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Prof. Dr. Valarie Akerson

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Virtual Teaching/Learning on Engineering Graphics Course in COVID-19 Pandemic

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Abstract: The COVID-19 pandemic has changed education forever. Universities and colleges had to transition to virtual teaching/learning modes suddenly. This article investigated and analyzed the students' performance in the Engineering Graphics course in the different teaching modes: traditional face-to-face, face-to-face then virtual, virtual, and hyflex modes. The virtual teaching mode brought new challenges to both students and instructors, including technical and management challenges. The technical challenges, for example, insufficient or outdated equipment and poor internet connections, could be solved easily. The financial support from college would partially alleviate the students' burden and improve their hardware. The students' self-management challenges, including fear of difficulties, distraction, lack of motivation, loss of interest, would significantly affect their performance. The students, who adapted to virtual teaching environment, performed better than in face-to-face mode. The other students, who could not overcome the technical and/or self-management challenges from virtual teaching mode, would withdraw, incomplete, or fail from this course.

Keywords: Engineering graphics, Teaching mode, Student

Introduction

Online teaching is not a new concept. It can be traced back to the correspondence course in the nineteenth century. With the quick spread of personal computers, modern online teaching was developed. In 1985, the first electronic classroom (ECR) was built in Nova Southeastern University. CALCampus realized the first synchronous learning in 1994. From the 1990s until today, all the universities and colleges built their own online teaching systems to provide remote teaching services for some courses and training to the faculty and staff. Due to the face-to-face tradition and the non-confidence to the equipment, universities and colleges did not provide all the courses as virtual mode until spring 2020. The sudden COVID-19 pandemic forced all universities and colleges to transition all of their courses to virtual teaching mode.

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With the development of the COVID-19 pandemic, Virginia State University (VSU) took the different teaching modes in the continuous semesters. Before the pandemic, in the fall semester of 2019, we took the traditional face-to-face teaching mode. In the spring semester of 2020, we took the traditional face-to-face learning before the Midterm exam and then transitioned to online mode in the second half of this semester. In the fall 2020 semester, we took pure virtual teaching/learning in the entire semester. Then, the hyflex mode was provided in the semester of spring 2021.

Compared to the traditional face-to-face teaching mode, virtual teaching has some apparent advantages. For example, the most attractive advantage is its flexible accessibility. Students can access the virtual classroom anywhere and at any time by personal computers or smartphones. It is very friendly to the part-time students. For the students who face financial difficulties, remote teaching will partially alleviate their burden by saving travel and housing cost. Online mode will provide immediate feedback to students. Students will learn from the experience and take actions quickly. However, some roles of traditional face-to-face teaching mode may not be substituted by virtual teaching. Face-to-face teaching can deliver hands-on experience, for example, physics or chemistry experiment, and machine operation. In the real classroom, instructors can reduce students' distractions by eye contact, body language, and games. In the virtual classroom, instructors lack efficient tools to keep the disciplines. Students' self-control capacities are the key to maintain their concentration. The real classroom environment may help students build positive interpersonal relationships and keep physical and mental health.

Engineering graphics is the core course for all engineering majors. This basic training will affect the learning of the related courses, for example, mechanical design, principles of mechanics, and manufacturing processes. The performance of the students in the Graphics class directly reflects the achievement of the students in the college. With the development of technology, the classic drawing on paper has been replaced with electronic drawing completely. The traditional face-to-face teaching in the physical classroom is changing into virtual teaching.

Research related to the students' performance in the engineering drawing course indicated no significant difference between in-class and online learning students if they did not have previous experience. Students with prior experience who participated in the in-class learning mode performed better than those in the online learning mode (Wang, Ma, Kremer, & Jackson, 2019). However, the data from an earlier research at North Carolina State University shows that in the upper-level CAD course, students from online learning got higher test grades than in-class learning (Branoff & Totten, 2006).

Educators in other fields did not give us an agreed answer. Some researchers proved that the student from face-to-face learning performed better (Terry, Lewer, & Macy, 2003) (Coates, Humphreys, Kane, & Vachris, 2004) (Anstine & Skidmore, 2005). Someone indicated that virtual learning students showed better performance (Brown & Liedholm, 2002) (Moazami, Bahrampour, Azar, Jahedi, & Moattari, 2014). The others found that there was no significant difference between face-to-face learning and virtual learning (Goette, Delello, Schmitt, Sullivan, & Rangel, 2017) (Jensen, 2011) (Navarro & Shoemaker, 1999).

This article will compare the students' performance in the Engineering Graphics at VSU before and in the COVID-19 pandemic and try to give us the answer.

Background

In VSU, ENGR 200 Engineering Graphics is the core course for most engineering majors, including Manufacturing Engineering, Mechanical Engineering Technology, Information Logistics Technology, and Electrical and Electronics Engineering Technology. This course will provide the basic training of engineering drawing for freshman and/or sophomore students. Students who successfully complete this course will be able to:

1. Create 2-D engineering drawings with dimension and annotation.
2. Use CAD software for the creation of 3D solid models and 2D engineering drawings.
3. Create 3-D solid model of basic mechanical parts.
4. Create assembly products.
5. Create 2-D drawings from 3-D solid model of a part.

In VSU, Siemens NX is adopted as the tool for engineering drawing. Blackboard is the tool for long-distance teaching. From spring 2020, a worldwide COVID-19 pandemic hit the USA higher education institutions. Students and faculty had to take online teaching/learning mode at home to keep safe. At VSU, students experienced face-to-face then virtual mode, virtual mode only, and hyflex mode in the Spring 2020, Fall 2020, and Spring 2021, separately.

Although faculty and students might involuntarily take the virtual teaching/learning mode during the pandemic based on the safety consideration, we could investigate the students' performance in the virtual classroom and compare the data to the traditional face-to-face teaching.

The Benefit of the Virtual Teaching/Learning Mode

Essentially, the traditional face-to-face and virtual online teaching/learning are not different. They are the processes to deliver knowledge, experience, skill, and sound attitude. The difference is the technique method.

Flexibility and accessibility are the significant advantages of virtual teaching/learning mode. Compared to the traditional face-to-face mode, the benefits of virtual teaching are accessibility of time and place, reduced financial costs, effective time management, and asynchronous discussions with classmates. From the beginning of the pandemic, VSU moved the Siemens NX from the local computers on campus into Amazon Web Services (AWS). The cloud service allows the students can access and utilize the software from anywhere and at any time. It provides great convenience to the students and instructors. AWS-based Siemens NX reduces the requirements to hardware. In our investigation, most of our students can run the software well on their personal computers.AWS provides individual storage space for each user. Students will never lose their work. And they can download their work when they need.

Challenges from Teaching and Learning in a Virtual Classroom

Instructors and students faced many unique challenges when teaching and learning with online mode, especially at the beginning of the sudden pandemic in the semester of spring 2020. Those challenges could be categorized into two types: technique challenges and management challenges.

Challenges of Teaching Side

For instructors, the technique challenges include small displays, speakers with poor quality, cameras with low resolution, unstable internet connection, etc. The management challenges include no eye contact with students, difficult communication with students, difficult class management, extra after-class time to help students, etc. Compared to the management challenges, the technical challenges could be overcome easily. Investing efficient money could solve most of the technical challenges. For example, in some time, instructors have to open multiple App. simultaneously, such as Siemens NX, PowerPoint, Adobe, Blackboard, et al. However, the small display of the notebook cannot show them together. The instructors have to switch the Apps frequently. It broke the continuity of the teaching and distracted the student’s concentration. Dual displays might be a good solution for this challenge. Another example is the physical blackboard. In a modern classroom, the projector and screen are the standard equipment. However, instructors still need blackboard to show the derivation, sketch, calculation, and critical points.

The management challenges may not be solved easily. For example, eye contact and body language are typical and effective methods in a face-to-face teaching environment. Instructors often use those methods to attract the students’ views and keep classroom discipline. Obviously, the long-distance teaching mode does not support them. Engineering graphics is a special course which has lots of hands-on skills and experiences. When instructors deliver their skills and experiences to the students, most students can accept them quickly. Few students need extra help. In the in-class environment, the instructors can teach them hand in hand. However, in the virtual classroom, the conditions are much different. In this case, instructors had to cost extra after-class hours to help those students individually at Zoom meetings. VSU hired 3-4 junior and senior students with previous experience as the teaching assistants for each class. These teaching assistants can help instructors answer the fresh students’ questions and deliver some skills and experiences. It saved the instructors’ time and effort.

Challenges of Learning Side

In the remote online mode, the students faced similar challenges with the instructors, such as single and small displays, computers with poor quality, and unstable internet connection. For students, those challenges may be more difficult than the faculty, especially in HBCU schools. Due to the financial consideration, most of our students are unwilling to update their hardware for online learning, which might affect the learning quality. Their outdated computer might cause the incompatibility of drawing software. In Engineering Graphics virtual classroom, the biggest challenge for students is the small display. All of our students used laptops. They had to show the Blackboard and Siemens NX simultaneously in the Engineering Graphics class. Students would watch the instructors' operations in the Blackboard, follow the instructors, and make their own drawings in Siemens NX. The small screen of the laptop computers pushed the students to switch between the two software frequently. Moreover, students might miss some small detail due to the low resolution.

In virtual teaching/learning mode, students' self-management might be the most headache problem for the instructors. Many students experienced absence and/or late. Some students had to fight for the disturbance from the environment. Students expressed stress in varying degrees after long-term virtual learning. In a separate environment, students might lose their motivation and interest in learning. Educators should pay enough attention to those psychological and social problems. Neu21

Students' Performances

Due to the sudden COVID-19 pandemic, VSU experienced four different teaching modes in four continuous semesters: traditional face-to-face teaching mode in Fall 2019; face-to-face then online mode in Spring 2020; pure online mode in Fall 2020; hyflex mode in Spring 2021. These changes in teaching modes provide us the abundant data to study and compare the different teaching modes. This article will use two cases to exhibit and analyze the students' performance in Engineering Graphics under different teaching environments.

Case I:

After the midterm, students had been familiar with the software and instructors' teaching style. They already grasped basic drawing skills and had some experience. To reduce the errors of investigation, a class-practice question (Fig. 1) is selected as the measurement to show the students' performance. Students were required to read these 2D orthographic drawings and figure out the approximate 3D model in their brains. Then they followed the instructors to build the 3D models, create detailed drawings and put all the necessary dimensions using Siemens NX.

From Fall 2019 to Spring 2021, 42 students attended the activities in these four continuous semesters. The numbers of students are 16, 9, 11, and 6, separately. The average scores of the four semesters are 70.6 (F2F), 95.8 (F2F, then virtual), 83.9 (virtual), and 95.7 (HyFlex), correspondingly. Obviously, the average grade of the students in the virtual classroom is higher than that in the traditional classroom.

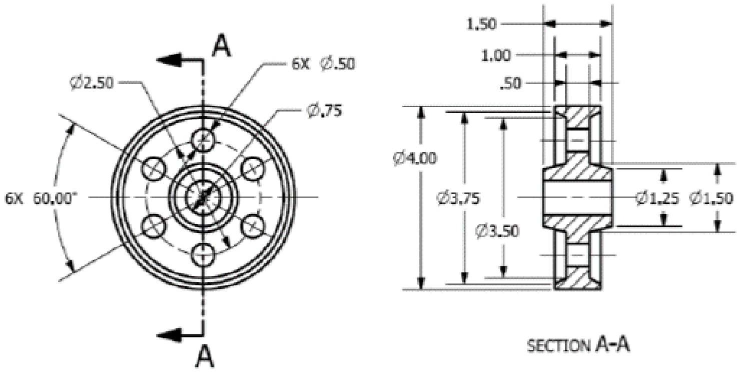

Figure 1. A Class-Practice Question

Figure 2 shows the students' performance in the four semesters. The score distribution in Fall 2019 (Face-to-Face) is a typical normal distribution curve. However, the distributions in Spring 2020 (face-to-face then online), Fall 2020 (online), and Spring 2021 (hyflex) are skewed. The mean values switched to the higher score. Apparently, students' performance in the virtual mode is better than that in the face-to-face mode. However, there must exist some reason which causes the skewed distribution.

After our investigation, we found that some students withdrew from the online classes and could not complete the learning in Spring 2020, Fall 2020, and Spring 2021. For example, at the beginning of the Fall 2020 semester, the initial enrollment is 19. At the end of the semester, two students withdrew and six students could not complete their learning. The loss of the students came from the worries of failing the class. The student's concerns reflected online teaching/learning challenges, including the technical and self-management challenges. The students, who did not attend the measurement activity, had difficulty in an online class. The remaining students were good at learning in an online environment. Thus, the distributions in Figures 2(a), 2(b), and 2(c) are skewed.

Although the data Figures 2(a), 2(b), and 2(c) are skewed, it does not mean that online mode is not better than face-to-face mode. Comparing the students whose score is over 90, the numbers of students in Fall 2019 (F2F), Spring 2020 (F2F then Virtual), Fall 2020 (Virtual), and Spring 2021 (HyFlex) are 1, 9, 8, and 5, separately. Comparing the students whose score is over 80, the numbers of students in Fall 2019 (F2F), Spring 2020 (F2F then Virtual), Fall 2020 (Virtual), and Spring 2021 (HyFlex) are 5, 9, 9, and 6, separately. Obviously, more students perform excellently in online class than those in face-to-face class.

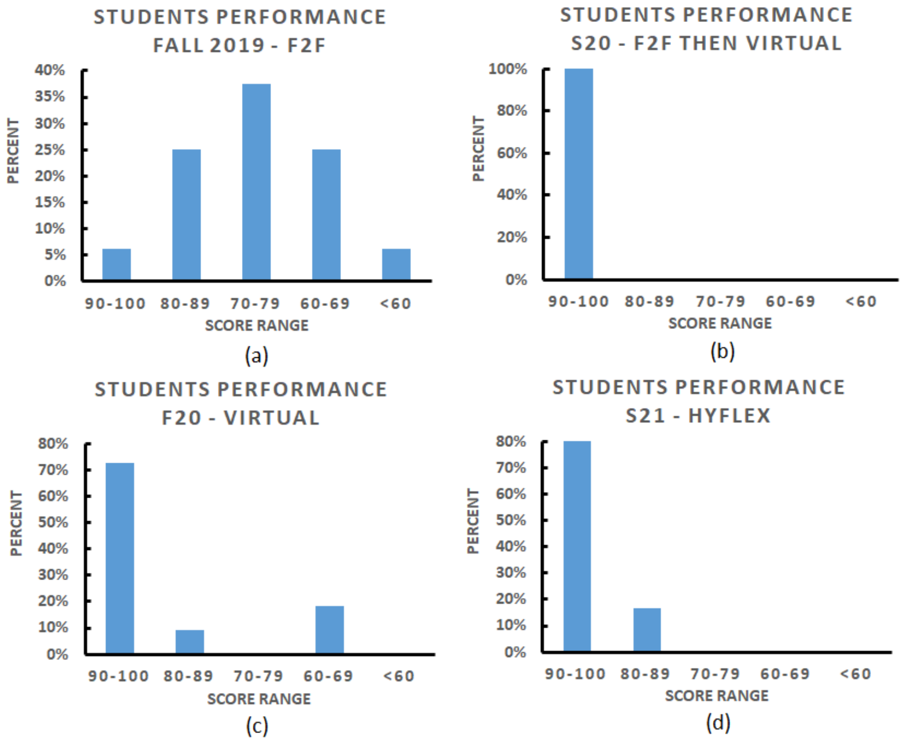

Figure 2. Case I: Students' Performance in Four Semesters

Case II:

At the end of the semester, students have been taught how to build detailed drawings and assemble the parts to a final package. They were also tested to measure the comprehensive knowledge and skills they learned from class, such as orthographic projection, dimensioning, sectional view, assembling, and software familiarity. Figure 3 is an example of the final project problem. Students were required to finish a package including:

1. To build the 3D models for every single part, create 2-D drawings and put all the necessary dimensions and sectional views in the Siemens NX;
2. To finish the 3D assembly model and 2D assembly drawing with parts list, balloons, and title block.

From Fall 2019 to Spring 2021, in these four semesters, 51 students attended the activities. The numbers of students are 26, 7, 11, and 7, separately. The average scores of the four semesters are 85.4 (F2F), 59.3 (F2F, then virtual), 74.7 (virtual), and 68.6 (HyFlex), correspondingly. Figure 2 shows the students' performance in these four semesters. The score distribution for the fall 2019 semester (F2F) is not a typical normal distribution curve, but it is still in a reasonable range. Instead, the distribution for spring 2020 (F2F, then Virtual), fall 2020 (Virtual), and spring 2021 (HyFlex) semesters are way off the typical distribution. From these data, we can see that the pandemic affected the students a lot, especially the comprehensive study of the assembly drawing.

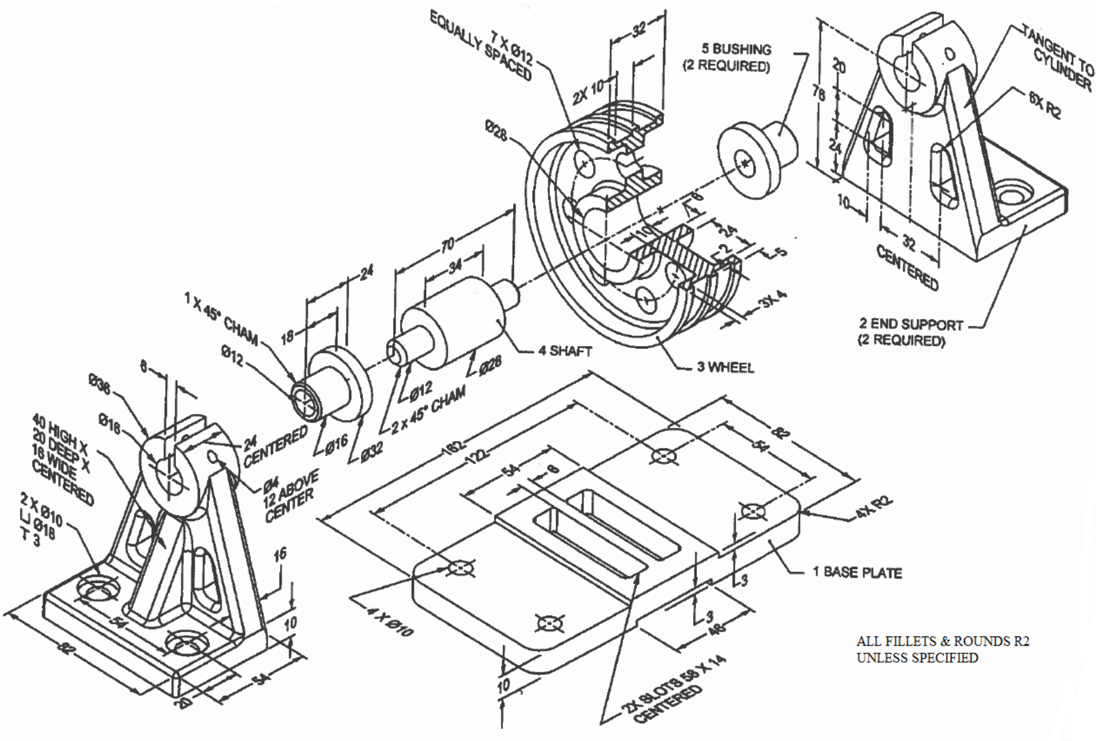

Figure 3. A Final Project Question

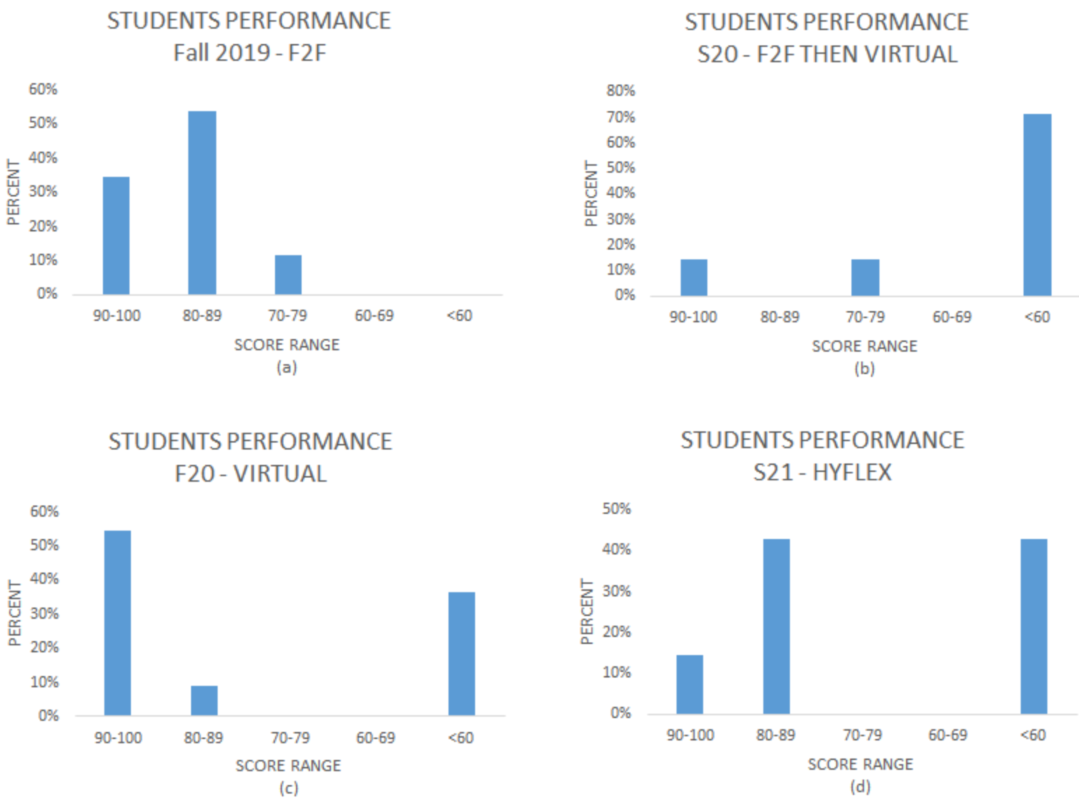

Figure 4. Case II. Students' Performance in Four Semesters

Analysis

After carefully analyzing the reasons behind this phenomenon, we found a few factors that have affected the engineering graphic teaching/learning experiences.

