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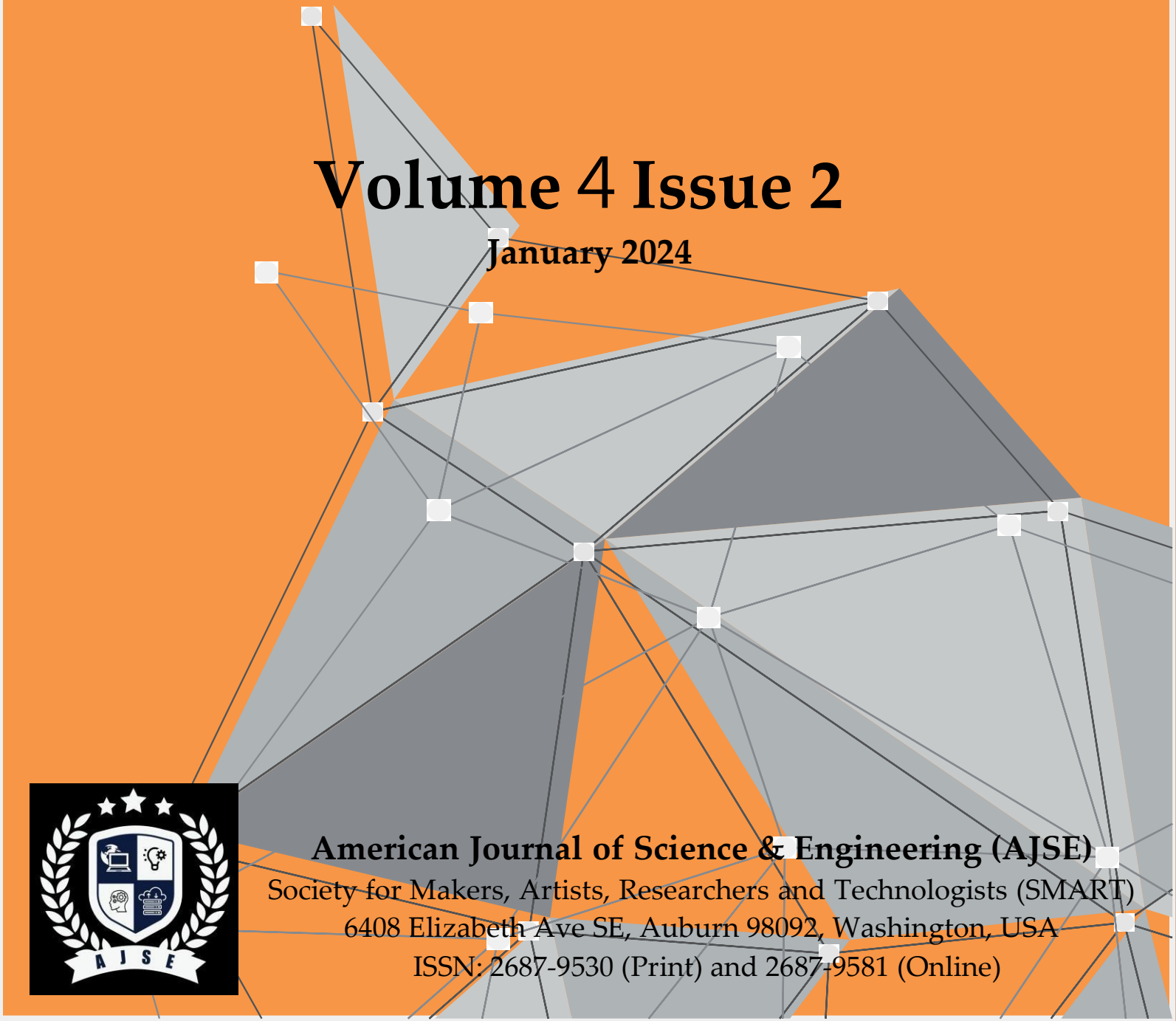

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Bio: Izzat Alsmadi is an Assistant Professor in the department of computing and cyber security at the Texas A&M, San Antonio. He has his master and PhD in Software Engineering from North Dakota State University in 2006 and 2008. He has more than 100 conference and journal publications. His research interests include: Cyber intelligence, Cyber security, Software security, software engineering, software testing, social networks and software defined networking. He is lead author, editor in several books including: Springer The NICE Cyber Security Framework Cyber Security Intelligence and Analytics, 2019, Practical Information Security: A Competency-Based Education Course, 2018, Information Fusion for Cyber-Security Analytics (Studies in Computational Intelligence), 2016. The author is also a member of The National Initiative for Cybersecurity Education (NICE) group, which meets frequently to discuss enhancements on cyber security education at the national level.

Editorial Board:

18-21	**EFFICIENT VANILLIN DETECTION IN FOOD PRODUCTS USING OPTIMIZED MIP ELECTRODE AND CHEMOMETRIC ANALYSIS** *Vanillin is a flavoring agent commonly used in the food and pharmaceutical industries. The detection and accurate quantification of vanillin, has attracted considerable interest due to its economic and its potential health effects. In this paper, we focused for the identification and quantification of vanillin in food products using a molecularly imprinted polymer polyacrylamide-based graphite electrode (MIPAM/GP) against a silver-silver chloride reference electrode and a platinum electrode. These sensors are designed to selectively recognize vanillin molecules based on their structural characteristics, thereby improving the sensitivity and specificity of detection. This research explores the rapid electrochemical detection of vanillin utilizing an optimized Molecularly Imprinted Polymer (MIP) electrode. The study assesses the Differential Pulse Voltammetry (DPV) responses generated by the MIP electrode when exposed to vanillin in various real food samples, including ice cream, yogurt, custard, and milkshakes. The data obtained from these samples is then subjected to analysis through K-Means clustering employing Principal Component Analysis (PCA). Remarkably, the results exhibit successful discrimination of each individual food sample, underscoring the efficacy of this electrochemical method. Cluster metrics, such as a maximum Silhouette Score of 0.5815, a maximum Calinski-Harabasz Score of 236.9719, and a minimum Davies-Bouldin Index of 0.3175, affirm the accuracy of the electrode-based clustering approach. This research highlights the potential of electrochemical systems combined with chemometric analysis for the efficient detection of vanillin adulteration in food products. The MIP electrode's effectiveness suggests its utility for immediate on-the-spot identification of varying vanillin levels across a wide array of food items, thereby contributing to rapid food quality assessment and assurance.* **DOI:** Saranjit Paul, Titir Sadhu, Shreya Nag (University of Engineering and Management, Kolkata, India)
22-26	**Accessible Home: Empowering Disability with Smart Home Automation** *In today's world, technology has the power to make life easier for everyone, including those with disabilities. The prototype includes the installation of various smart devices, such as automated entrance system, smart thermostats, smart leakage sensors, and automated lighting systems. Three individual nodes namely home access, gas detection, light automation and fall detection are proposed which are connected to a master node. A RFID card is used to access the entry gate at node 1. The second node detects LPG and carbon monoxide. When the sensors detect gas above threshold value, buzzer goes off alerting everyone. Temperature and humidity values are displaced on their OLED watch screen and speed of lights and fan using the relay. The third node detects a person's falls that will send notification to the emergency contact via Telegram and WhatsApp. All the three nodes are connected with the master node using ESP-01. The user can be instantly notified about any unusual event on their watch using ESP-NOW.* **DOI:** Saptarshi Mukherjee, Ankita Saha, Debanjana Das, Arpita Das, Rimi Sengupta, Abir Chatterjee (University of Engineering and Management, Kolkata, India)

Software Engineering Technology to Improve the Quality of Medical Processes

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ABSTRACT
In this paper, we describe some of the key observations resulting from our work on using software engineering technologies to help detect errors in medical processes. In many ways, medical processes are similar to distributed systems in their complexity and proneness to contain errors. We have been investigating the application of a continuous process improvement approach to medical processes in which detailed and semantically rich models of the medical processes are created and then subjected to rigorous analyses. The technologies we applied helped improve understanding about the processes and led to the detection of errors and subsequent improvements to those processes. This work is still preliminary, but is suggesting new research directions for medical process improvement, software engineering technologies, and the applicability of these technologies to other domains involving human-intensive processes.

Keywords: Continuous process improvement, process verification, medical processes

1. INTRODUCTION
This paper summarizes key lessons learned from our initial efforts to apply the technology and approaches of software validation and continuous software process improvement to the reduction of errors in medical care. Medical errors occur frequently and, as reported in the 1999 Institute of Medicine report, To Err is Human [15], preventable errors in hospitals alone cause at least 97,000 deaths per year in the US.

Our initial work offers considerable promise that software engineering approaches, originally developed to support software process improvement, can reduce the incidence of such errors. This work has also demonstrated that exploration of this domain is useful in pointing to areas in which software engineering technologies should be improved.

There is surprising similarity between healthcare systems and software systems, particularly human-intensive, distributed system. Healthcare systems typically involve many different types of human agents (e.g., doctors and nurses with different specializations and roles, pharmacists, lab technicians, and support staff), hardware devices (e.g., infusion pumps, radiation therapy machines, and patient monitoring devices), and software applications (e.g., computerized physician order entry systems, decision support systems, and electronic medical records). Coordination is particularly key in these systems, as humans are often participating simultaneously in several different processes at any given time, and their participation in each process may entail the parallel performance of many different subtasks and interactions with several different devices and software applications. In performing these tasks, it is common for exceptional conditions to arise, requiring specialized actions that may vary considerably depending upon the circumstances. Continual change is also a key issue in medical processes. Changes may result from the introduction of new devices, new software applications, new personnel, or even personal preferences. New medical studies may lead to new guidelines or standards of care. Still other changes come as reactions to errors that have recently occurred locally. Such changes are usually made based only on informal analysis of poorly understood processes. These many parallels between medical processes and software engineering issues suggest that the software engineering community has much to offer in the search for ways to improve healthcare.

The University of Massachusetts Medical Safety project has been investigating how software engineering technology, originally developed to improve the quality of software systems, could be effectively applied to improving the quality of medical processes. In particular, we have undertaken several case studies intended to shed light on the applicability to healthcare processes of the classical Deming Cycle [9] of continuous process improvement employing software validation tools for error detection. These case studies have involved developing models of healthcare processes that are unusually detailed and semantically broad,

analyzing these process models using finite-state verification and other analysis techniques, and then working with medical professionals to systematically improve the processes when errors have been found.

This project is succeeding in providing benefits to both healthcare and software engineering. The medical professionals involved have reported that this project has changed the way they view, describe, teach, evaluate, and improve their processes. Moreover, several serious problems have been uncovered and the medical processes have subsequently been improved. There have also been benefits to software engineering in that it has been necessary to enhance the technologies we have used in ways that should also improve their effectiveness when applied to software systems. Moreover, we now have a new perspective on software development, particularly for human-intensive systems.

2. APPROACH

The very broad outlines of our approach had been suggested in some earlier work [18, 19] that proposed that processes share many of the characteristics of application software and that technologies for the analysis and continuous improvement of application software might be usefully applied to processes. Applying these technologies to processes in domains other than software engineering was also suggested in [19]. The work we describe here provides substance and preliminary confirmation to these earlier suggestions.

The approach to process improvement that we have been developing is based on creating detailed, semantically rich models of the processes and then applying a number of different analysis techniques to try to detect errors in those processes. The analysis techniques not only detect errors, but also provide feedback about the source of the errors that can then be used to help determine how the processes should be improved. With help from the medical professionals, who in this case are the domain experts, computer scientists create the models and apply the analysis techniques to those models. When a defect is found in a process model, it needs to be examined carefully to determine if the problem is associated with our representation of the process, with any analysis artifacts, or if it is indeed an error in the process. If it is the latter, then domain experts propose modifications to the processes, often with the help of computer scientists who can explain the source of the problem and point out alternative solutions. The model of the modified process is then carefully reevaluated to assure that it has successfully dealt with the uncovered error and has not introduced new errors that violate the current stated requirements. With this approach, several alternative models can be considered and evaluated before a decision is made about the way the actual process should be modified. We have already had some experiences in which process model improvements were translated almost immediately into changes to actual medical processes. Thus, this approach provides a technological basis for process improvement applied not just to healthcare systems but also more broadly to other classes of human-intensive systems.

The medical community has tried to model and evaluate its processes for decades, and there is an industry devoted to helping hospitals to do so. Some of the medical professionals involved in our project had experiences with such efforts, which made them skeptical about the value of process modeling. But the greater specification breath and detail of our process modeling approach and the feedback obtained from rigorous analysis have led to valuable insights and process improvements so that they now feel the effort needed to create these models is warranted. The insights gained and the benefits of this approach have been described from both the medical perspective [12, 13], and from the computer science perspective [5-7, 20]. Here we present some observations that derive from our experiences using software engineering modeling and analysis techniques to create, validate, and improve medical processes.

Our project has been using specific software technologies to gain a deep understanding of medical processes and the nature of medical process improvement problems. Specifically, we are using the Little-JIL [2] process definition language to model the processes, the PROPEL [8, 21] property requirements engineering system to help elucidate and represent properties, and the FLAVERS [11] and SPIN [14] finite-state verification systems to detect defects in the Little-JIL process definitions and in the actual medical processes. Our recent work has also suggested that other analysis techniques, such as simulation and fault-tree analysis, might yield useful results. In this paper, we refer to specific features of these technologies, but use them as the basis for observations intended to be more broadly applicable to other technologies. While we have found the technologies that we have used to be effective in some ways, our experiences with them are more intended to form the basis for suggestions about the fundamental needs in this domain and about requirements for better technologies.

2.1 Modeling Processes

Process Modeling Language: Our use of the Little-JIL process definition language in this project has suggested the importance of certain features such as ***support for abstraction, hierarchical decomposition, concurrency, exception handling, and operations designed to support the flexibility that human agents expect for doing their tasks*** (e.g., non-deterministic choice). In addition, ***it is important that the language have well-defined semantics so that process models described in the language can be rigorously analyzed***.

To illustrate the kind of detailed modeling we are employing in this project, Figure 1 depicts a Little-JIL definition (where the term “definition” is used by Little-JIL to denote the more detailed, semantically rich models that can result) addressing a portion of a chemotherapy process. This figure and the ensuing description are only intended to give the reader a sense of the language; full details about the language can be found elsewhere [23]. A Little-JIL definition is centered on a coordination diagram of the process, such as the one shown in Figure 1, which defines the hierarchical task decomposition of the task being modeled. This hierarchical decomposition view of the process is a relatively natural structural representation that, nevertheless at times, can obscure some of the complicated control flow that is also being represented.

The coordination diagram in Figure 1 is a view of only the top-level process tasks, represented as steps (denoted in the diagram as nodes, called step bars). In this figure, the root step is

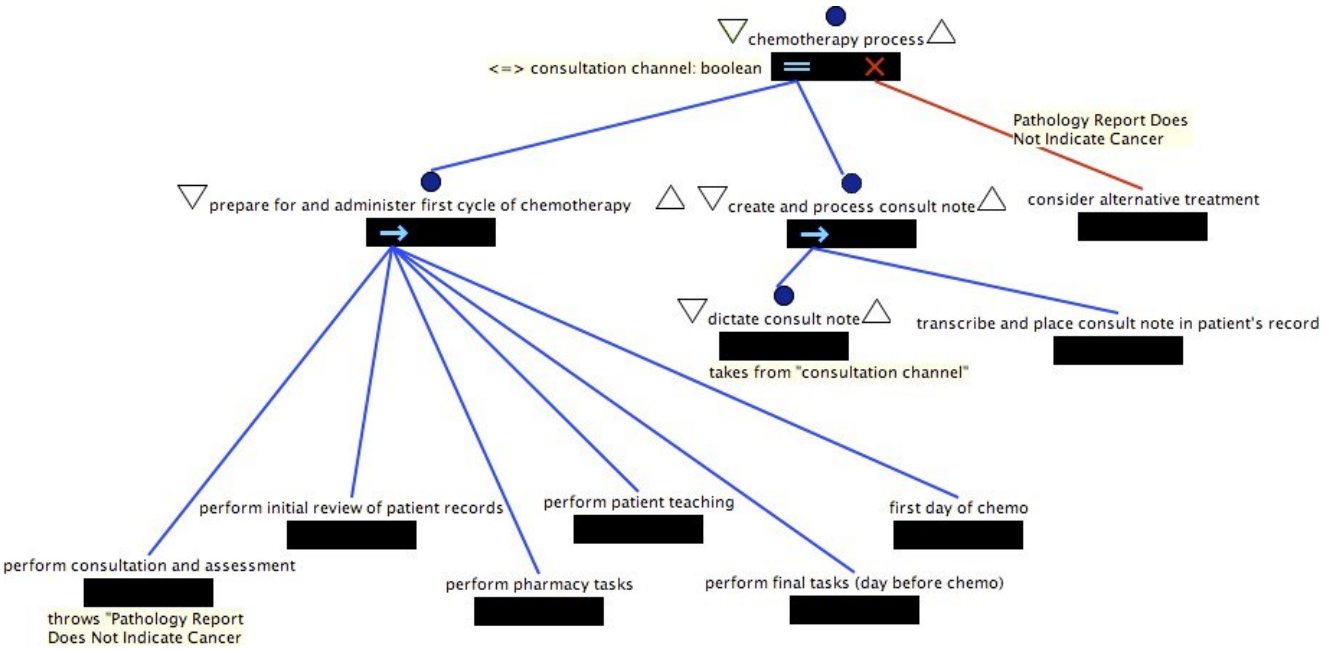

Figure 1. Top-level chemotherapy process definition in Little-JIL.

decomposed into two substeps executing in parallel (indicated by the equal sign in the step bar). Each substep can be further decomposed, or elaborated, down to the leaf steps, for which the process definer is unable to, or uninterested in, providing further detail. The first substep, `prepare for and administer first cycle of chemotherapy`, of the root step `chemotherapy process`, is decomposed into six substeps to be executed in sequence (indicated by the arrow pointing to the right in the step bar). Each step includes a specification of the type of agent, that is the type of participant who is to perform the tasks associated with each step, such as the type of doctor or nurse, hardware device, or software application. Specification of the agents, resources, artifacts, and some other features of the language as well as further decomposition of the steps in the diagram are not shown here.

