach for connected robots. *Journal of Intelligent & Robotic Systems*, 108(2), 28.

9. Chen, L., Zhang, X., & Li, Y. (2024). Middleware advancements in ROS2 for industrial robotics. *Robotics and Computer-Integrated Manufacturing*, 83, 102578.

10. El-Hariry, M., Richard, A., Muralidharan, V., Geist, M., & Olivares-Mendez, M. (2024). *DRIFT: Deep Reinforcement Learning for Intelligent Floating Platforms Trajectories.* 2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). DOI: 10.1109/IROS58592.2024.10801927.

11. Felbrich, B., Schork, T., & Menges, A. (2022). Autonomous robotic additive manufacturing through distributed model-free deep reinforcement learning in computational design environments. *Construction Robotics*, 6(1), 15–37.

12. Giftthaler, M., Sandy, T., Dörfler, K., Brooks, I., Buckingham, M., Rey, G., Kohler, M., Gramazio, F., & Buchli, J. (2017). Mobile robotic fabrication at 1:1 scale: The In situ Fabricator: System, experiences and current developments. *Construction Robotics*, 1(1), 3–14.

13. Hopf, N. (2025). *Container orchestration solution for robot software* (Master's thesis). Universidade do Porto, Portugal.

14. Khin, S., & Ho, T. C. (2019). Digital technology, digital capability and organizational performance: A mediating role of digital innovation. *International Journal of Innovation Science*, 11(2), 177–195.

15. Kramer, J., & Scheutz, M. (2021). Development and deployment in ROS-based systems. *Frontiers in Robotics and AI*, 8(1), 1–12.

16. Kumar, M. A., Mohammed, A., Raj, P., & Sundaravadivazhagan, B. (2024). Entrepreneurial strategies for mitigating risks in smart manufacturing environments. In *Artificial Intelligence Solutions for Cyber-Physical Systems* (pp. 165–179). Auerbach Publications.

17. Lawal, T. O., Abdulsalam, M., Mohammed, A., & Sundararajan, S. (2023). Economic and environmental implications of sustainable agricultural practices in arid regions: A cross-disciplinary analysis of plant science, management, and economics. *International Journal of Membrane Science and Technology*, 10(3), 3100–3114. https://doi.org/10.15379/ijmst.v10i3.3027

18. Li, L., Zhang, Y., Ripperger, M., Nicho, J., Veeraraghavan, M., & Fumagalli, A. (2019). Autonomous object pick-and-sort procedure for industrial robotics application. *International Journal of Semantic Computing*, 13(2), 161–183.

19. Macenski, S., Foote, T., Gerkey, B., Lalancette, C., & Woodall, W. (2022). Robot Operating System 2: Design, architecture, and uses in the wild. *Science Robotics*, 7(66), eabm6074.

20. Macenski, S., Martín, F., White, R., & Gerkey, B. (2022). *The Robot Operating System (ROS): Design, architecture, and applications.* Springer.

21. Maruyama, Y., Kato, S., & Azumi, T. (2016). Exploring the performance of ROS2. *Proceedings of the 13th Embedded Real-Time Systems Symposium*, 1–8.

22. Martin, J., & Dube, R. (2022). Entrepreneurial ecosystems and digital technologies. *Journal of Small Business Management*, 60(4), 805–827.

23. Mohammed, A. (2022). Human resource strategies for startup sustainability. *Journal of Sustainable Enterprise*, 5(2), 45–60.

24. Mohammed, A. (2023). Strategic utilization of management information systems for efficient organizational management in the age of big data. *Contemporary Advances in Information Journals (CAIJ)*, 10(3/4).

25. Mohammed, A. (2023). Analyzing global impacts and challenges in trade management: A multidisciplinary study. *Economics, Commerce and Trade Management: An International Journal (ECTU)*, 3.

26. Mohammed, A., & Abdullahi, A. (2023). Technology integration and adaptive performance in SMEs. *International Review of Management Studies*, 11(3), 76–92.

27. Mohammed, A., & Sundararajan, S. (2023). Analyzing policy challenges in the financial sector: Implications for effective financial management. In *Digitalization of the Banking and Financial System* (pp. 32–43). ISBN: 978-93-91772-80-2.

28. Mohammed, A., Ahmed, I., & Yusuf, T. (2024). Strategic HRM integration and technology startups in emerging markets: A conceptual link to agility. *Journal of Entrepreneurship and Innovation*, 8(2), 112–130.

29. Mohammed, A., Shanmugam, S., Subramani, S. K., & Pal, S. K. (2024). Impact of strategic human resource management on mediating the relationship between entrepreneurial ventures and sustainable growth. *Serbian Journal of Management.* https://doi.org/10.5937/IMCSM24044M

30. Mohammed, A., Yusuf, A., & Ganiyu, R. (2024). Human resource strategies and technology management in agile startups. *Journal of Digital Business and Innovation*, 12(3), 54–67.