First, the pandemic plays a critical role. Before the pandemic, all the performances in cases I and II showed either the typical normal or similar distribution. It indicated that the face-to-face, traditional mode for engineering graphics is well developed and has its advantages. Due to the sudden changes in the teaching/learning mode during the pandemic, both instructors and students are unprepared.

Second, Technical requirements affected the learning experience. One is the hardware and internet requirements. In the traditional mode, students can use university facilities and computer labs to complete homework assignments, graphic drawing, or projects without owning a personal computer. But in the remote mode, students need to have a computer or laptop with stable internet connections to engage in online learning. Some students live in a rural area and don't have a robust and stable internet connection, and need to participate in the online class on the phone. In this situation, they cannot see the screen the instructors shared, which is critical for engineering graphic class. Even though the instructors provided the recordings to allow students to watch them later, the download speed due to the unstable internet connections blocked the student from classes. Technical issues also have affected the submission of assignments and participation in the examination. In the spring 20, fall 20, and spring 21 semesters, at least six students got "incomplete" grades (counted as <60) due to this issue.

Insufficient or outdated equipment greatly damnifies the learning efficiency and then causes students to lose their learning interest. In HBCU, many students' financial conditions cannot support them to purchase better equipment. Those students had to give up this course. VSU provided a $500 technology stipend to each validated student in Fall 2020 to help students purchase computer and computer accessories. This policy could partially solve the technical challenge of students.

Third, online mentoring is much more complicated than the traditional mode. During the pandemic, our department still provided mentoring remotely for engineering graphic classes. The instructors and student assistants found that online mentoring and tutoring in Blackboard or Zoom is not easy. Even though we can share a screen to show students the drawing strategies and different commands, it is still difficult to ask students to do the step-by-step drawing with guidance. Usually, the mentoring time is much longer than the traditional mode.

Fourth, due to the lack of direct control from instructors in the online class, each student faced the self-management challenges, such as fear of difficulties, distraction, lack of motivation, loss of interest, etc. Some students could not solve their self-management issues and then give up; the others overcame those challenges and quickly adapted to the online teaching mode. They could utilize the resources of the online environment, for example, replaying the class recordings. Those students performed very well in online mode.

Fifth, even students did very well in the drawings for parts, students still have difficulties assembling the parts and convert the 3D assembly drawing to a 2D assembly package.

Conclusion

We compared the students' performance in Engineering Graphics in 4 semesters (Fall 2019, Spring 2020, Fall 2020, and Spring 2021). We experienced four different teaching/learning modes: face-to-face, face-to-face then virtual, virtual, and hyflex, correspondingly. We cannot simply answer Yes or No to this question: "Is virtual teaching equal or better than face-to-face teaching?"

After our investigation and analysis, we find two types of students in the Engineering Graphics class. Type I: the students who adapt to the online environment. They could utilize the resource of the online environment, for example, replaying the class recordings. They could practice anywhere at any time. Those students performed very well in online mode, even better than in face-to-face mode. Type II: the students who gave up on online class due to technical and/or self-management challenges. Those students faced many challenges, such as financial difficulty, insufficient equipment, poor self-control, lack of motivation, etc. If they could not overcome these challenges, they would have to withdraw from, incomplete, or fail the course. Financial support from college could help some Type II students to overcome the technical challenges.

For the instructors of Engineering Graphics, limited by the current hardware and software conditions, tutoring and grading in an online teaching environment are more difficult than in face-to-face class. Once a student cannot catch up with the teaching pace, his/her instructors have to spend extra time and effort on individual tutoring. The current technical conditions do not support the special requirement for marking/correcting homework of Engineering Graphics. Instructors have to make more effort to make special marks on the students' homework.

From Spring 2020, in response to the sudden COVID-19 pandemic, VSU moved the Siemens NX to Amazon Web Service (AWS). The cloud-based service provides more convenience to students and instructors. Students can access Siemens NX anywhere at any time. The files are stored in the cloud. Students can download or upload their work easily. It also reduced the requirements of students' computers. It partially alleviated the financial burden of students. Therefore, VSU will continue to keep the Siemens NX in the cloud.

In this article, we did not further discuss class management in the virtual teaching environment. We are seeking technical improvement and teaching style changes to attract students' concentration and increase students' motivation.

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Robust Multi-Objective Optimal Design of a Racing Car Suspension System

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Abstract: This paper presents a robust multi-objective optimal design of a racing car suspension system. Three design objectives are considered: passenger's head acceleration, suspension deflection, and tire deflection. The first objective concerns with the passenger's health and comfort. The second and third design objectives characterize the suspension stroke and tire's grip. To quantify the design objectives, the vertical dynamics of a quarter-car model employing an inerter is considered. The coefficients of the sprung spring and damping, tire stiffness, and inertance of the inerter are chosen as decision variables. Suspension systems' parametric variations are very common and cannot be avoided. To this end, a robust multi-objective optimization method that takes into consideration variations of the design parameters is considered. Unlike traditional multi-objective optimization problems where the focus is placed on finding the global Pareto-optimal solutions which express the optimal trade-offs among design objectives, the robust multi-objective optimization algorithms are concerned with robust solutions that are less sensitive to decision variables' perturbations. As a result, the mean effective values of the fitness functions are used as design objectives. Constraints on the design parameters and goals are applied. Numerical simulations show that the robust multi-objective design (RMOD) is very effective and guarantees a robust behavior as compared to that of the classical multi-objective design (MOD). The results also show that the robust region is inside the feasible search space and avoids all its boundaries.

Keywords: Robust multi-objective optimal design, Suspension system, Racing car, Inerter damper

Introduction

The role of a vehicle suspension system is to provide road comfort to the occupants, and guarantee stability and road handling. In general, vehicle suspension systems can be classified as active, semi-active, and passive

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suspension systems. Active suspension systems were last seen in racing cars such as Formula 1 (F1) in 1993 and blocked after that. Recently, F1 rejected a proposal to legalize active suspensions in 2021 F1 season (Keith, 2019). Passive suspensions have been widely used in racing cars due to their high reliability, simplicity, and low cost compared to the other types. Conventional passive schemes are based around two components - springs and shock absorbers (dampers). A new device called inerter was introduced in 2002 with the motivation to improve the mechanical grip of racing cars. Studies have shown that inerters can significantly improve ride comfort, tire grip, and handling in comparison to standard passive systems (Papageorgiou, Houghton, & Smith, 2009).

Several studies have been focused on the optimal design of passive suspension systems. For instance, Alfonso and his colleagues considered passengers' comfort and road handling in the multi-objective optimal design of a multi-body suspension system (Callejo, Jalon, Luq, & Mantaras, 2015). The front and rear dampers, springs, and relaxed lengths; bodywork stiffness; and rear antiroll bar were chosen as setup parameters. In another study, the design of a passive suspension system with an inerter was presented. Four design objectives were considered: suspension deflection, crest factor, occupant's head acceleration, and tire deflection (Xu, Sardahi, & Zheng, 2018). The spring stiffness and damper, spring constant of the tire, and the inertance of a quarter car model were selected as design variables. In another work, passive suspension systems of a half car model were designed in multi-objective settings (Bhargav Gadhvi, 2016). Three design objectives were used: minimization of the root-mean-square values in the cushion acceleration, maximizing of the tire grip, and minimization of the suspension stroke. The front tire deflection and rear tire deflection were selected as design parameters. While Jamali and the co-authors designed a passive suspension system of a vehicle under road excitation (Jamali, Shams, & Fasihozaman, 2014). They selected three objectives: the acceleration of the seat, working space, and vertical tire velocity. As tuning parameters, they chose the coefficients of the seat stiffness, suspension stiffness, seat damping, suspension damping, and the seat position. In other works, a full car model is used instead (Fossati, Miguel, & Casas, 2019). Therein, the multi-objective optimal design of a passive suspension system was carried out considering three cost functions: passenger comfort, tire grip, and suspension travel. The cost functions were evaluated by tuning six design variables: the driver seat stiffness and damper constants; and front and rear spring and damper coefficients. The optimal design of military vehicles' suspension systems have also drawn some attention. For example, Mahmoud investigated the optimal design of a passive suspension system for a military vehicle under three fitness functions: driver body vertical displacement, seat vertical displacement, and seat suspension working space (Mahmoud Mohsen, 2018). The stiffness and damping coefficients of the suspension system, driver seat suspension, and seat cushion were chosen as design parameters.

Research about the robust and multi-objective design of passive suspension systems is scarce. The literature records one work by (Loyer & Jézéquel, 2009). Therein, a robust multi-objective optimal design of an uncertain passive suspension of a quarter car was conducted. The road holding and ride comfort were considered as design objectives. The stiffness of the spring and the damper of the dash pot connected to the sprung mass were selected as design parameters. Two constraints on the wheel travel, and body bounce mode natural frequency were imposed. The spring mass and tire stiffness were considered uncertain, and the optimization problem was solved by a multi-objective evolutionary algorithm (MOEA). However, this work was applied to a passenger car that used a conventional suspension system. Furthermore, the design parameters were considered certain.

This paper presents a robust and multi-objective optimal design of a four-degree-of-freedom racing car with a non-conventional suspension system that implements an inerter in its configuration. The minimization of the passenger's head acceleration, suspension stroke, and tire deflection are chosen as the design goals. The coefficients of the sprung spring and sprung damping, tire spring, and the inertance are the setup parameters of the optimization process. To address unavoidable variations in these parameters, a robust multi-objective design is formulated to find the robust solutions that are less sensitive to perturbations in the decision variables. As a result, the mean effective values of the fitness functions are used as design objectives. Constraints on the design parameters and goals are applied. Numerical simulations are conducted on a quarter car model of a racing car. Details about this model are introduced in the next section.

Racing Car Suspension System Mathematical Model

The concept of "inerter" was first proposed in 2002 by (Smith M. C., 2002). Inerters are the mechanical equivalents of ungrounded capacitors, using the force–current analogy between mechanical and electrical circuits. In the industry sector, inerter is known as J-damper. Soon after it was introduced, the J-damper was implemented in the suspension systems of Formula 1 racing cars. McLaren Mercedes started using the J-damper in early 2005. In the same year, Kimi Raikkonen was the first one to race with a McLaren MP4- 20 having the inerter as a part of its suspension system at the 2005 Spanish Grand Prix and he won the competition. Inerters also have found their applications (Perlikowski, 2017) in the suspension systems of railway vehicles (Wang, Hsieh, & Chen, 2012), (Jiang, Matamoros-Sanchez, Goodall, & Smith, 2012), (Jiang, Matamoros-Sanchez, Zolotas, Goodall, & Smith, 2015), devices that absorb impact forces (Faraj, Holnicki-Szulc, Knap, & Seńko, 2016) or buildings' protection systems (Takewaki, Murakami, Yoshitomi, & Tsuji, 2012), (Chen, Tu, & Wang, 2015), and steering compensators for motorcycles (Evangelou, Limebeer, Sharp, & Smith, 2007). Inerters alleviate mechanical loads on the suspension and improves its handling and griping performance (Chen, Papageorgiou, Scheibe, & Wan, 2009). The fact that adding an inerter device into a suspension structure can

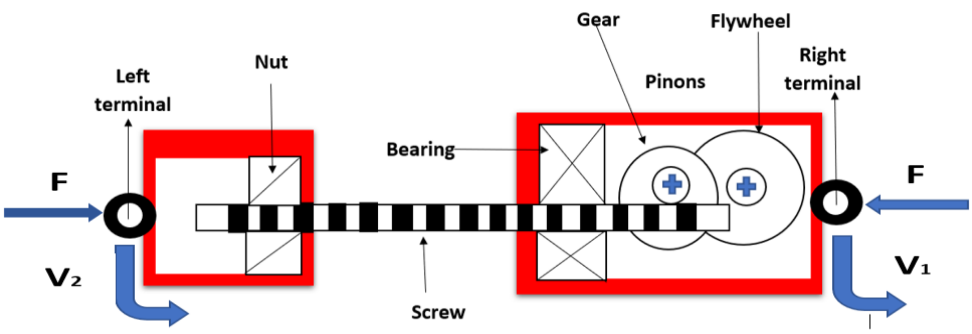

Figure 2. A One-Port (Two-Terminal) Mechanical Element

decrease its natural frequencies was algebraically proved by (Chen, Hu, Huang, & Chen, 2014). Schematically, the inerter element is a one-port (two-terminal) mechanical network as shown in Figure 1 (Smith M. C., 2002). A linear inerter can be constructed by meshing a nut, screw, bearing, gear, and flywheel which rotates in proportion to the relative displacement between the terminals. The screw forms one terminal of the device and the other terminal is mounted on the casing that houses the gears. The applied force induces relative acceleration on both terminals which is further transmitted into rotational motion of the flywheel using gear and pinion assembly. The dynamic equation of the inerter element reads.

$$F = B(v_2 - v_1), \tag{1}$$

where, F is the force at the two terminals of the inerter, B is the inertance of the inerter in kg, v_1 and v_2 are velocities of the two terminals of the inerter. A four-degree-of-freedom quarter car model implementing inerter in its suspension part is depicted in Figure 2 and its dynamic equations read.

$$m_t \ddot{z}_t = -c_t(\dot{z}_t - \dot{z}_p) - k_t(z_t - z_p) \tag{2}$$

$$m_p \ddot{z}_p = c_t(\dot{z}_t - \dot{z}_p) + k_t(z_t - z_p) - c_c(\dot{z}_p - \dot{z}_s) - k_c(z_p - z_s) \tag{3}$$

$$m_s \ddot{z}_s = c_c(\dot{z}_p - \dot{z}_s) + k_c(z_p - z_s) - c_s(\dot{z}_s - \dot{z}_u) - k_s(z_s - z_u) - B(\ddot{z}_s - \ddot{z}_u) \tag{4}$$

$$m_u \ddot{z}_u = c_s(\dot{z}_s - \dot{z}_u) + k_s(z_s - z_u) + B(\ddot{z}_s - \ddot{z}_u) - k_y(z_u - z_s) - k_y(z_u - z_r) \tag{5}$$

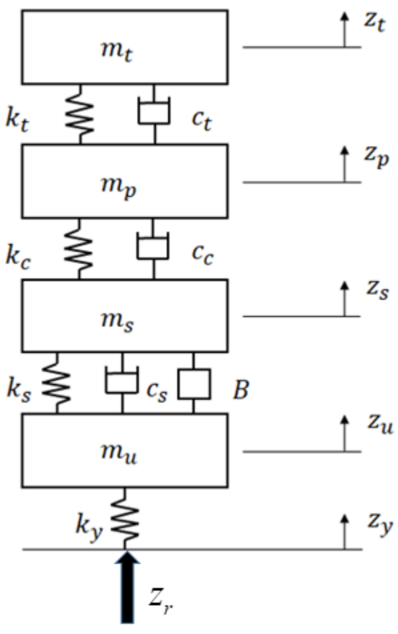

Figure 3. The Quarter Car Model of Passive Suspension System with Inerter (*Xu, Sardahi, & Zheng, 2018)*

Among them, m_t and m_p are respectively the equivalent mass of head and upper body, and lower body and cushion. That is, the passenger is modelled as a two-degree-of-freedom system by splitting the passenger's body mass into two parts: m_t and m_p such that m_p is connected to m_t by an assumed spring k_t and damper c_t. The cushion's elastic properties are modeled as an equivalent spring k_c and damper c_c which couple m_p to the sprung mass m_s. The suspension system is modeled as a spring with constant k_s, damper with coefficient c_s, and an inerter having B as its constant. These three components couple m_s and m_u (unsprang mass of the tire). The tire is assumed to be touching the road surface permanently during the movement of the car and its stiffness is represented by the equivalent spring k_y. The vertical displacement of the head and thorax, pelvis and cushion, sprung mass, and unsprung mass are denoted by z_t, z_p, z_s, and z_u, respectively. While z_r denotes the road excitation.

Robust Multi-Objective Optimization

Robust optimization has considerable advantage over traditional Multi objective optimization. Traditional multi-objective optimization problems seek to find global Pareto solutions without considering uncertainties in the system parameters. On the other side, robust multi-objective approaches seek to find the less sensitive trade-offs among the design goals. A Robust Multi-objective optimization problem can be stated as follows:

$$\min_{\mathbf{K}\in\mathbf{Q}}\left\{\mathbf{F}^{eff}\left(\mathbf{K}\right)\right\}, \tag{6}$$

where $\mathbf{F}^{eff}$ is the map that consists of the mean effective objective functions $f_i^{eff}: Q \to \mathbb{R}^1$ under consideration.

$$\mathbf{F}^{eff}: \mathbf{Q} \to \mathbb{R}^k, \mathbf{F}^{eff}(\mathbf{K}) = \left[f_1^{eff}(\mathbf{K}), \quad ..., \quad f_k^{eff}(\mathbf{K}) \right] \tag{7}$$

$\mathbf{K} \in \mathbf{Q}$ is a q-dimensional vector of design parameters. The domain $\mathbf{Q} \in \mathbb{R}^q$ can in general be expressed by mean effective inequality and equality constraints:

$$\mathbf{Q} = \left\{ \begin{matrix} \mathbf{K} \in \mathbb{R}^q \mid g_i^{eff}\left(\mathbf{K}\right) \le 0, i = 1, ..., l \\ and \quad h_i^{eff}\left(\mathbf{K}\right) = 0, j = 1, ..., n \end{matrix} \right\}, \tag{8}$$

where, l and n are respectively the number of the inequality and equality constraints. The mean-effective cost function f_i^{eff} is defined as:

$$f_i^{eff} = \frac{1}{\left|\mathbf{B}_\delta(\mathbf{K})\right|} \int\limits_{\mathbf{y}\in\mathbf{B}_\delta(\mathbf{K})} f_i(\mathbf{y}) d\mathbf{y}. \tag{9}$$

Where **δ** is a q-dimensional vector of parameters' uncertainties, $\mathbf{B}_\delta(\mathbf{K})$ is the δ-neighborhood of the solution **K** (**K** is randomly perturbed in the neighborhood of the solution as follows: [**K −δ, K +δ**]) and | $\mathbf{B}_\delta(\mathbf{K})$| is the hyper-volume of the neighborhood. To use this definition in practice, a finite set of r solutions can be randomly generated within the perturbed range of **K** and then used to evaluate $\mathbf{F}^{eff}$ (Deb, K.; Gupta, H., 2006).

