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Technology foresight for sensor applications in the Philippine manufacturing industry through scenario building

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Abstract—**The advent of the fourth industrial revolution (4IR) offers promising improvements in operational efficiency and profitability for various industries, and can be a key component to leapfrog the many sectors of manufacturing in the Philippines. This will necessitate the reskilling and upskilling of Filipino automation engineers and instrumentation technicians to commission and maintain smart technologies for production facilities. The further expansion of the country's manufacturing capacities presents an opportunity to locally develop products and solutions for process automation. This includes sensor technologies and applications that can boost the Filipino manufacturers' capabilities through locally-sourced automation components. Various sensor technologies and applications can be explored for further improvement through research & development. Through technology foresight, this study looks into the potential of Filipino technology firms to develop sensors that are locally designed and assembled, addressing the needs of growing industries. The use of scenario-building approach allows for the identification and ranking of the key predictable drivers based on the insights of industry professionals. Opportunities and risks are evaluated based on future possible scenarios.**

Keywords—Philippine manufacturing industry, sensor technologies, instrumentation and control, technology foresight, scenario-building

I. INTRODUCTION

4IR technologies cover the dimensions including digitalization, control, insight, and automation. These can be implemented through the use of embedded systems, data-driven controls, sensors, and human-centered automation [1]. Blockchain is one of the key technologies that can revolutionize the adoption of 4IR systems in the Philippines through the use of cryptography to allow for the secure transfer of digital information including finance, supply chain data, and business model formulation [2].

Another integral part of the 4IR is the Internet of Things (IoT), and is described by a system of interconnected sensors, actuators, and mobile devices that is intelligent, programmable and is capable of human interaction. IoT's applications extend from smart manufacturing, education, and human resources, to digital economy and E-governance, and is a key to the creation of self-sufficient smart cities [3]. When implemented in the Philippine manufacturing settings, these developments will boosts the competitiveness of local firms and enhance the efforts of various industries to adhere to the 17 Sustainable Development Goals (SDG) defined by the United Nations to address social and economic challenges, more particularly in the areas of clean and affordable energy, industry, innovation and infrastructure [4].

Industrial process instruments are used to measure the common variables including: temperature, pressure, flow, and volume. Quality can also be measured in terms of concentration or purity and requires special types of instruments called process analyzers [5]. Other applications that require special sensing technologies include that of detecting the presence of hazardous organic compounds in the atmosphere. For example, detecting presence of benzene or other volatile organic carbons can require relatively simpler mechanisms such as photoionization, electrochemical, and resistive sensors, or complex systems such as spectroscopic methods or gas chromatography [6].

Some of the prospective areas of research in sensing technologies include the following: pressure sensors (resonant, capacitive, piezoelectric, optical), position sensors (capacitive, potentiometric, eddy current based, optical, magnetostrictive linear position), force sensors (load cells, strain gauges, force sensing resistors), flow sensors (mass flow, positive displacement, velocity flow) [7]. As for potential applications, sensors can be connected to electronic control systems to operate smart factories featuring interoperability between different devices allowing for the convenient vertical integration of supply chains, while the use of robotics, artificial intelligence, and virtual reality techniques will enable human-machine integration for remote operation of process units in harsh or hazardous environments. The applications of these sensors can be extended to agriculture and smart farming. By connecting these devices to a server through IoT, proper crop cultivation can be done through environmental monitoring, as well as automated activation of sprinklers, LED lights, and air conditioners [8].

II. OBJECTIVES

This paper aims to identify patterns of technology development and adoption for sensor modules and subsystems used in various applications in the Philippine industries, and determine the feasibility of establishing sensor development industry to cater to the specific needs of local manufacturing firms. More specifically, this study aims to:

1. Create future scenarios for establishment of sensor design and development in the Philippines;

2. Determine the proper approaches to adopt recent advancements in the applications of smart sensors; and
3. Develop strategies for the strengthening of local capabilities to produce sensor technologies for the Philippine manufacturing industry.

III. Methodology

Through looking into possible future scenarios, technology managers are able to foresee critical factors and risks that can determine the success of firms venturing into certain industries across varying market conditions [9, 10]. A ten-stage process for technology foresight was first presented by Professor Glen Imbang and was used to develop future scenarios for process analytical instrumentation technologies, and safety industry [11, 12].