Figure 1 also shows that the root step `chemotherapy process` has a substep `consider alternative treatment` that acts as an exception handler (indicated by the ``X" on the `chemotherapy process` step bar to which the step `consider alternative treatment` is connected). In the step `perform consultation and assessment`, if the doctor determines that the patient's pathology report does not indicate cancer, the `Pathology Report Does Not Indicate Cancer` exception is thrown (the elaboration of the `perform consultation and assessment` step is not shown). A thrown exception propagates control up the step decomposition tree until it reaches a matching handler. Thus, control is transferred to the exception handler step `consider alternative treatment` where appropriate action is specified.

While step-sequencing specifications provide control over the order of step execution, Little-JIL also enables specification of synchronization through such constructs as a channel. In this figure, a channel is used to specify that a doctor cannot dictate a consult note before evaluating the patient's condition. But, because a consult note is primarily used for billing and legal purposes, the doctor may choose to dictate the consult note at any time after evaluating the patient, for example while the tasks in `prepare for and administer first cycle of chemotherapy` are already underway. This step sequencing flexibility is captured by the coordination diagram in Figure 1, in which “consultation channel“ (represented iconically as an annotation attached to the circle above the root step, `chemotherapy process`), is counted on to deliver a consult note to the step `dictate consult note`, which cannot start until after the arrival of the consult note artifact. The `perform patient consultation step`, which is not shown, is a substep of the `perform consultation and assessment step` and is the source of this artifact. Thus, this example shows that the `dictate consult note` step can potentially execute in parallel with tasks in `prepare for and administer first cycle of chemotherapy`, but only after receiving the appropriate paperwork.

Process Modeling and Elicitation: ***Carefully modeling processes leads to better understanding about those processes.*** It was not unusual to find that the medical professionals did not fully understand the processes in which they were participants. Usually they knew their tasks, but often had misunderstandings about what others involved in the process actually did or how artifacts were used. By understanding the process better, errors in the process sometimes become apparent. Thus, the activity of modeling a process often leads to the discovery of process errors and always leads to better understanding.

A multifaceted language that separates out the different issues that need to be addressed facilitates process elicitation. The Little-JIL language is multifaceted in that the step definition has many different aspects, each of which can be considered

separately. Thus, for example, in defining a step in the process, one has to consider the preconditions, the postconditions, the exceptions that could be thrown or handled by the step, the artifacts that are input to or output from the step, resources that might be requested or released, which agents should execute the step, the substeps that comprise the step, and the order in which these substeps should be executed. It is not necessary to consider all of these facets at once. In our project, a first pass was made at understanding and representing the process only involving step decomposition and control flow. Later passes through the process would then address other facets. Adding these additional facets, however, often resulted in changes to the overall step decomposition and control flow. Such changes are unavoidable, since as noted above, the domain experts were often not sure of the details of the process and had to consult with others involved in the process work or reevaluate their own process activities.

From the above list of facets, it is clear that Little-JIL supports the specification of a relatively broad range of semantic features of a process. This proved to be of considerable importance, as we found that the medical processes we wanted to define required strong semantic support for specifying such aspects as concurrency, exception handling, scoping, late binding, and flexible control flow that supported the freedom of choice often desired by human agents. Thus, the language supported detailed specification of how exceptional conditions are identified and handled, how parallel tasks must be synchronized, and how the assignment of personnel to tasks is indeed late-bound. On the other hand, the language did not insist that an ordering be imposed on selecting which substep to do next, if such an ordering was not actually required in the real process. This flexibility allowed us to define processes that more closely and completely modeled how they are actually performed. Having more accurate, complete, and detailed process definitions allowed for more meaningful and accurate analysis, as described further in the next subsection.

Abstraction and hierarchical decomposition facilitates developing the process models incrementally. The process modelers had to continually make choices about how many levels to which to decompose a task and the level of abstraction or granularity of that decomposition. Abstraction allows the activities associated with a task to be conceptualized. When it turned out that more detail was required, some tasks were then further decomposed so that these details could be elaborated. This allowed for incremental development of the model, and as discussed in the next subsection, allowed for incremental analysis, which provided incremental feedback.

Process Comprehensibility: With the inclusion of the different facets described above, the detailed process definitions quickly became large and complex. Even seemingly simple processes, such as “verify a patient's ID”, became unexpectedly large when the many variations of the process were defined. Some of our processes involved hundreds of steps, with all the facets of each step completely defined. To assist with this modeling and with comprehension, abstraction and hierarchical decomposition are extremely important. Any step in Little-JIL can be referenced many times, very much as though a step is a method call. A step, therefore, becomes an abstract representation of its definition, which for a non-leaf step is based on its hierarchical decomposition. Computer scientists are familiar and comfortable with these concepts, but we found that the domain experts had to be taught these concepts and their benefits.

Step decomposition in Little-JIL is a significant aid in understanding the basic breakdown of a task, but can also be somewhat misleading since the flow of control in Little-JIL is superimposed on the step decomposition view. For example, a parallel step may have several children, each of which can be further elaborated. This may appear to define only a simple task decomposition, but it also actually specifies that the execution of the descendant steps of one subtree can be interleaved with the execution of the descendants of the others. Thus on the positive side, Little-JIL succinctly and, from some perspectives, clearly represents these complicated potential traces. On the negative side, few domain experts (and probably many computer scientists) could be expected to completely grasp the complexity of what is being described.

The process definitions needed to be reviewed carefully and repeatedly by the medical professionals to assure that the definitions represented the actually processes appropriately. Thus, it is important that domain experts be able to understand, although it is probably not necessary that they be able to develop, the process definitions. Little-JIL coordination diagrams provide a visual spatial representation, as shown in Figure 1, that shows the step decomposition. The editing tool used to develop these diagrams can assist in efforts to understand process definitions by allowing the viewer to select the facets that are to be explicitly shown and by providing wizards that furnish more detailed information about steps and check for simple well-formedness. On the one hand, we were pleasantly surprised at how well some of the medical professionals learned the process definition language and were able to comprehend the Little-JIL process definitions. On the other hand, this comprehension was sometimes superficial. Thus, additional support is needed for domain experts to understand the process definitions. There are many alternative representations to help with model understanding that should be explored. For example, a role based view that shows the activities for a type of agent, such as the triage nurse, might be effective. We have experimented with creating a natural language, textual representation of the process definition. An example of a hyperlinked, textual representation for part of the process shown in Figure 1 is shown in Figure 2. As with the spatial representation, the viewer should be able to determine which facets of the process definition should be described and have some control over customizing the phrases that are used. Although a textual description did not address all the concerns about comprehensibility, the medical professionals greatly appreciated having a textual representation available for review.

2.2. Analyzing Processes

Analysis is a cornerstone of our approach. In fact, ***if the system is interesting enough to warrant being modeled then the model is probably complex enough to warrant careful scrutiny by rigorous and automated analysis techniques***. Without such scrutiny one should have serious concerns about the validity of the model and any decisions made based on that model. Thus as mentioned above, to support rigorous analysis, the semantics of the modeling language must be formally and precisely defined.

1. Chemotherapy Process

To perform the chemotherapy process, the medical professionals involved should, in no required order, prepare for and administer first cycle of chemotherapy and create and process consult note.

The medical professionals, however, cannot start create and process consult note before perform patient consultation (a substep of perform consultation and assessment) has completed.

2. Prepare for and Administer First Cycle of Chemotherapy (substep of Chemothereapy Process)

To perform this step, the medical professionals involved must have the **biopsy**, the **pahtolgy report** and the **patient chart**.

To prepare for and administer first cycle of chemotherepy, the medical professionals involved should perform, in order, each of the following steps:

a. Perform consultation and assessment
b. Perform initial review of patient records
c. Perform pharmacy tasks
d. Perform patient teacing
e. Perform final tasks (day before chemo)
f. Perform first day of chemo tasks

If during perform consultation and assessment, the medical professionals find out that the pathology report does not indicate cancer, the attending MD should consider alternative treatment. In this case, after successful completion of the step consider alternative treatment, the step chemotherapy process is considered complete.

Figure 2. Hyperlinked, textual view of part of the process shown in Figure 1.

Even with careful analysis, complex processes represented by detailed models are bound to contain defects, just as most interesting programs are bound to contain defects. Since we are creating models on which to base decisions and further reasoning, enough to justify this trust. As the models are repeatedly validated using a range of analysis techniques, we increase our confidence in their accuracy. Moreover, if decisions made using the models then fail to provide the expected results, that too is a form of validation that should result in carefully scrutiny to determine the cause and subsequent improvement to the model. Thus, users of the model must recognize this limitation and evaluate recommendations derived from the model carefully, especially when dealing with life-critical processes, such as many medical procedures.

The analyses that we have been considering include finite-state verification to determine if all traces through a model adhere to properties that indicate the legal sequences of events (e.g., [11, 14]), fault-tree analysis to reveal vulnerabilities if steps in the process are not executed appropriately [22], and discrete-event simulation [17] to determine the aggregate behavior after a large number of traces have been executed. These are by no means all the kinds of analyses that should be considered, but each is substantially different and provides distinctive kinds of feedback. Since we have the most experience with finite-state verification, here we emphasize our observations from those experiences. A more thorough description of our experiences applying finite-state verification to medical processes is given in [5].

Property Specification: Before applying finite-state verification, we first needed to determine the properties of the system that should be evaluated. We usually started with medical guidelines that we first restated as high-level requirement statements, being careful to use consistent terminology. For example, "administer chemo" might have a different meaning depending on the part of the process that is being described by the guidelines. These requirements are usually described at such a high-level of abstraction that they are process-independent, meaning that a wide range of approaches could be used to satisfy them. Although this makes them generally applicable in many different settings, it is usually difficult to determine what is actually required for them to be satisfied. For example, a high-level generic property for most medical processes is: "Do the right procedure, on the right patient, at the right time."

Working with the medical professionals, we translated each high-level property into a set of more specific and measurable requirement statements. Determining if it is the "right patient", for example, might require checking that the name on the ordered medical procedure matches the name on the wrist-band ID, matches the name on the medical chart, and matches the name and date of birth provided by the patient (assuming the patient is conscious and speaks and understands the same language as the medical professional checking the ID). For this second level of refinement, we were also careful to use the terms defined in a glossary, adding terms when necessary.

These refined requirements were still not precise enough to form the basis for verifying the processes, however. The patient ID verification example, raises questions such as "when does the patient ID need to be checked?", "do all three checks have to happen in any particular order?", and "can other events happen in between checking the patient chart and checking the patient ID?" The Propel system was designed to help elicit these types of details from domain experts and then to represent them as a finite-state automaton that can serve as the basis for finite-state verification. These low-level, detailed, and narrowly focused requirement specifications are frequently called properties. Before verification could be done using these properties, the events mentioned in the properties had to be mapped to events in the process.

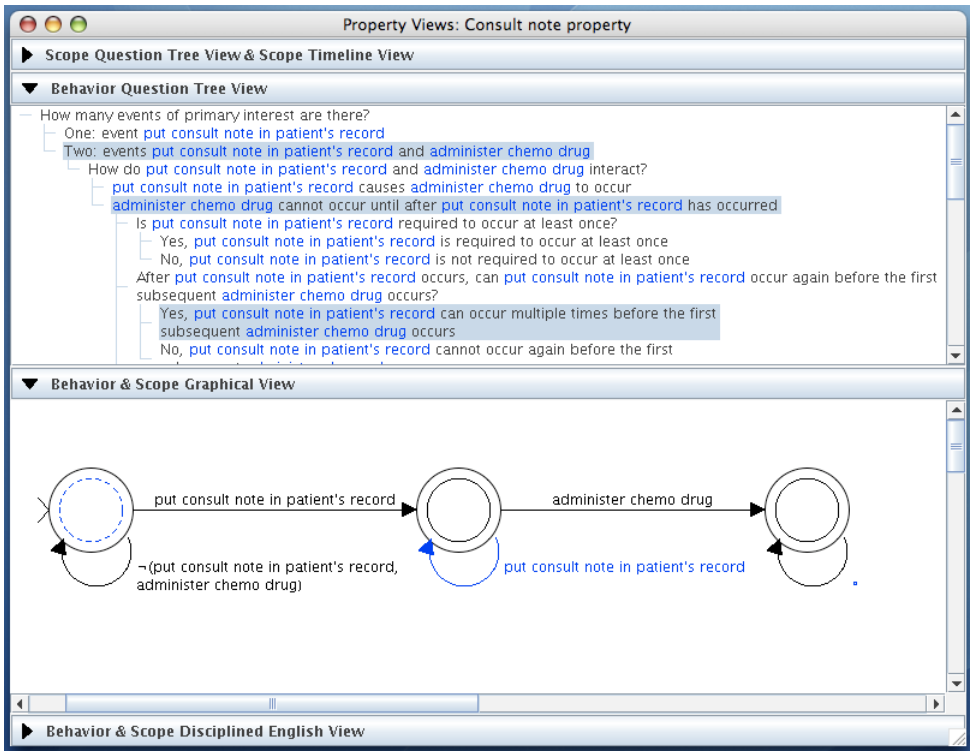

Figure 3. Screen shot of the PROPEL question tree and finite-state automaton templates used during the development of a property.

This mapping was usually straightforward, but needed to be done with care, since an event in the property might map to different events in the process definition. Taken together, these properties and the bindings of event names to step names provided a detailed and rather process-specific description of the overall requirements for the process.

To represent the properties, Propel provides templates for commonly occurring verification property patterns [10]. These templates explicitly indicate the options that need to be considered for each pattern. In some ways, this is similar to the facets of the Little-JIL process modeling language since, like the facets, they remind the user of the many different concerns that must be taken into consideration. Propel provides the specifier with three alternative representations of the templates: disciplined, natural language text where the options are represented as phrase choices; finite-state automata graphs where options are represented by optional transitions, labels, and accepting states; and by question trees that first select the appropriate pattern based on answers to a few initial questions, but then continue to pose questions about all the options associated with the selected pattern template. Figure 3 provides an example of the finite-state automaton view and the question tree view for a simple property that was developed to assure that there is a signed consult note in the patient's record before chemotherapy is administered.

The medical professionals initially had difficulty understanding the difference between a process model, an operational view, and a requirement or property specification, a goal-oriented view. Moreover, the medical professionals tended to think in terms of "war stories" about what went wrong. We could sometimes map such a story to an appropriate set of properties. More work is definitely needed to determine how to better exploit these war stories, which are examples of scenarios that led to process errors.

Developing the properties provided valuable feedback about the current process model. We usually started developing the process models before the properties, based on the medical guidelines and the information provided by the medical experts who were working with us. We made note, however, of any requirements that were mentioned during this process elicitation. Those requirements, plus existing guidelines or protocols, were the initial set of high-level requirements. We also asked the medical professionals to suggest other, perhaps unstated but important, properties. In these discussions, it was not uncommon for medical professionals to propose requirements about details that were not even represented in the current process models, even though the medical professionals making the suggestion might have been working with us for months on developing these models. Clearly, concentrating on the requirements provided a different perspective, one focused on the intent of the process. We decided that if a requirement was important enough to be stated, that the models should be developed to the point where the tasks relevant to that requirement are actually represented and can be reasoned about during analysis. Thus, for example, we usually decided not to model the low-level details about how a form is to be filled out. On the other hand, since patient ID errors are common and often serious, details about how to check patient ID were added to the process models after requirements about this aspect of the process arose. Thus, what was deemed important by the domain experts

determined the scope and granularity of the process models and the requirements for those models.