Robust Multi Objective Optimization Optimal Design of the Passive Suspension System

We consider the RMOD of the passive suspension system of the quarter car model given by Equations (2-5). Four pieces of information are needed for any RMOD: the design vector **K**, uncertainty vector **δ**, objective space $\mathbf{F}^{eff}$, and constraints. The design vector reads.

$$\mathbf{K}=\left[k_s,c_s,k_y,B\right]. \quad (10)$$

Springs are responsible for supporting the vehicle and absorbing large bumps. While shock absorbers dampen the motion of the springs after a bump by dissipating energy mostly through heat. Unlike shock absorbers, inerters absorb excess energy from tires and suspension and thus reduce the effect of the oscillations and help the car to retain a better grip on the road. So, these are very important design parameters. The corresponding vector of uncertainties is given by:

$$\boldsymbol{\delta}=\left[\delta_{k_s},\delta_{c_s},\delta_{k_y},\delta_B\right]=\left[5\%,10\%,10\%,5\%\right]. \quad (11)$$

The tire stiffness k_y and the shock absorber c_s experience large variations due to wear maintenance as reported in (Iroz, 2015) and (E. Abdellahi, 2001). The inerter B relays on the accurate knowledge of the gear ratios, radii, and inertias, and inertia of the flywheel. Also, an inerter's performance may deviate from its ideal one (C. C. Papageorgiou, 2009). As a result, we assume that the uncertainties δ_{k_y} and δ_{c_s} are twice that of δ_{k_s} and δ_B. The objective space is defined as

$$\min_{\mathbf{K}\in\mathbf{Q}}\left\{D_s^{eff}(\mathbf{K}),D_T^{eff}(\mathbf{K}),a_H^{eff}(\mathbf{K})\right\}, \quad (12)$$

where the superscript *eff* indicates the mean-effective value of the cost function, and D_S, D_T, and a_H are the suspension deflection, tire deflection, passenger's head acceleration, respectively. According to the mathematical model given in Equations (2-5), they are defined mathematically as follows:

$$D_s=z_s-z_u \quad (13)$$

$$D_T=z_u-z_r \quad (14)$$

$$a_H=\ddot{z}_t \quad (15)$$

According to Equation (13), the suspension travel describes the relative travel between the sprung mass and unsprung mass and its Root-Mean-Square (RMS) reads (Deb K. , 2001)

$$D_s^{RMS}=\left[\frac{1}{T}\int_0^T D_s^2(t)\,dt\right]^{\frac{1}{2}} \quad (16)$$

Where, T is the duration of measurement. Using the definition in Equation (16), the mean effective value of D_S is given by

$$D_s^{eff}=\frac{1}{\left|\mathbf{B}_{\boldsymbol{\delta}}(\mathbf{K})\right|}\int_{\mathbf{y}\in\mathbf{B}_{\boldsymbol{\delta}}(\mathbf{K})} D_s^{RMS}(\mathbf{y})d\mathbf{y}. \quad (17)$$

The Road handling is denoted by D_T which is defined as the relative travel between the unsprung mass and the road (see Equation (14). The RMS of D_T reads

$$D_T^{RMS} = \left[\frac{1}{T} \int_0^T D_T^2(t)\,dt \right]^{\frac{1}{2}}, \tag{18}$$

and its mean effective value is

$$D_T^{eff} = \frac{1}{|\mathbf{B}_\delta(\mathbf{K})|} \int_{\mathbf{y} \in \mathbf{B}_\delta(\mathbf{K})} D_T^{RMS}(\mathbf{y})\,d\mathbf{y}. \tag{19}$$

In accordance with ISO 2631-1 (Mechanical vibration and shock; evaluation of human exposure to whole body vibration in the working enviournment; part 1 general requirement), the RMS of the head acceleration a_H is given by

$$a_H^{RMS} = \left[\frac{1}{T} \int_0^T a_H^2(t)\,dt \right]^{\frac{1}{2}}. \tag{20}$$

Similarly, its mean effective value is given by

$$a_H^{eff} = \frac{1}{|\mathbf{B}_\delta(\mathbf{K})|} \int_{\mathbf{y} \in \mathbf{B}_\delta(\mathbf{K})} a_H^{RMS}(\mathbf{y})\,d\mathbf{y}. \tag{21}$$

The decision variables' search space is constrained to the following region:

$$\mathbf{Q} = \left\{ k_s \in [150, 450] \times 10^3, c_s \in [4,12] \times 10^3, k_y \in [116.5, 345] \times 10^3, B \in [0,4] \right\} \tag{22}$$

The ranges of k_s and k_y are chosen as k_{sN}*[0.5,1.5] and k_{YN}*[0.5,1.5], respectively, where k_{sN}= 300 kN/m and k_{YN}=233 kN/m (Bulman, 1997). The ranges of c_s and B are specified from the engineering point of view of suspension deflection (Kuznetsov, Mammadov, Sultan, & Hajilarov, 2011). Furthermore, constraints are imposed on the objective space. According to (A. Baumal, 1998) and (M. P. Nagarkar, 2016), the suspension travel should not exceed 125 mm to avoid hitting the suspension stop and a_H should be less than or equal to 4.5 m/s^2. For better tire gripping, the maximum deflection should not exceed 58 mm.

In the numerical simulation, z_r is modeled as a bump of height 0.1 unit (M. P. Nagarkar, 2016). Following (Kuznetsov, Mammadov, Sultan, & Hajilarov, 2011), we set m_t=2m/7 kg , m_p=5m/7 kg, c_t=1360 N.s/m, k_t=45005.3 N/m, c_c=900 N.s/m, k_c=10000 N/m, and m_u=20 kg, where m=65 kg. The sprung mass m_s is set to 180 kg following the work of Purdy and Bulman (Bulman, 1997) **.** This value is very close to the quarter mass of the 2017 Formula 1(F1) car, which was about 728kg according to Sportskeeda. However, in 2018, the mass was increased to 734 kg after adding the Halo (driver crash protection system). In order to follow the design method introduced in this paper, designers should adjust m_s based on to the weight of the car that they are dealing with. To solve this multi-optimization problem, NSGA-II (non-dominated sorting genetic algorithm) is used. It is one of the most widely used multi-objective optimization algorithms (Sardahi & Boker, 2018) and yields a better Pareto front as compared to other methods (Gadhvi, Savsani, & Patel, 2016). Also, it was shown by Deb and Gupta (Deb, K.; Gupta, H., 2006) that the algorithm is efficient in finding robust solutions of benchmark problems with two and three objectives. The reader can refer to (Deb K. , 2001) for more details about this algorithm. However, there is not a clear guide about setting up the number of populations and generations for NSGA-II. According to MATLAB documentation, the population size can be set in different ways and the default population size is 15 times the number of the design variables, nvars. Also, the maximum number of generations should not exceed 200×nvars. In this study, the population size and the number of generations is set to 50×nvars. For comparison purposes, the global Pareto solutions were also obtained using the same settings. For the robust solution, a finite set of 20 solutions (r=20) are randomly created within the neighborhood of the design parameters to account for their expected variations on the design objectives.

Results and Discussion

The global and robust Pareto fronts and sets and robustness of the suspension system in terms of the objective functions are discussed here. The optimization process results in 200 various solutions which means there are 200 different optimal and robust suspension configurations with different trade-offs among the design objectives. Projections of the global and mean-effective fronts are shown in Figures 3 and 4. The corresponding

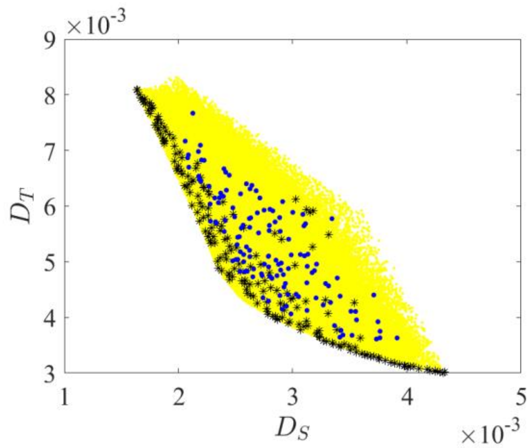

Figure 4. Projection # 1 of the Global and Robust Pareto Front (D_T Versus D_S). Yellow Region: Feasible Pareto Front, Black (*): Global Pareto Front, and Blue (•): Robust Pareto Front

Pareto set are shown in Figures 5 and 6. The yellow color in these figures denotes the feasible regions in the objective and parameter space defined in Equation (22). The global (D_S^{RMS} , D_T^{RMS} , and a_H^{RMS}) and robust (D_S^{eff} , D_T^{eff} , and a_H^{eff}) solutions are represented by the black (*) and blue (•), respectively. Both global and robust Pareto fronts demonstrate competing relationships among the design goals, which emphases the necessity of carrying out the design of the passive suspension system in multi-objective settings. The results also show that both global and robust regions are inside the feasible zone and the robust Pareto frontier avoids all the boundaries. Taking the robust Pareto front as an example, we notice that when D_S^{eff} =0.0039 (maximum value), D_T^{eff} and a_H^{eff} read 0.0036 and 3.1182 and respectively. While at the minimum value of D_S^{eff} =0.0021, D_T^{eff} =0.0072 and a_H^{eff} =3.6023. Meaning, both D_T^{eff} and a_H^{eff} goup when D_S^{eff} goes down and vice versa as it is evident from Figures 3 and 4. Between these two design options, there many robust and optimal options that the decision-maker can choose to implement. It should be indicated that the smaller a_H^{eff}, the better. Small values of a_H^{eff} mean that the amount of the transmitted forces to the pelvis and thorax is small. The projections of the

Pareto sets in Figures 5 and 6 show the robust and global solutions. The dession-maker can choose any point from these sets to implement. If a robust behavior of the suspension is required, the robust Pareto set offers 200

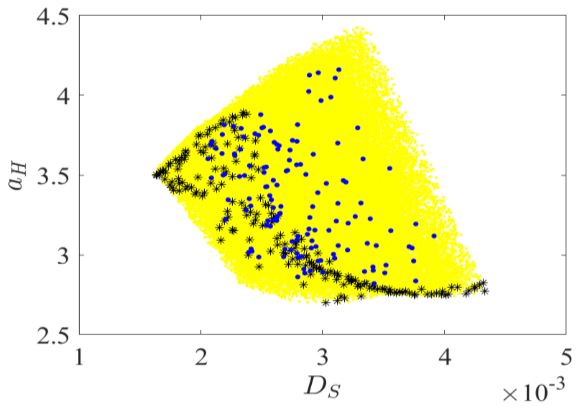

Figure 5. Projection # 2 of the Global and Robust Pareto Front (a_H Versus D_S). Yellow Region: Feasible Pareto Front, Black (*): Global Pareto Front, and Blue (·): Robust Pareto Front

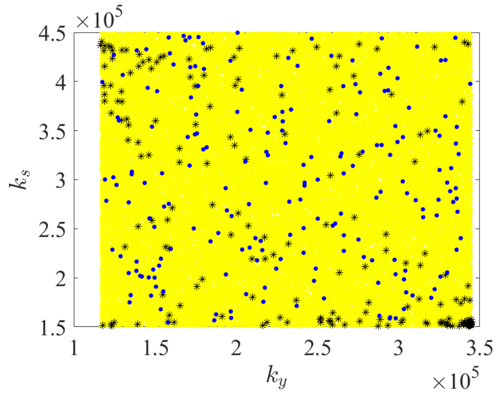

Figure 6. Projection # 1 of the Global and Robust Pareto Set (k_s Versus k_y).Yellow Region: Feasible Pareto Set, Black (*): Global Pareto Set, and Blue ( ): Robust Pareto Set

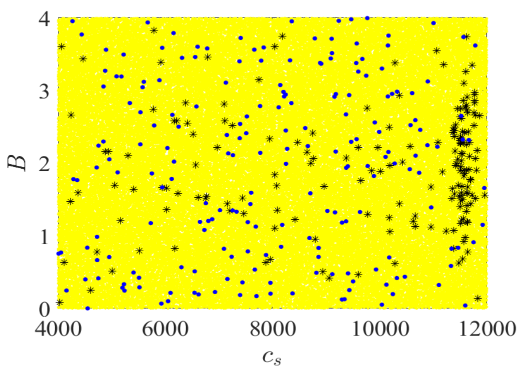

Figure 7. Projection # 2 of the Global and Robust Pareto Set (B Versus c_s). Yellow Region: Feasible Pareto Set, Black *: Global Pareto Set, and Blue ( ) : Robust Pareto Set

Differnt optinons to choose from. Since it is not practical to compare the robustness of the global Pareto front and mean effective Pareto frontier for all the solutions, two solutions from the robust and global Pareto sets are chosen randomly. Then, a random perturbation is generated according to the uncertainty vector defined in

Equation (11). After that, the same amount of perturbation is added to both solutions. Finally, the profiles of the absolute error between the perturbed and nonperturbed solutions for both global and robust solutions are depicted in Figures (7)-(12). The deviations in the suspension traveling in terms of its global ($|E_{Ds}|_G$) and robust ($|E_{Ds}|_R$) values are defined as follows

$$\left|E_{D_S}\right|_G = \left|D_{S_G} - D_{S_{GP}}\right|, \tag{23}$$

$$\left|E_{D_S}\right|_R = \left|D_{S_R} - D_{S_{RP}}\right|. \tag{24}$$

Where, D_{S_G} and D_{S_R} represent the global and robust D_S with no variations in the design parameter and $D_{S_{GP}}$ and $D_{S_{RP}}$ denote their corresponding values as result of the parametric perturbations. Similarly, the deviations in the global and robust responses of D_T and a_H can be defined in the following equation

$$\left|E_{D_T}\right|_G = \left|D_{T_G} - D_{T_{GP}}\right| \tag{25}$$

$$\left|E_{D_T}\right|_R = \left|D_{T_R} - D_{T_{RP}}\right| \tag{26}$$

$$\left|E_{a_H}\right|_G = \left|D_{a_{HG}} - D_{a_{HGP}}\right| \tag{27}$$

$$\left|E_{a_H}\right|_R = \left|D_{a_{HR}} - D_{a_{HRP}}\right| \tag{28}$$

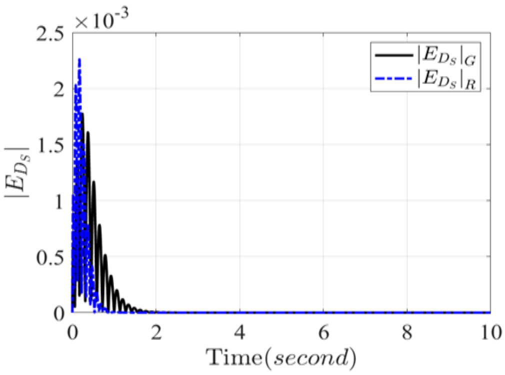

Figure 8. Profiles of the Absolute Deviations in the Suspension Travel $\left|E_{D_s}\right|$ for the Perturbed Non-Perturbed Global $\left|E_{D_S}\right|_G$ and Robust $\left|E_{D_S}\right|_R$ Solutions from the First Randomly Selected Solution

Where, the subscripts G, R, and P mean respectively global, robust, and perturbed. Generally speaking, the global profiles of D_S, D_T and a_H are more sensitive to the perturbation than the robust ones. Even though the profiles of these performance metrics under the robust solutions may show an initially increase (see Figures 9 and 11), they decay faster than their corresponding global solutions. This stresses out the need to handle such a design problem in robust and multi-objective settings to guarantee global behaver of the suspension system against the unavailable parametric variations.

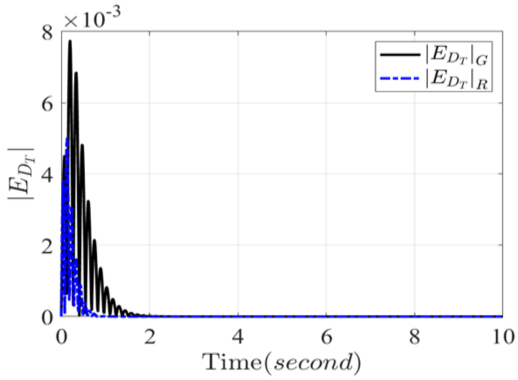

Figure 9. Profiles of the Absolute Deviations in the Tire Travel $\left|E_{D_T}\right|$ for the Perturbed and Non-Perturbed Global $\left|E_{D_T}\right|_G$ and Robust $\left|E_{D_T}\right|_R$ Solutions from the First Randomly Selected Solution.

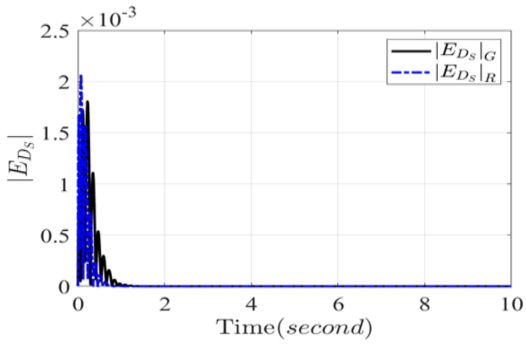

Figure 10. Profiles of the Absolute Deviations in the Suspension Travel $\left|E_{D_s}\right|$ for the Perturbed Non-Perturbed Global $\left|E_{D_S}\right|_G$ and Robust $\left|E_{D_S}\right|_R$ Solutions from the Second Randomly Selected Solution

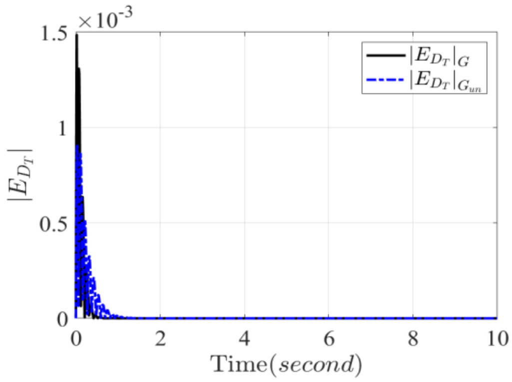

Figure 11. Profiles of the Absolute Deviations in the Suspension Travel $\left|E_{D_s}\right|$ for the Perturbed Non-Perturbed Global $\left|E_{D_S}\right|_G$ and Robust $\left|E_{D_S}\right|_R$ Solutions from the Second Randomly Selected Solution

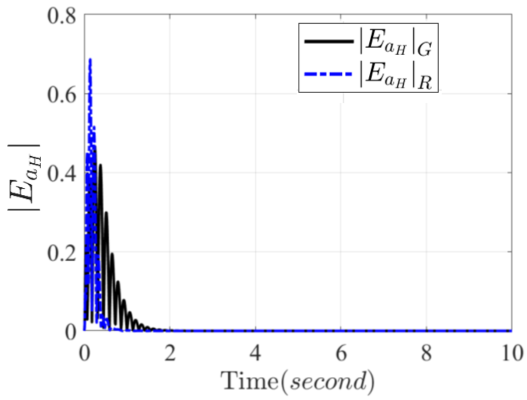

Figure 12. Profiles of the Absolute Deviations in the Suspension Travel $\left|E_{a_H}\right|$ for the Perturbed Non-Perturbed Global $\left|E_{a_H}\right|_G$ and Robust $\left|E_{a_H}\right|_R$ Solutions from the First Randomly Selected Solution

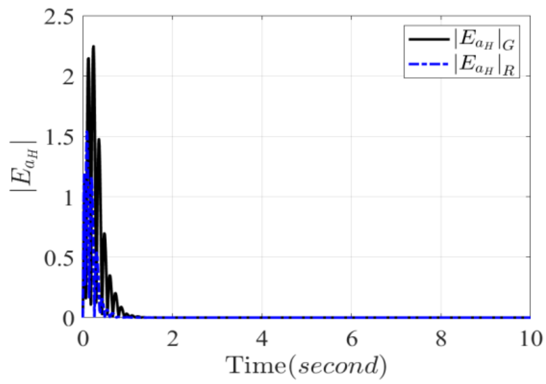

Figure 13. Profiles of the Absolute Deviations in the Suspension Travel $\left|E_{a_H}\right|$ for the Perturbed Non-Perturbed Global $\left|E_{a_H}\right|_G$ and Robust $\left|E_{a_H}\right|_R$ Solutions from Second First Randomly Selected Solution

Conclusion

We have studied the RMOD of a passive suspension system with an inerter device. The optimization problem with 4 design parameters and 3 objective functions is solved by the NSGA-II algorithm. The global and robust Pareto set, and front are obtained. The Pareto set includes multiple design options from which the decision-maker can choose to implement. Numerical simulations show that the robust multi-objective design is very effective and guarantees a robust behavior as compared to that of the classical multi-objective design. The results also show that the robust region is inside the feasible objective space and avoids all its boundaries. Also, the results show that the design goals are competing, and as a result, there are many optimal and robust passive suspensions with different degrees of compromises among the design objectives. Furthermore, the numerical simulations manifest that the solutions from the robust Pareto set are more robust than those from the global set.

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Neural Network Modeling and Optimizing of the Agglomeration Process

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Abstract: During the operation of the lead-zinc production while processing of polymetallic ores, problems arose related to the quality of products and the efficient use of equipment – agglomeration furnace and crushing apparatus. In the past time, such issues were resolved due to the experiences and based on mathematical modeling of processes. The mathematical model for optimizing such operating mode is a difficult program. Performing calculations is required a fairly large investment of time and resources. Therefore, the program of the mathematical model for optimizing the operating mode of the agglomeration furnace and the crushing device for sinter firing was replaced with a neural network by implementing the process of training the network based on the results of calculations on a mathematical model. The results obtained showed that neural network models were more accurate than mathematical models, which made it possible to solve production optimization problems of great complexity. The use of neural networks for modeling technological processes has made it possible to increase the efficiency of product quality control systems and automatic control systems for the roasting of sulfide polymetallic ores.

Keywords: Neural network, Modeling of process, Control systems, Optimizing management

Introduction

A promising area of application of the tools of the theory of artificial neural networks is the modeling of complex technological processes in the metallurgical industry of the mining and metallurgical complex. Mathematical models of technological processes are necessary for the application of effective modern methods and tools for studying the influence of technology on the properties of the final product of the appropriate quality, as for the tasks of optimizing management and making high-quality decisions.