- 1st Stage: Identification of Focal Issues
- 2nd Stage: Environmental Scanning
- 3rd Stage: Key Predictable Variables Identification and Characterization
- 4th Stage: Critical Uncertainties Identification
- 5th Stage: Clustering of Variables
- 6th Stage: Ranking of Variables for Key Driving Forces
- 7th Stage: Scenario Logics Selection
- 8th Stage: Scenarios Development
- 9th Stage: Evaluation of Scenario Coherence
- 10th Stage: Implications of Scenarios to Strategic Planning

IV. Focal Issues Identification

There is a need to find the means for the industry, academe, and government institutions to work collaboratively to ensure that R&D initiatives addresses the requirements of manufacturing operations, and that these developments are properly funded and supported, and that intellectual property rights are being protected [13]. Proper test environments and methodologies are needed to be established to determine technology readiness for scaling up mass production and commercialization [14].

Engineering and applied science programs should be enhanced by universities to prepare engineers and scientists for a career in research and development geared to address the needs of local manufacturing operations, particularly in areas of industrial instrumentation, process analytics, and distributed control systems. Technical-vocational training courses for automation technicians should be upgraded to cover smart manufacturing technologies. There is also a need for such training programs to be evaluated on continuous basis to match the growing needs of increasingly complex manufacturing processes. Also, R&D strategies should be based on proper assessment of opportunities, uncertainties, and market parameters, to ensure that investment decisions address the competition models [15]. The related variables can be plotted to allow for the formulation of unified approaches, targeting the critical issues.

V. Environmental Scanning

From the focal issues, STEEP and SWOT analyses were performed to evaluate the critical variables.

A. STEEP Analysis

Factors including Social, Technological, Economic, Environmental, and Political are presented in this section.

1) Social: Social awareness as a result of effective engineering education and technical-vocational training available in the Philippines.

2) Technological: Availability of locally developed sensing technologies for industrial and safety applications due to implementation of rigorous quality standards, and interconnection of automated systems featuring secure data transfer.

3) Economic: Improving local economic conditions creating the need for smarter automation solutions, while locally available technologies can support consumers in the event of global value chain disruptions.

4) Environmental: Strict imposition of the Clean Air Act and other DENR orders will prompt manufacturers to improve operational efficiencies to cut emissions and waste.

5) Political: Support from the key government agencies will help enforce Philippine policies to invigorate research and development activites to create technolgies that conform to international standards.

B. SWOT Analysis

Internal factors such as strengths and weaknesses, and external factors such as opportunities and threats are identified.

1) Strengths: Availability of Filipino researchers trained for new product development in the fields of instrumentation electronics and materials science & engineering.

2) Weaknesses: Technology benchmarking is needed to assess local competitiveness in the field of instrumentation.

3) Opportunities: Local suppliers can be tapped for raw materials including semiconductors, metals, and polymer resins for convenient and cheaper sources of key components.

4) Threats: U.S., E.U., and Japan-based automation firms remain the popular choices for manufacturing applications. China-based solutions offer more cost-competitive options.

VI. Key Predictable Variables Identification and Characterization

Factors and issues related to existing trends and developments are discussed and sorted according to the STEEP framework.

A. Socio-cultural

Engineering and applied science programs offered by Philippine universities can be improved to equip graduates with the research skills to design and develop sensor technologies and applications for various applications. Related programs include: applied chemistry, applied physics, instrumentation engineering, manufacturing engineering, and energy engineering.

B. Technological

Applications of wireless sensor networks can be enhanced by incorporating smart technologies including Big Data Analysis and Artificial Intelligence, while quality certifications will help marketability of products abroad.

C. Economic

Local sensor developers can gain cost advantage by sourcing materials from global value chains and Southeast Asian networks. Products and solutions developed locally can gain broad market share through efficient supply chains and excellent customer support.

D. Environmental

Locally developed sensors should be able to withstand extreme temperature swings and varying humidity conditions within the tropical regions to address the needs of local customers. Proper temperature and ingress protection rating should be considered in the design of equipment enclosures.

