

Situational Strategic Awareness Monitoring Surveillance System—Microcomputer and Microcomputer Clustering used for Intelligent, Economical, Scalable, and Deployable Approach for Safeguarding Materials

Kenly Maldonado and Steve Simske[▲]

Colorado State University—Systems Engineering; Santa Fe, New Mexico, United States
E-mail: krmald85@colostate.edu

Abstract. *The principal objective of this research is to create a system that is quickly deployable, scalable, adaptable, and intelligent and provides cost-effective surveillance, both locally and globally. The intelligent surveillance system should be capable of rapid implementation to track (monitor) sensitive materials, i.e., radioactive or weapons stockpiles and person(s) within rooms, buildings, and/or areas in order to predict potential incidents proactively (versus reactively) through intelligence, locally and globally. The system will incorporate a combination of electronic systems that include commercial and modifiable off-the-shelf microcomputers to create a microcomputer cluster which acts as a mini supercomputer which leverages real-time data feed if a potential threat is present. Through programming, software, and intelligence (artificial intelligence, machine learning, and neural networks), the system should be capable of monitoring, tracking, and warning (communicating) the system observer operations (command and control) within a few minutes when sensitive materials are at potential risk for loss. The potential customer is government agencies looking to control sensitive materials and/or items in developing world markets intelligently, economically, and quickly. © 2019 Society for Imaging Science and Technology.*

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1. INTRODUCTION

Several challenges have been communicated through government agencies, regarding gaps within the current industry in (1) monitoring, controlling, and safeguarding radioactive materials, (2) verifying that past nuclear fissile materials have been controlled and disposed of properly, and (3) energy safeguarding and security needs for developing modern tools with real-time data capability to control subsurface energy materials. These issues seem to be prevalent and require root cause problem assessment in order to appropriately attempt to meet the demands being requested from the government market segment. The issues seem to be (1) that there are not enough qualified personnel, locally and globally, to assist in the safeguarding process and (2) that the tools (systems) being used today cannot address those needs economically [1], effectively and/or intelligently. Identifying

the operational, functional, capability, performance, and physical characteristics of a new system that will be able to assist in controlling, monitoring, and intelligently assessing real-time data into valuable information when safeguarding radioactive materials, both locally and globally, is the impetus for the development of situational strategic awareness monitoring surveillance system (SSAMSS). The market segment will focus primarily on foreign markets, e.g., Asia, Africa, Russia, and Latin America. In this article, the root cause of the issue will be discussed in Section 2. In Sections section 3 and 4, we identify and analyze systems currently in use and we assess those systems for the traits desired by the customer. In Section 5, we compare current systems' functionality and assess for gaps. In Section 6, we identify a subset of components that can meet the functional needs of the customer, assess risks, and validate our chosen option. Sections 7 and 8 propose a system built through clustering Raspberry Pi computers and integrating microcontrollers, sensors and programming to meet the needs discussed earlier in the article. Finally, we summarize results of our assessment and propose the next steps.

2. HISTORY AND ROOT CAUSE PROBLEM

Historically, safeguarding energy materials, e.g., radioactive materials, tends to be personnel intensive and expensive, coupled with tools and security in order to control and monitor those materials [2]. There will never be removal of personnel from the process of safeguarding radioactive materials, but current industry approaches usually require highly trained personnel who operate a major part of the process. This can become more costly in developing nations. Root cause problem gap assessment requires a look at the current industry tools and how they are implemented overall. We assessed the utilization of personnel, hardware, software, applications, and web services, comparing the current industry estimated average utilization, in order to be able to better develop SSAMSS overall.

SSAMSS is being developed to use fewer personnel and approach synergy by using hardware, software, and web services with the attempt to reducing specialized personnel needs in developing nations as shown in Figure 1. That mixture is attempting to develop a configuration that uses

[▲] IS&T Member.

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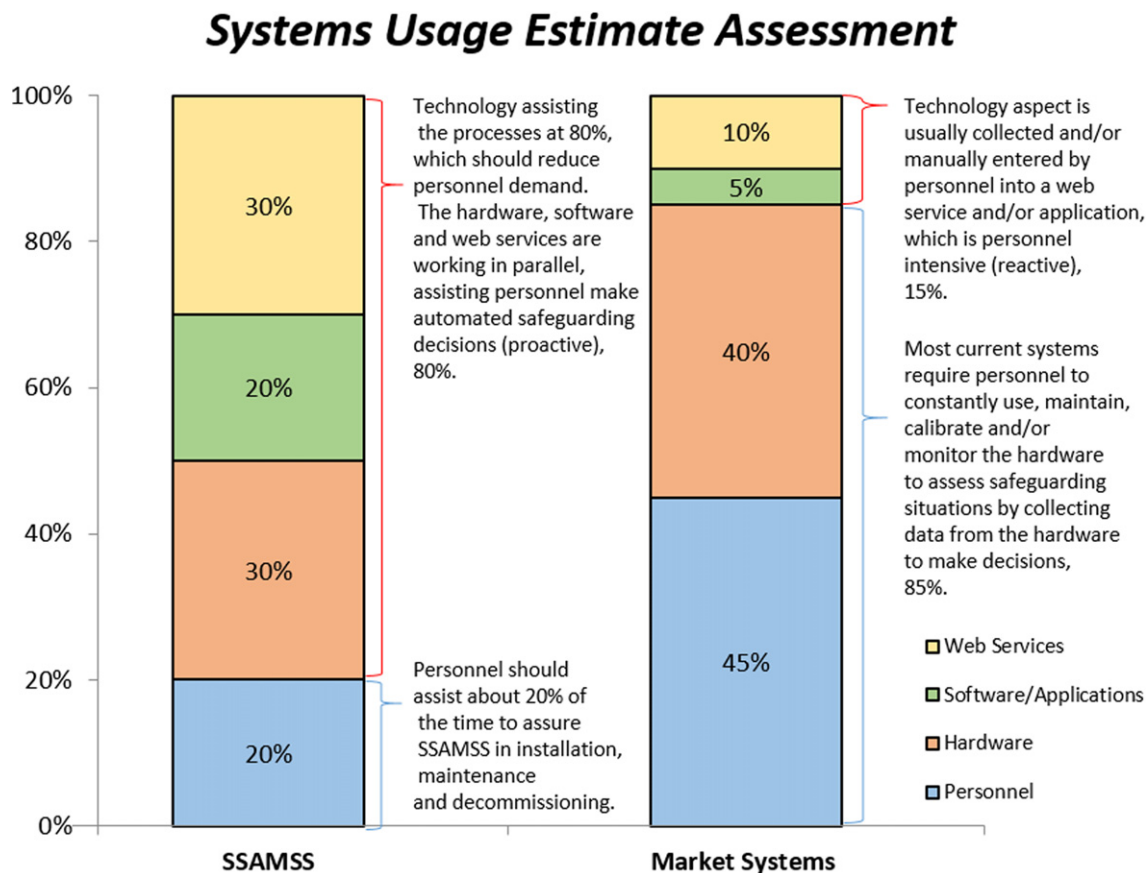