Abitova, G., Rzayeva, L., & Zadenova, T. (2021). Neural network modeling and optimizing of the agglomeration process. In M. Shelley & V. Akerson (Eds.), *Proceedings of IConEST 2021-- International Conference on Engineering, Science and Technology* (pp. 26-35), Chicago, USA. ISTES Organization.

Mathematical models are often simplified, limiting their actions to certain assumptions. Although the literature does not provide examples of the use of neural networks for modeling this kind of dependencies (in particular, in the lead-zinc production of non-ferrous metallurgy), the flexibility of neural network models allows them to be used to simulate the technological process and in the metallurgical production of non-ferrous metals during the processing and roasting of sulfide polymetallic ores.

In metallurgical industries, the task of introducing new innovative technologies is attractive, which can accelerate research in obtaining new promising metallurgical alloys, improve the quality and safety of methods for obtaining smelted metal, and reduce its cost. Due to the complex nature of the change in material properties, depending on the chemical composition of the ores being processed, the concentration of metals in the ores, heat treatment modes, and test conditions, the ability to choose the exact mathematical relationship between the composition and properties quickly decreases and may become impracticable [1].

A further solution to the problem of optimizing the control of metallurgical processes for the processing of polymetallic sulfide ores is possible by solving the problems of controlling large melting units (roasting and agglomeration furnaces, oxygen converters, etc.) including complex multiparametric processes. The introduction of automated neural network systems for melting process control will improve the quality of the smelted metal, reduce its cost (including the prime cost) and increase the safety of the technological process.

Methodology of the Research Problem

The research technique of this work involves the use of modern approaches on process optimization such as neural network modeling and mathematical modeling as well as numerical methods and analytical calculations of the obtained results. Also, a method of statistical analysis for decision making and using its while the learning process of neural network models is used in this research work.

It is necessary to use mathematical models that reflect the operation of the agglomeration furnace and associated technological equipment to make a reasonable choice of a firing plant. The mathematical models used for these purposes in the form of computer programs have a complex structure, large volumes, and take a significant amount of time for calculations.

In this case, the use of neural networks technologies to determine the accuracy of the results obtained when solving heat and energy transfer problems using multi-purpose computing systems is the best way to solve these kinds of problems.

In this work, the methods of modeling are used to solve the optimization of the operating modes of the agglomeration furnace and crusher machine on the fuel consumption for the furnace, electric energy for the crusher process.

The Structure of the Mathematical Model of the Firing Process

The unit model is designed to optimize the operating mode of the firing process, calculate the rates of energy consumption for the unit at a minimum cost of the workshop redistribution, and develop process flow charts for the agglomeration of the metal mixture. Figure 1 shows the interaction of the components of the furnace-agglomeration crushing plant model.

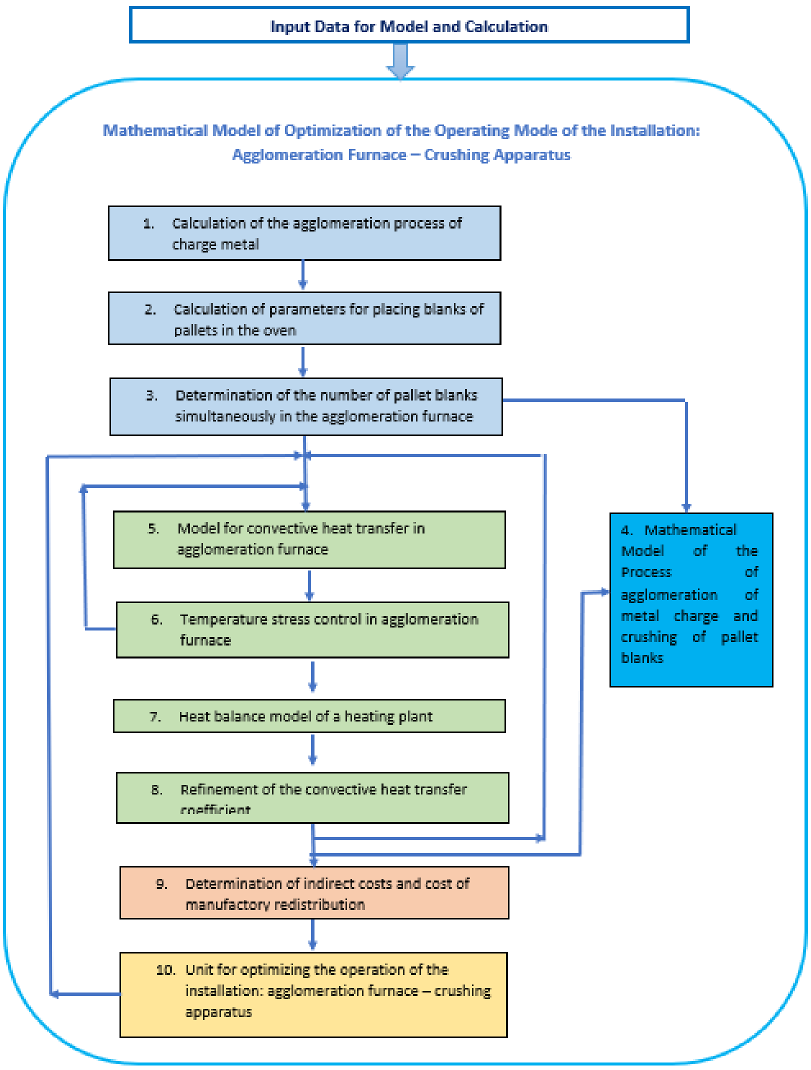

Figure 1. Block Diagram of the Model: Agglomeration Process

Choosing the Limitations of the Mathematical Model and Setting up a Computational Experiment

It Is difficult to use the above algorithm to determine the optimal operating parameters based on an enumeration of options because the amount of such computation is very large. Therefore, an algorithm is used, that is presented a set up a computational experiment. This algorithm provides information on how the objective function will be changed from changing the operating parameters [24-25].

To determine such a dependence, it is necessary to reasonably set the intervals of variation of the operating parameters. The boundaries of the various intervals are determined based on the following conditions:
1) For the final firing temperature of the metal on the surface, the range of variation is in the range from the temperature at which firing cannot be performed (the metal loses its plasticity) to the melting point of the metal (the metal turns into a liquid state).

2) For the permissible temperature difference at the end of the metal firing, the range of variation is from a temperature drop close to zero (5 – 10 ˚C) to the temperature difference between the melting point of the metal and the firing temperature. In practice, it is advisable to reduce this range somewhat by setting it in the range from 35 to 170 ˚C.

The required dependency and equation of mathematical modeling $y = f(x_1, x_2, x_3)$ is presented in the next form (Eq.1):

$$y = b_1 + b_2 * x_1 + b_3 * x_2 + b_4 * x_3 + b_5 * x_1 * x_2 + b_6 * x_1 * x_3 + b_7 * x_2 * x_3 + b_8 * x_1^2 + b_9 * x_2^2 + b_{10} * x_3^2 \quad (1)$$

where y is an optimization parameter; x_1, x_2, x_3 – variable parameters; b_i, - coefficients.

In order to find the coefficients bi, a second-order orthogonal planning matrix for a computational experiment is constructed for three factors x_1, x_2, x_3. On the basis of a computational experiment using the planning matrix, the coefficients bi are found for the dependence. The optimization problem is solved taking into account 8 constraints (Table 1). Using these data presented in table 1 we can determine the differences between existing and valid values that are presented in the form of dependencies between constraints and temperature of the firing process.

Table 1. The Eight Constrains for Optimization

Number of constrains	Type of construction
1	is the temperature of the gases in the working space of the firing furnace
2	is the using the rate of delivery of agglomeration pallets from the furnace
3	is the allowable temperature difference during the initial firing period
4	are the maximum temperatures of the using furnace materials
5	are the maximum temperatures of the using furnace materials
6	are the maximum temperatures of the using furnace materials
7	is the maximum possible gas flow rate for the agglomeration furnace
8	is the productivity of the agglomeration furnace

The differences between the valid and existing values are determined by the following formula (Eq.2).

$$\Delta y_1 = b_{1,i} + b_{2,i} * x_1 + b_{3,i} * x_2 + b_{4,i} * x_3 + b_{5,i} * x_1 * x_2 + b_{6,i} * x_1 * x_3 + b_{7,i} * x_2 * x_3 + b_{8,i} * x_1^2 + b_{9,i} * x_2^2 + b_{10,i} * x_3^2 \quad (2)$$

where i – current constraint number; y_i – the difference between the valid and calculated values of the i constrains; x_1, x_2, x_3 – variable parameters.

For calculation of these optimization tasks, during the study, it was used several modern computer tools and technics. For example, for analytical solutions were used the programs were designed using the Mathcad packet. The numerical methods were used to solve research questions using the PHOENICS packet. At the same time, for the processing and analysis of the research results, it was used modeling methods were based on the neural networks using the Nonresolution's packet.

Results

In this section, the results of the modeling are proposed for the process of processing polymetallic areas in the Kazakh industry plant. For this purpose, data from real installations of lead-zinc production JSC "Kazzinc" were taken as a basis. The firing furnace is a chamber lined with refractory bricks and enclosed in a metal frame. The agglomeration furnace is loaded and unloaded manually through a working window framed by a water-cooled frame and closed by a water-cooled steel damper lined with lightweight chamotte. The results of calculating the optimal modes of the real industry plant of Kazakhstan are given in table 2.

Table 2. The Calculating Results the Optimal Modes for the Firing Furnace and Crusher Machine

Title of controlled parameter	1	2	3	4	5	6	7
Temterature of agglomeration furnace (^{0}C)	870	903	815	868	810	780	751
The volume of pallets in the furnace (kg)	560	870	630	660	730	1200	1500
The firing process temperature (^{0}C)	1470	1980	1320	1670	1850	1950	1535
Temperature difference of firing (^{0}C)	99	87	76	68	54	82	79
Gas consumption (m^3/hour)	25	28	22	21	20	19	25
Agglomeration time of firing (sec)	1312	1418	1138	1248	1176	1096	1147
Self cost of production (tg/kg)	37,2	38,3	46,9	52,5	50,2	48,3	44,0

Table 2 is demonstrated just the main results which are important for optimization of the processing mode in the lead-zinc production. Because they mainly are influencing to the quality and accuracy of modeling results while the processing of polymetallic ores.

Verification of the Results of Neural Network Modeling

After training on the data obtained from the calculation in the program for optimizing the operating mode of the furnace-crushing sinter plant, the neural network was ready for operation and was used to make forecasts and make instant decisions.

As a result, the best learning outcomes of neural networks were the learning outcomes presented below in table 3 and figure 3. For example, table 3 below presents a comparative analysis of the learning outcomes and calculation according to the program for the determination of the number of pallet blanks in the agglomeration furnace.

The comparative analysis of results of the training and calculation according to the program that provides the determining of the surface temperature of metal charge at the end of agglomeration are shown in figures 2 and 3.

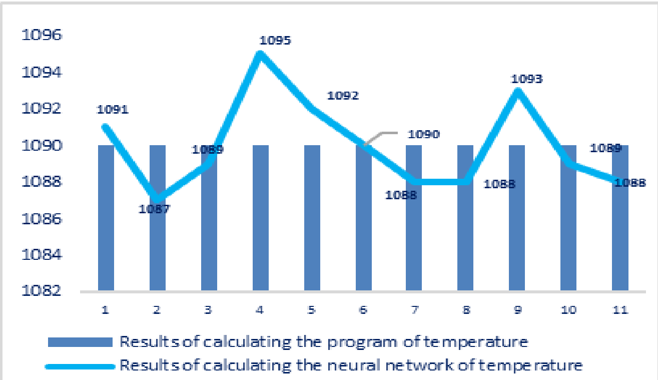

Figure 2. The Learning Outcomes of the Neural Network According to the Proposed Algorithm

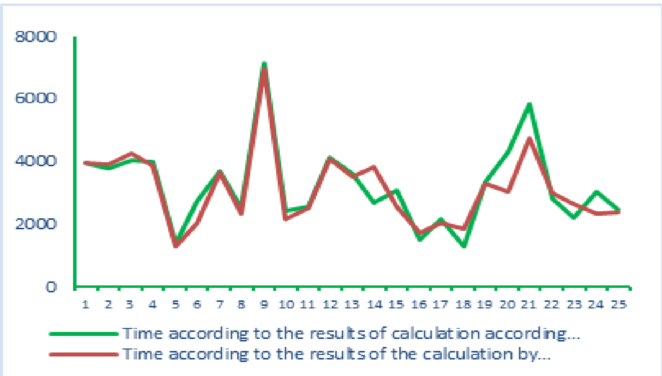

Figure 3. The Learning Outcomes of the Neural Network According to the Calculation Results

Figure 2 is demonstrated some of the learning outcomes of the designed neural network according to the proposed algorithm.

Figure 3 is demonstrated some of the learning outcomes of the designed neural network according to the calculation results.

Thus, according to the numerical experiments and the applying the trained neural network, the deviations were obtained that are presented in table 4.

Table 4. Comparative Results of Numerical Calculations and Calculations Using Neural Networks

	Deviations on the number of pallet, pcs.	Deviation on the time of agglomeration, sec.	Deviations on temperature at the end of agglomeration, °C
Maximum deviation	15	302	37
Mean deviation	12	254	25
Minimum deviation	7	9	1

Discussion

Thus, according to the numerical experiments and the applying the trained neural network, it was possible to get the comparative analysis of results of the training and calculation according to the program that provides the determining of the surface temperature of metal charge at the end of agglomeration.

As the result, we have obtained the following outcomes of the training and of the deviations:
- the neural networks calculation errors in the pallets number in the agglomeration furnace ranged from 11% to 24%;
- the neural networks calculation errors in the time of agglomeration of pallet blanks ranged from 0.2% to 7%;
- the neural networks calculation errors in the surface temperature of the pallet blanks were from 0.09% to 3%.

Conclusion

The use of neural networks to simulate technological processes of agglomeration roasting of polymetallic sulfide ores in lead-zinc production ensured an increase in the efficiency of product quality control systems and automatic control systems for roasting of sulfide polymetallic ores, optimizing production costs by 3%. Also, it increased the efficiency of energy reproducing. Operation of heating equipment by optimizing the operating mode of equipment is provided the increasing of effectiveness 10%.

Thus, from the above results, it is obvious that the obtained neural models adequately describe the real processes during the agglomeration of the charge and the firing of pallet blanks in the furnace. And it is proving that the research goals of this work are obtained. Future, it can be recommended to use for study the process of the firing of the other ores on the metallurgy plant and for calculating the design features of a heating and power plant. It can also be used to make forecasts and make instant decisions in the designing of any other heating equipment and its optimal control.

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Design of an Integrated Data Acquisition System for Aero Engine Testing Using LabVIEW® Virtual Instrumentation

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Abstract: Aero gas turbine engine development involves an exhaustive engine testing phase which is very critical. Gas turbine engine testing involves performance optimization, design validation, endurance tests. Various types of test facilities are configured to carry out these tests depending on the type of Gas turbine engine, the thrust class, size of the engine and the purpose of testing. Testing of the engine involves extensive instrumentation of various parameters to understand the health and the performance of the engine. This paper discusses about the development of a very high channel integrated Aero engine Data acquisition system (DAS) for 1200 channels. This DAS is capable of handling different sampling speed and acquisition of different types of parameters. Appropriate COTS based signal conditioners are configured and built with facility for easy trouble shooting and expansion capabilities. The distributed DAS is synchronized with IRIG – B time synchronization and external triggered acquisition. LabVIEW programming has been used as the backbone of the entire acquisition platform. Online data analysis, fault identification logics, auto calibration, replay features have been built into the software. Auto warning of engine operator on exceedance of parameter limits, online comparison of data with respect to standard data set, online faulty channel identification and isolation techniques also have been built in. The goal of the development described in this paper was based on the system requirements analysis defining the system architecture and design of the code that would be complete, user friendly and would implement the basic and most commonly used features but also maintain good scalability of the system for future changes

Keywords: Aero gas turbine engine, data acquisition systems, LabVIEW®

Introduction

In the evolving aviation field Gas Turbine Propulsion Technology holds the key in the development of both civilian and military airplanes. Gas turbines are a proven and reliable technology. Their power density, reliability, and safety are well established. Gas turbines have and will continue to play a key role domestically

Prabakar, V. & Srinivasan, K. (2021). Design of an integrated data acquisition system for aero engine testing using LabVIEW® virtual instrumentation. In M. Shelley & V. Akerson (Eds.), *Proceedings of IConEST 2021-- International Conference on Engineering, Science and Technology* (pp. 36-47), Chicago, USA. ISTES Organization.

and globally. Continued research and technology investments will enable gas turbines to maintain their place in the market.

In an aero engine development program testing of the engine prototype is an important phase. During the development phase many prototype engines are tested to study the aero thermodynamic performance of the engine at different operating conditions, design validation and endurance tests with different intended flight profiles [11]. Testing gas turbine engines in different types of test beds are crucial in ensuring the Aero engine meets all the performance demands with good structural integrity at all conditions. Acquiring reliable data quickly is critical to turbomachinery validation and testing programs. The ground test cells, which are primarily intended for testing new engines or engine components, can be used to test the technologies, designs and innovative materials developed for the engines of tomorrow.

Being developmental engines, these engines are necessarily instrumented with extensive instrumentation to understand and evaluate the engine performance. This instrumentation drives the requirement for a state of art Data acquisition system which includes the hardware and software installations need to collect the engine parameters and monitor the health and performance during the running of the test.

The instrumentation on a Gas turbine engine typically includes measurement of

- Pressure (Total pressure and Static pressure)
- Dynamic pressure
- Pressure of fuel and lubrication oil (wet medium)
- Temperature
- Flow (fuel and lubrication oil)
- Rotor speeds
- Vibration
- Strain
- Rotor tip clearance
- Actuator positions
- Angular locations
- Switch status

This paper describes about the design, development and implementation of a very high channel count integrated data acquisition system to handle the above set of parameters with suitable signal conditioners and appropriate monitoring systems.

The system is implemented with COTS based signal conditioners, integrated with LabVIEW based software the high-performance DAS performs data acquisition, monitoring and calculations in a guaranteed, deterministic manner. LabVIEW being a GUI based software development protocol and has been explored to the fullest extent in developing the system. Small channel count systems for aircraft engine testing have been configured and discussed widely. [2,5,6,7,10]. However, this paper discusses a configuration which has been successfully designed, developed and installed for a large channel count of 1200 channels.

System Architecture

This paper describes about a Data acquisition facility established to test a developmental gas turbine engine. Testing of an aero engine needs a high accuracy high performance Data Acquisition system during the developmental, design evaluation, efficiency estimation and production performance verification phases.
The total number of channels for each parameter catered in this work is shown in Table 1

Table 1. List of Parameters

Sl. No	Parameter Type	Channel Count
1.	Pressure	356
2.	Temperature	320
3.	Flow	32
4.	Speed	32
5.	Vibration	64
6.	Strain	64
7.	Dynamic Pressure	64
8.	Rotor Tip Clearance	16
9.	Voltage Channels	256

The general philosophy in a Data Acquisition system is as shown in Figure 1

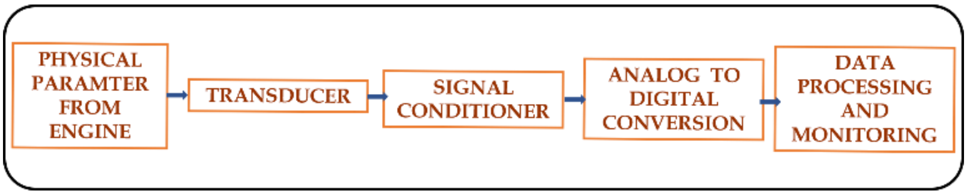

Figure 1. Data acquisition system philosophy

Physical Signal is acquired from the engine by the transducers. The signal from the transducers is conditioned using different signal conditioners and then digitized using suitable Analog to digital conversion techniques. The digitized signal is processed with suitable logics for validation and engineering unit conversion. The engineering unit converted data is further processed as per the individual requirements for online data monitoring and off line data analysis.

The pressure and temperature signals are handled using the Ethernet based scanners with built in signal conditioners and digitizers. The digitised data is then acquired by the central system using the TCP/IP protocol. The central acquisition system is a PXI architecture hardware capable of handling the signal conditioning requirement of all the other transducers used.

The data is synchronized using a IRIG B signal configured by a GPS receiver and distribution unit. The LabVIEW software is developed to command the scanners to start a external triggered acquisition, acquire signal from the engine mounted transducers and uses the configuration module for deciding the sampling speed, engineering unit conversion, rate validation, comparison validation before processing the readings for display and calculations. The processed data is parallely sent on the network for data distribution to the online monitoring clients.

Hardware Configuration

The Data system acquisition system is configured with COTS based hardware. This hardware is carefully selected after analyzing the various options. The main considerations were accuracy, sampling speed, ease of interface, maximum channel count per hardware, expansion, configuration, LabVIEW compatibility.

