Identification of Key Enablers of Sensors and Sensing Systems

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Abstract

Sensors and Sensing Systems (SASS) are important components of technology that collect data from any chemical sector, physical quantity and biological quantity. It can be found in a wide range of applications. As a result, it must be stable and properly applied to its application, as well as undergo continual system improvement. This research focuses on identifying sensors and sensing system enablers that may be used to improve and quality findings. The main enablers for SASS are determined using a Pythagorean fuzzy Analytic Hierarchy Process (AHP) technique. The identified enablers can be implemented successfully to enhance the sensing process.

Keywords
Sensors and Sensing Systems, Pythagorean fuzzy AHP, Enablers.

1. Introduction:

Sensors and sensing systems (SASS) are one of the most widely utilized systems in the world, and their application and demand are growing all the time. SASS is a sensing, controlling, monitoring, feedback, data storage, and data transfer system. A sensor is a component that can be used to measure a variety of physical and chemical properties. It also records, indicates and responds. Sensors turn the quantity being sensed into electrical impulses, which are then sent to the system. A sensing system is a set of sensors and electronic and electrical components that are used to carry out a specific task and its processes.
SASS is now playing a major role in the manufacturing industry, healthcare, research, and the industrial sector, among other. It is mostly employed because of its characteristics, which include system accuracy, precision, standards, advanced technology, continuous improvement, error-free operations, system feasibility, a wide range of applications, and a variety of data transmission and storage methods (Chehri et al., 2020).

As sensors and sensing systems are so crucial, they should be utilized to their full potential (Zahedi et al., 2021). The study focuses on the main enablers of sensors and sensing systems due to the importance and range of applications (Hakki and Ibrahim 2021). Enablers are the system's key functions, and their utilization improves the system. By reviewing and referring to research publications, different enablers were found and categorized into different categories for evaluation. Fifteen enablers were determined and classified into three different categories that is 1st Improvement, 2nd Technology and 3rd Feasibility and cost effectiveness. Key enablers are identified using the Pythagorean fuzzy AHP method. This method determines relative weights and ranking is decided.

2. Literature Review

In sensors and sensing systems, data collecting is one of the most important phases, and data transmission should be error-free (Walaa et al., 2020). For the measurement of various quantities, various sensing and controlling components are connected to the internet of things (Chang and Martin 2021). In the medical field, a new strategy to improving system response can be designed (Zahedi et al., 2021). As its accuracy, dependability, and efficiency, SASS is employed in manufacturing systems for atomized manufacturing processes employing sensor feedback control (Xiaa et al., 2020). The system requires constant improvement and an effective solution; several methods for transmitting data with the optimum energy efficiency are being investigated (Chehri et al., 2020).
Internet of Things has to deal with many issues while incorporating with devices having insufficient computing capacity, which impact on privacy and security. Block chain secure interface technology is used in IOT to avoid signal control authority (Marko et al., 2021). To overcome system demands, advancement should be done in sensing systems where a new technology specific integrated circuit is implemented (Hakki and Ibrahim 2021). Protection and fault detection in data transmission is essential for any system; a new technology name high voltage direct current is used (Dimitrios et al., 2020). While considering system demand its quality should not be compromised, hence technology

advancement is done for to maintain system quality and reliability (Kanoun et al., 2005). Wireless data transmission for different applications using variety of sensors and data can be remotely accessed (Nanhore et al., 2013).

The feasibility of the system plays major role in system process and operations. Recently wireless communication has been developed which is more energy efficient and operated for longer duration (Lee et al., 2008). Where wireless data transmission has 2 consents that is low speed data service over geographical areas and high-speed data service for local areas Jean, L. (2001). Sensors have large number of outputs for ease a special multilayer structure is used which minimizes the outputs connections (Pan and Zhu 2005). To bring effectiveness in outputs a robust design of system is done for constant data flow. Sensors and sensing systems are applied for precious applications which detects and alarms, due to which wastage and scrap is reduced. This result is cost saving of the system where one of the examples is water quality management system (Pasika and Gandla 2020).

3. Methodology

Pythagorean fuzzy AHP method is an analytical hierarchy process designed with fuzzy logic theory (Figure 1). AHP is a multi criteria decision making process designed in 1970's by primary theoretician of AHP Thomas L. Saaty. Steps followed to determine the key enablers of sensors and sensing systems (Table 1):

- Identifying and determining enablers for sensors and sensing systems.
- Categorizing the enablers into different category.
- Applying Pythagorean fuzzy AHP method for determining the weights.
- Forming matrices and finding the local weights of main as well as sub factors.
- Forming matrices and finding the global weights of main as well as sub factors.
- Ranking the enablers according to global weights.