Figure 1. Estimated initial assessment between SSAMSS versus industry (tool) system visually showing potential gaps, e.g., underutilization of technology.

80% of the effort toward technology and 20% toward personnel versus the current average of most industry tools being ~85% personnel and hardware intensive with ~15% utilizing technology with greater details developed in Fig. 1. Above all, our aim is satisfying the customer requirements that will address those gaps, operationally and functionally, with respect to performance and capabilities. The problem statement developed through the initial assessments is that the industry is utilizing scanning systems that are singular technologies, costly, and require highly qualified personnel to safeguard materials. Those personnel make decisions through manual data assessment collected through those singular technologies. Oftentimes, those personnel are expensive to deploy and are not always available, both locally and globally. To improve the problem development of versatile surveillance with scanning potential, a system is needed that can automatically filter data that, in turn, is used to create information through artificial intelligence (AI). That automation and intelligence developed in an economical way is SSAMSS's way of addressing the problem to reduce both potential threats and personnel needed, both globally and locally. Ultimately, closing the gap of underutilization of modern technologies aims to increase effectiveness of personnel usage.

Table I. Rating requirement table.

Rating of Requirements				Trade Off Assessment
0	Worst	No	None	Initial Cost \$
1	Poor	Some	High	Operations Cost \$
2	Fair	Maybe	Medium	Intelligence
3	Best	Yes	Low	Reliability
				Maintainability
				Scalability

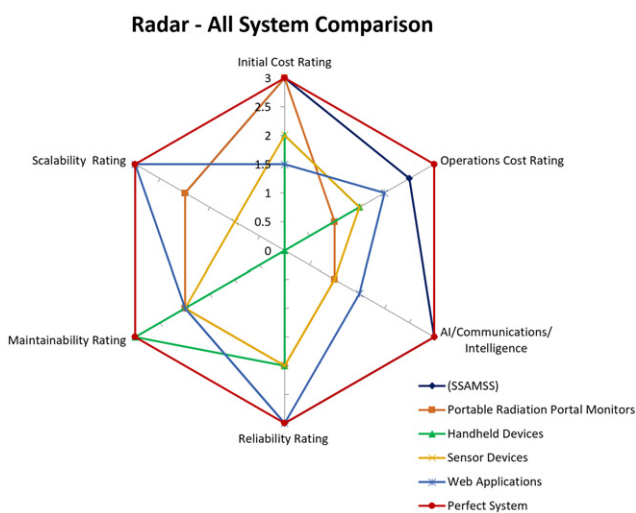
3. TRANSLATING QUALITATIVE TO QUANTITATIVE NEEDS

The current industry system performance needs are assessed to translate details out of the most commonly used tools by industry standard; the results are listed in Table I. Also important is analyzing how these systems address the safeguarding of radioactive materials. The needs are assessed through the customer and the market segment by using an initial gap assessment. System development requires a more rigorous assessment and analysis to ensure that the new conceptual tool and/or system (SSAMSS) is developed optimally. This optimization during development helps by meeting the criteria through proper review of key elements to ensure performance.

These criteria of the new system also have to be accepted by industry, market, and customer segments to confirm future acceptance. A tradeoff assessment matrix coupled with

Table II. Tradeoff assessment matrix.

Trade Off Assessment Matrix														
Systems	Estimated Initial Costs \$	Initial Cost Rating	Operations Cost/1yr	Operations Cost Rating	AI/Communications/Intelligence	AI/Communications/Intelligence	Reliability Rating	Reliability	Maintainability	Maintainability Rating	Scalability	Scalability Rating	Total	Perfect System Rating
(SSAMSS)	2000.00-5000.00	3	Low-Medium	2.5	Yes	3	Best	3	Fair	2	Fair	2	15.5	3
Portable Radiation Portal Monitors (PRPM)	10000.00-25000.00	3	High	1	some	1	Fair	2	Fair	2	Fair	2	11	3
Handheld Devices	1000.00-8000.00	2	Low-Medium	1.5	None	0	Fair	2	Best	3	worst	0	8.5	3
Sensor Devices	1000.00-5000.00	2	Low-Medium	1.5	Some	1	Fair	2	Fair	2	Poor	1	9.5	3
Web Applications	NA	1.5	Medium-High	2	Some-Maybe	1.5	Best	3	Fair	2	Best	3	13	3
Perfect System		3		3		3		3		3		3	18	3

**Figure 2.** Radar operational system comparison chart.

a rating requirement table is a sufficient way to rate systems against one another. Rating the systems from best to worst and then scaling them numerically helps give an overall weighted score as shown in Table II. Taking qualitative data and being able to quantify those details of the systems enables a better understanding of what the customer and the market consider as value-add.