The main acquisition hardware is the NI – PXI. (NI-PXIe 8880) PXI platform provides the ruggudisation, data synchronization and the flexibility in choosing the signal conditioner cards in terms of channel counts and sampling speeds. The pressure and temperature which forms the bulk of channels are handled by intelligent ethernet based digital scanner modules from Scannivalave Corp. The data transfer protocol used in this work is Ethernet TCP/IP, which is a widely used industry standard, easy to adopt and configure. The hardware configuration realized for this work is depicted in figure 2.

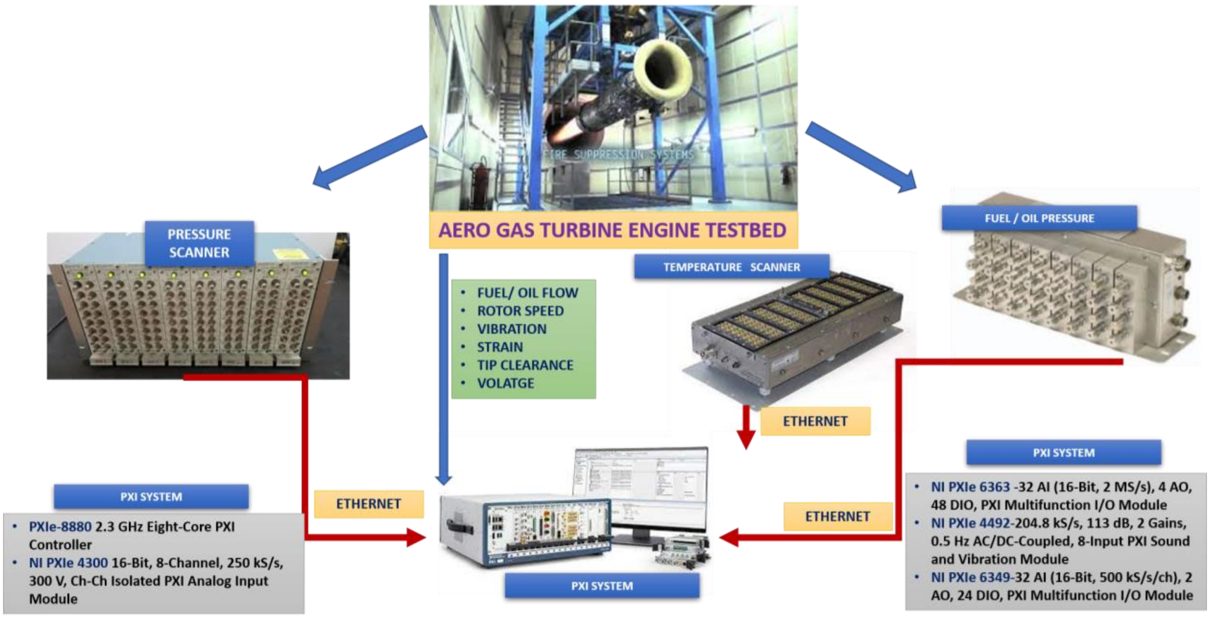

Figure 2. Hardware Configuration

Pressure Measurment

In a gas turbine engine both static and total pressure are measured. Static pressures are measured with the wall static pressure tappings and total pressure is measured using multi point rakes installed on the engine at various locations, Multi point rakes vary as per annular passage available typically from five points in the fan exit to around nine points in the jet pipe exit. Gas turbine being a harsh environment in terms of temperature and vibrations copper tube are used to sense the pressure and carry it to the transducers.

Pressure channels are acquired using Intelligent, Ethernet based Pressure scanners. These pressure scanners are configured as per range and integrated into intelligent controller chassis. These controller chassis are builtin with the analog to digital converters. Suitable compensation for temperature is also carried out. Other features include provision for multi point calibration and inlet lines purging. The digitized data are converted to engineering unit data using the calibration chart fused in the hardware. The engineering unit data is then available on the Ethernet TCP/IP transmitted to the main host computer as and when requested.

Temperature Measurment

Temperature in GTE is mainly measured using K type thermocouple. K type thermocouple can measure the entire range in a GTE, R type is also used for high temperatures. The thermocouples are mineral insulated cables embedded on to the casings and components to have a direct skin temperature measurement and for gas path measurements thermocouple rakes are introduced in the gas passages. Extension cables are used to connect these thermocouples to Intelligent thermocouple scanners. These thermocouple scanners use 22-bit Analog to digital conversion and the digitsed signal is conveterd to engineering unit using the standard table conversion fused inside the EEPROM. Depending on the particular type of thermocouple used the look up table for conversion is selected and processed. Cold junction compensation is carried out by measuring the compensation carried out by measuring the junction temperature at eight locations and computing the final reading.

A few channels of temperature are also measured using the Resistance temperature detectors (RTD). Platinum RTD (PT100) is used in the GTE inlet for a very accurate measurement. The RTD channels are processed using NI signal conditioner card NI PXIe 4357configured in the main PXI system.

Flow and Speed Measurment

Flow measurement in a GTE involves measurement of fuel flow and lubrication flow. Turbine flow meters are used for this application for the good accuracy, repeatability and wide measuring range it can handle. Speed is measured using magnetic pulse sensors. They have a simple construction, rugged and accurate with good repeatability. These sensors are used to measure the most critical parameter in GTE the high spool speed N1, low spool speed N2. Both the flow and speed sensors provide a variable frequency output. These frequency outputs are handled through the PXIe signal conditioner card. - NI PXIe 6349

Vibration and Strain Measurement

Engine vibration and strain are critical parameters to be measured during the engine testing. These parameters are to be monitored critically for the health of engine during testing. Vibration transducers (accelerometers) are mounted multiple locations of the engine. Accelerometers are mounted internal to the engine for measuring the bearing housing vibrations and externally to monitor the casing vibrations.

Strain gages are mounted at multiple locations both in static and rotating members of the engine. Both vibration and strain are acquired using high bandwidth, NI PXI cards with simultaneous sampling. The gain and the low pass filter characteristics are programmable. Depending on the requirements these values are fixed for each specific channel. (NI PXIe 4492)

Rotor Tip Clearance Measurement

The rotor tip clearance is another important measurement being monitored continuously. The tip clearance during the engine runs indicates the growth of the rotor blade during max operating conditions and any rotor shaft undulations are monitored for any unusual behavior during the engine testing. Tip clearance probes based on the variable capacitance principle are mounted on the various stages of the rotors. These signals are handled by the NI PXIe 4300 with high bandwidth, simultaneous sampling, high dynamic range, selectable AC/DC coupling.

Voltage Measurment from Transducers

As a part of the facility many switch positions, pressure transducers from air supply facilities, position sensors are to be measured. These transducers are both engines mounted as well as mounted on the various other infrastructures required to support the engine testing activities like various compressors, valve operations. These signals are mostly steady state operations without transients are acquired using the NI (NI PXIe 6363) card in the PXI system.

Software Development

The software development for this integrated Data Acquisition system was the most critical activity. The software requirements were conceived based on the requirements of testing a developmental engine rather than a production version engine. The testing philosophy for a developmental engine testing relies entirely on the test data. Feedback on the performance of the engine systems during engine testing gives valuable inputs for the designers to optimize the design parameters. LabVIEW based virtual instrumentation was the main tool used in this development. LabVIEW a GUI based development platform being so versatile and easy to use shortens the development time considerably. LabVIEW a graphical programing langauge is flexible, resusable and self documenting. Sub rutines can be easily saved in library and reused. This dramatically reduces the development time. Visual HMI interfaces is easiest in LabVIEW with immediate visualisation of the screens can be configured with less effort compared any other programming language. [1, 13,15]. Built in DAS related display which are simply drag and drop operations are easy to use. Online graphs, trend plots are easy to configure and provides the engine operator a easy guide while testing the engine.

LabVIEW integration with the standard hardware systems is made simpler with all the device drivers available in all platforms. The virtual instrumentation developed for this data acquisition application is mainly divided into five main modules. The general data flow is depicted in Figure 3.

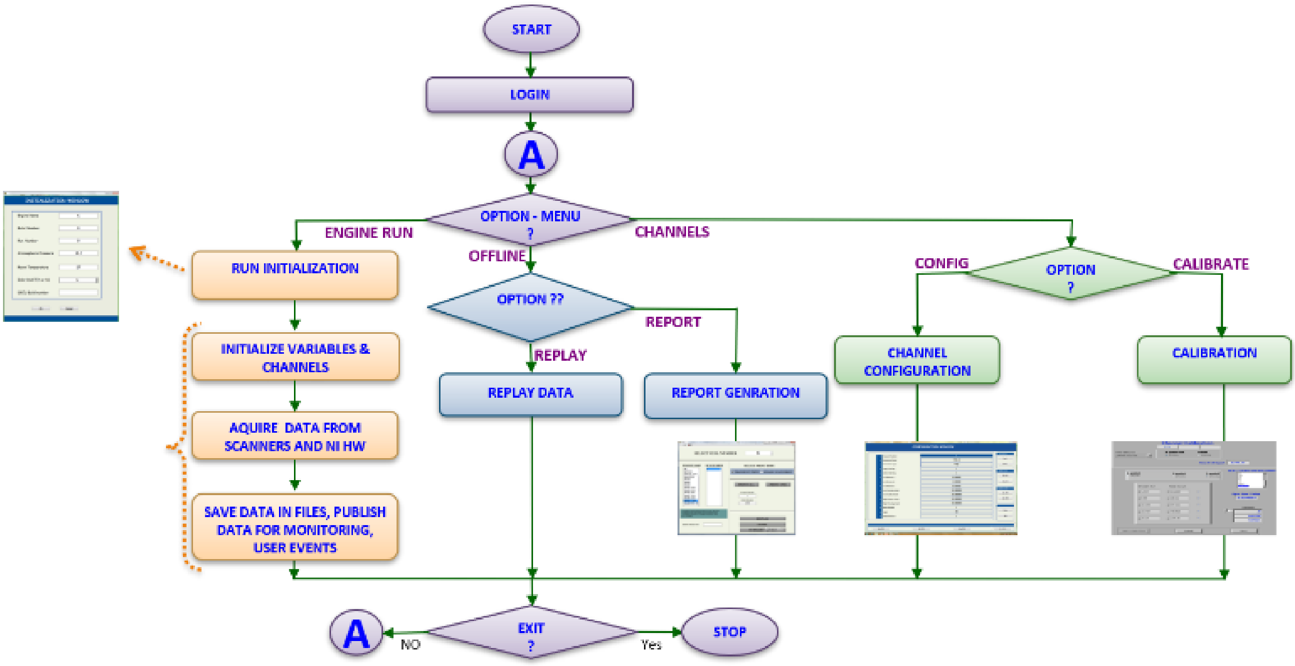

Figure 3. Data Flow diagram

- Channel configuration
- Data acquisition
- Data processing
- Display processing
- Calibration module

Channel Configuration

The channel configuration module is design to take various inputs required to configure a hardware channel. It determines the Channel number, parameter name, parameter type, the required engineering unit conversion, the sampling rate, the warning and caution limits. The inputs are designed to have editable fields and scroll down menu as applicable.

The channel number is a block of running numbers allotted for each parameter types. The parameter name is designated as per the standard nomenclature followed for Aero Gas turbine engines which typically considers the location of the instrumentation in the engine, the angular and radial location and the parameter type. The details are stored in the configuration block of the data files with proper indexing.

Data Acquisition Module

The Data acquisition VI mainly deals with initiation of the acquisition with default setting parameters, initialization of the networks and start of triggered acquisition. On receipt of the initialization command from the VI the DAS systems start acquiring the data and after internal processing the data is transmitted on to the network. The sampling rates from the data acquisition devices are fixed by the configuration module.

Data Processing

Data processing VI is configured with multiple sub VI to cater for data acquisition from multiple DAS. Data is received in engineering units from the pressure and temperature scanners whereas raw data is received from the PXI DAS. The data processing module converts this raw data into engineering units based on the conversion logics built in. The engineering unit data is time stamped and the engineering unit converted data is stored on to a data file indexed with the engine test numbers. This data is further used by the client machines for display purposes and computation of engine functional parameters as required.

Display Processing

The engineering unit converted data is further handled by the display processing module both for online and offline activities. Testing of aero gas turbine engines requires extensive online monitoring for various parameters for engine performance calculations and assessing the engine safety. Few of the critical parameters for a typical aero engine monitoring are

- Operating Lines and Stall Margins
- Auxiliary Power Extraction
- Fuel Flow
- Specific Fuel Consumption
- Engine Airflow
- Bleed Airflow
- Vibration Levels
- Pressures and Temperatures
- Humidity
- Rotor Speeds
- Engine Pressure Ratio

These parameters are required by the engine controller and the system specialists conducting the engine tests for taking appropriate decisions during the engine testing. Extensive Graphical user interfaces have been developed to facilitate the user to take quick decisions. Few of the GUI developed are depicted below in figure 4 , 5 and 6.

Figure 4 depicts the engine operator critical display module which are built with operator ergonomics, caution and warning limits.

Figure 5 depicts the Engine Performance Display Module which presents the critical performance channels online and guides the operator to assess the engine.

Figure 6 depicts the channels overview display which at a glance provides the information from all the stations.

This helps the operator and the module specialists to provide critical information on the overall behaviour of the engine.

Figure 4. Engine Operator Critical Display Module

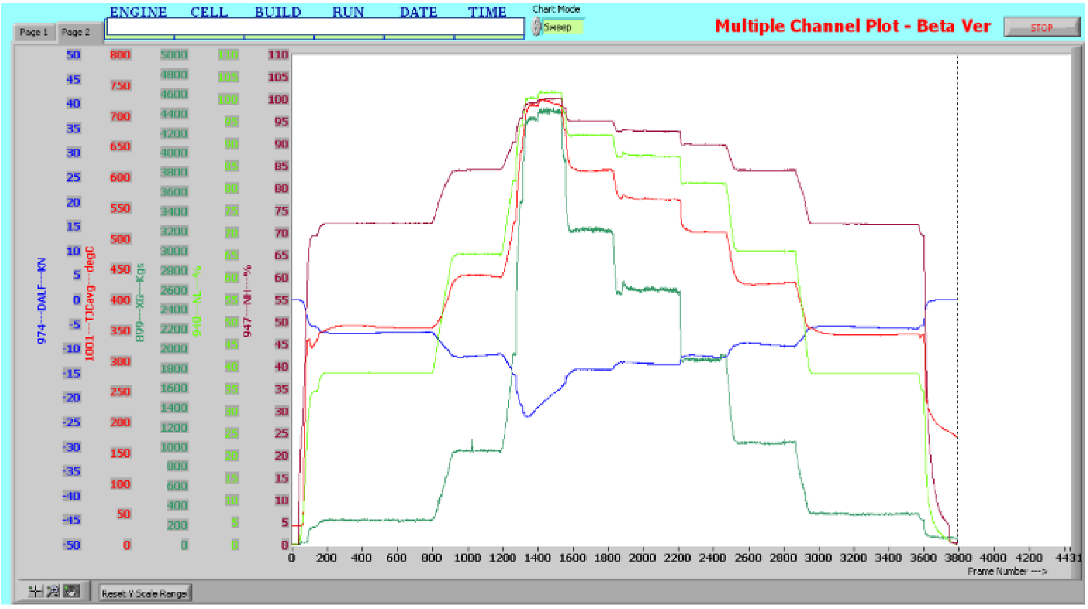

Figure 5. Engine Performance Display Module

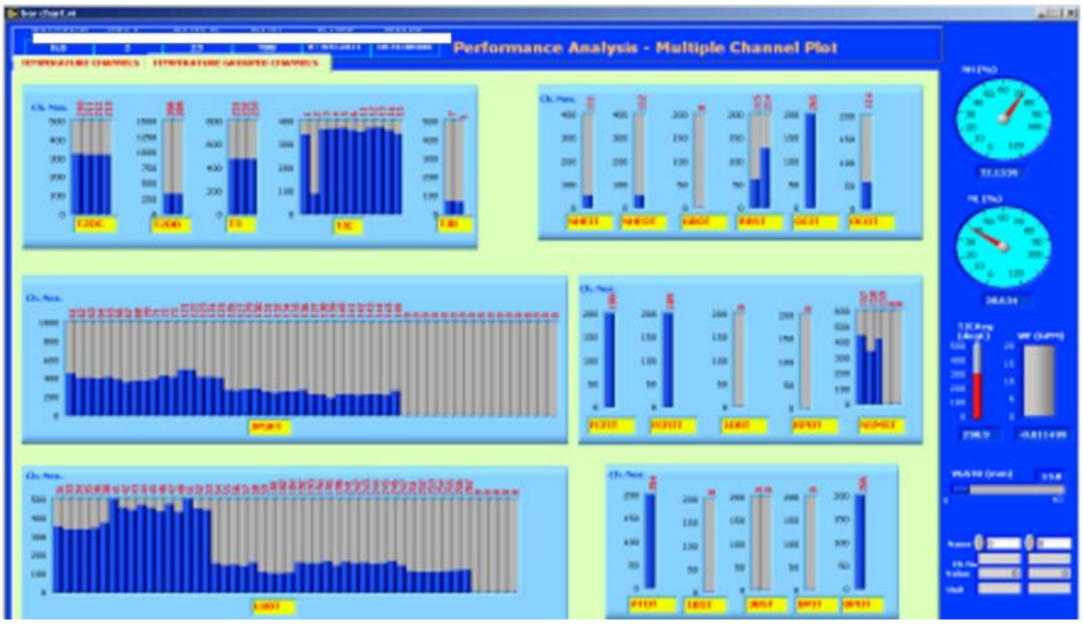

Figure 6. Channels overview display module

Calibration Module

A calibration module is developed which handles the entire calibration related activities of the DAS system. Refer figure 7 The sensor details, calibration coefficients, date of calibration, due date for the next calibration are fields of this VI. Interactive editable user displays are developed for easy and fast updation of the field entries. The calculation of the calibration coefficients are automated so as to avoid any erroneous manual entries. It provides the facility to select the channel number, unit, facility for either n-point-data-set for coefficient computation or look up table creation and create report for record of changes in coefficients

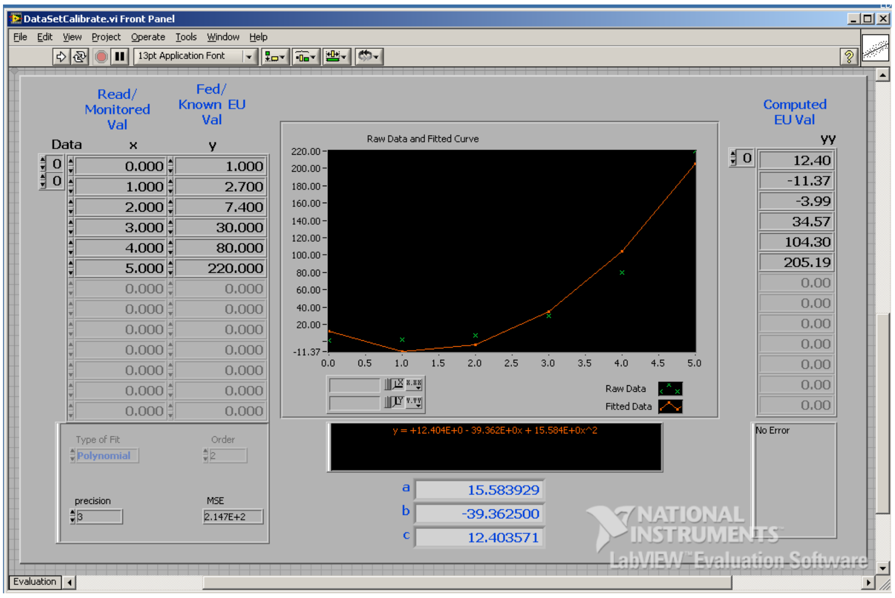

Figure 7. Calibration Module

Conclusion

A state of the art Data acquisition system has been configured for a very high channel count instrumentation requirement for a Aero Gas turbine engine. This system has been installed and successfully has been providing a consistent reliable data. Various online performance calculations have been incorporated which facilitates in easy and crucial decision making. Online client displays have also been configured for simultaneous analysis by various system specialists.

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A New Shape Generation Framework Based on Machine Learning and Topology Optimization

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Abstract: Lately, an algorithmic tool, known as Generative Design, that supports products' design has been introduced in several industries with manufacturing procedures. Generative Design can be described as the technology that focuses on the generation of plethora of designs that all respect designer-set criteria such as loading conditions, support conditions, etc. Due to this feature, generative design can be used as an intuition creating tool that actually suggests several rough prototypes to the designer who can use them as inspiration for the final prototype. In this work, a novel shape generation framework based on topology optimization, machine learning and image editing is proposed, aiming at performing generative design in architectural design. In detail, the proposed framework constitutes a combination of Solid Isotropic Material with Penalization (SIMP) (Bendsøe, 1989), Long Short-Term Memory networks (LSTM) (Hochreiter & Schmidhuber, 1997) and various image filters. SIMP is used for optimizing the shape according to the designer's criteria and constraints while LSTMs and image filtering are used for shape differentiation and process acceleration. The proposed framework is tested over a number of topology optimization problems used as benchmark tests in modern literature.