Table 1. Key parameters

Linguistic terms	Matrix of weight values (tik)
Certainly Low Importance	0.03749
Very Low Importance	0.07560
Low Importance	0.16825
Below Average Importance	0.42510
Average Importance	0.84819
Above Average Importance	1.69237
High Importance	3.76658
Very High Importance	9.51689
Certainly High Importance	19.45161
Exactly Equal	1.00000

STEP 1

Develop a pair wise comparison matrix based on the inputs received from the expert's panel using a linguistic evaluation equation

$$X = (xik)\ m \times \mathrm{n}$$

STEP 2

Using the lower and upper values of membership and non-membership functions compute the differences matrix $D = (dik) m \times n$

$$dikL = \mu^2\, ikL - Vi^2\, kU$$
$$dikU = \mu i^2\, kU - Vi^2\, k\mathrm{L}$$

STEP 3

Compare the interval multiplicative matrix $S = (Sik) \times \mathrm{n}$

$$SikL = \sqrt{1000^{dL}}$$
$$SikU = \sqrt{1000^{d\mathrm{U}}}$$

STEP 4

Compute the determinacy value $\tau = (\tau ik) \times n$

$$\tau ik = 1 - (\mu^2\, ikU - \mu^2\, ikL) - v^2\, ikU - v^2\, ik\mathrm{L}$$

STEP 5

Determine the matrix of weights, $\mathrm{T} = (tik)\ m \times n$ before normalization by multiplying the determinacy degrees with $S = (Sik)\ m \times m$