The next step is to input the most common systems, (1) handheld devices, (2) sensor devices, (3) portable radiation portal monitors (PRPM), (4) web applications, (5) the ideal system based on current industry needs, and (6) SSAMSS concept to a weighted score as shown in Figure 2. This comparison turns qualitative data into quantitative data and ensures that proper development is heading in a positive direction.

4. OPERATIONAL DEVELOPMENT

Through market research, surveys, data, and related articles from Homeland Security and Department of Energy, categories were chosen as value-add for operation consideration. These organizations found the following categories to be of value operationally: (1) initial cost \$; (2) operations cost \$;

(3) AI, communication, and intelligence; (4) reliability; (5) maintainability; (6) scalability (Figure 3b). The majority of the systems seem to be focused more on (1) initial cost \$, (2) scalability, (3) maintainability, and (4) reliability. The radar comparison chart was one out of the two charts that were chosen to assess the current technologies against individual tool scores, categorical scores, and operational requirements. Visualization of that data to assess those systems' strengths and weaknesses operationally helped turn qualitative data into quantitative data, and then into critical information.

Comparing the current system (tools) requirements not only to other tools but also against what a perfect system would be and against SSAMSS concepts is useful in providing guidance to the future of these systems and in ensuring that they are heading in the right direction. Further assessment of a perfect system could be coupled with a Kano graph (Fig. 3), which graphs customer satisfaction and functionality and compares them to excitement attributes (customer delighters), performance attributes (customer satisfiers), and threshold attributes (customer dissatisfiers) to help predict future customer requirements. Another attribute to consider is Moore's law when selecting and projecting hardware components for SSAMSS. Being able to accurately project the future component selection can be beneficial.

The Pareto bar chart (Figure 4) was developed in order to give another visualization to better understand the rated information. Pareto charts show that 20% of the effort creates 80% of the yield that can then be reviewed further by another concept, the 4/50 rule. This rule states that 4% of the effort should produce 50% of the benefit.

These concepts could potentially help maximize which of the six operational requirements to focus on. They could optimize and/or maximize efforts toward focusing on the gaps with more precise assessments. Further assessment of the graph shows the overall scores of the comparisons. It also shows that (1) compared to a perfect system, you can see the gaps numerically within the other systems, (2) SSAMSS is really a PRPM and web application combined and (3) is potentially used as a guide to further understand where future development of these types of systems may be going.

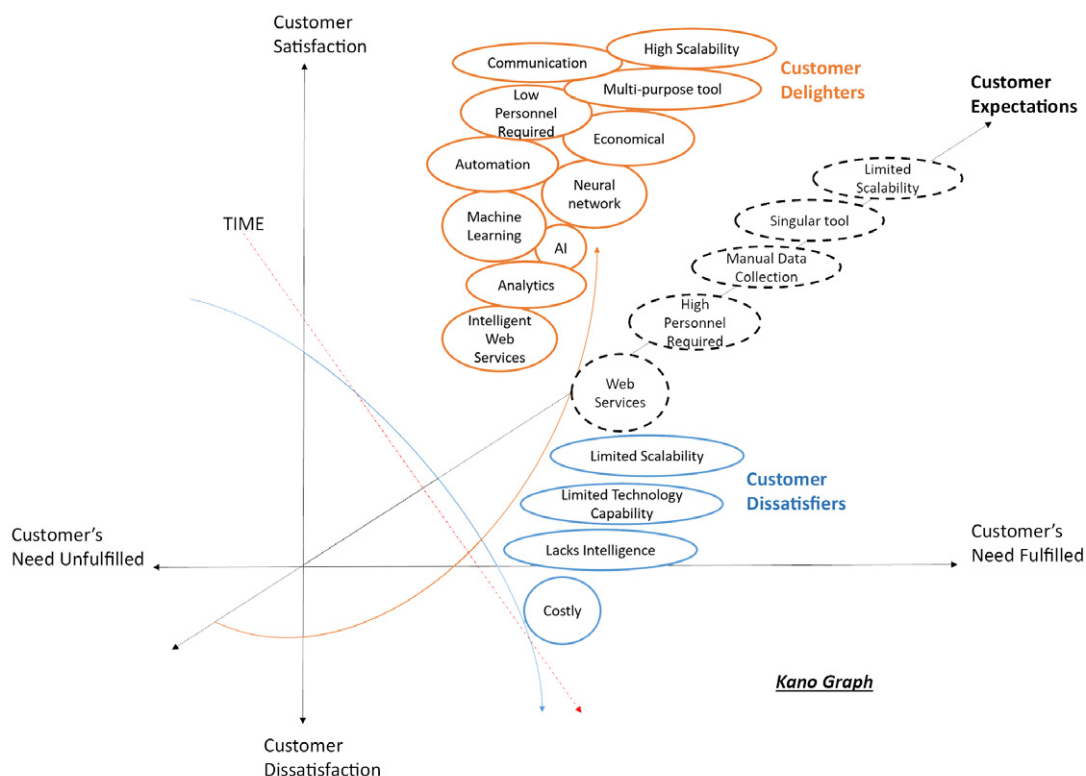


Figure 3. Kano graph of customer expectation.