E. Political

Government support can help boost R&D and NPD activities in the Philippines. New product development for sensing devices should take into account the industrial standards such as International Electrotechnical Commission (IEC), Underwriters Laboratories (UL), National Electrical Manufacturers Association (NEMA), EU's Comité Européen de Normalisation Électrotechnique (CENELEC), and Appareils destinés à être utilisés en Atmosphère Explosive (ATEX) for hazardous environments, so that locally manufactured devices can penetrate foreign markets, where certain certifications are required by some jurisdictions in specific applications.

VII. Critical Uncertainties Identification

The effect of the COVID-19 pandemic experienced by all economies during the lockdowns where all modes of transportation and cargoes were affected presents a powerful reminder that the global value chains are not immune to disruptions [16]. Also, the war in Ukraine and the resulting sanctions brought about by the political developments in Europe and the U.S. demonstrates the idea that global consumers must not be dependent on a single source of raw materials. Otherwise, manipulation of the supply chains can become a tool for economic, as well as political control [17].

Implementation of AI in automation of manufacturing process promises enhanced operational efficiency and personnel safety. However, the recent growth of AI capabilities has been drastic enough that even the AI experts themselves have become weary of its future [18]. Lastly, whistleblowers from IT and defense sectors have sown fears among technology enthusiasts that people became weary of using mobile devices to manage personal data [19]. Information security concerns need to be addressed by tightening policies and implementation of encryption technologies will give users the confidence to fully utilize online means of transferring personal data as well as business transactions.

VIII. Clustering of Variables

After the environmental scanning, identified Key Predictable Variables are sorted and related factors are combined into clusters.

A. Social factors

Socially conscious Filipino engineers can be trained for R&D and new product development, and local technicians can be equipped with the skills towards best maintenance practices. Key government agencies such as the Commission on Higher Education (CHED) and Technical Education and Skills Development Authority (TESDA) can spearhead enhanced training programs in instrumentation technologies to prepare Filipino professionals for careers in automation through design, project commissioning, or field services.

B. Technological

Local capability to manufacture sensors, using controlled environments and calibrated equipment in accordance with international quality standards. Manufacturers can seek guidance from various certification bodies such as UL, or EU's CENELEC,

C. Economic

The flexibility of Filipino firms to utilize global value chains for sourcing raw materials, while taking advantage of Philippine economic policies will allow factories to scale up production capabilities.

D. Environmental

The drive towards efficient manufacturing practices also results to less waste and emissions. Thereby reducing energy and raw materials consumption.

E. Political

Philippine policies to support research and development can help Filipino scientist create breakthroughs in sensing technologies.

IX. Variables Ranking for Key Driving Forces

Insights were gathered from professionals and industry experts with local experience through engineering, services and R&D for sensor applications. Through expert survey, the variables are ranked by industry professionals according to each factor's impact on technology development and the uncertainty on the technology adoption and commercialization, and mapped using the scenario matrix to present future possibilities with each scenario generated from the related variables.

TABLE I. Impact & Uncertainty

Cluster	*Impact*	*Uncertainty*
1. Philippine policies for S&T	7.18	6.03
2. Locally developed sensor tech	6.52	6.00
3. Implement Int'l quality standards	8.03	5.58
4. Global value chains	7.67	5.83
5. Philippine economic conditions	6.88	5.67
6. Local demand for sensors	7.82	5.79
7. Political developments	6.73	6.12
8. Social awareness on automation	7.09	5.45
9. Environmental impacts	7.85	5.27
10. Data security for 4IR	7.48	5.91
11. Filipino technicians	7.36	5.73
12. Engineering and R&D	7.73	5.55

X. Selection of Scenario Logics

Future scenarios are created through the formation of different clusters by interconnecting the related variables.

1. Philippine policies for the advancement of Science & Technology.
2. Locally developed sensor technologies.
3. Implementation of international quality standards across the industries.
4. Global value chain disruptions.
5. Local economic conditions.
6. Local demand for cost effective sensors.
7. Political developments in the Philippines.
8. Social awareness on industrial efficiency resulting from automation.
9. Environmental impacts of manufacturing industries.
10. Data security issues by interconnecting manufacturing facilities.
11. Level of training of Filipino technicians in sensor applications.
12. Engineering programs for the design and development of sensor applications.