$$tik = \frac{(SikL + SikU)\quad \tau ik}{}$$

STEP 6

Calculate the normalized priority weights, w_i

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m} \sum_{k=1}^{m} t_{ik}}$$

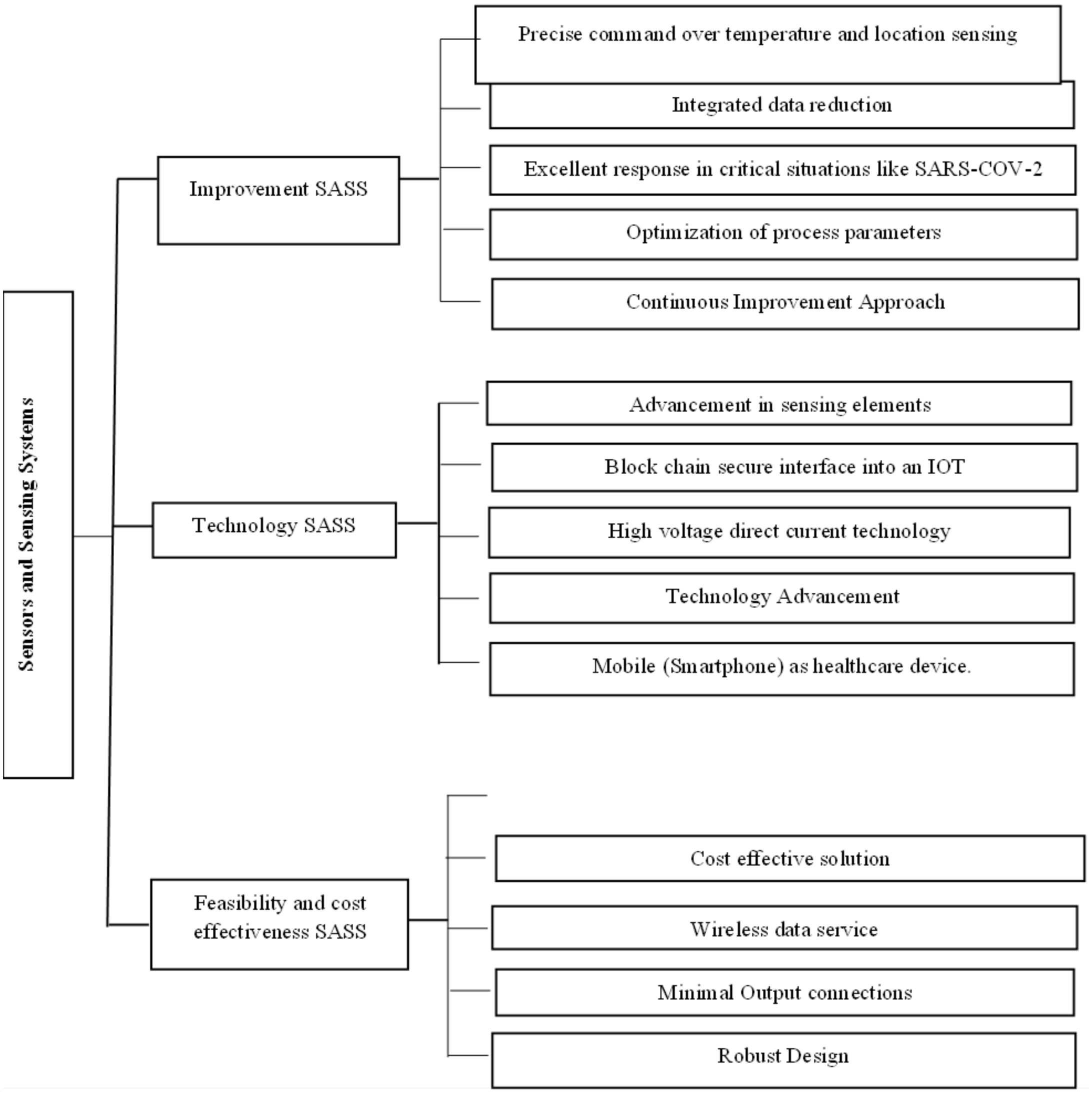

Figure 1. Decision hierarchy of the research problem

Tree diagram for decision hierarchy of the problem statement is drafted above which encapsulates key factors with their enablers.

In the Table 2a and Table 2b below, the ISASS, TSASS as well as FCSASS are the key factors which encapsulate the group of enablers which are directly related to the particular key factor.

Table 2a. Pairwise comparison matrix for main SASS

	ISASS	TSASS	FCSASS	Weight	Rank
ISASS	EE	CLI	CLI	0.023414	3
TSASS	CHI	EE	LI	0.449107	2
FCSASS	CHI	HI	EE	0.52748	1

The below table describes pairwise comparison matrix for ISASS. The numberings are given as per the sequence provided in the tree diagram.

Table 2b. Pairwise comparison matrix for ISASS sub-criteria

	ISASS1	ISASS2	ISASS3	ISASS4	ISASS5	Weight	Rank
ISASS1	EE	CHI	AAI	LI	AI	0.367	1
ISASS2	CLI	EE	LI	HI	VHI	0.23	3
ISASS3	BAI	HI	EE	AAI	AI	0.123	4
ISASS4	HI	LI	BAI	EE	VHI	0.236	2
ISASS5	AI	VLI	AI	VLI	EE	0.045	5

The below Table 3 describes pairwise comparison matrix for TSASS. The numberings are given as per the sequence provided in the tree diagram.

Table 3. Pairwise comparison matrix for TSASS sub-criteria

	TSASS1	TSASS2	TSASS3	TSASS4	TSASS5	Weight	Rank
TSASS1	EE	CLI	VLI	HI	BAI	0.06	5
TSASS2	CHI	EE	HI	LI	VHI	0.38	1
TSASS3	VHI	LI	EE	VLI	AI	0.13	4
TSASS4	LI	HI	VHI	EE	CLI	0.16	3
TSASS5	AAI	VLI	AI	CHI	EE	0.26	2

The below Table 4 and 5 describes pairwise comparison matrix for FCSASS. The numberings are given as per the sequence provided in the tree diagram.

Table 4. Pairwise comparison matrix for FCSASS sub-criteria

	FCSASS1	FCSASS2	FCSASS3	FCSASS4	FCSASS5	Weight	Rank
FCSASS1	EE	CLI	HI	LI	CLI	0.06	5
FCSASS2	CHI	EE	CLI	BAI	LI	0.23	3
FCSASS3	LI	CHI	EE	VLI	AI	0.24	2
FCSASS4	HI	AAI	VHI	EE	AI	0.19	4
FCSASS5	CHI	HI	AI	AI	EE	0.29	1

Table 5. Final weight of sub-SASS

Main SASS	Main SASS Weight	Sub- SASS	Sub-SASS local weight	Global Weight	Global Rank
ISASS	0.0234135	**ISASS1**	0.367006634	0.008592925	11
		ISASS2	0.229600131	0.005375752	13
		ISASS3	0.122527403	0.0028688	14
		ISASS4	0.235742312	0.005519562	12
		ISASS5	0.04512352	0.001056501	15
TSASS	0.4491068	**TSASS1**	0.060026422	0.026958275	10
		TSASS2	0.383634632	0.172292925	1
		TSASS3	0.13136127	0.05899524	8
		TSASS4	0.163953294	0.07363254	7
		TSASS5	0.261024382	0.117227827	5
FCSASS	0.5274797	**FCSASS1**	0.055433943	0.029240277	9
		FCSASS2	0.233278735	0.123049786	4
		FCSASS3	0.238381848	0.125741574	3
		FCSASS4	0.186158966	0.098195066	6
		FCSASS5	0.286746509	0.151252949	2