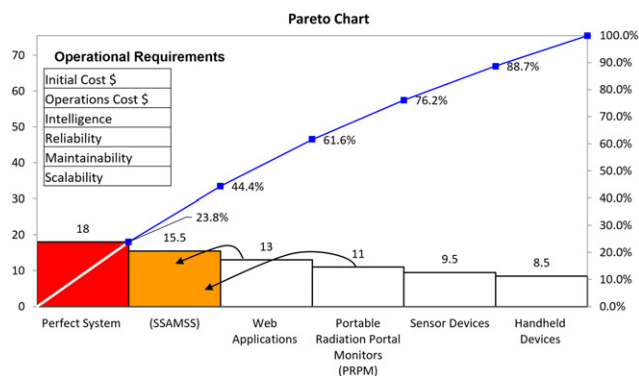


Figure 4. Pareto operational comparison chart—systems comparison.

The graphs in this section reaffirm that SSAMSS's initial assessment of the industry's gaps is being addressed.

5. FUNCTIONAL DEVELOPMENT

Reviewing the tools operationally is necessary to understand what is wanted overall by the customers and market segment at the highest level. The next step is to review those same systems in a comparison requirement matrix to assess their functional requirement gaps. Industrywise, the systems are used to (1) track, (2) monitor, (3) control, and (4) assist in safeguarding radioactive materials that are shown in Table III. There is an increasing need for technologies to

assist in safeguarding materials at this time since the demand to safeguard radioactive materials globally is on the rise.

Many of the current systems are specific to trained personnel who require the system to function the majority of the time as an extension to an individual. These systems are maintenance intensive and lack intelligence to assist in reducing the overall load of safeguarding materials. Another related consideration was commercial off-the-shelf (COTS) smart surveillance systems (state of the art). These systems, although current, are expensive to purchase per unit, cost more to deploy logistically, are not as adaptable to integrating other sensors into the system, and are not being utilized in safeguarding materials by the government.

6. COMPONENTS SELECTION

Capitalizing on Moore's law, small capable computers should be considered as viable component options. Small computers and/or microcomputers can be configured in hybrid configurations to increase performance. For example, when using microcomputers in parallel, they can be set up to have computational nodes and processing nodes that compute large data sets into information. These options for components give an opportunity to meet the functional and operational objective's identified needs economically. The microcomputer was reviewed and ultimately *selected* for its modularity, processing power, and economical affordability. Our process was to compare microcomputers (Table IV) that were able to meet our development variables that

Table III. Functional comparison table of industry tools.

Current vs SSAMSS Functional Requirement Comparison				
Today's Requirements	Web-based, manual entry, barcode scanners, specially trained personnel intensive	Singular advanced technologies, web based, specially trained personnel intensive	Single technology, specially trained personnel intensive	Single technology with expansion options, specially trained personnel intensive
Examples	National Source Tracking System (Web)	Portable Sensor	Hand held	Portable Radiation Portal Monitors
Visual Examples				
Requirement Gaps	Error prone, human factors, training, labor intensive, misplaced barcodes, stolen or lost material, reactive approach, no AI, matrix	Human factors, cost, training factor, Singular utilization, reactive approach, no AI, scalability is costly	Error prone, human factors, labor intensive, training, misplaced reading information, reactive approach, no AI, scalability is costly	labor intensive, training, large, takes up a lot of space, reactive approach, no AI, only a scanner, scalability is costly
SSAMSS Addressing those Requirement Gaps	Web-based capabilities, programmability, multi-utilization, economical, automation through intelligence	Web-based capabilities, programmability, adaptability to new technology attachments, multi-utilization, economical, physical device	Web-based capabilities, programmability, multi-utilization, economical, physical device	Web-based capabilities, programmability, multi-utilization, economical, physical device, takes up small space, quickly expandable, AI, cost effective, scanner plus surveillance system

can compute to the level of, if not higher than, the current industry system tools. Commercial off-the-shelf and modified off-the-shelf (MOTS) are two available options to meet customers' needs. Market demographics and remote location, usually in developing nations outside of the United States, are the targeted demographics.

In order to ensure a proper selection of the primary component, the microcomputer, a process of reviewing and assessment was completed. The first review was to select the top three viable options to develop SSAMSS. Then these three options were compared against each other in a table to see advantages and disadvantages the microcomputer components had to offer. Through the comparison, it was determined that one of the microcomponents was a microcontroller (Arduino) and that the other two were microprocessors (microcomputers). The microcontroller is excluded as a viable primary component but could be utilized in SSAMSS build as a hybrid option if needed. That left Raspberry Pi and the NVidia Jetson Nano (microprocessors) as the two potential components to pick to develop SSAMSS around [3]. Both are capable but have huge price differences, and one may be potentially more costly to get in foreign locations.

Further assessment was needed to ensure that the correct component for SSAMSS was selected. Through the risk assessment, shown in Table V, VI, and VII, the Raspberry Pi 4 was compared against the NVidia Jetson. This helped to answer the primary questions about what the components need to do in order to perform optimally to ensure functionality and operational compliance in order to develop SSAMSS effectively.

This was then placed in a risk assessment decision matrix to weigh the collected risk assessment. The result showed that, overall, the Raspberry Pi 4 microcomputer was the best option. However, the hybrid options are another route if needed, as both components have high processing capabilities to complete AI.