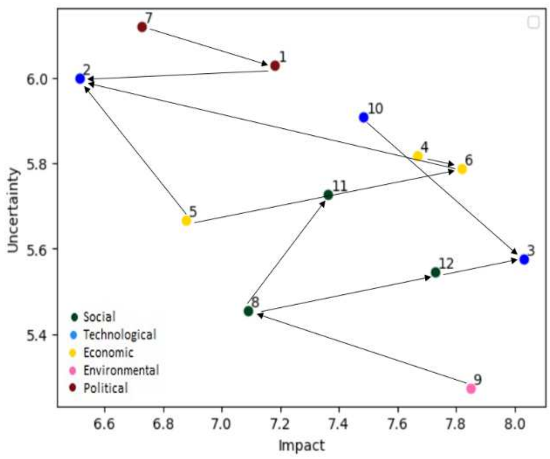

Fig. 1. Impact and uncertainty scatter plot.

The **1st Scenario Logic** demonstrates the future where technology push provides low-cost sensors to be available for the local market. The following variables are considered for this scenario: 1, 2, 3, 4, 5, 7, and 12.

The **2nd Scenario Logic** exhibits the future where market pull creates the need for sensor technologies to address the needs of the manufacturing industry. The following variables are considered for this scenario: 3, 4, 5, 6, 8, 9, 10, 11 and 12.

The **3rd Scenario Logic** shows the future where synergistic growth of locally-developed sensor technologies match the increasing requirement of local applications. All identified variables are considered for this scenario.

XI. Development of Scenarios

A. 1st Scenario Logic

The first Scenario Logic demonstrates the future having continuous R&D efforts resulting to low-cost locally available sensor devices and instrument accessories.

Through economies of scale, mass-production of locally designed sensors will allow for these products to be marketed at competitive price points. Thereby allowing for these technologies to be more accessible to local consumers

B. 2nd Scenario Logic

The second Scenario Logic demonstrates the future having expanded manufacturing sectors in the country presenting the need for automation solutions to be locally available to address the long lead time brought about by importing and shipping technologies from abroad.

Through expanding the operating capacities of local manufacturing facilities, the automation required to operate the plant equipment will create the need for immediate access to sensors and field instruments. This will create an attractive environment for investors to venture into developing locally produced sensor devices for process measurements.

C. 3rd Scenario Logic

The third Scenario Logic demonstrates the future where new product development for sensor devices and equipment in the Philippines matches the increased demand for automation technologies.

XII. Scenario Coherence Assessment

The possible scenarios that were developed are assessed according to the criteria and related variables previously identified.

A. 1st Scenario Logic

An important aspect of the technology push strategy for marketing sensor applications is the establishment of excellent customer support and service engineers that can address the concerns of end-users. This can be done if Filipino technicians are properly trained and evaluated through the following: Technical Education and Skills Development Authority (TESDA) certification, assessment, continuous improvement, reskilling and upskilling through technical training through programs aligned with the continuously evolving trend in sensing technologies.

B. 2nd Scenario Logic

Vertical and horizontal integration of local manufacturing firms requires the use of smart manufacturing technologies to ensure that operating parameters and production rates are matched between upstream and downstream facilities. The further expansion of local manufacturing firms to increase production capacities will create the need for automation equipment and services to be locally accessible for shorter lead times of required spare parts and vendor support.

C. 3rd Scenario Logic

Structured training and certification programs for field service technicians and engineers will ensure that relevant workforce is locally available. Evaluation models can be utilized to ensure technical training programs effectively address the need for relevant skills due to increasing complex systems brought about by integrating smart technologies into the production facilities [20, 21].

XIII. Implications to Strategic Planning

The use of SWOT matrices allows for strategies to be developed across identified scenarios.

1. Matching strategy makes use of the industry's strengths to exploit the opportunities.
2. Change strategy gets rid of the weaknesses of the firms to make use of the opportunities.
3. Neutralization strategy uses strengths to counteract the threats.
4. Defensive strategy avoids threats by managing weaknesses.