4. Result

The present work used Pythagorean fuzzy AHP method to resolve the identification of key enablers for SASS problem. The rank evaluated using three selected methods is shown in Table 6. The ranking obtained from selected method can be better visualized and helps the decision maker to access preferences. The comparative ranking of the enablers is obtained using selected method are shown in Figure 2 which suggests that first rank to block chain Technology is the most important enabler with a global weightage 0.1723 as well as feasibility and cost effectiveness is obtained as key main factor with a main factor weightage 0.5274 while implementing SASS. In this, the feasibility and cost effectiveness factor gained maximum importance and Improvement factor gained least importance. The study's findings include the identification of key enablers and global ranking. TSASS2, FCSASS5, FCSASS3, FCSASS2, TSASS5 are the top five enablers. These enablers lies in technology as well as feasibility and cost effectiveness. ISASS1, ISASS2, ISASS3, ISASS4, ISASS5, and ISASS6 are the least important enablers, and these enablers are from the improvement. This method can also be applied to solve complex selection problems in other engineering domains.

Table 6. Main factors and their weightage

Main factors	Most Important enablers	Global weightage	Ranking
Technology	Block chain secure interface into an IOT	0.1723	1
Feasibility and cost effectiveness	Robust Design	0.1513	2

Feasibility and cost effectiveness	Wireless data service	0.1257	3
Feasibility and cost effectiveness	Cost effective solution	0.1230	4
Technology	Mobile (Smartphone) as healthcare device	0.1172	5