The new technology will be intelligent with an emphasis on artificial intelligence, machine learning, and neural networking. It must be capable to not only assess potential threats but also communicate that information, both locally and globally. Most of the current systems are developed in a reactive way and are initially costly. Those costs are high operational costs, scale-up costs, and maintenance costs. These systems are expensive and also lack intelligence and usually have limited communication capabilities and versatile functionality. These are the reasons for the component

Table IV. Components comparison: Jetson Nano versus Raspberry Pi versus Arduino.

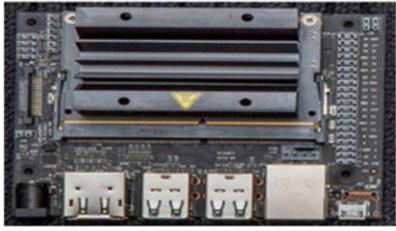
			
	<i>Jetson Nano Dev Kit</i>	<i>Raspberry Pi 4</i>	<i>Arduino R3</i>
	<i>MicroComputer (MicroProcessor)</i>		<i>MicroController</i>
MSRP	\$99	\$35-55	\$22
CPU	Quad-core ARM® Cortex-A57 MPCore processor (1.43 Ghz)	1.5 GHz 64-bit quad-core ARM Cortex-A72 CPU	Intel Quark (x86) (32-bit)
GPU	Nvidia Maxwell™ architecture with 128 Nvidia CUDA cores	VideoCore VI graphics, 4Kp60 HEVC video	-
RAM	4 GB 64-bit LPDDR4	1GB, 2GB & 4GB LPDDR4 SDRAM	32K bytes of Flash memory/2K bytes of SRAM
Connectivity	Gigabit Ethernet	Dual Band 802.11ac WiFi, Bluetooth 5.0, Gigabit Ethernet	-
Ports	USB: 4x USB 3.0, USB 2.0 Micro-B Camera: 1x MIPI CSI-2 DPHY lanes (Raspberry Pi camera compatible) LAN: Gigabit Ethernet, M.2 Key E	USB: 4x USB 3.0, 4k HDMI, Audio, Camera Connector	PWM Digital I/O Pins 6
Pins	40-Pin GPIO	40-Pin GPIO	Digital I/O Pins 14 (of which 6 provide PWM output)
Power Consumption	~ 4 Amps/ 5 Volts	~2 Amp / 5 Volts	~ 1 A/4.5 Volts

Table V. Risk assessment importance rating table.

Microcomputer (Component) Design Risk Assessment [Raspberry Pi (Pi) vs Jetson (J)] (80/20 or 4/50 approach will help refine these vulnerabilities)	
<i>Category to Compare between Components</i>	<i>Importance Rating (related to failure)</i>
[A] If the component cannot compute properly (Processing Power)?	1
[B] If the component is too costly (Costly per Unit)?	2
[C] If the component does not work consistently (Reliability)?	3
[D] If the component is difficult to fix (Maintainability)?	4

selection being crucial; it not only has to be economical and durable but also be able to perform the AI aspects that are required (benchmarking processing and AI comparison are fairly close to each other as shown in Tables V, VI, and VII).

7. RASPBERRY PI CLUSTER

New systems should utilize parallel computing, parallel processing, and parallel analysis through control (master/server) node and processing (worker/client) nodes. The parallel computing focus will be on AI, analytics, and image processing as tasks that will be required in order to ensure that SSAMSS can handle all the data. In turn,

that data will become valuable information to assist in safeguarding radioactive materials, both locally and globally. This will be done by fully taking advantage of the clustering capability that can be performed through combining more than one Raspberry Pi as a detailed example has been created in Figure 5. Through clustering Pi devices, together SSAMSS should be able to process video, images, and/or data that will be collected by available sensors, options, cameras, images, radioactive detectors, vibration sensors, and other options [4]. Another beneficial aspect, which is still economical, is that you are able to have several types of sensors to connect into the Pi collector. This can be used to create hybrid systems such as coupling the Pi with Arduino (microprocessor and microcontroller).

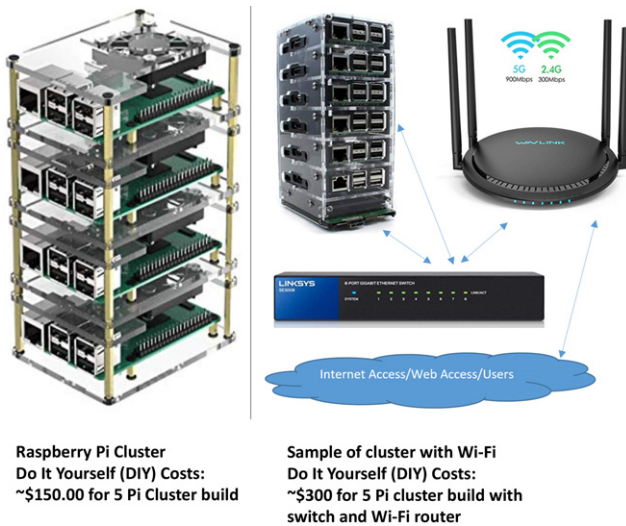
Onsite economical micro supercomputing that has modularity with low power consumption is a great benefit for SSAMSS. In comparisons, other smart surveillance systems similarly used by governments, i.e., China, use cameras with AI to track commuters and/or individuals. These systems, e.g., SenseTime, have large infrastructures that require large costs (\$63,261 a day to operate), maintenance, and employees. Another disadvantage of these systems is that they are not easily deployable and/or scalable. This is where the benefits of SSAMSS come into play as being a system that can be intelligent, economical, and deployable when safeguarding materials. These clusters are composed of a multitude of interconnected microcomputers that have the capability to perform high processing power at an

Table VI. Risk assessment table.