Keywords: Generative design, Topology optimization, Machine learning, Solid isotropic material with penalization, Long short-term memory networks

Introduction

In the past few years, new construction and manufacturing methods have been introduced mainly due to 3D printing advances in methods, cost and materials handled. At the same time, artificial intelligence has gained significant attention and significant breakthroughs have been made in several sciences. The construction industry, although being an industry that is resilient to differentiations, has been experimenting with new methods both in design and in construction methods for quite some time. Computer-aided procedures are becoming more and more involved in the everyday practices of the industry. One of the newly introduced practices is generative design (Attar et al, 2009, Pedro & Kobayashi, 2011) which in a few words, can be

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described as the automated algorithmic process of producing a large number of different prototypes of a specific structure that all satisfy constraints and targets defined by the designer. These prototypes can either be used as is or be used as inspiration for the designer. In the past, artificial design was introduced mainly through nature inspired algorithms (Lindenmayer, 1975; Meinhardt, 1976) while several methodologies applied in architectural design have been proposed (Von Neumann, 1951; Wolfram, 2002; Stiny, 1980).

This work proposes a novel framework for generative design that is based on combining time-series classification, topology optimization and image filtering. Topology optimization is used for initializing the shape and fine-tuning the various proposed shapes. Machine learning-based time-series classification is used for accelerating the procedure while creating intuition from previous applications. Image filtering imposes shape differentiation in addition to the outputs of the machine learning process. It can be witnessed in this work that by combining the above, a very successful shape generation framework is created. The performance of the proposed framework is validated through results obtained by applying it to a number of topology optimization benchmarking tests frequently used in up-to-date literature.

Shape Generation Framework

The framework presented in this work is a combination of SIMP method, LSTM networks and image filtering techniques. SIMP is used twice. The first use focuses on performing topology optimization under user-defined criteria on an initial domain. The second use is for performing topology optimization on topologies proposed by LSTMs and image filtering techniques.

Framework formulation

The proposed methodology is based on an iterative combination of SIMP, LSTMs and image filtering. In order to apply the framework, the number of meshes used, the parameters of topology optimization and the number of image filters to be used need to be defined by the user. The parameters of topology optimization and SIMP are the number of finite elements per axis, the loading and support conditions, the volume target and the filtering size and type. If all of the above are defined, the shape generation can be performed.

At first, SIMP executes 20 iterations for each of the J meshes defined by the user. For each finite element a record is kept of the density value per iteration along with the density of the 24 elements that are closer to that one. As a result, an input of twenty-time steps of twenty-five densities per finite element is created. This serves as an input for the bidirectional LSTM that is used in this framework. The LSTM then predicts a topology that is close to a final, optimized topology per finite element. For each of the LSTM proposed topologies, a series of K image filters are applied and a result of $J \times K$ different topologies are produced. Finally, SIMP is applied on each of the proposed topologies as a fine-tuning step for the proposed topologies. In the current work, the final SIMP application involved twenty operations of SIMP. In Figure 1, a flowchart of the proposed formulation is presented.

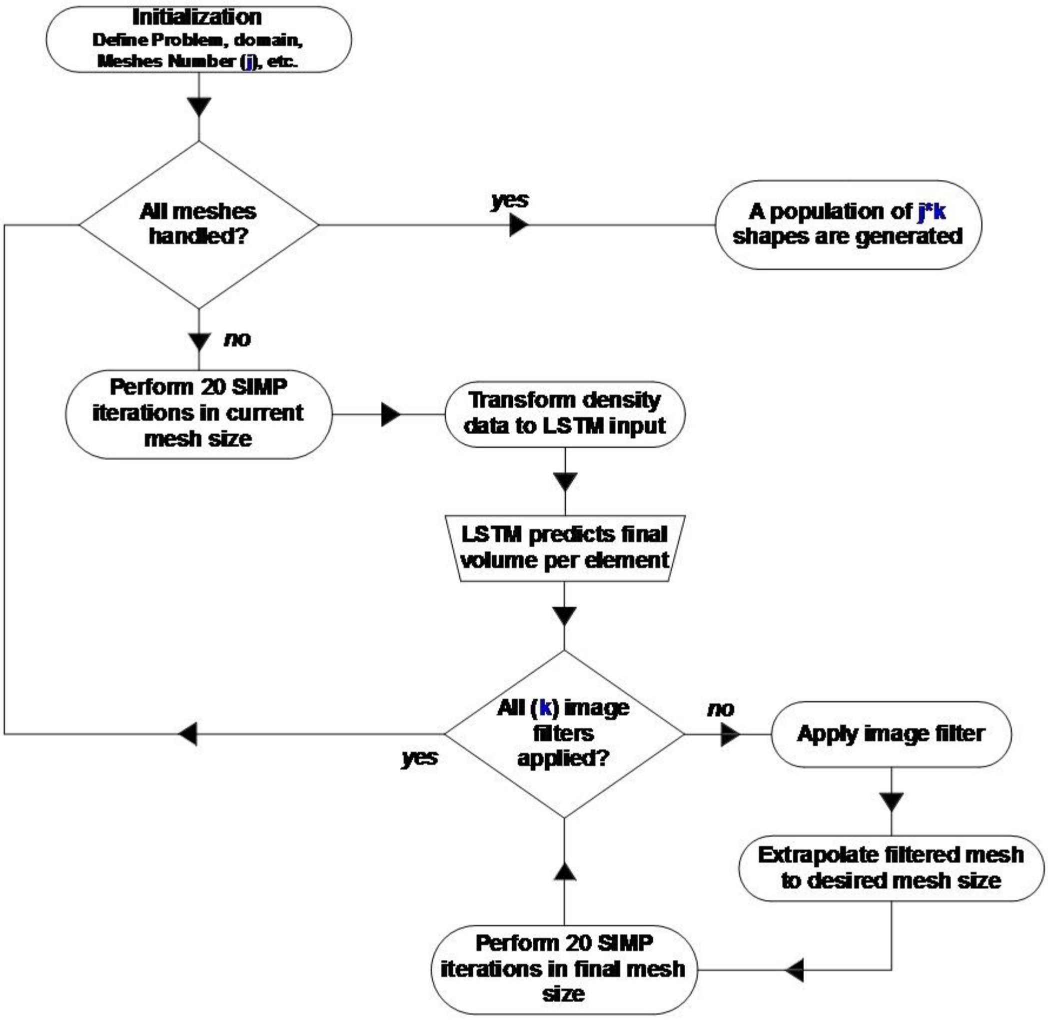

Figure 1. Flowchart of the Proposed Framework

LSTM Architecture and Training

In the current work, an LTSM network is used for classifying the density time-series of finite elements as per their final value. LSTMs have been used successfully in several time-series classification problems. LSTMs are a variation of Recurrent neural networks (RNNs) (Rumelhart et al, 1985) that were introduced in order to deal with the vanishing and/or exploding gradient problem that often occurred in RNN usages. The network used here is a bidirectional LSTM as seen in Figure 2.

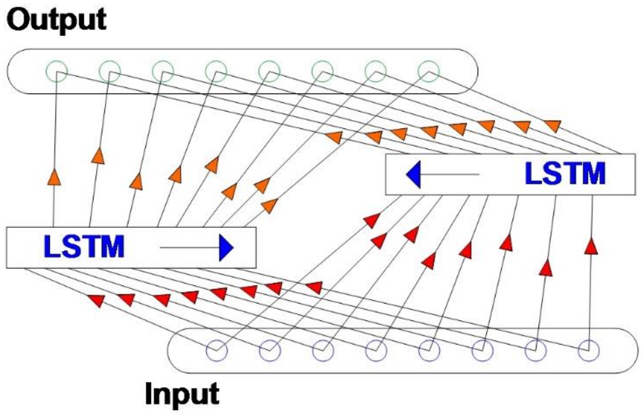

Figure 2. Bidirectional LSTM

The network used in this work consists of five layers as presented in Figure 2. The first one is the density time-series input layer. The second one is the bidirectional LSTM and the third one is a fully connected layer. The fourth one is a *softmax* layer and the final one is the classification output layer.

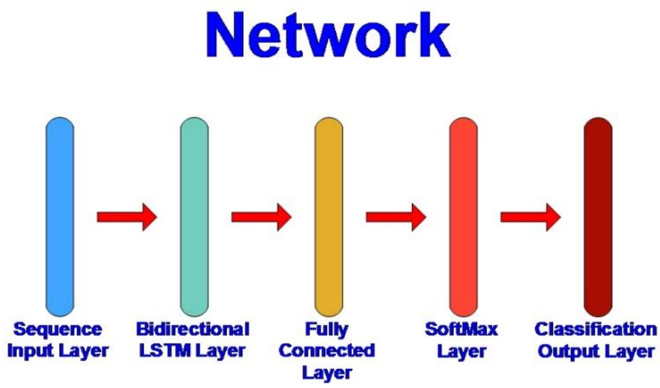

Figure 3. Bidirectional LSTM

The network is used for predicting the final density $d_{i,T}$ of a finite element after SIMP has converged, based solely on the density value of that element and neighboring elements in the first twenty iterations of SIMP, as seen bellow.

$$\begin{bmatrix} d_{1,1} & d_{1,2} & \cdot & \cdot & d_{1,t} & d_{1,t+1} & \cdot & \cdot & d_{1,T-1} & d_{1,T} \\ d_{2,1} & d_{2,2} & \cdot & \cdot & d_{2,t} & d_{2,t+1} & \cdot & \cdot & d_{2,T-1} & d_{2,T} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ d_{ne-1,1} & d_{ne-1,2} & \cdot & \cdot & d_{ne-1,t} & d_{ne-1,t+1} & \cdot & \cdot & d_{ne-1,T-1} & d_{ne-1,T} \\ d_{ne,1} & d_{ne,2} & \cdot & \cdot & d_{ne,t} & d_{ne,t+1} & \cdot & \cdot & d_{ne,T-1} & d_{ne,T} \end{bmatrix}$$

$$\underbrace{\qquad\qquad\qquad}_{\text{Training Input}} \quad \underbrace{\qquad\qquad\qquad}_{\text{Not used}} \quad \underbrace{\quad}_{\text{Target}}$$

In detail, the formulation of the LSTM goal can be described as follows:

$$\underbrace{\begin{matrix} [D_{1,1} & D_{1,2} & \dots & D_{1,t}] \\ [D_{2,1} & D_{2,2} & \dots & D_{2,t}] \\ . & . & \dots & . \\ . & . & \dots & . \\ [D_{ne-1,1} & D_{ne-1,2} & \dots & D_{ne-1,t}] \\ [D_{ne,1} & D_{ne,2} & \dots & D_{ne,t}] \end{matrix}}_{\text{Input}} \quad \underbrace{\begin{matrix} \rightarrow \\ \rightarrow \\ . \\ . \\ \rightarrow \\ \rightarrow \end{matrix}}_{\text{LSTM}} \quad \underbrace{\begin{matrix} d_{1,T} \\ d_{2,T} \\ . \\ . \\ d_{ne-1,T} \\ d_{ne,T} \end{matrix}}_{\text{Output Target}}$$

$$where\ D_{i,j} = \begin{bmatrix} d_{k-2,l-2} \\ d_{k-2,l-1} \\ . \\ . \\ d_{k,l} \\ . \\ . \\ d_{k+2,l+1} \\ d_{k+2,l+2} \end{bmatrix}$$

In the above expressions, $d_{k,l}$ represents the density of the element in the k^{th} row and l^{th} column in the mesh. In order for the LSTM to be able to succeed in the classification, a training must be performed once. In the current work, another example was used for creating several density time-series. The example used can be seen in Figure 4. Seven different meshes were created, resulting to 145,000 finite element density time-series. The final densities were divided in 3 separate classes as seen bellow:

$$d_{i,T} \in \begin{cases} [0,0.1] \Rightarrow d_{i,T} = 0 \\ (0.1,0.9) \Rightarrow d_{i,T} = 0.50 \\ [0.9,1] \Rightarrow d_{i,T} = 1 \end{cases}$$

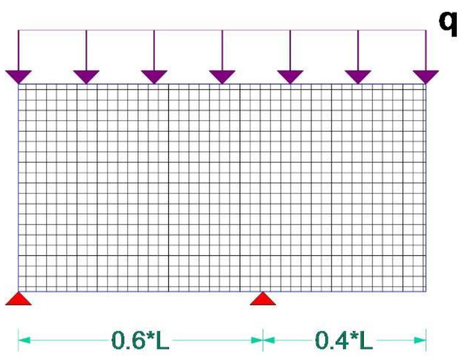

Figure 4. Training example

In the training example, the target volume was equal to 40%, the support conditions are two simple supports on the bottom of the x axis while the loading conditions can be described as a distributed load on the top of the domain along the x axis.

Results

In order to evaluate the performance of the proposed framework, three examples of topology optimization that are often used in up-to-date literature are selected. Each example is handled by the proposed generative design framework and a population of 50 different shapes is created. In all the examples presented here, seven different mesh FE populations are used [1,000, 5,000, 7,000, 10,000, 20,000, 25,000, 75,000]. The description of each example is as follows. It is worth pointing out that no symmetry is imposed in any of the test examples used.

Test Example A

In Test example A, the volume fraction is equal to 40% while the length in the x axis is equal to L, and the height (y axis) is equal to $0.5 \cdot L$ as it can be seen in Figure 5. The loading conditions are 4 concentrated forces distanced at L/3 while the support conditions can be described as fully fixed boundary conditions of a length equal to $0.25 \cdot L$ at the middle of the x axis.

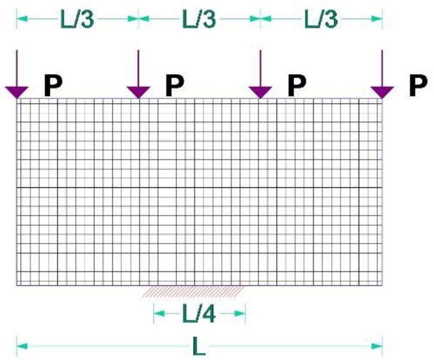

Figure 5. Test Example A

In Figure 8, the results of the proposed framework with respect to this test example are presented.

Test Example B

In Test example B, the volume fraction is equal to 30% while the length in the x axis is equal to L, and the height (y axis) is equal to $0.5 \cdot L$ as it can be seen in Figure 6. The loading conditions involve one concentrated force at the middle of the right end of the domain while the support conditions can be described as fully fixed boundary conditions of a length equal to $0.5 \cdot L$ at the top left part of the x axis.

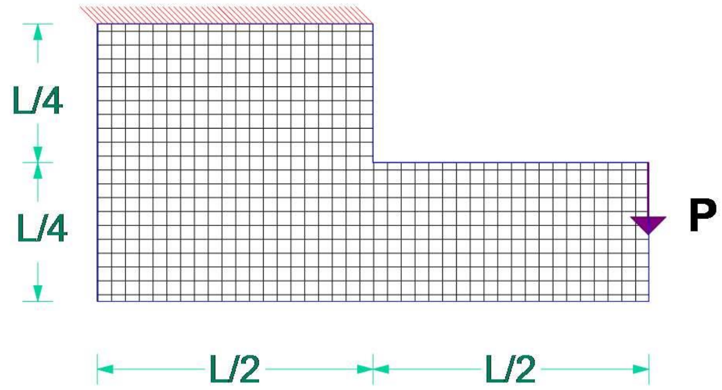

Figure 6. Test Example B

In Figure 9, the results of the proposed framework with respect to this test example are presented.

Test Example C

In Test example C, the volume fraction is equal to 20% while the length in the x axis is equal to L, and the height (y axis) is equal to $0.5 \cdot L$ as it can be seen in Figure 7. The loading conditions involve a distributed load along the x axis at the upper part while the support conditions can be described as five simple supports along the x axis at the bottom of the domain with the distance between each support being equal to $L/6$.

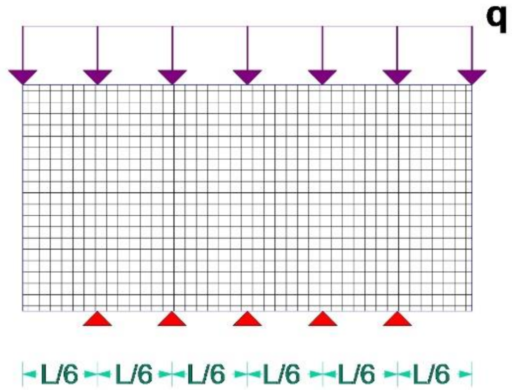

Figure 7. Test Example C

In Figure 10, the results of the proposed framework with respect to this test example are presented.