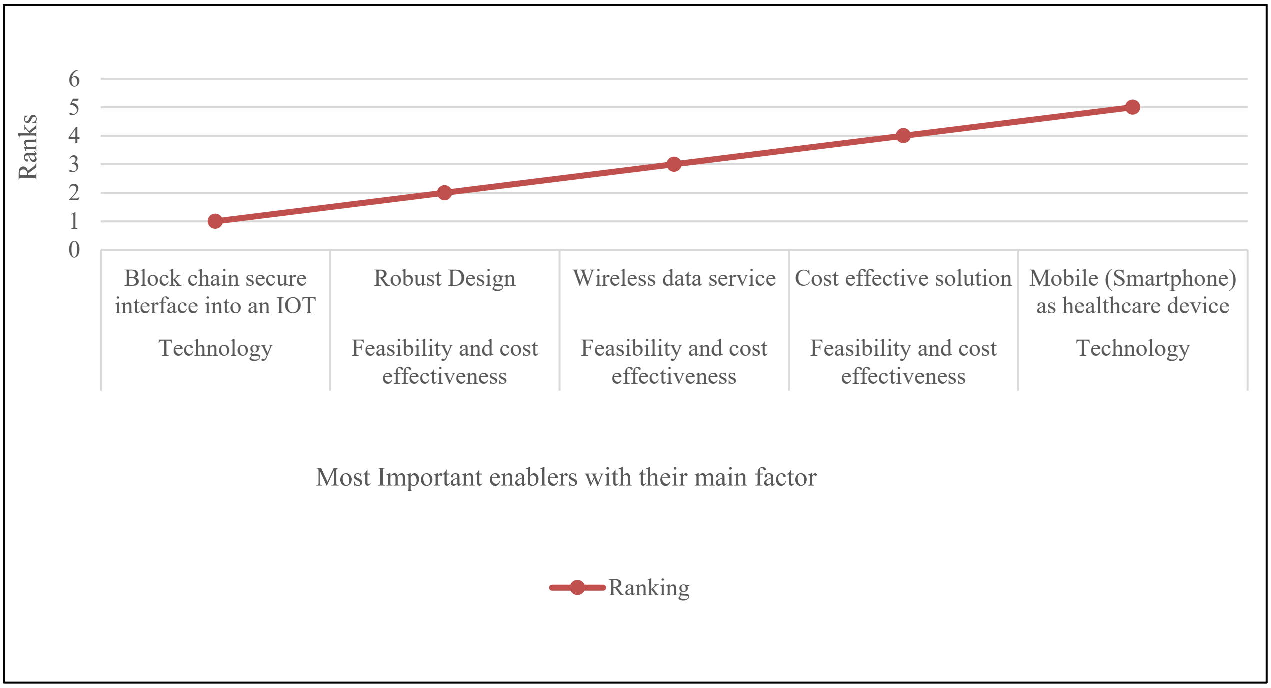

Figure 2. Graphical representation of rankings main factor

5. Conclusion:

Taking into account the importance and diversity of Sensors and sensing systems application. The system's improvement and stability must be maintained. The Pythagorean fuzzy AHP approach is utilized for multi-criteria decision-making and enabler identification. The key enablers identified are technology, feasibility, and cost effectiveness. Block chain safe interface into an iot, robust design, wireless data service, cost effective solution, and mobile (Smartphone) as a healthcare device are among the top enablers. For their enhancement, these enablers can be incorporated in any sensors and sensing system. As a block chain secure interface, it provides security and privacy to the system. Robust design contributes to improved performance and lower maintenance costs. Wireless data transmission is becoming one of the most efficient ways to send data. If SASS is implemented, the cost of the applicable system will be reduced. As long as a mobile device is connected to SASS, novel and one-of-a-kind solutions can be created. All of these enablers will contribute to the enhancement of various SASS.

Abbreviation	Meaning
SASS	Sensors and Sensing Systems
ISASS	Improvement Sensors and Sensing Systems
TSASS	Technology Sensors and Sensing Systems
FCSASS	Feasibility and cost effectiveness Sensors and Sensing Systems

References

Hakki, S and Ibrahim, '*Design and implementation of smart pressure sensor for automotive applications*', Measurement, Vol. 176, pp.02-07, 2021.

Marko, S. Pavlovic, N. Bacanin, N. Fadi L., '*Increasing privacy and security by integrating a Block chain Secure Interface into an IOT Device Security Gateway Architecture*', vol. 7, pp.01-06, 2021.

Jean, L., Wireless Communication with the Interactive Multimedia CD-ROM, 1st ed., Springer-Verlag US, 2001.

Dimitrios, T. Psaras, V. Tsotsopoulou, E. Mirsaeidid, S. Hong, Q. , '*Voltage and Current MeasuringTechnologies for High Voltage Direct Current Super grids: A Technology Review identifying the Options for Protection, Fault Location and Automation Applications*' , vol. 8 , pp. 203398-203428, 2020.

Walaa M. El-Sayed and Hazem M. El-Bakry, Salah M. El-Sayed, '*Integrated data reduction model in wireless sensor networks*', Applied Computing and informatics, Vol 16 No. 1, pp. 215-014, 2008.

Lee, G., Kwon, Y., Seok, W. And Lee, M., '*A simple dynamic clustering approach to achieve energy efficiency for wireless sensor networks*', International Journal of Pervasive Computing and Communications, Vol. 4 No. 2, pp. 185-197, 2008.

Pan, Z. And Zhu, Z., '*Flexible full-body tactile sensor of low cost and minimal output connections for service robot*', Industrial Robot, Vol. 32 No.6, pp. 485-491, 2005.

Chang, V and Martin, C., '*An industrial IOT sensor system for high-temperature measurement'*, Journal of Computers and Electrical Engineering, Vol.95, pp. 107439, 2021.

Zahedi, A. Amirhossein, S. Smith, N. Keshteli, M., '*Utilizing IOT to design a relief supply chain network for the SARS-COV-2 pandemic'*, Applied Soft Computing Journal, Vol.104, pp.107210, 2021.

Pasika, S and Gandla, S., '*Smart water quality monitoring system with cost-effective using IOT'*, Journal of Heliyon, Vol.6, pp.7, 2020.

Xiaa, C. Pan, Z. polden, J. Huijun, L., '*A review on wire arc additive manufacturing: Monitoring, control and a framework of automated system*', Journal of Manufacturing Systems, Vol.57, pp.31-45, 2020.

Chehri, A. Rachid, S. Hakem, N. Chaibi H., '*Science Direct Enhancing Energy Efficiency of Wireless Sensor Network for Mining Industry Applications-NC-ND license'*, Peer-review under responsibility of KES International, Vol. 176, pp.261-270, 2020.

Olfa kanoun., '*Sensor Technology Advances and Future Trends'*, Instrumentation and Measurement, Vol. 53, pp. 1497-1501, 2005.

Gary W. Hunter, Joseph R. Stetter, Peter Hesketh and Chung-Chiun Liu, '*smart sensor system'*, The Electrochemical Society Interface, Vol. 19, No. 4, 2015.

Snehal D. Nanhore, Mahip M. Bartere., '*Mobile Phone Sensing System for Health Monitoring'*, Vol. 2, pp. 01-04, 2013.

Biographies

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