Probability	Very High	L	M	H	H (J, B)	H
	Likely	L	M (J, D)	M (J, C)	H	H
	Possible	L	L (Pi, D)	M (Pi, C) ,	M	H
	Unlikely	L	L	L	M (Pi, A)	H
	Very Likely	L	L	L	L (Pi, B) , (J, A)	M
		Insignificant	Minor	Moderate	Major	Catastrophic
Consequences						

Table VII. Risk assessment decision matrix.

Evaluator	Probability of Risk Occurrence	Consequence of Failure Occurrence	Risk Importance A	Risk Importance B	Risk Importance C	Risk Importance D	Result
Raspberry Pi	2	3	2	1	3	3	2.3
Jetson	3	4	1	4	4	4	3.3

**Figure 5.** Raspberry Pi microcomputer cluster DIY example.

economical scale. Using the Watershed algorithm, You Only Look Once (Yolo) for example, it can filter through large sets of images. The cluster will have the processing power to process multiple forms of sensory data beyond image files. This data will be turned into valuable information to assist in safeguarding.

The cluster [5] could be developed to have a server program on the master node and client programs on the worker node. This will assist the parallel computing process by collecting images and performing object detection. These and other more in-depth processes will be used in an economical way due to the Pi clusters. The Pi collectors, on the other hand, act as the eyes while the cluster acts as the brain to make programmed decisions and communicate those decisions out to the web services while informing the appropriate parties. Raspberry Pi clusters are the best option to develop SSAMSS intelligence capabilities. Although this technically is a micro supercomputer, it does have certain limitations such as SD card capacity [6].

8. SYNERGY FOR SSAMSS

Microprocessors (Raspberry Pi 4), microcontrollers (Arduino) microclusters, sensors (infrared, thermal camera, pixel camera, stereovision camera, night vision camera, vibration, radioactive sensor, and/or other options), and programming (e.g., Python, Linux, or Tensor Flow Lite) can be used in a combined way to create system synergy [8]. The microcomputer (microprocessor) can be coupled with sensors and/or if the sensor is not capable, potentially a microcontroller to assist SSAMSS to meet its objectives. Writing in Python, parallel computing and parallel processing is how we will tie together the components.

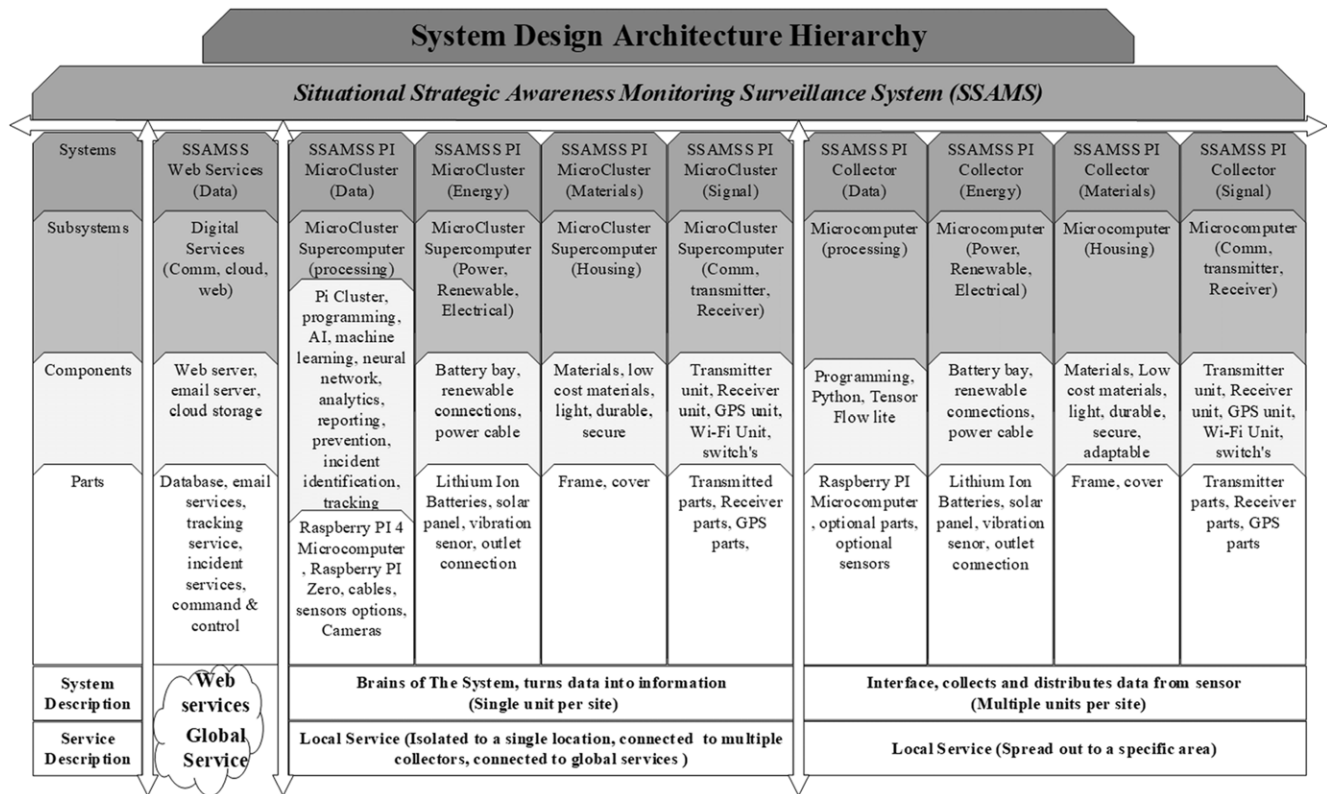


Figure 6. SSMASS architectural concept visualization diagram.