The properties that we specified and verified were primarily concerned that specific sequences of events did (or did not) occur. Occasionally we encountered a few properties concerned with state information, which, as is usually done, we dealt with by creating events that set or check a value. We encountered few properties that were concerned with timing events. One such example is the need to use or return a unit of blood within a set time period. There were a number of properties, however, that were concerned with efficiency, since inefficiency can impact patient safety. For example, a property might be that there is a check on the patient's ID before a critical procedure is performed. On the other hand, we might also want to check that no more that "N" such checks are performed before the procedure, since processes that have excessive checks are inefficient (and ineffective since the medical professionals may become lax about performing checks if they are deemed to be excessive.) In [5] an example with a richer sequence of events is used to determine if the process is inefficient. This property was based on a nurse's intimate knowledge of the process and where inefficiencies often arise.

Issues surrounding the ***specification and handling of exceptions have been particularly interesting, and often problematic***. Most of the errors that we have found in the process models and in the processes themselves involve exceptions. This is not surprising since studies have shown that errors are most likely to occur during the handling of exceptional cases. Medical guidelines, however, often do not even indicate what is to be done in such situations. This leads to variation in how medical professionals respond to these situations and, consequently, is more likely to lead to errors. From a technological point of view, the analysis tools that we used should be significantly improved to handle exceptional cases better. For example, often the properties were wrong because exceptional cases were not taken into account. That is, the property was stating what was expected only if no exceptions arose. Better support for indicating when exceptional and non-exceptional situations are to be considered in the property specifications should be explored.

Finite-state Verification: Finite-state verification problems are known to often explode in size, making it impractical to analyze large systems. Thus, we employed a number of optimization techniques when creating the internal representation of the Little-JIL process definitions. These optimizations are conservative but often reduce the size of the model by introducing some imprecision. The consequences of this imprecision are that the counter example traces through the internal model that violate the property may not correspond to actual executable traces through the process model. Thus, they are a false positive or spurious indication of an error. It is interesting to note that in our analysis of Little-JIL processes, spurious error reports hardly ever occurred. We believe that this is because this process language mostly describes control and event flow and does not represent compound objects or references to such objects using aliasing, which are known to degrade the results of static analysis. Moreover, unlike programs, most of the traces through our process models tended to correspond to actual executable behavior. Although this is a known benefit associated with analyzing high-level designs, it is interesting to see that it also applies to the detailed models provided by a process definition language, such as Little-JIL.

Using finite-state verification, we mostly found errors in the process models, as opposed to errors in the actual processes themselves. Although this might seem somewhat disappointing, as noted above, validating the models is an important part of process improvement. Before process models can be used for decision-making, they should be carefully validated. Using analysis techniques, we found numerous defects in our process models, but we also found some interesting and subtle errors in the actual processes that could have serious consequences. Analysis of the process models were also useful in helping to determine the causes of these errors and in evaluating alternative potential solutions for correcting them.

The set of property specifications associated with a process model continued to grow as the process was modified, as defects were found in the process models, and as errors were found in the processes themselves or in the clinical setting. This set of properties was invaluable. It provided a baseline set of requirements against which to verify the process models after any change. As this collection grew, we gained more confidence in the requirements and in the processes that adhered to these requirements. We suspect that domain experts will be more willing to consider process improvements knowing there is a detailed model of the process and its properties that can be used to evaluate those improvements,

Other analyses: As mentioned above, we intend to use the process models as the basis for a range of analysis techniques. Two techniques that we have initially explored are fault-tree analysis and discrete-event simulation. Fault-tree analysis creates a tree representation of how a hazard could occur in terms of what would need to fail or be faulty. The trees are then translated into Boolean flow equations that can be evaluated to determine minimum cut sets. Each minimum cut set indicates the collection of failures that would have to occur together for the hazard to arise. Historically fault trees have been used in traditional engineering disciplines such as mechanical engineering (although Leveson [3, 16] and others has also explored their use in systems engineering). In this prior work, fault trees tended to be large and were usually created by a team of safety experts. One of the drawbacks of this approach is that it is difficult to be sure that fault trees created in this way are sufficiently complete and accurate. We have demonstrated that fault-trees can be derived automatically from Little-JIL process definitions, using a template for each step kind and facet of the language [4]. The resulting fault trees are surprisingly large and complicated. Although one could argue that the fault trees derived from a process model may also be inaccurate if the process model is inaccurate, the process model is significantly simpler than the derived fault tree. Moreover, the process model should have first undergone rigorous validation before the corresponding fault-tree was generated and analyzed. In addition, a single, carefully validated process model can be used to derive a very large number of fault trees, namely a different one for each hazard to be studied. To give a sense of the complexity and size of these trees, a fault tree for a single hazard derived from a blood transfusion process is given in Figure 4.

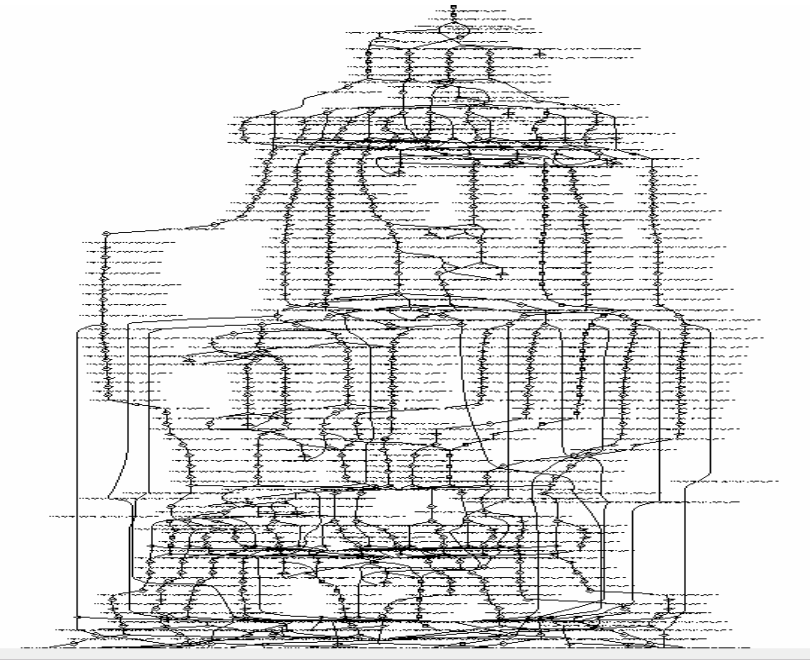

Figure 4. Example of a fault tree for a single hazard derived from a medical process.

We have also been experimenting with using the process models to drive discrete-event simulations. Simulations can be used to evaluate performance and efficiency. For our emergency room case study, one of the issues is how to determine the best resource mix that delivers optimal flow and minimal waiting times. For example, would it be better to hire more nurses, more doctors, or add more beds to reduce waiting time for patients? Here again, we suspect that our more detailed and validated model will be a better foundation for considering these issues than the high-level models that are currently used for simulation.

3. Conclusion

We have described how software engineering technologies and approaches can be incorporated into a Deming Cycle of continuous improvement to medical processes. This approach entails creating a process model that is detailed and addresses a broad range of semantic issues, extensively analyzing that model to validate that it is a reasonable basis for making decisions about the real process, and then using the validated model to detect errors and other problems in the actual process, with the eventual goal of improving that process. This approach to process improvement is being evaluated by applying it to critical processes from the medical domain. Currently we are involved in three case studies, emergency room flow, blood transfusion, and chemotherapy administration, each of which has different characteristics and places different demands on the supporting technology that we are developing. This work has led to a number of observations that seem particularly important.

The choice of a modeling language should depend on what one wants to do with the model and the process. In our case, we want to reason about how medical errors can occur, and how to guard against them. To be the basis for definitive reasoning the process modeling language itself must have well-defined semantics. But if the reasoning is to be relevant to a real-world process, then the language must also be capable of capturing in detail all aspects of the way in which the process might be performed. This dictates the selection of a process modeling language that allows fine-grain details to be represented. But, the language also needs to support the specification of such semantics as complex control flow, concurrency, exception handling, and scoping. While being quite precise about such issues, the language must also provide for the flexibility desired by humans.

Needing to deal effectively with each of these semantic issues creates challenges for a process language. Exception handling, for example, is an important element in human-intensive systems, but specifying it adds complexity both to the process and to the process model. Often process descriptions are not clear about what exceptional situations might arise and how to deal with them if they do. In the medical domain, this can be a source of wide variation in behavior, which is undesirable and often leads to errors. Once the exceptional conditions and how to handle them are determined, this information needs to be represented in the model, which itself can be difficult to do with most process modeling languages. Even with a supportive language, such as Little-JIL, representing exceptions has proven to be tricky and error prone. Exceptions also complicate the specification of requirements and any analysis being applied. We found that they were a major source of errors in the models and in the actual processes.

Additional specification complexity is added when the model incorporates execution semantics. Our work has the eventual goal of using executing process definitions to provide coordination support and proactive guidance to humans. This should not be

undertaken unless these process models have been extensively analyzed. Our experience has indicated, however, that there are considerable challenges in developing an executable process language that has sufficient clarity, semantic breadth, and capacity for detail.

In our opinion, if a process is complicated enough to warrant precise and detailed modeling then the accuracy of the model requires careful scrutiny. This is particularly true for detailed models, such as the models we are developing using Little-JIL. Our experience suggests that these sorts of detailed and complex process models should be developed incrementally so that high-level, more-abstract views of the process can be validated before more-detailed models are developed. The scope and granularity of the model should be determined by the questions the model is intended to address. There is no doubt that detailed models require more effort to develop and maintain, but provide more definitive, in-depth feedback (in other words, there is no free lunch). But, our work has been quite satisfying in that the detailed process models and the analysis that we have applied have indeed discovered errors in actual medical processes. Indeed every step in this approach, from process modeling, to property specification, to process model verification has led to the discovery of errors of one kind or another in the actual processes.

Future work: This work has already suggested many directions for future research. A number of these directions are suggested by attempts to use process models to introduce automation. As already noted, we would like to eventually use validated process models to guide medical professionals while they are actually executing their processes in a clinical setting. For example, a doctor's hand held device could indicate the current process status for each patient and highlight the most urgent items according to the most recent recommended protocols. There are human interface issues in how to represent this information on the handheld device so that it can be immediately understood and used. There are other interesting issues in how to determine and maintain coherence between the actual process and the process model.

One of the most frequently asked questions is what is the cost in terms of time and effort to elicit and evaluate a process. To date, all the process models were developed and analyzed concurrently with technology development and involved students who were learning about using that technology. It would be interesting to assess the cost of having trained computer scientists work with medical professionals on complex processes to experimentally evaluate the costs and error detection effectiveness. Related questions revolve around the generalizability of medical processes and the degree to which each hospital might have to create its own hospital-specific process models. We believe, that for well-designed process models, the customization of a general process to a particular hospital setting should mostly involve changes to the low-level process steps. This hypothesis needs to be evaluated. Moreover, there is the issue of how many processes would need to undergo such careful modeling and validation. In the medical domain, it has been suggested that the number of such processes may be surprisingly small, in which case it would not be infeasible to develop models of each of these if this approach were to be found to indeed reduce the number of medical errors and help improve the efficiency of medical care. Medical protocols change frequently, however, so at least the generic versions of these models would need to be updated regularly and then recustomized. Clearly there are interesting issues about how to do this efficiently and accurately. As noted above, process models could be used to provide guidance during real execution of the process. In addition, they seem to hold considerable promise as teaching aids. Both are important when processes are being changed frequently. It is currently difficult for medical professionals to stay up-to-date on the latest recommended protocols without such assistance. Providing updated process models that can provide on-line guidance would help address this problem.

Finally, we note that the proposed approach does not seem to be specific to any particular set of technologies or restricted to any particular domain. We have demonstrated its effectiveness by using a specific modeling language and set of analysis tools, but other languages and tools could be used as well to support process improvement. We have tried to indicate the requirements for these capabilities. The medical domain has proven to be an interesting and challenging domain, and an important one to address, but we believe the approach is applicable to many domains, especially those that rely importantly upon complex, human-intensive processes.

Going further, we now envision a new paradigm for system development and improvement that is driven by a detailed understanding and evaluation of a coordination model that provides the context in which application software and hardware devices will be used. Evaluation of this model could be used to derive context requirements for the software and hardware devices, and analysis techniques could subsequently be applied to determine the consistency among these requirements and the provided components. In the medical domain, this would allow the processes to be evaluated with respect to the medical devices and software systems that are employed. A preliminary description of such an approach is provided in [1]. To achieve this vision will require advances in process modeling, software analysis, and system safety. In today's world, processes, software, and hardware devices rarely operate in isolation from each other, and thus process improvement must be considered in this broader system context.

One of the most gratifying aspects of the research described here is its suggestion that the approaches, understandings, and technologies that the software engineering community has developed over the past few decades may have profoundly important impacts upon a very broad spectrum of other disciplines. We have already seen the potential of the work of our community to effect important improvements in medical care. We can see glimpses of applicability in such other domains as law, government, manufacturing, and fundamental scientific research. No less gratifying is the sense that grappling with the problems of these domains is enriching software engineering research by confronting our approaches and technologies with novel challenges that promise to ultimately improve the work in the software engineering domain as well.

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5. REFERENCES

1. G. S. Avrunin, L. A. Clarke, E. A. Henneman and L. J. Osterweil Complex Medical Processes as Context for Embedded Systems. *ACM SIGBED Review, special issue on Workshop on Innovative Techniques for Certification of Embedded Systems*, *3* (4). 9-14.
2. A. G. Cass, B. S. Lerner, E. K. Mccall, L. J. Osterweil, S. M. Sutton Jr. and A. Wise, Little-JIL/Juliette: A Process Definition Language and Interpreter. in *22nd International Conference on Software Engineering*, (Limerick, Ireland, 2000), 754-758.
3. S. S. Cha, N. G. Leveson and T. J. Shimeall, Safety Verification in Murphy Using Fault Tree Analysis. in *10th International Conference on Software Engineering*, (Singapore, 1988), 377--386.
4. B. Chen, G. S. Avrunin, L. A. Clarke and L. J. Osterweil, Automatic Fault Tree Derivation from Little-JIL Process Definitions. in *Software Process Workshop and Process Simulation Workshop*, (Shanghai, China, 2006), Springer-Verlag LNCS, 150-158.
5. B. Chen, G. S. Avrunin, E. A. Henneman, L. A. Clarke, L. J. Osterweil and P. L. Henneman, Analyzing Medical Processes. in 30th *International Conference on Software Engineering*, (Leipzig, Germany, 2008), to appear.
6. S. C. Christov, B. Avrunin, G.S., Chen, B., Clarke, L. A., Osterweil, L.J., Brown, D., Cassells, L., Mertens, W., Rigorously Defining and Analyzing Medical Processes: An Experience Report, in *Workshop on Model-Oriented Trustworthy Health Information Systems (MOTHIS)*, (Nashville, TN, 2007). (to appear in LNCS Volume on Models in Software Engineering Workshops and Symposia at MoDELS 2007, Reports and Revised Selected Papers, Editor: Holger Giese)
7. L. A. Clarke, Y. Chen, G. S. Avrunin, B. Chen, R. Cobleigh, K. Frederick, E. A. Henneman and L. J. Osterweil, Process Programming to Support Medical Safety: A Case Study on Blood Transfusion. in *Software Process Workshop 2005*, (Beijing, China, 2005), Springer-Verlag, 347-359.
8. R. L. Cobleigh, G. S. Avrunin and L. A. Clarke, User Guidance for Creating Precise and Accessible Property Specifications. in *14th ACM SIGSOFT International Symposium on Foundations of Software Engineering*, (Portland, OR, 2006), 208-218.
9. W. E. Deming *Out of the Crisis*. MIT Press, Cambridge, 1982.
10. M. B. Dwyer, G. S. Avrunin and J. C. Corbett, Patterns in Property Specifications for Finite-State Verification. in *21st International Conference on Software Engineering*, (Los Angeles, CA, 1999), 411-420.
11. M. B. Dwyer, L. A. Clarke, J. M. Cobleigh and G. Naumovich Flow Analysis for Verifying Properties of Concurrent Software Systems. *ACM Transactions on Software Engineering and Methodology*, *13* (4). 359-430.
12. E. A. Henneman, G. S. Avrunin, L. A. Clarke, L. J. Osterweil, C. J. Andrzejewski, K. Merrigan, R. Cobleigh, K. Frederick, E. Katz-Basset and P. L. Henneman. Increasing Patient Safety and Efficiency in Transfusion Therapy Using Formal Process Definitions. *Transfusion Medicine Reviews*, *21* (1). 49-57.
13. E. A. Henneman, R. Cobleigh, G. S. Avrunin, L. A. Clarke, L. J. Osterweil and P. L. Henneman Property Specification to Improve the Safety of the Blood Transfusion Process. *Transfusion Medicine Reviews*. to appear.
14. G. J. Holzmann *The SPIN Model Checker*. Addison-Wesley, 2004.
15. L. T. Kohn, J. M. Corrigan and M. S. Donaldson (eds.). *To Err is Human: Building a Safer Health System*. National Academy Press, Washington DC, 1999.
16. N. G. Leveson *Safeware: System Safety and Computers*. Addison-Wesley, 1995.
17. J. Misra Distributed Discrete Event Simulation. *ACM Computing Surveys*, *18* (1). 29-55.
18. L. J. Osterweil, Software Processes are Software, Too. in *Ninth International Conference on Software Engineering*, (Monterey, CA, 1987), IEEE Computer Society Press, 2-13.
19. L. J. Osterweil, Software Processes Are Software, Too, Revisited. in *19th International Conference on Software Engineering*, (Boston, MA, 1997), 540-558.
20. L. J. Osterweil, G. S. Avrunin, B. Chen, L. A. Clarke, R. L. Cobleigh, E. A. Henneman and P. L. Henneman, Engineering Medical Processes to Improve their Safety: An Experience Report. in *Proceedings of the IFIP Working Group 8.1 Working Conference on Situational Method Engineering: Fundamentals and Experiences (Method Engineering 2007)*, (Geneva, 2007), Springer-Verlag, 267--282.
21. R. L. Smith, G. S. Avrunin, L. A. Clarke and L. J. Osterweil, PROPEL: An Approach Supporting Property Elucidation. in *24th International Conference on Software Engineering*, (Orlando, FL, 2002), 11-21.
22. W. Vesely, F. Goldberg, N. Roberts and D. Haasl. Fault Tree Handbook U.S. Nuclear Regulatory Commission, Washington, D.C., 1981.
23. A. Wise. Little-JIL 1.5 Language Report, Department of Computer Science, University of Massachusetts, Amherst, 2006, 28.