TABLE II. SWOT Matrix: 1st Scenario Logic

1st Scenario: Technology-push	***Strengths*** 1. Lower cost through mass production. 2. Local tech support.	***Weaknesses*** 1. IP protection. 2. International certification required.
Opportunities 1. Filipino scientists for R&D and NPD. 2. Less local competition.	***Matching strategy*** 1. Trained Filipino scientists to develop products using local materials and tech.	***Change strategy*** 1. Establish local certifications to conform with international standards.
Threats 1. Low cost alternatives from China and SEA. 2. Established brands from US, EU, etc.	***Neutralization strategy*** 1. Develop Filipino tech support and service engineers for local and foreign customers.	***Defensive strategy*** 1. Strengthen IP laws and international patents to market across the GVC.

TABLE III. SWOT Matrix: 2nd Scenario Logic

2nd Scenario: Market-pull	***Strengths*** 1. Shorter delivery times. 2. Quick access to local services.	***Weaknesses*** 1. Low R&D funding. 2. Few specialists in sensing applications.
Opportunities 1. Diversified customer needs. 2. Partnerships between suppliers and consumers.	***Matching strategy*** 1. Form strategic alliances and partnerships between local firms for broader market access.	***Change strategy*** 1. Industries to partner with academic institutions to develop R&D capability for local applications.
Threats 1. Weak policy implementation for safety and quality. 2. Rate of technology adoption.	***Neutralization strategy*** 1. Develop local standards for tech adoption to enhance safety and quality.	***Defensive strategy*** 1. Key government agencies to lead research for tech policy implementation.

TABLE IV. SWOT Matrix: 3rd Scenario Logic

3rd Scenario: Integrated approach	***Strengths*** 1. Local supply chain. 2. Availability of natural resources.	***Weaknesses*** 1. Ease of doing business. 2. FDI limitations.
Opportunities 1. Broad market potential. 2. Upstream and downstream market growth.	***Matching strategy*** 1. Integration of technology developers and manufacturers to enhance production and marketing.	***Change strategy*** 1. Enable FDI for broader funding sources and exploit local and global value chains.
Threats 1. Steep learning curve for technicians. 2. Weak internet for IoT, Big Data, etc.	***Neutralization strategy*** 1. Include industry exposure as part of training for Filipino technicians.	***Defensive strategy*** 1. Allow entry of foreign tech investors to expand local capabilities.

XIV. Conclusions & Recommendations

The scenario-based foresight approach allows for technology managers to look into more detailed view of possible eventualities and the corresponding variables to consider in the event that the investors will venture into yet undiscovered business opportunities [22, 23]. The manufacturing sector's drive towards the profitable, safe, and environment-friendly approaches, can contribute to the increase in demand for low-cost but effective sensor technologies. Through getting a glimpse of the future possibilities, potential investors do not need to venture blindly, and that if risks are encountered, mitigating measures can be devised [24].

Through Scenario 1, local manufacturers can develop Filipino-produced sensing devices and measuring equipment through the technology-push scenario, providing the option for manufacturing operators in the country to have a local source for their instrumentation needs, with shorter delivery lead times and convenient customer service features [25, 26]. Scenario 2 presented the future where the growing manufacturing industry (food processing, chemicals, pharmaceuticals, etc.) creates the demand for locally sourced instrumentation solutions or the market-pull scenario [27, 28]. This creates a market environment where the design, manufacture, and distribution of home-grown automation solutions becomes an attractive investment opportunity.

Lastly, Scenario 3 explores the possibility of having an increase rate of development and production of sensors and field instruments in the Philippines that matches the growing need of expanding manufacturing sectors. In this scenario, it is critical for sensor developers to plan and strategize the roll out of new products in a timely manner, so as to address the needs of growing industries [29]. Prior studies have projected the potential of scaling up the adoption of robotics and artificial intelligence in the country [30, 31], but the future scenarios presented allowed for the specific analysis of the potential for the sensor technologies development.

The scenario-building approach allows industry analysts and managers to evaluate and formulate decisions on venturing into new technology markets, while weighing the risks and potential rewards. It gives consideration for managers to explore options such as forming partnerships, creating joint ventures, or simply tapping into foreign investors or technology providers to expand financial and technical capabilities in order to succeed when venturing into R&D and new product development. The insights developed through looking into the Philippine manufacturing setting allow for strategies to be developed for innovations aimed towards economies with similar industrial dynamics [32].

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