The development of SSAMSS needs to have a system that is executable while capable of meeting the operational, functional, and performance objects. At the same time, it encompasses similar physical characteristics in order to entice customers through market familiarity as shown in Figure 6.

Image processing along with data processing will play a significant role in how SSAMSS utilizes object detection and object counting. The collected data from the Pi sensors will turn collected raw data into actionable information. The importance of SSAMSS is the cluster that should be able to perform a high number of operations through parallel computing as data is distributed throughout that cluster. Power consumption of a single Pi is 2 A at 5 V or 10 W/hr of power consumption. For a small cluster of 5 Pi units, the power consumption would be 60 W/hr. The power consumption of the Pi units can be decreased by selecting a skimmed-down version to build the cluster, similar to a Pi 0 versus a Pi 4. This data will be collected from selected sensors such as infrared detectors, vibration sensors, camera, and/or different camera types. The cluster and parallel computing should be able to handle algorithms which will be programmed to execute simultaneously from parallel devices running in sync to produce a final output. The primary focus for programming within these clusters will be the Python language. Utilization of other skimmed-down program languages and algorithms will be key in developing the programming using script libraries that are geared toward

image processing, utilities, and algorithms. As shown in Figure 7, the suggested system overview is how the system will work between the customer and the device.

Another benefit of these calculations could be used to assess how many nodes are needed to process images. Python-scripted equations can be used to assist in the processing of power and cost. This was done by a group of researchers looking at Python language equations to calculate the number of nodes needed to process images on a Raspberry Pi cluster [7]

$$N_{\text{compute}} = \text{math.ceil} \left(\frac{(N_{\text{images}} \times T_{\text{seq}})}{N_{\text{cpu-act}}} \right) \quad (1)$$

where

- N_{compute} —number of required computing nodes in the cluster;
- N_{images} —number of images per second that could be loaded in sequential order to the cluster system;
- T_{seq} —time to process one segment of arrived images where one image has reserved one CPU core;
- $N_{\text{cpu-act}}$ —number of CPU cores on Raspberry Pi that are reserved for processing from head node.

Another Python tool is `Osu_BW.py` which tests the bandwidth between master and worker nodes through messaging and timing by utilizing an open source Raspbian OS (Linux-based OS), message passing interface (an image processing application), and an SSH connection. This