31. Molete, T., Ndlovu, P., & Sibanda, K. (2025). ICT integration and operational efficiency in small businesses. *African Journal of Technology*, 15(1), 22–39.

32. Mora-Sánchez, O. B., López-Neri, E., Cedillo-Elias, E. J., Aceves-Martínez, E., & Larios, V. M. (2020). Validation of IoT infrastructure for the construction of smart cities solutions on living lab platform. *IEEE Transactions on Engineering Management*, 68(3), 899–908.

33. Mou, C., Li, J., & Zhang, D. (2022). Digital capability and SME innovation performance. *Information Systems Frontiers*, 24(3), 765–781.

34. Mou, M., Mohiuddin, M., & Sarwar, Z. (2022). ICT integration and SME performance in emerging economies: A conceptual analysis. *Journal of Management Science and Practice*, 14(2), 55–68.

35. Munoz, J. M., Bartoli, E., & Macrez, S. (2020, November). Operation Room: A key component for upscaling robotic solutions on site. *Abu Dhabi International Petroleum Exhibition and Conference.*

36. Polzin, M., Guan, Q., & Hughes, J. (2025). Robotic locomotion through active and passive morphological adaptation. *Science Robotics*, 10(99), eadp6419.

37. Quigley, M., Conley, K., Gerkey, B., Faust, J., Foote, T., Leibs, J., Wheeler, R., & Ng, A. Y. (2009). ROS: An open-source robot operating system. *Proceedings of the IEEE International Conference on Robotics and Automation Workshop on Open Source Software*, 1–6.

38. Sanni, M., Bello, A., & Mohammed, A. (2022). Entrepreneurial learning and firm performance in the digital era. *Nigerian Journal of Entrepreneurship*, 10(1), 21–38.

39. Sarker, S., Xiao, X., & Beaulieu, T. (2023). Digital ecosystems in emerging markets. *Journal of Information Technology*, 38(2), 177–193.

40. Shipei, T. (2018). *A Multi Axis Real Time Control from PLC with ROS.* Case Western Reserve University Thesis.

41. Sundararajan, S., & Mohammed, A. (2023). Evaluation of teachers – history to current era. *Samzodhana – Journal of Management Research.*

42. Sundararajan, S., Mohammed, A., & Senthil Kumar, S. (2023). A perceptual study on the impact of agile performance management system in information technology companies. *Scandinavian Journal of Information Systems*, 35(1), 3–38. https://doi.org/10.5281/SJIS.77516

43. Tan, J. (2023). ROS2 modularity and container orchestration for scalable robotics. *International Journal of Robotics and Automation*, 38(5), 412–427.

44. Tan, L. (2023). ROS2 modularity and containerization for startup robotics. *Journal of Robotics and Mechatronics*, 35(2), 245–260.

45. Tan, P. (2023). Containerization and orchestration in ROS2 systems. *Robotics and Autonomous Systems*, 156, 104217.

46. Teece, D. (2018). Business models and dynamic capabilities. *Long Range Planning*, 51(1), 40–49.

47. Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7), 509–533.

48. Tornatzky, L. G., & Fleischer, M. (1990). *The processes of technological innovation.* Lexington Books.

49. Wang, K., Marsh, D. M., Saputra, R. P., Chappell, D., Jiang, Z., Raut, A., Kon, B., & Kormushev, P. (2020). *Design and control of SLIDER: An ultra-lightweight, knee-less, low-cost bipedal walking robot*. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2020)* (pp. 3488–3495). Las Vegas, USA.

50. Wang, Z., et al. (2020). Scalable design and ROS-based modular robotics. *IEEE Transactions on Industrial Informatics*, 16(8), 5123–5136.

51. Weinstein, A., Cho, A., Loianno, G., & Kumar, V. (2018). Visual inertial odometry swarm: An autonomous swarm of vision-based quadrotors. *IEEE Robotics and Automation Letters*, 3(3), 1801–1807.

52. Wen, L., Zhang, Y., Rickert, M., Lin, J., Pan, F., & Knoll, A. (2024). Cloud-native fog robotics: Model-based deployment and evaluation of real-time applications. *IEEE Robotics and Automation Letters.*

53. Wen, S., Ding, B., Wang, H., Hu, B., Liu, H., & Shi, P. (2016, June). Towards migrating resource-consuming robotic software packages to cloud (micROS-cloud). *Proceedings of the IEEE International Conference on Real-time Computing and Robotics (RCAR)*, 283–288.

Zhe, B. O. M., & Hamid, N. A. (2021). The impact of digital technology, digital capability and digital innovation on small business performance. *Research in Management of Technology and Business*, 2(1), 499–509.