On the gas-sensing mechanism of resistive based SnO_2 QD gas Sensor

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***Abstract*—Tin oxide (SnO2) finds extensive application in metal-oxide-semiconductor systems as a gas-sensing material, owing to its distinct physical and chemical attributes. Among these attributes, grain size stands out as a pivotal factor that significantly shapes the gas- sensing properties. An all-encompassing model is introduced, encompassing the complete spectrum of gas-sensing processes involving receptor function, transducer function, and utility factor. The characteristics of the sensor are defined as dependent on factors such as grain size, width of the depletion layer, thickness of the film, density of oxygen vacancies, concentration of gas, pore dimensions, and operational temperature. This model offers a thorough mathematical elucidation of the impact of SnO2's size variations, spanning from partial depletion to volume depletion.**

Keywords*— Gas Sensor, Tin oxide, Quantum Dot, Sensing Response

I. INTRODUCTION

In the past ten years, there has been a notable rise in the emphasis placed on air quality. The need for technologically advanced sensors is experiencing substantial growth, resulting in a rapid expansion of the gas sensor market. Gas sensors play a critical role in detecting gas leaks [1], ensuring public safety [2], and aiding in medical diagnoses [3]. Among the diverse array of gas sensors available, significant attention has been directed toward tin oxide (SnO2) gas sensors due to their uncomplicated design [4], straightforward manufacturing process, cost-effectiveness, and consistent chemical properties [5]. Presently, room temperature gas sensors hold significant appeal due to their lack of heating elements, contributing to energy efficiency and mitigating explosive risks. SnO2 possesses a wide bandgap and exhibits n-type semiconductor behaviour, adopting the rutile structure with octahedral coordination. As an innovative functional semiconductor, quantum dots (QDs) of SnO2 exhibit unique traits such as small grain size (< 10 nm) and an expanded specific surface area. This results in a substantial exchange of electrons between a considerable number of atoms and gas molecules ad- sorbed on the surface. The gas-sensing characteristics of these QDs hinge on their grain size, showcasing a notable influence stemming from their size [6]. The influence of grain size on the gas-sensing attributes of semiconductor sensors has captivated significant attention from the scientific community. Researchers have effectively elucidated the underlying sensing mechanism from a theoretical perspective. C. Xu introduced a neck-controlled model, dis- closing that the sensor's response peaked when the grain radius (r) closely aligned with the width of the depletion layer (w) [7]. Conversely, the response displayed an inverse relation- ship with grain size when r exceeded w by a substantial margin. However, the aspect of the entire grain achieving volume depletion status wasn't addressed for cases where the grain radius was smaller than the depletion layer width ($r < w$).

Moreover, Yamazoe introduced an all-encompassing framework for semiconductor gas sensors, encompassing the receptor function, the transducer function, and the utility factor[8]. The receptor function addressed the individual crystal's reaction to the target gas under investigation, while the transducer function cantered on the conversion of each crystal's response into device resistance. The utility factor elucidated the dampening of device response (alteration in resistance) within a real porous sensing structure due to the consumption of stimulant gas during its internal diffusion. Hence, as a crucial facet of the receptor function, the impact of grain size became notably significant over the past decade, particularly during the rise of nanomaterials in advanced electronic devices.

This work integrates the receptor function, transducer function, and utility factor to develop an all-encompassing mathematical model. This model is utilized to examine the influence of size on the gas-sensing characteristics of semiconductor grains, spanning from partial depletion to volume depletion. The validity of this proposed model is additionally confirmed through experimental findings.

II. COMPREHENSIVE MATHEMATICAL MODEL FOR THIN FILM GAS SENSORS

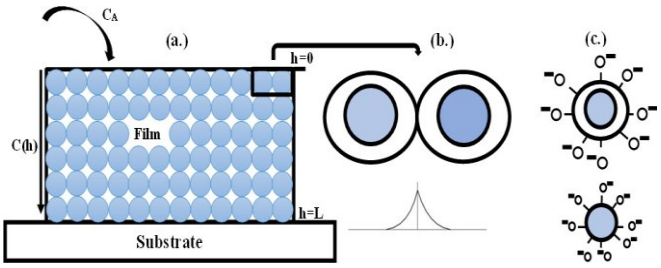

Fig. 1. Gas-sensing mechanism of SnO2 QD resistive based gas sensor: (a) the utility fac- tor, (b) the transducer function and (c) the receptor function of partial depleted and volume depleted grains.

The gas-sensing process within a semiconductor gas sensor comprises three key com- ponents: the receptor

function, transducer function, and utility factor [9]. The utility factor characterizes the diminished response within the sensing body due to the consumption of stimulant gas during its progression through the film's interior [10]. As depicted in Figure 1(a), the thin film consists of an aggregation of SnO2 quantum dots (QDs). Upon exposure to a reducing environment with a concentration denoted as CA, the reducing gas permeates the film by infiltrating the gaps between the grains, adhering to Knudsen diffusion principles. The diffusion equation can be formulated as follows [11].

$$C(h)=\frac{\cosh\left[(L-h)\sqrt{K_c/D_k}\right]}{\cosh\left(L\sqrt{K_c/D_k}\right)} \tag{1}$$

$$D_k=\frac{4r_p}{3}\sqrt{\frac{2G_cT}{\pi M}} \tag{2}$$

The Knudsen diffusion constant (DK) is determined by factors such as temperature (T), the radius of the pores (rp), and the molecular weight (M) of the gas that is diffusing. The gas constant is denoted as Gc [12]. The distribution of gas concentration within a thin film is influenced by parameters like the thickness of the film (L), the distance from the film's surface (h), and a reaction constant (Kc). The transducer function is focused on establishing a connection between two individual grains, converting the response of each grain into measurable electrical properties. This conversion is typically described using the concept of a Schottky barrier, as depicted in Figure 1(b). On the other hand, the receptor function explains how a single grain responds when it is stimulated by an external source, as shown in Figure 1(c). The grains possess inherent oxygen vacancies, which result in quasi-free electrons after ionization. These electrons are then captured by the oxygen adsorbed on the surface, leading to the creation of a depletion layer [13].

The presence of ionized oxygen vacancies creates a Schottky barrier within the region that has experienced depletion. Previous experimental assessments have determined that the width of this depletion layer is approximately 4.2 nm [14, 15]. Consequently, when the grain radius surpasses this width (r > w), the grain becomes partially depleted. Conversely, when the grain's radius is smaller than the depletion layer width (r < w), the entire grain undergoes volume depletion. The total resistance of a grain (Ra) consists of the combined resistances of both the bulk of the grain (Rb) and the depletion layer (Rgb). If we represent Ra(h) as the resistance of a SnO2 grain positioned at a depth h within the thin film, it can be expressed as follows:

$$R_a(h)=R_b+R_{gb}=\rho_0\frac{2(r-w)}{A}+\rho_{gb}\frac{2w}{A} \tag{3}$$

ρ0 and ρgb represent the resistivities of the grain's bulk and the depletion layer, respectively. The term r refers to the grain radius, and w represents the width of the depletion layer. Additionally, A signifies the effective area for electron tunneling at the boundaries between grains. The resistivity of the grain bulk (ρ0) is alternatively known as the flat-band resistivity and can be computed using Equation (4).

$$\rho_0=\frac{1}{nqu} \tag{4}$$

Here, n represents the electron density, q stands for the elemental charge, and μ signifies the electron mobility. The resistivity ρgb exhibits an exponential relationship with ρ0 and both contribute to the overall resistivity of a grain. While in partially depleted grains, ρgb takes precedence, the influence of ρ0 cannot be dismissed in grains exhibiting volume depletion [16, 17]. The connection between the barrier height of the depletion layer, denoted as V(x) and the space charge density, represented as σa(x) is described by the Poisson equation, as shown in Equation (5) [18].

$$\frac{\partial^2V(x)}{\partial x^2}=\frac{-\sigma_a(x)}{\varepsilon} \tag{5}$$

The symbol ε denotes the dielectric constant. The presence of space charge within the depletion layer is influenced by the oxygen vacancies. These innate imperfections have been demonstrated to exhibit a gradient distribution within a semiconductor grain, as evidenced by previous studies [19-21]. However, in minuscule crystalline structures like quantum dots (QDs), the gradient is sufficiently minimal that it is reasonable to assume the distribution of oxygen vacancies is uniform [8]. Consequently, the charge density within the depletion layer can be formulated using Equation (6).

$$\sigma_a(x)=qN_d \tag{6}$$

Here, Nd represents the concentration of oxygen vacancies, which is presumed to be ionized in a first-order manner. The Schottky barrier height described in Equation (8) can be de- rived by applying the boundary conditions outlined in Equation (7).

$$\begin{cases}V(w)=0\\V'(w)=0\end{cases} \tag{7}$$

$$qV_a(x)=\frac{q^2N_d}{2\varepsilon}(x-w)^2 \quad 0<x<w \tag{8}$$

The calculations for the barrier height at the grain boundary and the resistivity of the depletion layer (ρgb) are performed using Equations (9) and (10), respectively.

$$qV_{sa}=qV_a(0)=\frac{q^2w^2N_d}{2\xi} \tag{9}$$

$$\rho_{gb}=\rho_0\exp\left(\frac{qV_{sa}}{KT}\right)=\rho_0\exp\left(\frac{W^2}{2L_D^2}\right) \tag{10}$$

$$L_D=\sqrt{\xi KT/q^2N_d} \tag{11}$$

Here, K signifies the Boltzmann constant, while T denotes the temperature. The concept of the Debye length (L_D) is introduced in Equation (11) [22]. Consequently, the formulation for the total resistance R_a can be represented as given in Equation (12).

$$R_a = \int_0^L R_a(h)\partial h = \frac{2\rho_0 L}{A}\left[r - w + w\exp\left(\frac{w^2}{2L_D^2}\right)\right] \quad (12)$$

In an environment with a reducing atmosphere, the resistance of an individual SnO2 quantum dot (QD) grain (Rg) is comprised of the combined resistances from the grain's bulk (Rb) and the depletion layer (Rgb'). Correspondingly, Rg(h) represents the resistance of a SnO2 grain situated at a depth h within the thin film. This resistance can be expressed using Equation (13).

$$R_g(h) + R_b + R_{gb'} \quad (13)$$

The dispersion of electrons (nR) released back into the depletion layer following gas expo- sure exhibits an essentially uniform distribution. It is posited that this distribution is directly proportional to the concentration of oxygen vacancies (Nd), as outlined in Equation (14).

$$n_R = \alpha N_d \quad (14)$$

The parameter α indicates the percentage of captured electrons that are returned to the depletion layer. Its value ranges from 0 (in the presence of air) to 1 (in a vacuum or an atmosphere devoid of oxygen), and it is correlated with the partial pressure of oxygen or the presence of reducing gas [23]. Consequently, when the thin film is exposed to a reducing gas, a connection can be established between the space charge density σg(x) and the concentration of oxygen vacancies Nd. This relationship is illustrated by Equation (15).

$$\sigma_g(x) = q(N_d - n_R) = (1-\alpha)qN_d \quad (15)$$

In a similar manner, the calculation of the barrier height at the grain boundary and the resistivity of the depletion layer (ρgb) is achieved using the Poisson equation, as expressed in Equations (16) and (17).

$$qV_{sg} = qV_g(0) = \frac{(1-\alpha)q^2w^2N_d}{2\xi} \quad (16)$$

$$\rho_{gb'} = \rho_0 \exp\left(\frac{qV_{sg}}{KT}\right) = \rho_0 \exp\left[(1-\alpha)\frac{w^2}{2L_D^2}\right] \quad (17)$$

For the sake of analysis, let's assume that the adsorbed oxygen exists in the form of [O-] [9], which is capable of capturing electrons on the surface of the grain. Additionally, considering that the oxygen vacancies act as donors and are uniformly distributed, we arrive at the following equations as presented in Equation (18).

$$[O^-] = N_d w \quad (18)$$

The concentration of liberated electrons within the depletion layer, denoted as [e-], can be formulated according to Equation (19)

$$[e^-] = \alpha N_d \quad (19)$$

Upon exposure of the sensor to C_4H_{10}, the gas molecules undergo reactions with the oxygen that is adsorbed on the surface. These reactions are commonly represented by Equations (20) and (21).

$$O_2 + 2e^- \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} 2O^- \quad (20)$$

$$C_4H_{10} + 13O^- \xrightarrow{K_2} 4CO_2 + 5H_2O + 13e^- \quad (21)$$

In this context, k1, k-1, and k2 represent the rate constants of the reactions. The reverse process of Equation (20) occurs at a comparatively slower rate and can therefore be disregarded. As a result, the rate at which [O-] accumulates is expressed using Equation (22)

$$\frac{\partial[O^-]}{\partial t} = K_1P_{O_2}[e^-]^2 - K_{-1}[O^-]^2 - K_2P_{C_4H_{10}}[O^-]^{13} \quad (22)$$

In this scenario, Po2, signifies the concentration of O2, while PC4H10, represents the concentration of C4H10. When the system reaches a steady state, Equations (20) and (21) attain equilibrium in accordance with the derived Equations (23) and (24).

$$K_1P_{O_2}[e^-]^2 - K_2P_{C_4H_{10}}[O^-]^{13} = 0 \quad (23)$$

$$\alpha = \left(\frac{K_2N_d^{11}w^{13}}{K_1P_{O_2}}\right)^{0.5}\left(P_{C_4H_{10}}\right)^{0.5} = \beta[C(h)]^{0.5} \quad (24)$$

The symbol β denotes the coefficient of proportionality. As a result, the expression for the resistance of a SnO_2 grain at a depth h denoted as Rg(h), can be formulated according to Equation (25).

$$R_g(h) = \frac{2\rho_0}{A}\left\{r - w + w\exp\left[\left(1-\beta[C(h)]^{0.5}\right)\frac{w^2}{2L_D^2}\right]\right\} \quad (25)$$

Therefore, the expression for R_g can be found as Equation (26).

$$R_g = \frac{2\rho_0 L}{A}\left\{r - w + \frac{4L_D^2}{wm}\exp\left(\frac{w^2}{2L_D^2}\left(1-\beta C_A^{0.5}\right)\left[\exp\left(\frac{mw^2}{4L_D^2}\right)-1\right]\right)\right\} \quad (26)$$

$$m = \beta C_A^{0.5} L\sqrt{\frac{K_c}{D_k}}\tanh\left(L\sqrt{K_c/D_k}\right) \quad (27)$$

Here, the parameter m is introduced straightforwardly in the equation. When the grain's radius exceeds the depletion layer width (r > w), the grain experiences partial depletion. As a result, the sensor's response is derived as described in Equation (28).

$$S = \frac{r - w + w\exp\left(w^2/2L_D^2\right)}{r - w + \frac{4L_D^2}{wm}\exp\left(\frac{w^2}{2L_D^2}\left(1-\beta C_A^{0.5}\right)\left[\exp\left(mw^2/4L_D^2\right)-1\right]\right)} \quad (28)$$

The response of volume-depleted grain is formulated as Equation (29).

$$S = \frac{r^2 m\exp\left(\frac{r^2}{2L_D^2}\beta C_A^{0.5}\right)}{4L_D^2\left[\exp\left(mr^2/4L_D^2\right)-1\right]} \quad (29)$$

III. RESULTS AND DISCUSSIONS

Consequently, based on the comprehensive mathematical model for gas sensing in semi- conductors, a series of mathematical simulations were conducted utilizing the following parameters: dielectric constant (ε) set at 8.85×10^{-10} F/m, proportional coefficient (β) at 0.005 $ppm^{-0.5}$, reaction constant (k_c) at 10,000 mol/(L s), depletion layer width (w) fixed at 4 nm [24, 25], elemental charge (q) at 1.6×10^{-19} C, concentration of oxygen vacancies (N_d) set to.