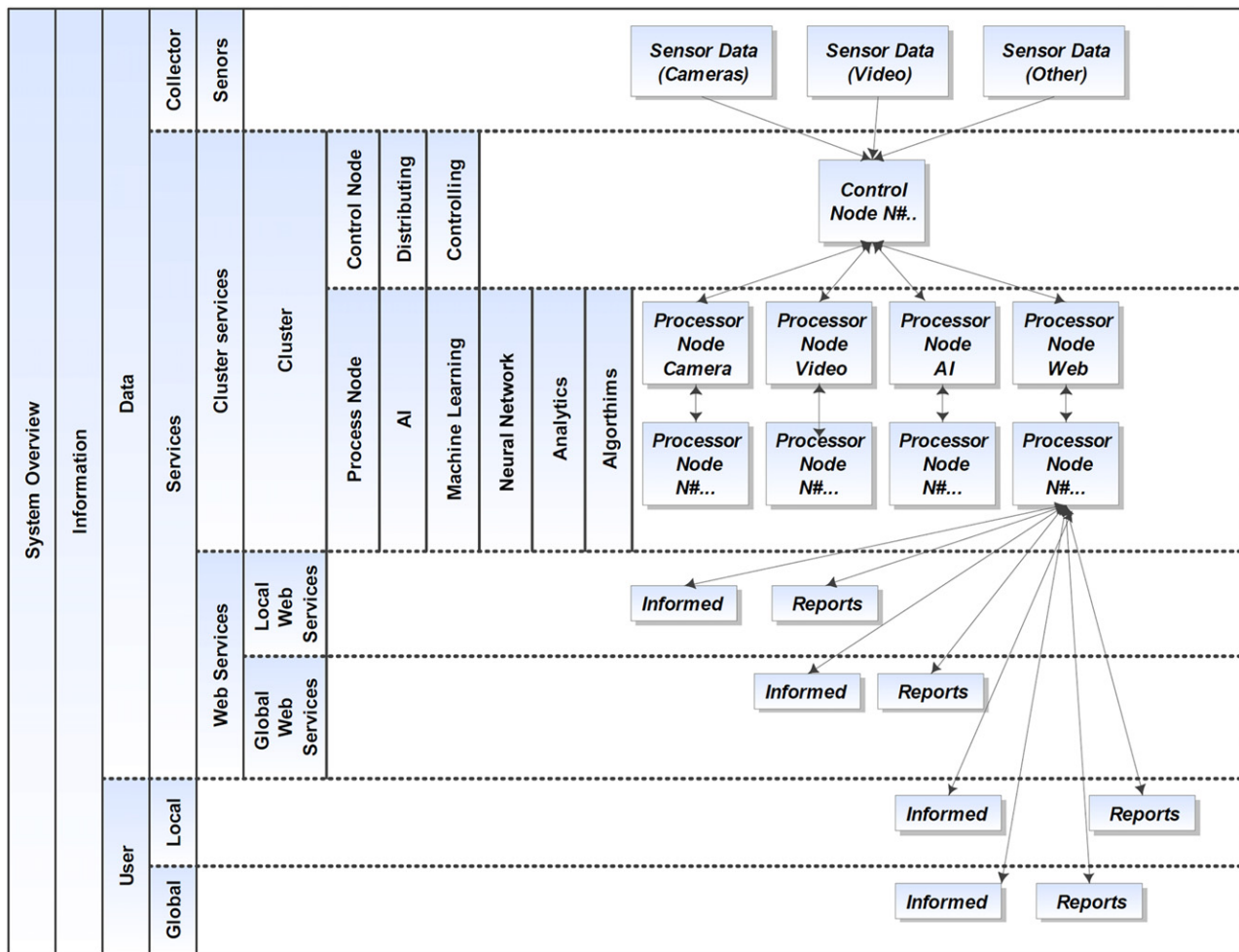


Figure 7. Suggested system overview.

Secure Shell Protocol (SSH) connection enables a Rivest-Shamir-Adleman (RSA) encryption algorithm to ensure security while logging into the system [8]. Singularly, the Pi is able to perform well. Collectively, (series/parallel) Pi controllers with proper configuration will give SSAMSS the structure required to be able to deliver its objectives both economically and effectively. Connecting sensors (vibration, thermal, radiation detection, and others) and cameras (stereo vision, thermal, 3D, night vision, and pixel camera to process video and images) working together will process the collected data. Just like the human eye, there will be a breakdown of how to process images, (1) classification, (2) localization, (3) single/multiple object detection, and (4) image segmentation [9].

There are examples where development of stereovision, thermal, infrared, and night vision cameras and/or other sensors are coupled with a single Raspberry Pi microcomputer [10]. What makes SSMASS different when compared to other examples [11] is a scalable Raspberry Pi microcluster at location that is processing the data. That data will be turned into information through intelligent analytics from the micro supercomputer.

9. CONCLUSION

SSAMSS is a system that is feasible to construct and addresses current industry gaps. The diagram shown in Figure 8 gives visualization on how SSAMSS overall should work to address industry gaps. Objectively, as a concept, it is trying to reduce costs associated with modern day systems and reduce personnel intensity by using affordable, commercial, and modifiable off-the-shelf components to build a system that is less personnel intensive and more technology intensive. This is to help reduce costs, maintainability, modularity, scalability, and deployability. Through the research, it appears that modern day systems (tools) are user and hardware intensive (45% total personnel and 55% technology/hardware) unlike SSAMSS (20% total personnel versus 80% technology/hardware). Addressing the root cause problem objectively led to feasible component building. This then led to selecting Raspberry Pi microcomputers, Pi sensors, and Pi clusters.

The next phase will be to develop the logical, hardware, software, programming, energy, and signal architecture in order to start developing a prototype. The development of SSAMSS is important since people are utilizing microcomputers for safeguarding purposes in some fields. What those

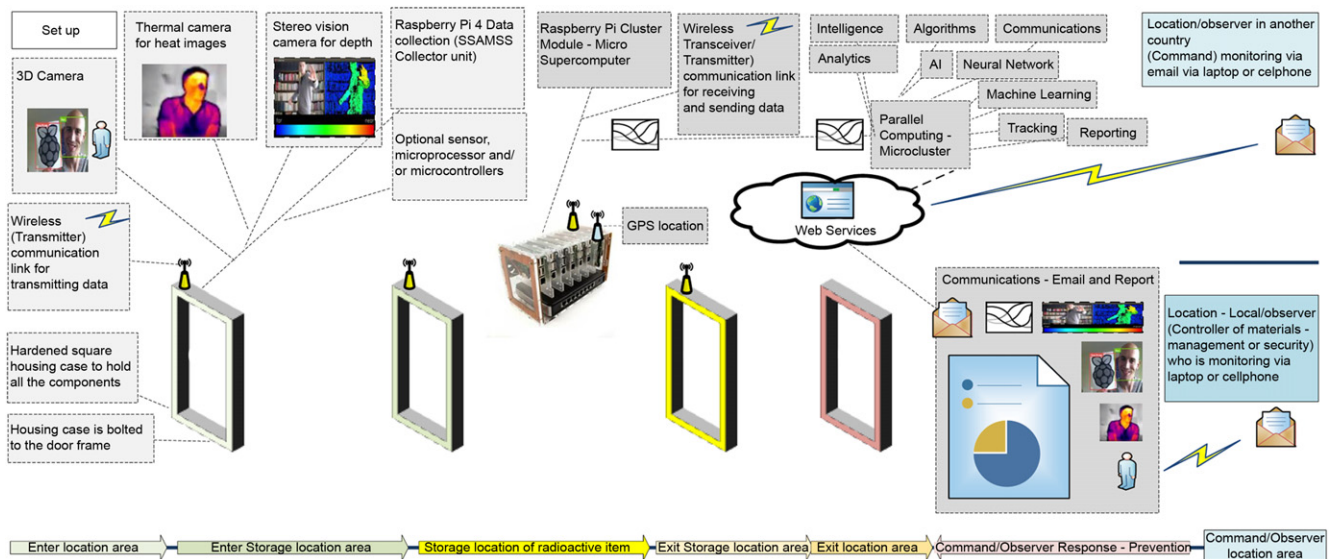


Figure 8. SSMASS local concept visualization diagram.

groups do not understand yet is that adding an onsite and scalable cluster or micro supercomputer will add tremendous value while safeguarding valuable assets economically and plausibly.

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