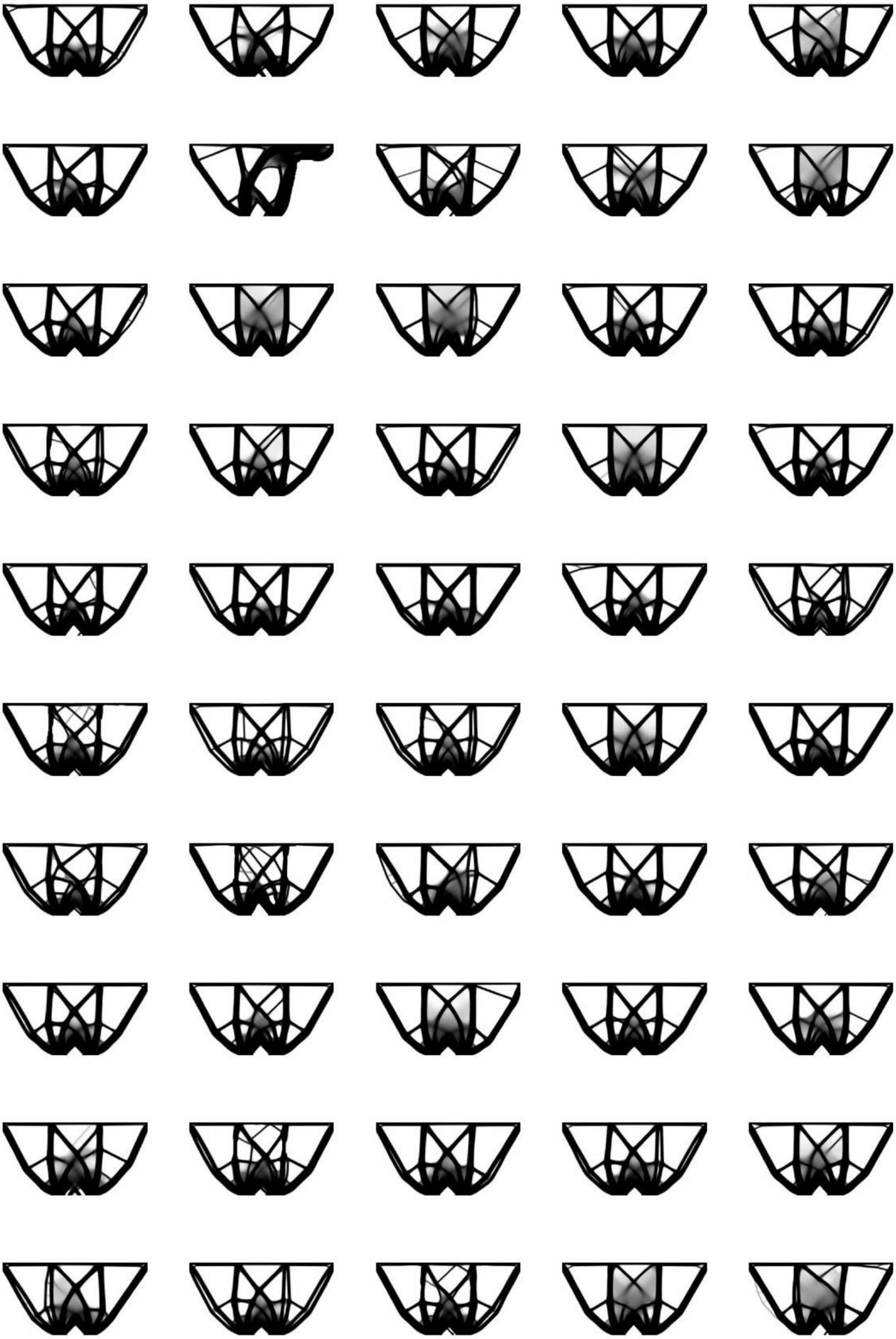

Figure 8. All 50 Generated Shapes for Test Example A

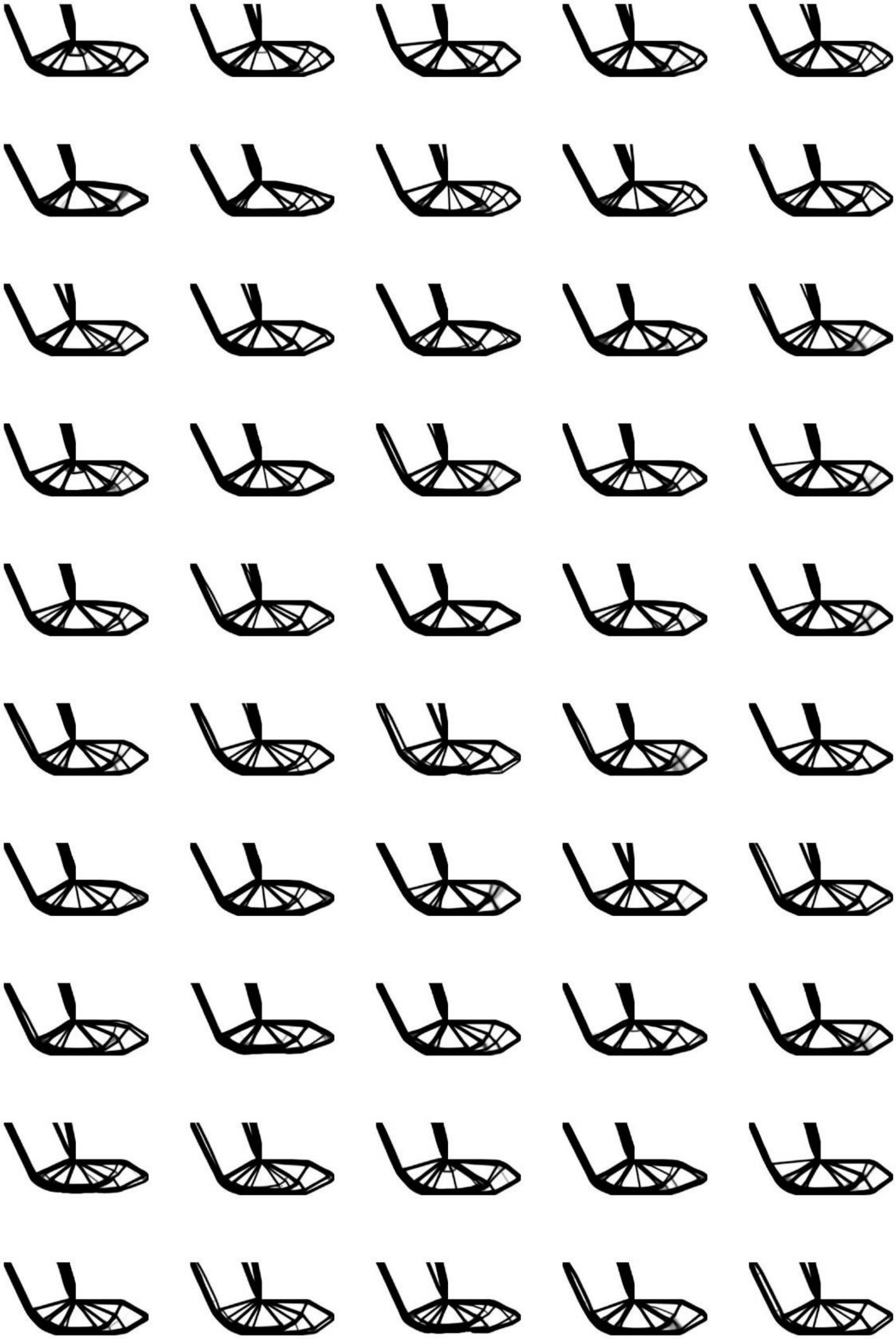

Figure 9. All 50 Generated Shapes for Test Example B

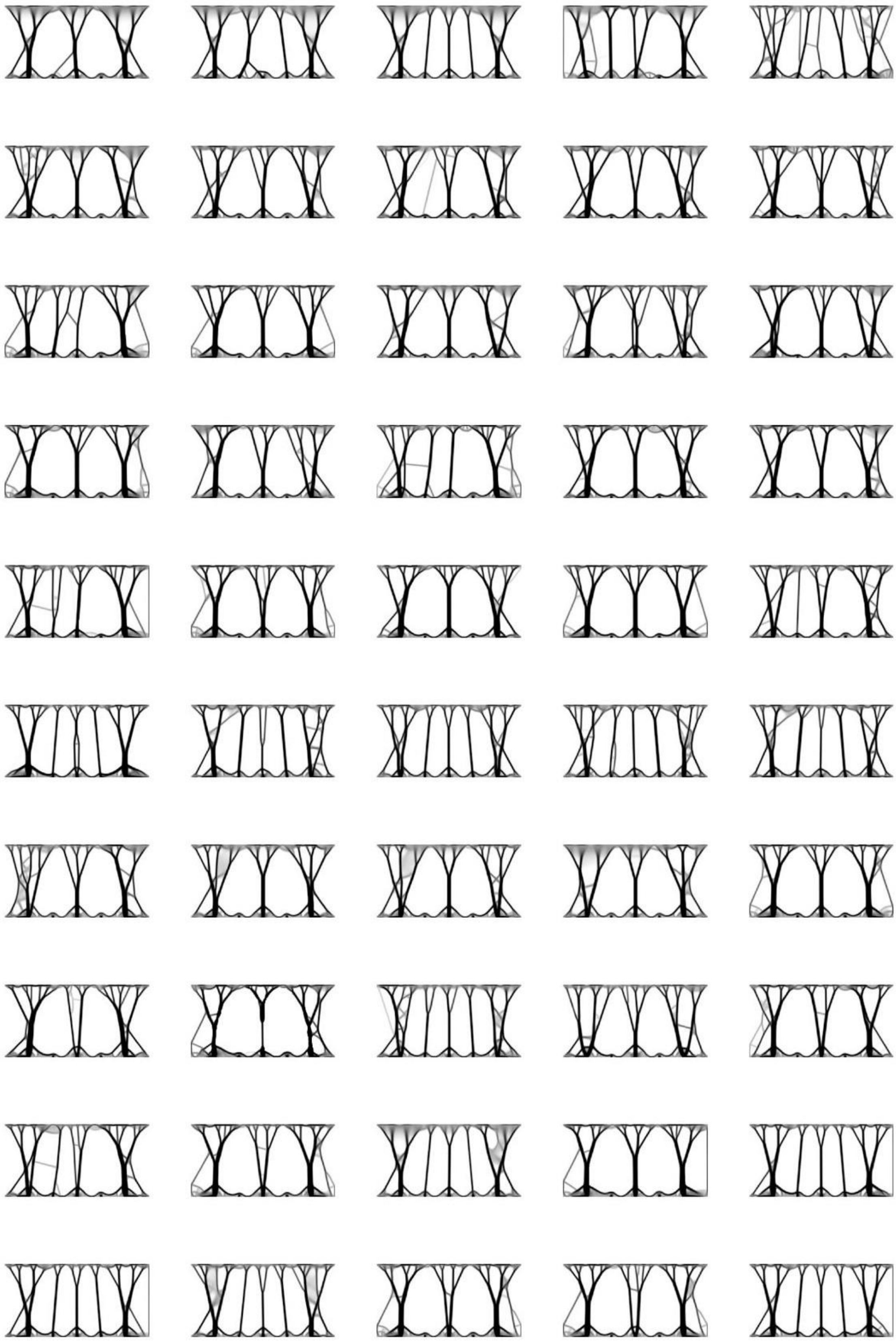

Figure 10. All 50 Generated Shapes for Test Example C

As it can be witnessed in the result presented previously, the proposed formulation has the ability to generate a large number of models regardless of loading conditions, support conditions and volume fraction.

Conclusion

The results of the proposed framework as displayed previously, clearly show that it is capable of providing a large number of preliminary designs that satisfy design criteria and can work as prototypes on which the designer can work. It can be witnessed that the proposed framework has the ability to handle any shape generation problem regardless of the parameters of the problem. The current framework could be further improved in order to efficiently handle 3D topology optimization problems and export results in a format that can be handled by 3D printers.

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Minors Would Be Safe Browsing of Internet through Intelligent Systems

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Abstract: The boom in mobile technology has created conditions where any type of information on internet is easily accessible to users, including minors, whose intuitive ability is surprising in daily use of cell phones and tablets to find diversity of topics. It is feasible, without proper supervision by parents, it can bring unfavorable situations for everyone, particularly children. This research has as a main objective the use of AI algorithms, as an alternative to identify, without human intervention in real time, some cyber threats that put the emotional and physical cyber-security of children at risk when browsing internet. After a systematical review of technical literature, some algorithms have been evaluated and implemented as a software application for analysis and reduction of texts extracted from Web pages (urls) that minor could access, to determine whether the associated texts are positive or negative, through sentiment analysis. Additionally, with classification techniques and neural network models, that application has been improved to predict of categories for extracted texts (without human intervention) that result in blocking parameters for these unwanted url, for not been suitable in its content for minor. As conclusion, an AI software have been implemented and tested for automatically-block of identified unsuitable domains.

Keywords: Artificial intelligence, Children / Minors, Cyber-security, Internet, Neuronal networks

Introduction

The risks most frequently in educational centers for the area of internet security are virtual threats and theft of personal information (González, 2020). According to statistics, 25% of children have a public profile, where they can expose their name, intimate messages, and, some of their personal photographs (DIDE, 2019). The development of intelligent software applications that suggest and transmit knowledge to children, requires determining information patterns to meet their interests and needs. It is important to be able to filter access to internet pages that contain information not suitable for them, such as: grooming (pedophile deception) or sexual abuse, where children can be exposed to uncomfortable situations, teasing and harassment, causing them irreparable psychosocial damage, which can even end in suicide (OMS, 2020). It is difficult for parents /

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mentors to monitor what children surf the Internet all the time. Taking this scenario into account, the present research aims to: develop and implement a first version of an intelligent system that allows identifying information patterns with content considered unsuitable for children's mental health when browsing the Internet, based on artificial intelligence resources.

The following are established as the specific objectives of this research:

- Review the literature related to AI mechanisms to obtain information from web pages (urls), which allow the analysis and identification of the content or meaning of the texts found.
- Implement AI algorithms, which classify the texts found into specific categories, in such a way that could blocking parameters or give access to the urls that the minor intends to access.
- Develop machine learning algorithms that allow, in graphic form, to visualize the results found in the analysis of texts.
- Implement filtering and / or blocking mechanisms for pages (url) classified as risk, to limit access for minors.

Theoretical Framework

Healthy childhood: Positive and Ethical Behaviors.

In (Vazquez, 2012), positive and ethical behaviors towards children are considered, the next ones: the resolution of conflicts in a peaceful and empathetic way, affective, and respectful communication, capacity for acceptance, self-esteem and self-control; recognition and management of emotions, good treatment towards others, solidarity, promoting well-being, and guaranteeing a good quality of life. It is imperative that minors understand the risks that exist on the internet and know how to act in adverse situations, for this, the importance of the support and supervision of parents, guardians, and teachers to protect them (Oden, 2019). (UNICEF, s.f.) conclude the need to make a collective effort to create and strengthen laws and policies that ensure the integrity of the minor. Likewise, (Anderson, 2018) and (Inmaculada, 2018) describe the need to instill in children the use of technology and its advances, in an ethical and responsible manner.

Mechanisms to Determine Criteria for Secure Access to Contents

The Internet programs and social networks most used by girls and boys have use policies for a healthy coexistence: (YouTube, s.f.), (Google, s.f.), (WhatsApp, s.f.), (Facebook, s.f.). These applications have parental control tools (Digital, 2018) that help parents and guardians of minors to manually delimit (configure), pages or information to children (they limit inappropriate content, time spent on the Internet, monitoring of the child's browsing in the network), but most of the time, the detection of web pages -urls- inappropriate for the minor, happens once the access has been made. The proposed intelligent system, in this area, would take a cognitive approach, that is, according to the grouping ("frequencies of uses") of "words" tokens and contextual evaluation, the neural network would be conforming to the child's preferences, as long as it complies with the "established rules" for safe Internet browsing, reducing the availability of harmful material from the internet and their access to it. Likewise, in (Sánchez, 2018) it stands out as intolerant behaviors the next ones: violence, manipulation, consumerism, abuse, hedonism, triumphalism, utilitarianism. The studies (Lopez, 2020), (Zwilling, 2019) also coincide in the creation of educational programs that allow students to strengthen civic awareness to eradicate behaviors of violence and intolerance towards people, facilitating their educational integration and social one.

Regulations / Associated Laws

(T. Lange, 2019) Emphasizes that security problems in social networks arise from the privacy of information, when the conditions of use are not fully known, or if users are registered in applications such as Facebook, WhatsApp, and others, with a false identity; generate violations of good practices pursued by this type of application. Ethics has been an important factor in the design, implementation and use of social networks and AI as mentioned in (Taddeo, 2018) where projects have implemented regulations to define and explain when and how an AI system can make decisions and what would be their impact. (Finnemore, 2016) describes elements of a Cybersecurity standard to define the behavior, properties, and collective expectations that Internet programs must cover and under which standards they must be governed.

Existing Resources to Identify Contents

In the area of Cybersecurity, (Dilek, 2015) mentions how AI has been participating, through the implementation of artificial neural networks (ANN), intelligent agents, intrusion detection, and prevention systems (IDPS), artificial immune system (AISs). In (Leenen, 2019) semantic technology is mentioned to derive the meaning of information. The challenge would be for “smart” programs to be able to understand the meaning of what they are reading, to be able to transmit it, teach it or identify its content. In the present research and development of the intelligent system, algorithms, and Python libraries (Rojas, 2020) focused on the area of AI for text recognition (PLN) were analyzed. To understand and evaluate the use of neural network models, some "corpus" already trained, freely accessible, are studied; related to genres of violence, sex, conversations with drug topics and others that are not specific to minors, to detect "tokens", "bigrams", "analogies", and "phrases" that allow to determine candidates for blocking pages Web. In the same sense, the Kaggle platform (Kaggle, s.f.) contains datasets trained in the area of linguistics for text treatment and classification, based on labels (id) and category definition corresponding to each identifier, examples, the dataset: topical_chat.csv (Alexa, s.f.) (created by Amazon, contains around 8,000 conversations and 184,000 messages, the main classification of which is determined by feelings of anger, fear, happiness, sadness, and surprise). Kaggle's dataset df2_4_model.csv (Sanker, s.f.) contains small texts that report bullying attitudes and texts of stories with positive attitudes. Sorting large volumes of information in a matter of minutes, even seconds, is a primary and highly desirable feature of AI in intelligent systems.

Important tools within the PLN (Talamé, 2019) are those that refer to the processes of tokenization, normalization (stemming and lemmatization), identification of stopwords (data cleaning), parsing to see the relationship of words, phrases, and sentences that determine the meaning of the texts, identification of the grammatical structure of the texts (separation of nouns, verbs, adverbs, adjectives, entities) and those that allow debugging or eliminating unimportant tokens within the texts, that is, words or characters that do not imply a meaning within the context.

Sentiment analysis is one of the most used techniques in AI to be able to identify positive or negative emotions in texts (Fadili, s.f.). However, it is possible to classify a text in certain categories, through tools such as: "word bags" techniques, resulting in the frequency of occurrence of each word in the text, that is, through vectors or arrangements, each position implies the number of times each word exists within the text (CountVectorizer), or how important each word is within the text (TF-IDF), (Akere, 2019), this algorithm provides a numerical representation of each word, according to its importance within the text, it can be used as data source for training and validation of a neural network model.

State of Art

AI has made important advances in task automation. Table 1 highlights those that involve text comprehension, aimed at education and elaboration of tasks “without human intervention”, sentiment analysis, where platforms such as Facebook, Amazon and Twitter have entered.

Table 1. AI Implementations Involved in Safety and Education of Minors

Intelligent System	Reference	Description
SafeChat	(K MacFarlane, 2016)	Use of Ontology for Semantic Web (OWL) through intelligent agents that filter web pages
Smart Tutorial System	(A. Almasri, 2019)	Its purpose is to generate knowledge without human intervention
Chatbot	(Microsoft, s.f.), (Amazon, s.f.)	They work on the basis of voice and text recognition, through PLN, characterized by their machine learning, conversations are carried out without human intervention. Example: LTKA-Bot
Scarlet	(G. Terzopoulos, 2019)	It works using PLN, data analysis and ML. Requires use of the cloud and "smart speakers"

Methodology and Materials

This research is, on the one hand, exploratory in nature, supported by technical literature related to the moral and social impact that the use of the internet and social networks has on boys and girls. On the other hand, at the engineering level, methodological work has been carried out on the review of the literature on AI tools that allow conceiving, designing, and generating a technical solution to the research problem.

Prototype Implementation with Open-Source Tools

Three main processes are visualized for the Intelligent System to be implemented:

a) Analysis of URLS to obtain their texts, including voice recognition
b) Creation and Training of Neural Network working with historical data
c) Prediction of the Meaning of texts through the Neural network, defining rules to block pages

The functionalities of the intended intelligent system, at the level of design, programming, and testing, as an experimental prototype of the same to achieve self-managed text processing, have been developed in Python in the Anaconda-Spyder IDE. The associated classes / objects to support the three previous processes identified (a, b, and c) are listed in Table 2.

Table 2. Previous Definition of Classes for the Design of the Intelligent System

Class in Python	Functionality
Scrap_URL. get data for neural network (*process a*)	*Extract text from URL's* that the minor access. Remove_Stop_words, punctuation characters, special characters, HTML. Remove empty data.
Prepare_Text. Prepare data for model (*process b*)	*D*ivision of text into paragraphs, sentences and words, through Python tools for tokenize, stemming, lemmatize, vectorize and TF-IDF.
Prepare_Params_Block. Manual (*process b*)	Creation of lists of adjectives and verbs with specific categories to determine blocking based on occurrence. In this phase of the process, existing datasets were analyzed (Kaggle, Amazon), related to topics that are not according to the age of minors. Therefore, the use of MATLAB and Microsoft ai services were of great help to determine this list.
Model_PLN (*process c*)	*Analyze meaning of texts in phrases or words. To do this, vectorize, classify, create and train a Model.* In this step of the process, the use of AI classification algorithms, allowed to delimit some domains not proper for minors. Likewise, through the sentimental analysis, using concepts of polarity and subjectivity, it was possible to identify adjectives and verbs, both negative and positive, to obtain their number of occurrences within the text, analyzing both words and phrases, taking into account their grammatical structure. Some models used are: Gensim, Sklearn, Word2vec, Nltk.
Graph_Result_Model (*process c*)	*Generate metric plots with matplotlib, seaborn to analyze the accuracy of the model, using Python libraries for word-cloud, confusion matriz and ROC.*

Results

The importance of having included voice detection to extract the texts is that search engines (such as Google) already implement voice searches. The first results of the analysis of trained datasets, allowed to identify categories of words of positive and negative, that delimit the possible blocking of URLs, in the same way, they allowed to understand how to measure the model evaluation, since the texts of all the urls, to have a greater volume of real data. In Figure 1, a graph generated by the intelligent system is observed, with the words (points close to) the word "death" of the query made. These tokens show that the content is not related to being a negative behavior, but rather that it was an event of nature that caused some collapses and perhaps deaths.

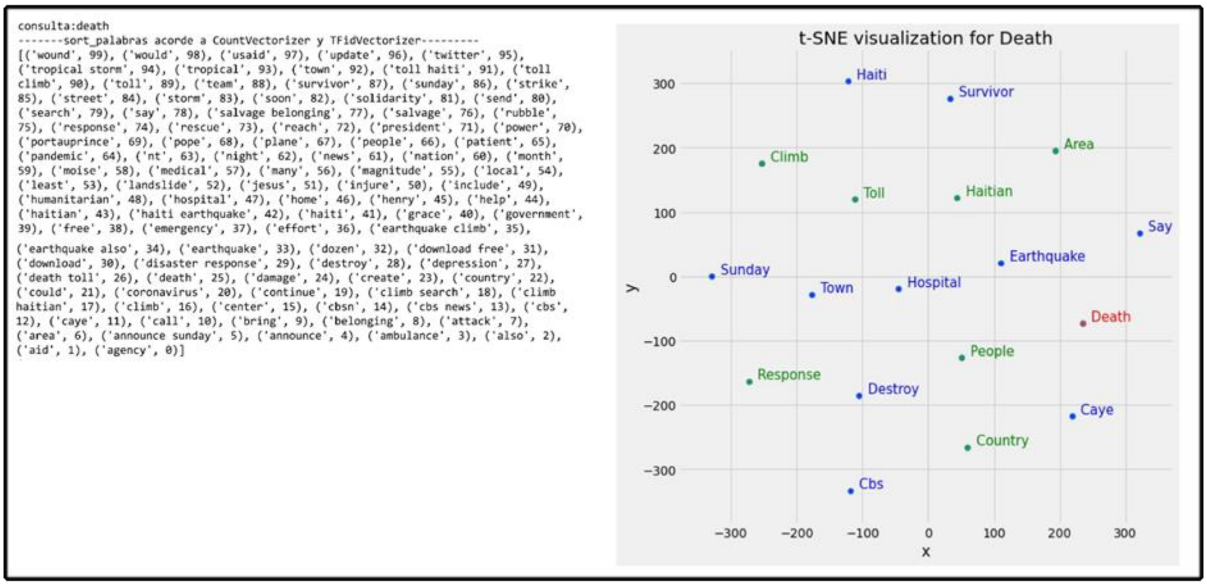

Figure 1. Smart System Output Graphics in URL's analysis

The AI neural network models allow, through a correct interpretation of their results, to be able to differentiate a page that can be educational in nature and therefore beneficial for the minor, without forgetting the accompaniment of their parents and guardians, that is why care must be taken in combining the variants that finally determine if the url is blocked. As an example, we can see figure 2, with the topic of suicide, with tokens related to education on suicide prevention, therefore the page should not be blocked.