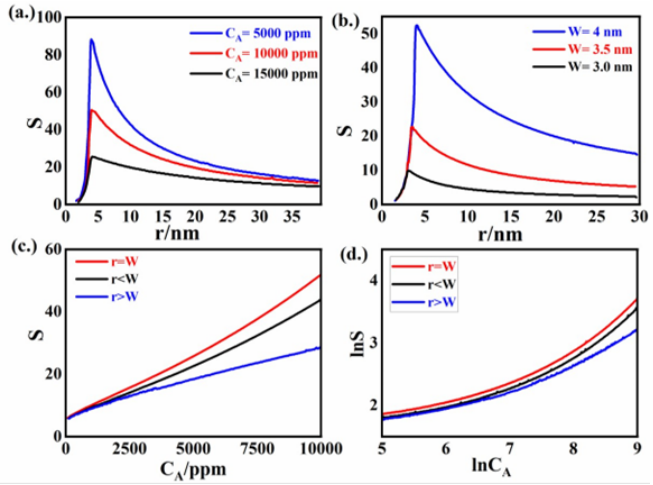

Fig. 2. Simulation results of theoretical model: the relationship between sensor response and (a) grain size at various concentrations, (b) grain size at various depletion layer widths, (c) gas concentration in linear coordinates, (d) gas concentration in logarithmic coordinates.

8.5×10^{25} m^{-3} [22], Boltzmann constant (k) at 1.38×10^{-23} J/K [26], and gas constant (Gc) at 8.314 J/(mol K) [27]. The remaining parameters are configured to align with experimental conditions: temperature (T) is 298 K, gas concentration (CA) is 10,000 ppm, and the film thickness (L) is 381 nm. Volume-depletion and partial-depletion grain sizes are defined as 3.9 nm and 10 nm, respectively. The resulting trends are depicted in Figure 2(a), illustrating the sensor response's negative correlation with grain size when r > w. The response reaches its maximum at r = w and subsequently diminishes with further reduction in grain size. This finding corroborates the anticipated size effect from the gradient-distributed oxygen vacancies model [19]. Consequently, the value of the depletion layer width (w) proves to be pivotal in determining semiconductor sensor performance. Previous studies have approximated the value of w to range between 3 and 4.2 nm [15, 28]. The impact of w on the sensor response is graphically presented in Figure 2(b), revealing that the response peak consistently aligns with r = w, with response magnitude increasing alongside the depletion layer. Lastly, Figures 2(c) and 2(d) elucidate the influence of gas concentration on sensor response, depicted in both linear and logarithmic coordinates, respectively.

IV. CONCLUSIONS

A detailed mathematical model has been formulated to describe the behavior of semiconductor gas sensors, considering elements such as the receptor function, transducer function, and utility factors. Through simulations, it has been observed that the sensor response achieves its maximum value when the grain radius matches the depletion layer width. The relationships between sensor response and factors like gas concentration, film thickness, operational temperature, ionized donor density, and pore radius have been quantified. These simulation outcomes have been validated against real-world experimental thin film gas sensors, indicating the strong suitability and effectiveness of the mathematical model for describing the behavior of semiconductor gas sensors.

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REFERENCES

[1] X.F. Liu, H.P. Dong, S.H. Xia, Micromachined catalytic combustible hydrogen gas sensor based on nano-structured SnO2, Acta Chim. Sin. 71 (2013) 657–662.

[2] V. Krivetskiy, K. Zamanskiy, A. Beltyukov, A. Asachenko, M. Topchiy, M. Nechaev,A. Garshev, A. Krotova, D. Filatova, K. Maslakov, M. Rumyantseva, A. Gaskov, Effect of AuPd bimetal sensitization on gas sensing performance of nanocrystalline sno2 obtained by single step flame spray pyrolysis, Nanomaterials 9 (2019) 728.

[3] A.A. Vasiliev, A.E. Varfolomeev, I.A. Volkov, N.P. Simonenko, P.V. Arsenov,I.S. Vlasov, V.V. Ivanov, A.V. Pislyakov, A.S. Lagutin, I.E. Jahatspanian, T. Maeder, Reducing humidity response of gas sensors for medical applications: use of spark discharge synthesis of metal oxide nanoparticles, Sensors 18 (2018) 2600.

[4] Y. Fu, J. Li, H. Xu, SnO2 recycled from tin slime for enhanced SO2 sensing properties by NiO surface decoration, Mater. Sci. Semicond. Process. 114 (2020) 105073.

[5] O. Kendall, P. Wainer, S. Barrow, J. van Embden, E. Della Gaspera, Fluorine-doped tin oxide colloidal nanocrystals, Nanomaterials 10 (2020) 863.

[6] H. Liu, S. Xu, M. Li, G. Shao, H. Song, W. Zhang, W. Wei, M. He, L. Gao, H. Song,J. Tang, Chemiresistive gas sensors employing solution-processed metal oxide quantum dot films, Appl. Phys. Lett. 105 (2014) 163104.

[7] X. Chaonan, T. Jun, M. Norio, Y. Noboru, Relationship between gas sensitivity and microstructure of porous SnO2, Denki KagaKu 58 (1990) 1143–1148.

[8] N. Yamazoe, K. Shimanoe, New perspectives of gas sensor technology, Sens. Actuators B: Chem. 138 (2009) 100–107.

[9] N. Yamazoe, J. Fuchigami, M. Kishikawa, T. Seiyama, Interactions of tin oxide surface with O2, H2O and H2, Surf. Sci. 86 (1979) 335–344.

[10] G. Sakai, N. Matsunaga, K. Shimanoe, N. Yamazoe, Theory of gas-diffusion controlled sensitivity for thin film semiconductor gas sensor, Sens. Actuators B: Chem. 80 (2001) 125–131.

[11] G. Sakai, N. Matsunaga, K. Shimanoe, N. Yamazoe, Theory of gas-diffusion controlled sensitivity for thin film semiconductor gas sensor, Sens. Actuators B: Chem. 80 (2001) 125–131.

[12] N. Matsunaga, G. Sakai, K. Shimanoe, N. Yamazoe, Diffusion equation-based study of thin film semiconductor gas sensor-response transient, Sens. Actuators B: Chem. 83 (2002) 216–221.

[13] S.R. Morrison, Mechanism of semiconductor gas sensor operation, Sens. Actuators 11 (1987) 283–287.

[14] J. Liu, Z. Zhai, G. Jin, Y. Li, F.F. Monica, X. Liu, Simulation of the grain size effect in gas-sensitive SnO2 thin films using the oxygen vacancy gradient distribution model, Electron. Mater. Lett. 11 (2015) 34–40.

[15] J. Liu, X. Liu, Z. Zhai, G. Jin, Q. Jiang, Y. Zhao, C. Luo, L. Quan, Evaluation of deple- tion layer width and gas-sensing properties of antimony-doped tin oxide thin film sensors, Sens. Actuators B: Chem. 220 (2015) 1354–1360..

[16] J. Liu, J. Lv, J. Shi, L. Wu, N. Su, C. Fu, Q. Zhang, Size effects of tin oxide quantum dot gas sensors: from partial depletion to volume depletion, J. Mater. Res. Technol. 9 (2020) 16399–16409.

[17] C. Xu, J. Tamaki, N. Miura, N. Yamazoe, Grain size effects on gas sensitivity of porous SnO2-based elements, Sens. Actuators B 3 (1991) 147–155.

[18] J. Liu, Y. Gao, X. Wu, G. Jin, Z. Zhai, H. Liu, Inhomogeneous oxygen vacancy distribu- tion in semiconductor gas sensors: formation, migration and determination on gas sensing characteristics, Sensors 17 (2017) 1852.

[19] J. Liu, S. Gong, L. Quan, Z. Deng, H. Liu, D. Zhou, Influences of cooling rate on gas sensitive tin oxide thin films and a model of gradient distributed oxygen vacancies in SnO2 crystallites, Sens. Actuators B: Chem. 145 (2010) 657–666.

[20] J. Liu, Y. Gao, X. Wu, G. Jin, Z. Zhai, H. Liu, Inhomogeneous oxygen vacancy distribu- tion in semiconductor gas sensors: formation, migration and determination on gas sensing characteristics, Sensors 17 (2017) 1852.

[21] J. Liu, S. Gong, Q. Fu, Y. Wang, L. Quan, Z. Deng, B. Chen, D. Zhou, Time-dependent oxygen vacancy distribution and gas sensing characteristics of tin oxide gas sensitive thin films, Sens. Actuators, B 150 (2010) 330–338.

[22] N. Yamazoe, K. Shimanoe, Theory of power laws for semiconductor gas sensors, Sens. Actuators B: Chem. 128 (2008) 566–573.

[23] J. Liu, S. Gong, L. Quan, Z. Deng, H. Liu, D. Zhou, Influences of cooling rate on gas sensitive tin oxide thin films and a model of gradient distributed oxygen vacancies in SnO2 crystallites, Sens. Actuators B: Chem. 145 (2010) 657–666.

[24] J. Liu, S. Gong, L. Quan, Z. Deng, H. Liu, D. Zhou, Influences of cooling rate on gas sensitive tin oxide thin films and a model of gradient distributed oxygen vacancies in SnO2 crystallites, Sens. Actuators B: Chem. 145 (2010) 657–666.

[25] C. Xu, J. Tamaki, N. Miura, Relationship between gas sensitivity and microstructure of porous SnO2, Denki Kagaku oyobi Kogyo Butsuri Kagaku 58 (1990) 1143–1148.

[26] B. Fellmuth, C. Gaiser, J. Fischer, Determination of the Boltzmann constant-status and prospects, Meas. Sci. Technol. 17 (2006) R145–R159.

[27] MichaelJ. Moran, Fundamentals of Engineering Thermodynamics, 4th ed., J. Wiley & Sons, 2000.

[28] J. Liu, X. Liu, Z. Zhai, G. Jin, Q. Jiang, Y. Zhao, C. Luo, L. Quan, Evaluation of deple- tion layer width and gas-sensing properties of antimony-doped tin oxide thin film sensors, Sens. Actuators B: Chem. 220 (2015) 1354–1360.

INTELLIGENT ORTHOSIS WITH PAIN RELIEVERHEAT BELT

AN INTELLIGENT DEVICE FOR VARIOUS ORTHOPEDIC SUPPORTS

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***Abstract*— Nowadays there are many different types of orthopedic supports available in the market. These include supports like heat belts, knee caps, collar belts, wrist and arm support, back supports etc., which are used as supports for various body pains, swells, sprains. Many of these orthopedic supports are available in electrically or battery-operated form with regulators installed in them in order to control the temperature passed by those supports. But all these supports are available in manually-controlled form. Theuser always has to regulate the temperature. This does not provide an actual amount of temperature to thatspecific body part that will help in faster relief of pain. Other than this problem, there are users that face with wrong usage of their orthopedic supports. This mainly includes older peoples who have to use such supports on a daily basis but lack with caretakers around them. Due to this problem, they do not get enoughguidance for the usage of their supports properly. With the help of our INTELLIGENT ORTHOSIS, wehave come up with a solution that will fix all these problems in one go. This device can be installed in many types of orthopedic devices that are usually used in a daily basis by people with issues in their muscles and joints. With this solution, the absence of caretakers can be easily compensated in order to help older peopleget proper treatment of their muscular or joint problems.**

Keywords*— *Orthopedic support, Intelligent Orthosis, FSR Module, Locomotor.

I. INTRODUCTION

In this paper, we have introduced an intelligent device for the orthopedic supports available in the market. This device enables automatic temperature transfer in orthopedic supports based on the pain occurring in the portion where the support is worn. This allows proper and accurate passage of temperature in order to obtain faster pain relief. For this intelligent cure of pain, we have implemented the use of several sensors, microcontroller, temperature passing devices and control systems that will lead to an instant relief from pain at that moment. The temperature passing all over the support will be completely harmless and effective for the user.

II. COMPONENTS LIST

1. Any orthopedic support
2. Power Supply
3. Arduino UNO microcontroller
4. Electrodes
5. FSR (Force Sensing Resistor) Module
6. Peltier Module
7. Switch
8. Buzzer
9. Connecting Wires
10. LED light

III. METHODOLOGY

Working principle of Intelligent Orthosis:

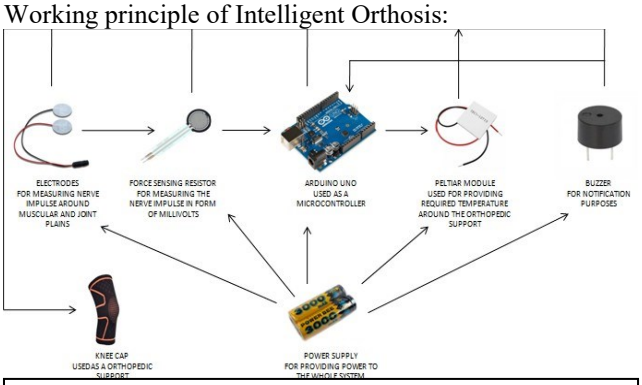

Figure: 01 WORKING PRINCIPLE OF INTELLIGENT ORTHOSIS

This is the working principle of our prototype where it will be automatically detect the amount of pain and pass temperature based on it for pain relief. In order to measure the pain, we have used electrodes that will measure the nerve impulse from the muscular or joint plains and provide it to FSR module. Since the nerve impulse is measured in millivolts so, the FSR will measure the nerve impulse in form of millivolts and provide the data to Arduino UNO for further processing. The Arduino UNO will control the Peltier module based the inputs of electrode and FSR module. The Peltier module will pass the required temperature uniformly all over the orthopedic support that will provide enough warmth to the orthopedic device which would be harmless and effective for the user. In additional, there is a buzzer attached to it in order to provide various notifications to the user regarding the proper usage of the support. This way, it will work as a guidance system for older people as well.

IV. CIRCUIT ANALYSIS

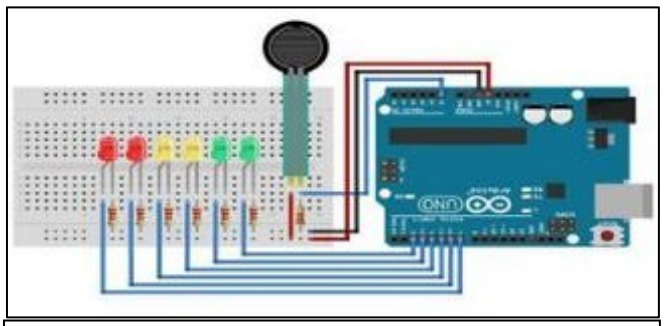

Figure: 02 CIRCUIT DIAGRAM FOR TESTING THE MEASUREMENT PROCESS

This is the image of the circuit representing the way we connected the FSR module with Arduino uno. Thiscircuit is used for testing and calibration purposes. Here, the LED lights represent the amount of the input of pain in the device. The LEDs will glow brighter as the nerve impulse received starts increasing. This system will be connected to the orthopedic device in order to measure pain from our body. In that case, thePeltier module starts functioning based on the input received from electrodes and FSR module.

V. PROTOTYPE DESIGN

By the help of the above given circuit and block diagram, we came up with a prototype of our Intelligent Orthosis that can function the mentioned operations. In this given image, all components are not attached yet. This is a basic assembling of the device to an orthopedic support.

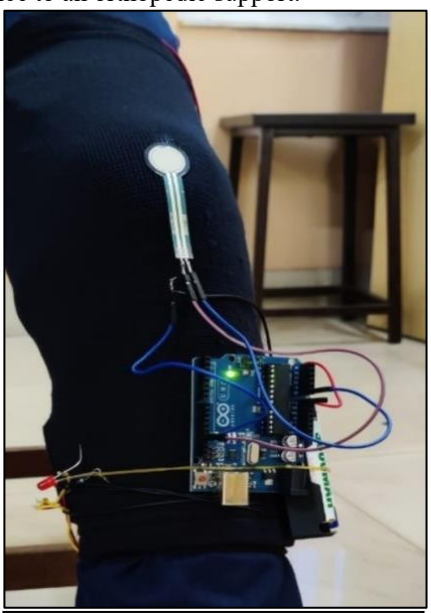

Figure: 03 Prototype Design

VI. RESULTS

The paper has been finished with success with the utmost satisfaction. The paper gives a clever plan for growing an automated health support for various people. Provisions are created to improve the code. It has been examined with live records and has supplied a prosperous result. Then the code has been tested to determine expeditiously. The device created met its objectives, with the aid of using being truthful to apply. This code is advanced with measurability in mind. Further modules can't be really different as soon as necessary. The code is advanced with a popular approach. However, there is nonetheless plenty of scope for future development and accessories in practicality. This device is able to measure the pain out of a joint or muscular plain and provide enough heat that can relieve pain and won't be harmful for the user.

VII. APPLICATION AND FUTURE SCOPE

1. Other than orthopedic patients, this device can also be used by athletes with locomotor issues.
2. This can provide safety from external injuries like the other safety guards.
3. A memory function will be installed to keep a daily based record of use of the device providing theconsultant help for better treatment.
4. Useful for older people to get proper treatment in absence of others or without taking others help.

VIII. CONCLUSION

To develop this paper, we have learned Arduino IDE Programming. With the success of this paper, we would like to develop much more advanced devices to provide help to our society. In the end, we would like to thank our mentor Ms. Susmita Das Madam for her great contribution in our paper. Without her guidance and support, this paper wouldn't become a success.

REFERENCES

[1] 1. Pappas E, Zampeli F, Xergia SA, Georgoulis AD. Lessons learned from the last 20 years of ACL-related in vivo-biomechanics research of the knee joint. Knee Surg Sports Traumatol Arthrosc. 2013;21(4):755–66. [PubMed] [Google Scholar] Figure: 01

[2] Kettunen JA, et al. Cumulative incidence of shoulder region tendon injuries in male former elite athletes. Int J Sports Med. 2011;32(6):451–54. [PubMed] [Google Scholar]

[3] LaBella CR, et al. Effect of neuromuscular warm-up on injuries in female soccer and basketball athletes in urban public high schools: cluster randomized controlled trial. Arch Pediatr Adolesc Med. 2011;165(11):1033–40. [PubMed] [Google Scholar]

[4] Pasanen K, et al. Effect of a neuromuscular warm-up programme on muscle power, balance, speed and agility: a randomised controlled study. Br J Sports Med. 2009;43(13):1073–78. [PubMed] [Google Scholar]

[5] Barber-Westin SD, et al. Reducing the risk of noncontact anterior cruciate ligament injuries in the female athlete. Phys Sportsmed. 2009;37(3):49–61. [PubMed] [Google Scholar]

[6] Hicks-Little CA, et al. Menstrual cycle stage and oral contraceptive effects on anterior tibial displacement in collegiate female athletes. J Sports Med Phys Fitness. 2007;47(2):255–60. [PubMed] [Google Scholar]

[7] Zazulak BT, et al. The effects of the menstrual cycle on anterior knee laxity: a systematic review. Sports Med. 2006;36(10):847–62. [PubMed] [Google Scholar]

[8] Belanger MJ, et al. Knee laxity does not vary with the menstrual cycle, before or after exercise. Am J Sports Med. 2004;32(5):1150–57. [PubMed] [Google Scholar]

[9] Slivka D, et al. Local heat application enhances glycogenesis. Appl Physiol Nutr Metab. 2012;37(2):247–51. [PubMed] [Google Scholar]

[10] Naperalsky M, Ruby B, Slivka D. Environmental temperature and glycogen resynthesis. Int J Sports Med. 2010;31(8):561–66. [PubMed] [Google Scholar]

EFFICIENT VANILLIN DETECTION IN FOOD PRODUCTS USING OPTIMIZED MIP ELECTRODE AND CHEMOMETRIC ANALYSIS

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***Abstract*— Vanillin is a flavoring agent commonly used in the food and pharmaceutical industries. The detection and accurate quantification of vanillin, has attracted considerable interest due to its economic and its potential health effects. In this paper, we focused for the identification and quantification of vanillin in food products using a molecularly imprinted polymer polyacrylamide-based graphite electrode (MIPAM/GP) against a silver-silver chloride reference electrode and a platinum electrode. These sensors are designed to selectively recognize vanillin molecules based on their structural characteristics, thereby improving the sensitivity and specificity of detection. This research explores the rapid electrochemical detection of vanillin utilizing an optimized Molecularly Imprinted Polymer (MIP) electrode. The study assesses the Differential Pulse Voltammetry (DPV) responses generated by the MIP electrode when exposed to vanillin in various real food samples, including ice cream, yogurt, custard, and milkshakes. The data obtained from these samples is then subjected to analysis through K-Means clustering employing Principal Component Analysis (PCA). Remarkably, the results exhibit successful discrimination of each individual food sample, underscoring the efficacy of this electrochemical method. Cluster metrics, such as a maximum Silhouette Score of 0.5815, a maximum Calinski-Harabasz Score of 236.9719, and a minimum Davies-Bouldin Index of 0.3175, affirm the accuracy of the electrode-based clustering approach. This research highlights the potential of electrochemical systems combined with chemometric analysis for the efficient detection of vanillin adulteration in food products. The MIP electrode's effectiveness suggests its utility for immediate on-the-spot identification of varying vanillin levels across a wide array of food items, thereby contributing to rapid food quality assessment and assurance.**

Keywords*— *Vanillin, K-means clustering, PCA, MIP, electrochemical, DPV, Silhouette Score, Calinski-Harabasz Score, Davies-Bouldin Index.

I. INTRODUCTION (*HEADING 1*)

Vanilla holds a place in contemporary culinary trends, being one of many natural flavourings used in a wide variety of food products, including sweets, beverages, medicines, and fragrances. In vanilla, vanillin (4-hydroxy-3-methoxybenzaldehyde) is the main flavour component (1.0-2.0% by weight), out of more than 200 compounds present, giving the desired flavour and aroma [1,2]. The natural vanillin found in vanilla has beneficial properties to human health, including antibacterial, anticancer and anti-mutagenic properties. It also plays a role against UV and X-ray-induced chromosomal abnormalities, acting as a DNA-PK inhibitor to facilitate DNA repair and prevent mutations. Despite these benefits, only a small fraction, around 0.2%, of the market demand is met by natural vanillin from vanilla, with the majority, around 98%, coming from synthetic vanillin synthesized by means chemical or biochemical methods. While the popularity of synthetic vanillin stems from its affordability and accessibility, research points to potential downsides such as headaches, nausea, vomiting as well as kidney and liver damage due to excessive consumption.

In the fields of food science, medicine and pharmacology, it is becoming increasingly important to develop simple, accurate and economical methods for the quantification and monitoring of vanillin. The determination of natural vanillin in various food samples or vanilla extracts has been performed using a variety of chemical techniques. These include methods such as thin layer chromatography, gas chromatography, UV spectroscopy, high performance liquid chromatography, capillary electrophoresis, and micelle electrodynamic chromatography, among others [3,4]. However, these methods are generally not suitable for on-the-go detection of vanillin due to the high cost as well as the complex and time-consuming procedures involved in sample preparation. Electrochemical analysis methods have been studied recently and have been proven to provide and effective and fast alternative to these problems [5-11]. Electrochemical sensors are used for detecting and the quantification of vanillin can be improved by incorporating metals with carbon-based sensors. The physical and chemical properties of graphene allow it to use in a wide range of applications. Synthetic methods have been developed in a number of methods, usually relayed to the properties of MIP [12,13]. In many places, for establishing reconnaissance sites in polymer, surface printing method is used. Simpler and cheaper MIP technology can be used as vanillin detection sensor design using this technology. The sensitivity of the sensor surface is greatly increased.

In this work, the presence of vanillin (VNL) in food products was analysed using a molecularly imprinted polymer polyacrylamide-based graphite electrode (MIPAM/GP). We have used samples such as ice cream, yogurt, custard and milkshakes in which the MIPAM/GP electrode showed accurate results compared with HPLC analysis when evaluating VNL in those samples. Here K-Means Clustering technique was used to visually inspect the different sample clusters' distribution on scatter plots with three similarity indexes such as Silhouette Score, Calinski-Harabasz Score, Davies-Bouldin index. Hence the electrode efficacy was investigated using quantitative indications of cluster quality, and a combination of metrics and visualizations to assess the clustering results.

II. EXPERIMENTAL

A. Chemicals and Reagents

Merck, an Indian company, supplied the vanillin. From Sigma Aldrich in the United States, powdered graphite (99%), acrylonitrile, ethylene glycol dimethyl acrylate (EGDMA), and benzoyl peroxide were purchased. The ethanol and paraffin oil were purchased from Merck in India. Purification was not required because all compounds were analytical-grade substances. 18 M of resistivity Millipore water was utilized for the experiment. All of the studies were conducted at 25 °C.

B. Apparatus and Technique

The Metrohm Auto lab PGSTAT101 Potentiostat/Galvanostat with three electrodes was utilized to carry out the electrochemical analysis. The three- electrode system consisted of an Ag/AgCl reference electrode, a Pt counter electrode, and a MiPAM/GP working electrode. The HPLC analysis was conducted using an Agilent Infinity preparative HPLC system (DEABG0597, G1161B). An Agilent 1260 was included with the HPLC system.

C. Synthesis of molecular imprinted polymer

The polymer substance was claimed to have been synthesized in a previous work [14]. 0.95 grams of graphite was dispersed in 15 ml ethanol using ultrasonication for 40 mins. AM's (0.05g) and VNL (0.05g), was next added followed by 60 min of sonication. Benzoyl peroxide (1 mg) and the crosslinker are then added. 400 µL of EGDMA were added, and they were sonicated for 60 minutes to be added to the mixture. Polymerization was carried out using a hot water bath for 40 mins at 30ºC. Repeated distilled water rinses were carried out to produce the ready-made polymer. Further investigation was performed after the material was dried in air.

D. Fabrication of electrode

The MIPAM/GP was created using a mortar-pestle electrode. Three to four drops of paraffin oil were added to 300 mg of synthesized MIP material before it was ground. A glass capillary with a 2.5 mm inner diameter was filled with the paste, using a thin metallic rod. On the reverse side, a platinum wire made electrical contact with the material.

E. Experimental setup

The electrochemical experiments were accomplished using a system comprising three different electrodes, a working electrode (MIPAM/GP), a reference electrode (Ag/AgCl), and a counter electrode (platinum) connected with Potentiostat PGSTAT1010 which was then interfaced with a computer. The voltammetry responses were realized over the NOVA interface for users. A graphical representation of the setup used during the experimentation process is depicted in the given Figure.1.

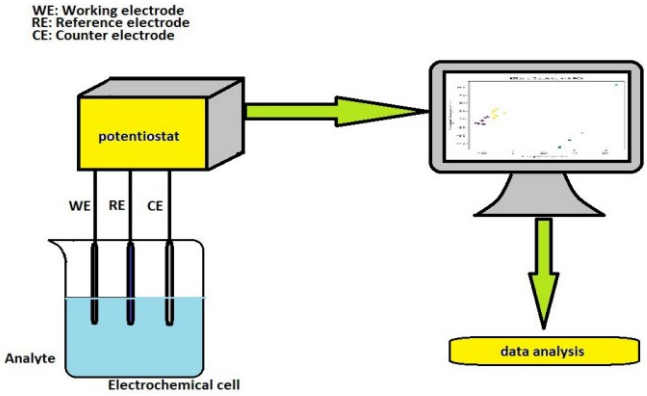

Fig.1. Experimental set-up

F. Real sample analysis

The evaluation of the performance of the electrodes is carried out using four samples of ice cream, yogurt, custard, and milkshakes. Each 2 g of the sample was mixed with 100 ml of water. HPLC and electrochemical analysis was performed on the obtained solutions.

G. Data analysis

The electrochemical data obtained were analysed using Python in Google Colab. Four sets of repetitions were noted for each of the four different samples which are ice cream (S1), yogurt(S2), custard(S3), and milkshakes(S4). K-Means clustering using principal component analysis (PCA), was used to assess the separability of the clusters. A combination of few metrics such as Silhouette Score, Calinski-Harabasz Score, Davies-Bouldin Index was studied to evaluate the quality of the clustering results.

III. RESULTS & DISCUSSIONS

Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections A-D below for more information on proofreading, spelling and grammar.

Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

A. Principle component analysis

PCA does a transformation (orthogonal) of a set of data which is linear with good correlation into a set of variables without any correlation called principal components (PCs). When dealing with a high number of features 227 in this case), it's important to consider dimensionality reduction techniques or feature selection methods before performing K-Means clustering. High-dimensional data can lead to increased computation time and potential issues with clustering performance. One common approach is to use Principal Component Analysis (PCA) to reduce the dimensionality of your data while retaining the most important information. The DPV responses obtained using MIP electrode for different samples S1, S2, S3 and S4 were analysed using PCA for dimensionality reduction. Four repetitions were taken for individual samples.

B. *K-means clustering*

K-Means clustering is an unsupervised learning algorithm is used in clustering problems and in grouping of unlabelled dataset into different clusters. It is a centroid based algorithm in which each cluster is associated with a centroid. This algorithm takes dataset as input and divide the dataset into k number of clusters. The main aim of this algorithm is to create defined clusters for better understanding. This algorithm does two primary tasks that is determining the best value for centroid or k centre by iterative process and assigning the values to the closest k centres. Here, we gave data inputs of four different samples S1, S2, S3, S4 with different concentrations of VNL into this algorithm which gave us four defined clusters. To check its credibility and efficiency, we performed clustering on the data sets with different numbers of components. As shown below in Fig.2, Fig.3, Fig.4, Fig.5 and Fig.6 are the K-Means scatter plots with different number of components (2, 4, 6, 8, 10). For most efficient clustering, we should get Silhouette Score closer to 1, higher Calinski-Harabasz Score and lower Davies-Bouldin Index.

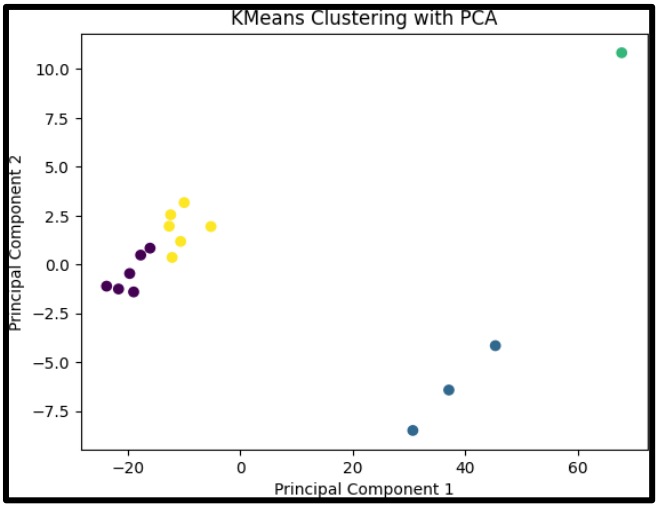

Fig.2. Number of components =10

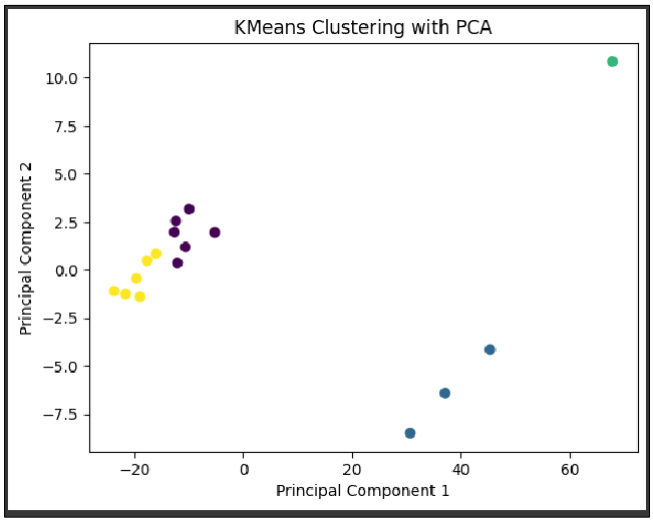

Fig.3. Number of components = 8

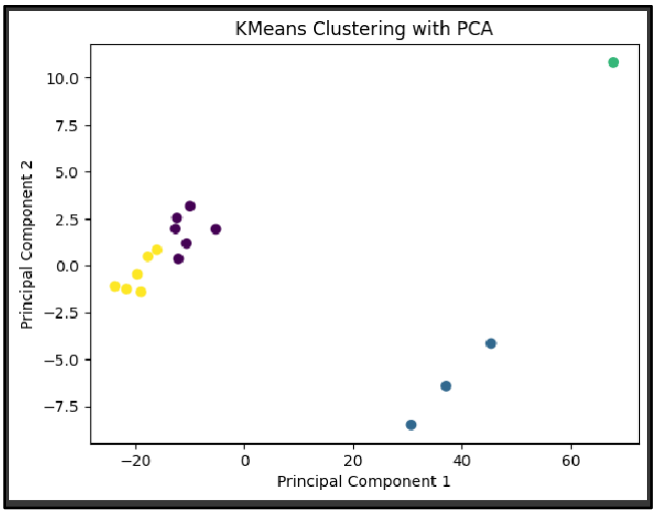

Fig.4. Number of components = 6

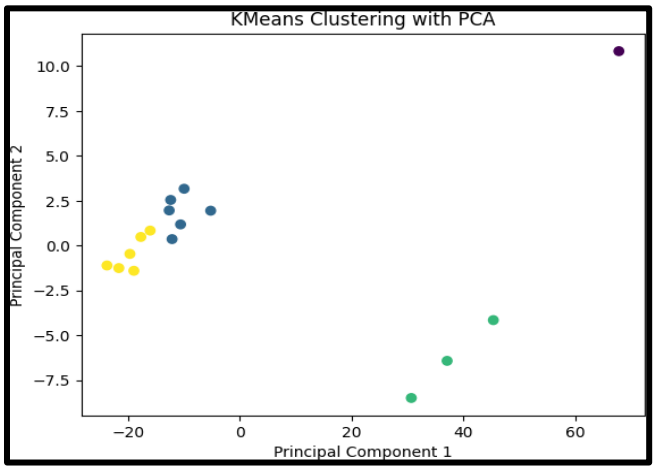

Fig.5 Number of components = 4

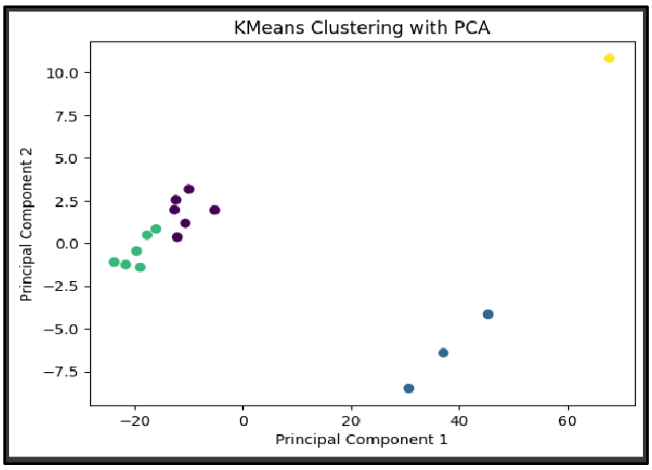

Fig.6. Number of components = 2

From the derived K-Means scatter plots, we can clearly distinguish the different clusters of each sample. Therefore, we can clearly state, that the electrochemical sensors can recognize and identify the presence of VNL of different concentrations in the given samples.