In figure 3, can see some results obtained from the neural network model, with domains and tokens classified as negative, for having content not suitable for minors.

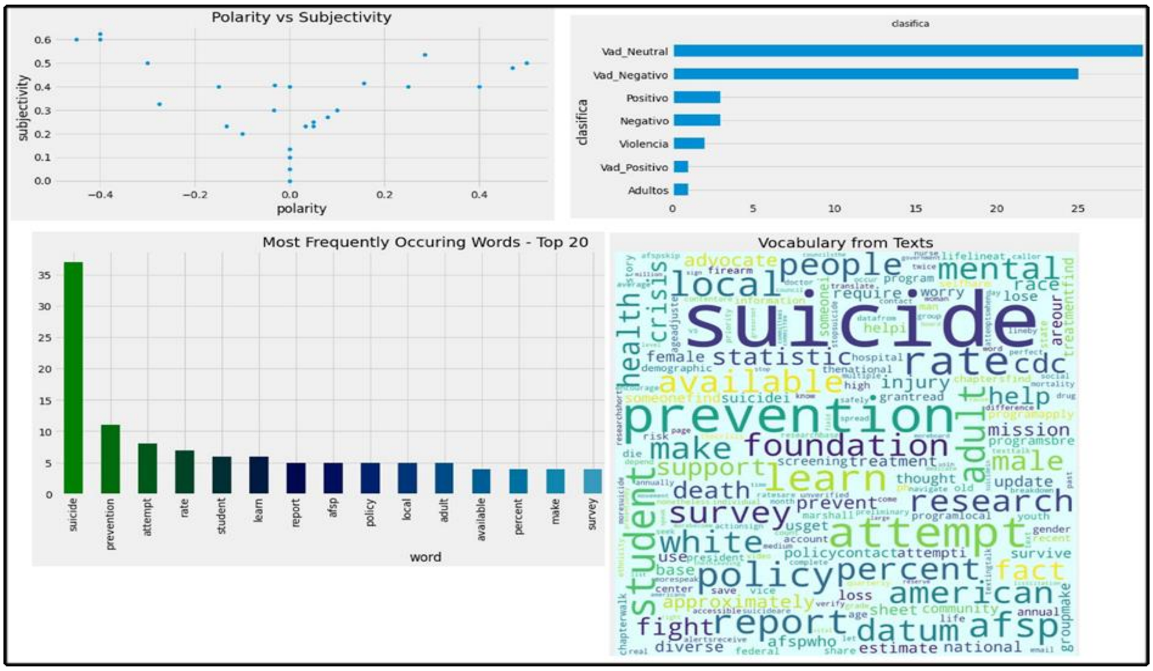

Figure 2. Graphs Related to the Evaluation of the Model for Topic: Suicide

	A
18	www.ohxxx.net
19	rolotube.com
20	farmhub.net
21	tubetria.mobi
22	xhamstervideo.info
23	eleggans.com
24	xchica.com
25	es.xhamster.com
26	fotonovelasxxx.com
27	sexo8.com
28	es.gamcore.com
29	libfx.com
30	www.gumtree.co.za
31	www5.javmost.com
32	chaturbate.com
33	www.elindependiente.com
34	www.elconfidencial.com
35	www.redwap2.com
36	
37	
38	
39	
40	
41	

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	A	B
1	Token	Clasify
2	chivolitas	Adults
3	sexo9	Adults
4	having-sex	Adults
5	xnxx	Adults
6	redwap	Adults
7	sexo-9	Adults
8	porn	Adults
9	sexmovies	Adults
10	aliexpress	Adults
11	love_sex	Adults
12	xvideos	Adults
13	dirty	Adults
14	wap	Adults
15	anal	Adults
16	sexual	Adults
17	histories-sex	Adults
18	tags/sex	Adults
19	tag/sex	Adults
20	free/sex	Adults
21	sex-video	Adults
22	ninfomana	Adults
23	erotico	Adults
24	ileg	Adults
25	liberacion-sin-regl	Adults

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Figure 3. Domains and Tokens Classified as Negative, for Having Content not Suitable for Minors

Conclusion

In this first phase of the research, it is possible to identify AI algorithms that allow word processing to obtain a reliable source of data as input to the neural network model. An Intelligent System prototype was implemented and tested, for the automatic blocking of domains not appropriate for the minor, whose information will serve as a pattern for future predictions, thus reducing response time to the minor, as the analysis of these URL's classified as negatives, are not necessary again. Good classification results are observed to conceptualize the category of texts, with sentiment analysis, identifying phrases or words such as: positive, negative and neutral, the latter being of great importance in order not to determine a blockage when the topics could be negative in nature, but they do not imply risk for the minor, on the contrary, they allow giving a reflective education for the minor, as long as he learns how to act in risky situations. On the other hand, the category of elements determined by their theme: violence, drugs, bullying and adults, was obtained with AI classification algorithms, increasing the vocabulary used to block pages, depending on the number of occurrences within the text. The use of similar, dissimilar, synonymous and antonym word implementations was helpful for this purpose.

The level of precision of neural networks could depend on the amount of data available, the higher the volume, the better the training process of the models involved. Future activities for this research will be focused on generating new datasets, whose content corresponds to the age range of minors, in order to identify their preferences and predict actions that put the minor at risk. Implement the final interface for mobile devices such as cell phones and tablets, which allow the use of intelligent software in Internet browsing performed by minors on these devices.

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Work-Based Experiences for School Pupils in Universities

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Abstract: Because of many scientific issues, that are pervading our everyday lives while being open research fields and, therefore, rarely touched in secondary schools, education systems worldwide are challenged to a closer and synergic connection with scientific research, which however is still remarkably lacking. While researchers' involvement in education and public outreach is still largely insufficient, misconceptions and oversimplification in science education and communication are a major issue. This work examines how experiences of work-based learning for secondary school pupils in universities can establish more structural connections, that might help in building mutual trust and in making science education more responsive to current scientific and technological challenges

Keywords: Public engagement with science, Science education, Physics education, Outreach

Introduction

The need for an effective communication between scientific research and society, both to correctly inform the public about scientific issues of urgent societal relevance and to improve the way scientific research is conducted [1]. [2]. , is widely known to the broadest community of physicist, and the sad times we are living in make it even clearer. However, the dialogue between science and society still presents too many difficulties and criticalities, because of mutual mistrust, misconceptions and oversimplification, which are currently a widespread problem, often mirrored in science teaching in schools [3]. .

An increasing number of initiatives aim to create connections between the world of scientific research and secondary school, both in schools and in laboratory environments created specifically for school pupils at universities or research centers [4]. [5]. . Work based learning, that is the learning occurring in a real work environment, has been practiced for centuries. In recent times, the term has been used to encompass all those activities aiming at improving technical and academic skills relevant in the labor market and at developing employability skills [6]. [7]. . In this sense, work-based learning in many countries is an integral part of secondary and higher education, as well as important in lifelong learning and continuing education. In secondary education, work-based learning is often integrated with school-based learning, aiming at combining the school (formal) education with non-formal, real-life learning experiences, which typically involve a partnership between a school and an organization/enterprise (the employer). These programs range from short

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term activities of career exploration with limited workplace exposure, such as job shadowing, work-place tours, guest speakers, to more extensive and substantive ones, such as internships and school-based enterprises, up to activities whose primary goal is the direct employment of the student, like apprenticeship.

In many countries, these experiences are introduced within national curricula in the vocational education and training systems, as systematic policies for creating a direct contact of schools and students with enterprises. In this context, the involvement of universities and research centers as employers is minimal. On the other side, many work based activities, such as research internship, shadowing and many other participatory activities which aim at ongoing learning and at supporting career choice, are commonly practiced in universities as parts of outreach programs towards schools [8]. [9]. and are of particular interest in our discussion.

Integration of Formal and Non-Formal Education

As mentioned, the context of work-based learning is generally that of integrating young people into the workforce and the involvement of universities, if any, is minimal. An interesting approach has been adopted in Italy, where work based learning (named piano per le competenze trasversali e l'orientamento - PCTO - plan for soft skills and guidance, formerly known as school-work alternation [10].) has been extended to the general education system ("Licei"), starting from school year 2015-2016. At the final regime reached in the 2017/2018 school year, all students (16-19-year-old) in the last three years of the secondary education cycle have a mandatory PCTO period. Initially, students had to perform a total 200 hours (for students in "Licei") or 400 hours (students in technical and vocational education). The duration has been then reduced to about 90 hours in three years, because of problems of sustainability.

Though initially not intended for this purpose, this policy intervention is having a significant effect on the interaction between schools and universities, with several thousands of students that perform every year their PCTO experience in universities [11]. , a fact that offers suggestions for a strategic reconsideration by policy makers, schools, academic and research institutions, as well as individual scientists and teachers, of the relationship between science education and scientific research. For example, our physics department started PCTO activities with two schools involving 40 students in the school year 2015/2016, while currently the number of schools increased to 10 and the number of pupils to more than 300 with more than 20 researchers involved, mostly graduate students and postdocs. These numbers are similar to those of our two PNLS programs in physics and materials science [12]. , meaning that PCTO is allowing for additional outreach programs, beyond those that are directly funded to the department. After an initial decrease at the beginning of the pandemic crisis, the numbers are again increasing thanks to techniques and technologies for distance teaching and learning, that do not have significant limitations in terms of number of participants than the usual laboratory activity.

Moreover, the duration of PCTO activities is about 30 hours per year, significantly larger than those of usual outreach activities in universities. This larger duration, similar to a regular science course in formal school, allows for a sustained interaction with students. Finally, the most important fact is the remarkable reversal of the relationship between schools and universities that PCTO is determining. While outreach programs are usually proposed by universities to schools, PCTO activities are requested by schools to universities, workplaces that for their own nature can involve a large number of students in activities that meet their interest, as most of them have at least a bachelor's degree in their near future.

Participatory Activities in Education and Public Outreach

Science outreach evolved in recent years from early processes of unidirectional knowledge-transfer towards forms of public engagement that provide both researchers and the public with opportunities for two-way communication and mutual learning, often with a participatory approach. The basic idea of participatory approaches is to shift the focus from the contents of the activity to the interaction among participants, in order to establish a communal environment that fosters both learning and engagement. Indeed, many of these activities can be straightforwardly classified as work-based experiences.

Citizen science projects and research internships [8]. ,[13]. are well known examples, which entail the participation of non-experts in real research projects. Citizen science projects have been classified into three modes depending on the level of participants' engagement: contributory, collaborative and co-creative modes [13]. . The three modes go from the basic level of volunteering, with minimal cognitive engagement, to a high degree of commitment and to peer-to-peer interaction among participants and professional researchers. A similar classification has been given for participatory approaches, adopted both in museums [14]. and in active learning techniques in science education [14]. .

This methodological convergence allows for the integration of formal and non-formal education through participatory activities that meet the requirements of work-based learning. Very interesting, in this sense, appear inquiry- and project-based participatory activities that are offered by many science museums with the aid of professional researchers [16]. . There is also an increasing number of after- or out-of-school programs that are stimulated and supervised by scientific institutions. These initiatives are often coordinated at the national and supranational levels, like for example the italian "Piano Nazionale Laure Scientifiche" (PNLS- National Plan for Scientific degrees) [4]. , an initiative of the minister of education (MIUR), which entails the interaction between schools and universities at the local level, through laboratories and workshops related to research performed in universities. For most pupils, these programs represent the only opportunity of contact with cutting-edge research topics and are much appreciated by both school students and teachers, though somewhat perceived as weakly related with school programs [5]. .

Requirements for Work-Based Experiences

In fact, an important requirement for high quality work-based learning [6]. is the connection with the school curriculum. Students must engage meaningfully with the experience offered and see the connection with what they are taught in formal school. In this sense, activities related to advanced research topics require a careful design. Participation of school students in citizen science projects or internships in research laboratories can suffer some limitations because students and teachers may not be well trained. Research internships are often practiced with a limited number of students and after a careful selection process [8]. .

To bridge efficiently school programs with research topics, researchers and teachers must share the learning goals. In this sense, the active participation of school students and teachers in the design of educational activities appear as an essential requirement. This allows to improve and customize the activities to suite specific needs and demands. For example, schools can improve the quality and the relevance of their education by collaborating with researchers in recycling dismissed laboratory equipment, either of the school and of the university [8]. . Most schools in Italy possess quite rich collections of scientific instruments acquired over decades. In ancient schools there are many instruments of appreciable historical value, which are often collected and showcased in real museums [17]. [20]. . However, even when cataloged and exposed, these instruments are only rarely used for didactic purposes [[17]. [18]. . Therefore, in these last five years, we have developed a PCTO activity in which physicists and technicians of the physics department of University of Calabria have helped some schools of the region in recovering disused instrumentation of the school laboratories.

The peculiar aspect of the old instruments, and of the comparison with newer ones, is that they allow the students to perceive the evolution of the knowledge associated to the development of the scientific instruments. In this sense, the activity can allow to frame the studied phenomenon within a broader and interdisciplinary context, which involves also other disciplines of the school curriculum. Beyond teaching pure physics, the goal is to create an environment that helps students to place natural phenomena within both the historical and the research context in which they were investigated. It is therefore a matter of integrating the study of physics with human culture and thought, as these have been developed over the historical periods. It seems to us that this can have a more lasting impact on students, especially those who do not have a degree in physics in their future horizon [21]. . When appropriate, the activity involved also visits at the university research laboratories, where the physics of the examined instruments is applied to current research topics.

For example, in almost every school we visited, we found tubes, such as those pictured in fig.1, dating back to different periods. These tubes are replicas of those invented in the second half of the 19^{th} century to study electrical discharges. The tubes in fig.1a)-1c) are glass tubes of various dimensions and shapes, partially evacuated and with two metal electrodes, between which travelled those called by the time cathode rays and later individuated as electrons in a series of famous experiments by Thomson (fig.1d). We therefore used these tubes, and others not shown, to develop didactic paths for PCTO activities that were much appreciated by students and teachers because they allowed students to discuss some of the important scientific discoveries occurred at the beginning of the 20^{th} century and led to the second scientific revolution. Most of these old tubes are not in line with current safety regulations, because of several factors such as their fragility, the generation of x-rays etc, and cannot be used by the students, but there are modern replicas commercially available, such as the Braun tube in fig.1d, that allows to repeat the Thomson experiments and to measure the charge to mass ratio of the electron. Moreover, the tubes allow also to illustrate the laws of Newtonian mechanics by studying the deflection of electrons into electric and magnetic fields. The path also involved a visit to research laboratories where students have been introduced to electron spectroscopic techniques currently used for studies of ion and electron spectroscopy [22]. [23]. of surfaces. During the visits students interacted with researchers that use these techniques for studying nanoscience and nanotechnology. In this way, starting from historical questions "what is an electron?", students' reflections are guided to actual research topics and their implications, following a thematic path strictly connected with what they are taught in several disciplines of the school curriculum.

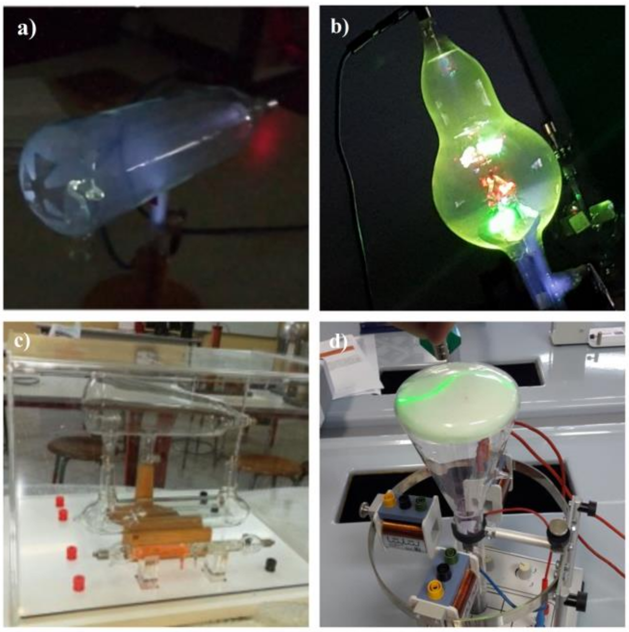

Figure 1. Some Discharge Tubes

The use of this material, to produce experimental activities and workshops co-designed by researchers and teachers, can thus be naturally connected with school programs and also meet another important requirement for work-based activities, that is the fact that they result in products and services that demonstrate learning. Indeed, because these equipments generally lies abandoned in some shelf in the lab, these activities produce also an economical value. Furthermore, the experimental apparatuses could then be used to produce other work experiences, like exhibits and science festivals, with the involvement of other socio-economical actors, like tour operators and the local government (see Figure 2).

Taking advantage of the possibilities offered by PCTO, it was possible to extend the recovery of school equipment, creating important moments of connection with the entire territory, and not just between the school and the university. In fact, the recovered experimental equipment was used for other activities, such as scientific exhibitions and festivals, with the involvement of other partners, such as tour operators and local administrations. This is how the School Science Fest was born, an exhibition of scientific equipment restored during the school-work alternation activities (figure 2). The exhibit, a collateral event of the 104th congress of the Italian Physical Society (SIF), was held on 20th and 21st September 2018 at the cloister of San Domenico in Cosenza and was animated by about a hundred students, within the context of their PCTO project. A reduced version of the exhibition was also presented during the 2018 and 2019 editions of the EU Researchers' Night at the University of Calabria, while an extended and longer version scheduled for spring 2020 was postponed due to the pandemic.

Figure 2. Some moments of the "School Science Fest", an exhibit of laboratory equipments of some schools in Calabria, some of which dating back to the early twentieth century and recovered during SWA projects carried out in collaboration with the Department of Physics of the University of Calabria. The fest was held in the Cloister of "S. Domenico" in Cosenza as a side event of the 104° Congress of the Italian Physics Society (SIF) and was animated by the school pupils of the SWA activities.

Conclusion

The above-mentioned examples show that public engagement activities, carefully designed to meet the requirements for high quality work-based learning, can generate a virtuous circle of scientific research, science education and communication that can produce both cognitive and emotional engagement; can create stronger connections among school programs, everyday life and current research topics; and can help involved scientists in better defining their role in the local community.

The recovery of the equipment that we have carried out integrates formal and informal education, encouraging a meaningful interaction of students and teachers with university environments, achieved through a synergy between the outreach programs of both universities and the PCTO program in schools. This type of integration between formal and informal education, through activities co-designed with the active participation of teachers, brings together an experimental activity, a multi- and inter-disciplinary approach strictly connected to the whole school curriculum and an efficient action of support and guidance to career choice for the students. This results in opportunities for teachers' professional development, allowing for larger connection with school curricula. Finally, this mechanism of integration between educational structures can allow for new forms of education, also through the involvement of other socio-economic actors, apparently not connected to each other. The activity received the unanimous and enthusiastic participation of students and teachers in all the events held. This makes clear the need to give back the laboratory its centrality in the life of school communities, because an intense and meaningful laboratory activity represents, above all, a strong moment of socialization.

Thus, in an era of rapid technological innovation driven by multidisciplinary convergence and integration, education settings need to converge and integrate too. The integration of formal and non-formal education through work-based learning experiences, aided by a substantial methodological convergence through participatory approaches and by flexibility in school programs and schedules, can favor the collaboration of secondary schools with universities. Specific policy interventions in this direction need to be encouraged and promoted, because they can create opportunities for a structural connection between scientific research and education, much needed and beneficial for all involved actors.

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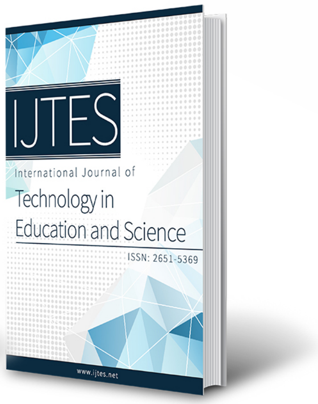

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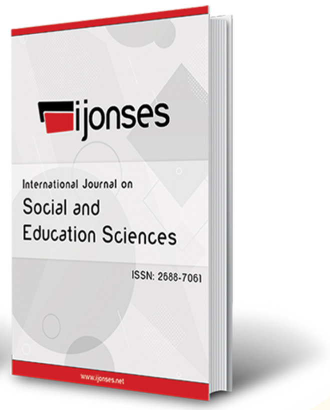

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