C. *Study of performance metrics*

After performing K-Means clustering using PCA, the separability of the clusters was accessed. One common approach is to use metrics that evaluate the quality of the

clustering results. Here are a few metrics that we have considered:

1. Silhouette Score: The silhouette score measures how close each data point in one cluster is to the points in the neighbouring clusters. A higher silhouette score indicates better-defined clusters.
2. Calinski-Harabasz Index (Variance Ratio Criterion): This index measures the ratio of between-cluster variance to within-cluster variance. Higher values indicate better-defined clusters.
3. Davies-Bouldin Index: This index measures the average similarity between each cluster and its most similar cluster. Lower values indicate better clustering.

The observations are summarized in Table I, three different metrics were studied for different numbers of principal components (2, 4, 6, 8, and 10). These metrics provide quantitative indications of cluster quality, but no single metric is universally best. Hence a combination of metrics and visualizations was used to assess the clustering results. The effectiveness of these metrics can be influenced by the nature of the data and the inherent properties of the clusters themselves. The optimum combination of a maximum value of Silhouette Score: 0.5815, Calinski-Harabasz Score: 236.9719, and a minimum value of Davies-Bouldin Index: 0.3175 was observed for number of components = 2 as depicted in Table I.

TABLE I

Performance metric parameters

No. of components	Silhouette Score	Calinski-Harabasz Score	Davies-Bouldi n Index
10	0.5497	221.7167	0.3534
8	0.5498	221.8255	0.3532
6	0.5503	222.1046	0.3526
4	0.5530	223.7028	0.3494
2	0.5815	236.9719	0.3175

CONCLUSION

The current research encompasses a learning on rapid electrochemical detection of vanillin using an optimized MIP electrode. The DPV responses obtained at the MIP electrode for four various vanillin based real samples ice cream, yogurt, custard, and milkshakes were analysed using K-Means clustering using PCA tool, and effective discrimination of individual samples were observed. Successful data clustering was achieved. Different optimum cluster metrics such as, maximum Silhouette Score - 0.5815, maximum Calinski-Harabasz Score - 236.9719, and minimum Davies-Bouldin Index - 0.3175 proved effective clustering accuracy of the electrode. Hence, the use of an electrochemical system and analysis using chemometrics may be highly efficient in the detection of vanillin adulteration. Electrochemical measurements using molecular imprinted techniques are useful for detecting liquid phase adulteration of food to decipher the food grade rapidly, and quantitatively. This MIP electrode efficacy can serve for immediate on-spot identification of varying vanillin traces in a wide range of food stuffs.

REFERENCES

[1] L. Chen, K. Chaisiwamongkhol, Y. Chen, and R. G. Compton, “Rapid electrochemical detection of vanillin in natural vanilla,” Electroanalysis, vol. 31, no. 6, pp. 1067–1074, Jun. 2019, doi: 10.1002/elan.201900037.

[2] A. Sharma, S. C. Verma, N. Saxena, N. Chadda, N. P. Singh, A. K. Sinha, “Microwave- and ultrasound-assisted extraction of vanillin and its quantification by high-performance liquid chromatography in Vanilla planifolia,” J. Sep. Sci., vol. 29, pp. 613–619, 2006.

[3] G. Lamprecht, F. Pichlmayer, and E.R. Schmidt, “Determination of the authenticity of vanilla extracts by stable isotope ratio analysis and component analysis by HPLC,” J. Agric. Food Chem., vol. 42, pp. 1722–1727, 1994.

[4] T. Sostaric, M.C. Boyce, and E.E.J. Spickett, “Analysis of the volatile components in vanilla extracts and flavorings by solid-phase microextraction and gas chromatography,” J. Agric. Food Chem., vol. 48,pp. 5802–5807, 2000.

[5] N. Hareesha, J. G. Manjunatha, B. M. Amrutha, N. Sreeharsha, S. M. Basheeruddin Asdaq, and Md. K. Anwer, “A fast and selective electrochemical detection of vanillin in food samples on the surface of poly (glutamic acid) functionalized multiwalled carbon nanotubes and graphite composite paste sensor,” Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 626, p. 127042, Oct. 2021, doi: 10.1016/j.colsurfa.2021.127042.

[6] M. Qianwen, D. Yaping, L. Li, W. Anqing, D. Dingding, and Z. Yijun, “Electrospun MoS2 composite carbon nanofibers for determination of vanillin,” Journal of Electroanalytical Chemistry, vol. 833, pp. 297–303, Jan. 2019, doi: 10.1016/j.jelechem.2018.09.040.

[7] L. Huang, K. Hou, X. Jia, H. Pan, and M. Du, “Preparation of novel silver nanoplates/graphene composite and their application in vanillin electrochemical detection.,” Mater. Sci. Eng. C Mater. Biol. Appl., vol. 38, pp. 39–45, May 2014, doi: 10.1016/j.msec.2014.01.037.

[8] T. Zabihpour, S.-A. Shahidi, H. Karimi-Maleh, and A. GhorbaniHasanSaraei, “Voltammetric food analytical sensor for determining vanillin based on amplified NiFe2O4 nanoparticle/ionic liquid sensor,” Food Measure., vol. 14, no. 2, pp. 1039–1045, Apr. 2020, doi: 10.1007/s11694-019-00353-8.

[9] S. Nag, D. Das, H. Naskar, B. Tudu, R. Bandyopadhyay, and R. B. Roy, “Detection of Metanil Yellow Adulteration in Turmeric Powder Using Nano Nickel Cobalt Oxide Modified Graphite Electrode,” IEEE Sens. J., 2022. http://doi.org/10.1109/JSEN.2022.3178768

[10] S. Nag, S. Pradhan, H. Naskar, R. B. Roy, B. Tudu, P. Pramanik, and R. Bandyopadhyay, “A simple nano cerium oxide modified graphite electrode for electrochemical detection of formaldehyde in mushroom,” IEEE Sens. J., vol. 21, 12019 – 12026, 2021.

[11] M. Nouri, S. Shahriari, and G. Pazuki, “Increase of vanillin partitioning using aqueous two-phase system with promising nanoparticles.,” Sci. Rep., vol. 9, no. 1, p. 19665, Dec. 2019, doi: 10.1038/s41598-019-56120-8.

[12] S. Nag, S. Pradhan, D. Das, B. Tudu, R. Bandyopadhyay, and R. B. Roy, “Fabrication of A Molecular Imprinted Polyacrylonitrile Engraved Graphite Electrode for Detection of Formalin in Food Extracts,” IEEE Sens. J., vol. 22, 42–49, 2022.

[13] S. Nag, D. Das, H. Naskar, B. Tudu, R. Bandyopadhyay and R. B. Roy, "A Novel Molecular Imprinted Polymethacrylic Acid Decorated Graphite Electrochemical Sensor for Analysing Metanil Yellow Adulteration in Food," in IEEE Sensors Journal, doi: 10.1109/JSEN.2023.3300732.

[14] S. Nag, D. Das and R. B. Roy, "Voltammetry Application of Molecularly Imprinted Polyacrylamide as Vanillin Receptor in Desserts," in IEEE Sensors Journal, vol. 23, no. 4, pp. 3446-3452, 15 Feb.15, 2023, doi: 10.1109/JSEN.2023.3235933.]

Accessible Home: Empowering Disability with Smart Home Automation

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***Abstract*— In today's world, technology has the power to make life easier for everyone, including those with disabilities. The prototype includes the installation of various smart devices, such as automated entrance system, smart thermostats, smart leakage sensors, and automated lighting systems. Three individual nodes namely home access, gas detection, light automation and fall detection are proposed which are connected to a master node. A RFID card is used to access the entry gate at node 1. The second node detects LPG and carbon monoxide. When the sensors detect gas above threshold value, buzzer goes off alerting everyone. Temperature and humidity values are displaced on their OLED watch screen and speed of lights and fan using the relay. The third node detects a person's falls that will send notification to the emergency contact via Telegram and WhatsApp. All the three nodes are connected with the master node using ESP-01. The user can be instantly notifiedabout any unusual event on their watch using ESP-NOW.**

***Keywords*— RFID, Smart Watch, OLED, ESP-NOW**

I. INTRODUCTION

Home automation has become an innovative trend in the modern world of technology breakthroughs, changing how we interact with and regulate the places we call home. This technology transformation offers the possibility of a more open, self-sufficient, and satisfying way of life for people with disabilities. Home automation includes a variety of gadgets and systems that may be connected into residential settings to automate certain operations and provide homeowners more control over certain aspects of their homes. The World Health Organization estimates that approximately 15% of the global population lives with some form of disability, ranging from mobility impairments to sensory and cognitive challenges. Simple daily tasks that most people take for granted can become big problems for these people, lowering their independence and overall quality of life. Some of the reported literatures are discussed. The home automated systems using IoT [9-12] and Arduino based systems [1-8] helps in smart home technologies aimed at enhancing the health and independence of older adults. In [4], authors have presented a home security system using Arduino, ESP8066 and it aims at designing an advanced home automation system using normal web server and Wi-Fi technology to monitor and control the security of a smart home environment. The authors in [6] described a method and apparatus for prevention of fire detection algorithms used data from sensors for temperature, smoke, and combustion products. The development of a home automation system discussed in [9] utilizes IoT and an Android application for controlling various household devices remotely. The authors focus on enhancing user convenience and energy efficiency in smart homes especially for elderly people.

The authors presented a system for interconnecting sensors [12], actuators, and other data sources with the purpose of multiple home automations. The benefits of the proposed prototype are numerous. It not only promotes independence and autonomy but also enhances the quality of life for individuals with disabilities. With the proposed prototype, people with disabilities can enjoy a comfortable and safe living environment that is tailored to their unique needs. Overall, the Accessible Home project is a step towards creating a more inclusive society, where everyone has access to the same opportunities and resources. Studying home automation for people with impairments is really important on a number of aspects. By promoting increased independence, social inclusivity, and safety and security through modern technologies, it promises to improvetheir quality of life overall. Additionally, it can lighten the strain on loved ones, resulting in financial savings and promoting advancements in technology. In the end, it increases public awareness of the difficulties that individuals with disabilities confront and emphasizes the value of establishing inclusive and accessible living spaces, taking steps towards a more just and compassionate future for all.

II. METHODOLOGY

Three distinct nodes, each with a specific task to complete, have been created for our project andare each connected to a master node. The first node, which will serve as an automated entry system,is made up of an RFID reader, NodeMCU-ESP8266, and a servo motor as shown in figure 1. To getentry when trying to enter and to close the door when leaving, a person must scan a card or keyring. The second node is made up of Arduino Uno, DHT11 temperature and humidity sensors, MQ2and MQ7 carbon monoxide and LPG sensor, a buzzer and a relay as shown in figure 2. The DHT11 sensor will display the temperature and humidity on the OLED screen on the watch, and we can control the lights using relay and when the sensors detect LPG or carbon monoxide above the threshold value the buzzer will start and exhaust fan will turn on for ventilation. The third node known as the

master node includes an OLED, button, an accelerometer, a pulse sensor and NODEMCU-ESP8266 as shown in figure 3.The third node is designed to be worn as a watch, and ifthe user falls and is unable to get up the MPU6050 will alert the emergency contact via Telegram and WhatsApp. Additionally, there are panic button that, when hit, will alert family members via Telegram and WhatsApp. A pulse sensor will display the user's heart rate on the OLED. ESP-NOWis a communication protocol which allows devices to directly communicate with each other without the need for a centralized router or access point. The ESP-01 will be used to connect all three nodes to the master node so that the user can receive notifications on their watch immediately. The first node will communicate the entry access data which is door open and door close and the second node all will communicate all the sensor values such as temperature, smoke and carbon monoxideto the master node which will show notifications on the watch and will send notifications via Telegram and WhatsApp as shown in figure 4. The algorithm for the same is shown in Figures 5, 6, 7 along with their circuit diagram, experimental setups in figures 8, 9, 10 and results shown in Figures 11 to 19.

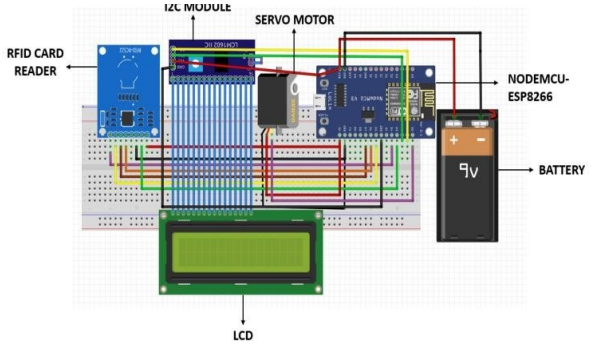

Figure 1: Circuit Diagram of our first node using Fritzing

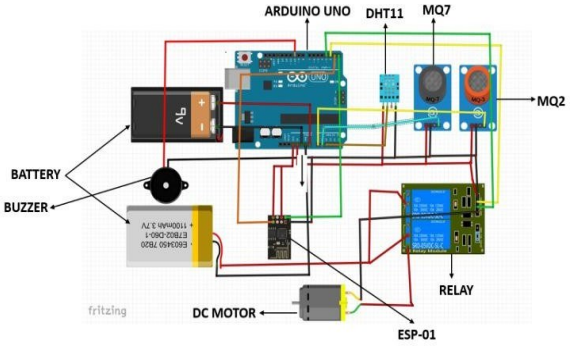

Figure 2: Circuit Diagram of our second node using Fritzing

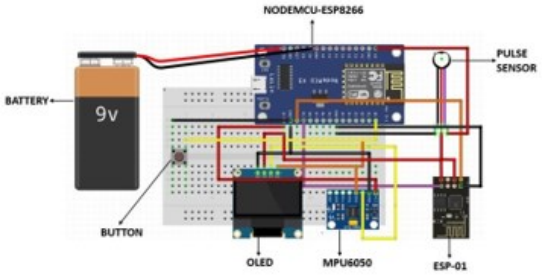

Figure 3: Circuit Diagram of our master node using Fritzing

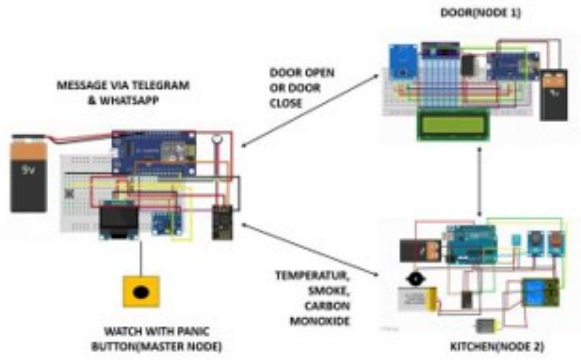

Figure 4: Connection among all the nodes

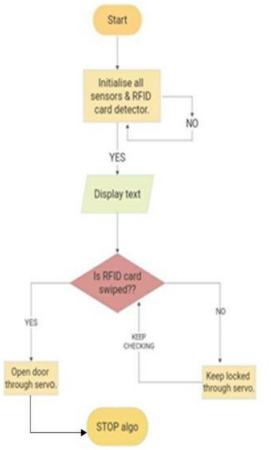

Figure 5: Algorithmic Chart of our Node

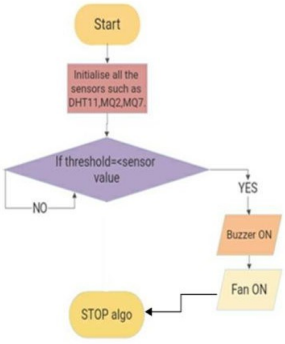

Figure 6: Algorithmic Chart of ourFirst Second Node

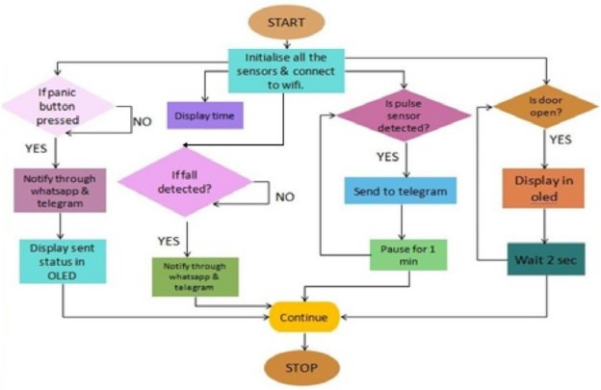

Figure 7: Algorithmic Chart of our master node

III. RESULTS

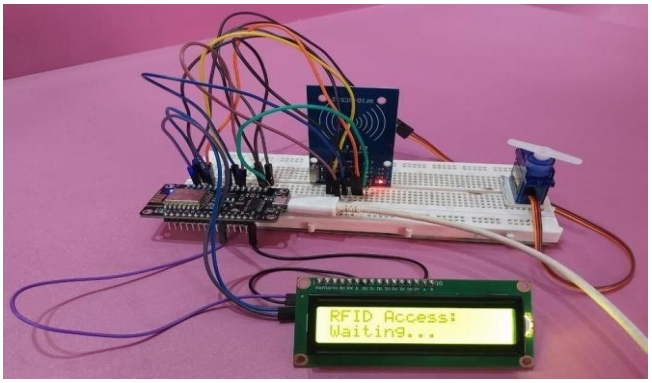

Figure 8: Experimental Setup of Our First Node

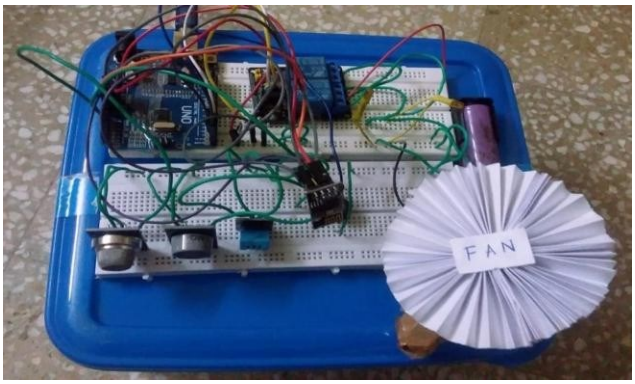

Figure 9: Experimental Setup of Our Second Node

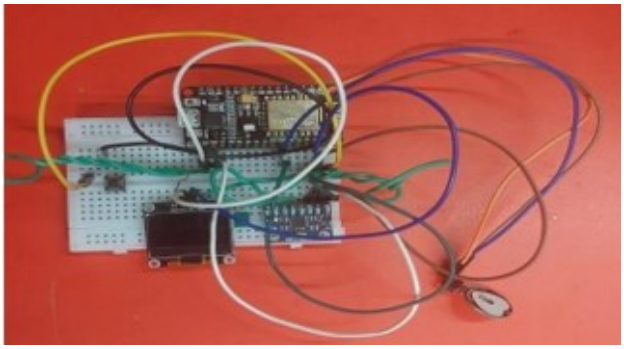

Figure 10: Experimental Setup of Our Master Node

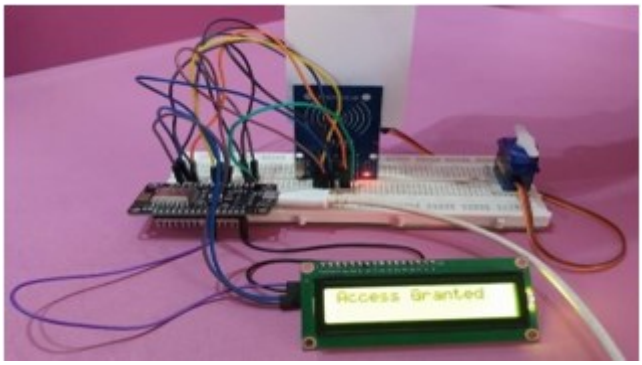

Figure 11: When Card is tapped LCD showsAccess Granted and servo opens

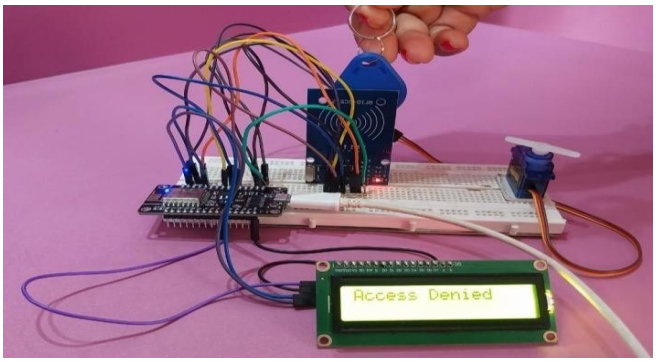

Figure 12: When Keychain is tapped LCD shows Access Deniedand servo closes

```
LPG Value: 220
Smoke Value: 205
Temperature: 30.90
Humidity: 85.70
LPG Value: 221
Smoke Value: 206
Temperature: 30.90
Humidity: 85.50
LPG Value: 220
Smoke Value: 205
Temperature: 30.90
Humidity: 85.50
```

Figure 13: Initial values from all when nothing is present

```
LPG Value: 369
Smoke Value: 204
Temperature: 30.90
Humidity: 85.00
LPG Value: 363
Smoke Value: 207
Temperature: 30.90
Humidity: 85.00
LPG Value: 338
Smoke Value: 223
Temperature: 30.90
Humidity: 85.00
LPG Value: 270
```

Figure 14: Values from the sensors the sensors when high LPG is detected

```
LPG Value: 243
Smoke Value: 343
Temperature: 30.90
Humidity: 85.00
LPG Value: 244
Smoke Value: 326
Temperature: 30.90
Humidity: 85.00
LPG Value: 240
Smoke Value: 325
Temperature: 30.80
Humidity: 89.70
```

Figure 15: Values from the sensors smoke is detected

{"LPG":254,"Smoke":219,"Temperature":30.4,"Humidity":85.2,"Relay1On":true,"Relay2On":true}
{"LPG":244,"Smoke":208,"Temperature":30.5,"Humidity":85.1,"Relay1On":true,"Relay2On":false}
{"LPG":240,"Smoke":209,"Temperature":30.5,"Humidity":83.8,"Relay1On":true,"Relay2On":false}
{"LPG":236,"Smoke":266,"Temperature":30.5,"Humidity":83.8,"Relay1On":true,"Relay2On":false}
{"LPG":236,"Smoke":361,"Temperature":30.5,"Humidity":83.8,"Relay1On":true,"Relay2On":false}
{"LPG":236,"Smoke":373,"Temperature":30.5,"Humidity":84.1,"Relay1On":true,"Relay2On":true}
{"LPG":237,"Smoke":364,"Temperature":30.6,"Humidity":83.4,"Relay1On":true,"Relay2On":true}
{"LPG":245,"Smoke":344,"Temperature":30.5,"Humidity":84.3,"Relay1On":true,"Relay2On":true}
{"LPG":232,"Smoke":337,"Temperature":31.2,"Humidity":83.9,"Relay1On":true,"Relay2On":true}
{"LPG":244,"Smoke":326,"Temperature":30.6,"Humidity":84.1,"Relay1On":true,"Relay2On":true}
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{"LPG":227,"Smoke":306,"Temperature":30.6,"Humidity":83.6,"Relay1On":true,"Relay2On":true}
{"LPG":237,"Smoke":280,"Temperature":30.5,"Humidity":84.6,"Relay1On":true,"Relay2On":true}
{"LPG":226,"Smoke":273,"Temperature":30.6,"Humidity":79.5,"Relay1On":true,"Relay2On":false}
{"LPG":225,"Smoke":267,"Temperature":30.6,"Humidity":84.1,"Relay1On":true,"Relay2On":false}
{"LPG":226,"Smoke":263,"Temperature":30.5,"Humidity":84.1,"Relay1On":true,"Relay2On":false}
{"LPG":239,"Smoke":272,"Temperature":30.6,"Humidity":84.1,"Relay1On":true,"Relay2On":false}
{"LPG":230,"Smoke":261,"Temperature":30.6,"Humidity":84.1,"Relay1On":true,"Relay2On":false}
{"LPG":230,"Smoke":257,"Temperature":30.6,"Humidity":84.3,"Relay1On":true,"Relay2On":false}
{"LPG":228,"Smoke":253,"Temperature":30.6,"Humidity":84.1,"Relay1On":true,"Relay2On":false}

Figure 16: Transmitted JSON packet using when high ESP-NOW

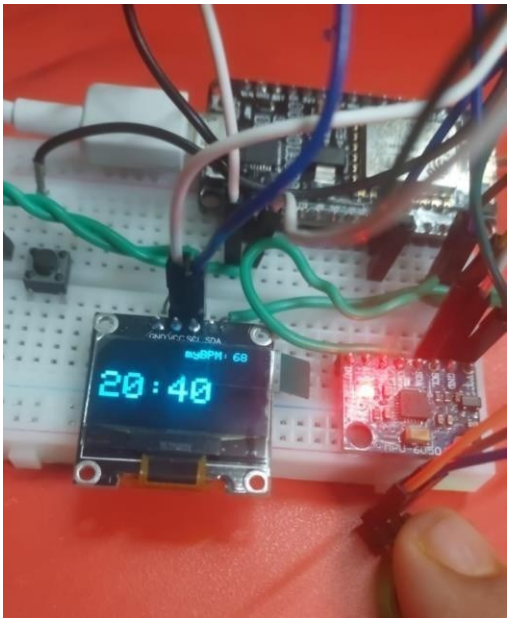

Figure 17: Time and Heart Rate on OLED

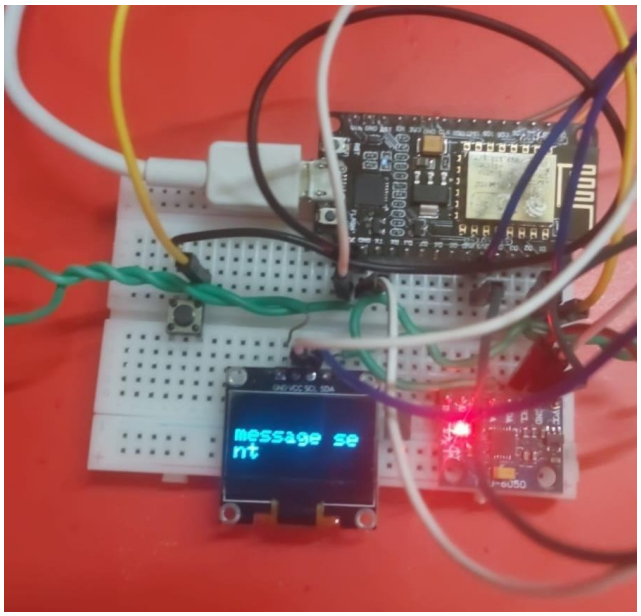

Figure 18: Message displayed on OLED when panic button pressed

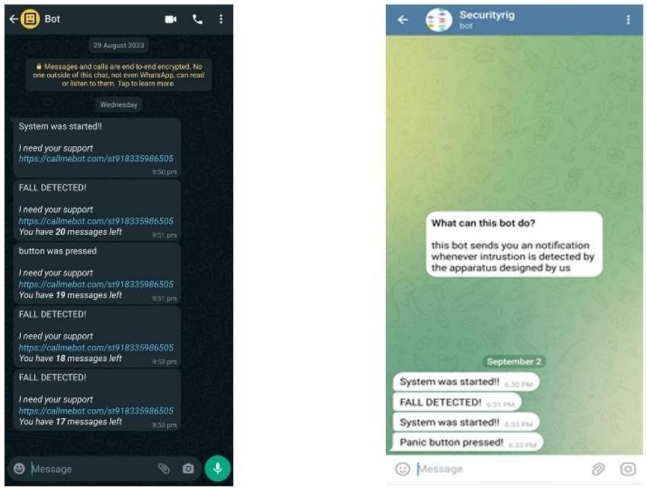

Figure 19: Automated Message VIA WhatsApp and Telegram when fall Detected & panic button pressed

CONCLUSION

Home automation has emerged as an innovative force in the wake of rapid technical advances, providing an abundance of opportunities for people with disabilities. Our study displayed that home automation technologies have a significant impact on disabled people's independence and general quality of life. These technologies have evolved to be more inclusive, adaptable, and intuitive with user-centered design concepts at their core, thereby removing obstacles to daily activities. In a nutshell home automation offers a viable way to make the environment moreaccessible and inclusive for those with impairments. It encourages inclusivity, improves safety, lessens the strain on the loved ones, and fosters innovation while enabling users to live more independent lives. We can create a future where technology serves as an efficient tool for equality, autonomy, and a higher standard of living for all members of society by recognizing its innovative potential.

REFERENCES

[1] Sohibun, I Daruwati, R G Hatika, D Mardiansyah. MQ-2 Gas Sensor using Micro Controller Arduino Uno for LPG Leakage with Short

Message Service as a Media Information. Sohibun et al 2021 J. Phys.: Conf. Ser. 2049 012068.

[2] Kaustav Bandyopadhyay, Debasmita Ghosh, Shubhajyoti Ghosh, Soumen Bhowmick, Sumani Mukherjee, Dr. Rabindranath Ghosh(2019). IoT Based Home Security System using Atmega328P, ESP01 and ThingSpeak Server. IARJSET ISSN:2393-8021, Vol.6 Issue- 5.

[3] Bababe Adam B, Ashish Kumar J, Rajiv Kumar(2017). LoRa-Based Intelligent Home Automation System. IJEAT ISSN:2249-8958,Volume-6 Issue-3.

[4] Ilyas Baig, Chiktay Muzamil, Salahuddin Dalvi. Home Automation Using Arduino WiFi Module ESP8266.

[5] Xueyi Wang, Joshua Ellul, George Azzopardi(2020). Elderly Fall Detection Systems.

[6] May Zaw, Htay Myint(2020). Arduino based Fire Detection and Alarm System Using Smoke Sensor. IJASRE, Vol.6, Issue.4, ISSN:2454-8006.

[7] Shubham Soni, Rajni Soni and Akhilesh A.Waoo (2021). RFID-Based Digital Door Locking System. IJMM, ISSN: 2582-8835, Volume-1 Issue-2.

[8] Bruce Brew, Steven G Faux, Elizabeth Blanchard(2022). Effectiveness of a Smartwatch App in Detecting Induced Falls. PMCID: PMC8981002 PMID: 35311686.

[9] Nesreen Alsbou, Naveen Mohan Thirunilath, Imad Ali(2022). Smart Home Automation IoT System for Disabled and Elderly. IEMTRONICS, IEEE International.

[10] Diponkar Kundu, Md. Ebrahim Khallil, Tushar Kumar Das, Abdullah Al Mamun, Ahmmad Musha(2020). Smart Home Automation System Using on IoT. International Journal of Scientific & Engineering Research, Volume 11, Issue 6, ISSN 2229-5518.

[11] Muhammad Abbas Khan ,Anis Nurashikin Nordin ,El-Sayed Ahmed ,Hiren Mewada, Yousef Ibrahim Daradkeh ,Saim Rasheed, Elsayed Tag Eldin and Muhammad Shafiq(2022). Smart Android Based Home Automation System Using Internet of Things (IoT). Sustainability.

[12] Cristina Stolojescu-Crisan, Calin Crisan, Bogdan-Petru Butunoi(2021). An IoT-Based Smart Home Automation System. Sensors.