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Pakistan Academy of Sciences

Review Article

Adaptation of Outcome-Based Education System in Pakistan for Engineering Disciplines and its Critical Evaluation

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Abstract: Pakistan has become a part of the Washington Accord in 2017 and started making reforms in its education sector. Outcome-Based Education (OBE) has been emphasized by Pakistan Engineering Council (PEC) for the accreditation of all engineering degree programs. This paper presents some basic literature on the existing educational models in the world and the Outcome Based Education-OBE structure that has been implemented in Pakistan yet. Pakistan has successfully designed the Program Education Objectives (PEOs) and Program Learning Objectives (PLOs) for the academic sector. PEOs are the mission/vision statements that define the career and professional goals which the program is preparing students to achieve. PLOs are the quantifiable statements that define the knowledge and skills expertise of the students upon graduation ceremony. A survey has been conducted by employers to assess the skill level of fresh graduates against 12 PLOs of the OBE system in Pakistan. Of these, the PLOs related to four measurable statements namely: (i) Problem Analysis, (ii) Design of Solutions, (iii) Investigation, and (iv) Environment & Sustainability are found underperformance as surveyed from the industry sector following the performance of freshly graduated students. The survey also includes the Key Performance Indicator (KPI) evaluation of faculty members both from the department heads and the students too. This result shows underperformance of 15 % of the teaching faculty as per prescribed grading ranges. However, the OBE faces some difficulties as well and unfortunately, there are not so many graduates who entered into the industry after learning from OBE. It will, therefore, take some time to deliver the results of OBE implementation in Pakistan. Furthermore, some other education reforms from around the globe have been presented in this paper and some suggestions have been provided.

Keywords: Outcome Based Education, Pakistan's Educational Reforms, Program Education Objectives, Program Learning Objectives.

1. INTRODUCTION TO EDUCATIONAL MODELS

Education is typically a dimension that deals with the method of teaching and learning environment in schools. It is a continuous process of facilitating, learning, acquisition of knowledge, wisdom, skills, morals, belief, habits, and personality grooming. On the whole, education plays a vital role in the development and polishing of a society and a community. It is believed that economic growth is directly related to the education infrastructure in a positive direction [1].

UNICEF is providing facilities for learning and skill development in 147 countries across the globe with the objective of quality, learning skills, equality to all, and emergency and fragile context [2]. In different parts of the world, countries have adopted and developed techniques for learning and teaching environments, and day by day these systems have been in a continuous process of making reforms in their design. Globally, there are seven (7) models designed for education and academic institutions. These models include Science Technology Engineering Mathematics (STEM), Project Based Learning, Inquiry Based Learning, Interdisciplinary Collaborative Learning, Neuroscience, Place-Based Education, and Multiage Learning models [3]. The Model STEM uses four basic and strong tools of life altogether by creating a meta-discipline. It encourages

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students in a curriculum that is driven by problem-solving, discovery, and exploratory learning and thus developing a thought-provoking habit [4]. The Project-Based Learning model of education provides students with small tasks in a well-designed process of problem solutions, inquiry, and clear objectives. The projects are usually assigned to the students in several groups for their learning [5]. The Inquiry-Based Learning model of education is a learning process involving the interest, curiosity, and perspective of students. The Interdisciplinary Collaborative Learning model is an education model that uses some recreational environment by uniting all the academic disciplines of medicine, science, arts, and humanities. It involves some common subjects between the two groups. The Neuroscience is an education model that typically involves the use of one's intellectual capacity by some research methodology. It is also commonly termed as mind and brain educational technique [6]. The Place-Based Education model offers interaction of local community and surrounding environment with the learner and this typically involves excursions and field visits. Multiage learning is a system where students are not separated by their grades and it uses some flexible groups where students can be taught together without distinguishing by their grades. These multi-age groups are created on the basis of pedagogical choices of school or learning program [7].

2. OUTCOME-BASED EDUCATION (OBE)

In 1989, an international proposal has been suggested for undergraduate studies of professional engineering degrees and this is termed as Washington Accord [8]. This agreement has to be signed between the regulating body and the academia of countries. It resulted in the proposal of different reforms in education and among these, the Outcome-Based Education (OBE) is one. The OBE system offers an educational reform that works on a very clear concept of what students are supposed to know and are potentially able to do [9]. It is often termed as Performance Based Education in some parts of USA where the student's learning outcome constitutes the whole academic environment including teaching method and materials, grading and assessment techniques, and recreational activities.

The Education Commission of the USA traces this reform back to the 1930s with a study involving 300 colleges and 30 high schools. The participant institutes have redesigned their academic model following the need and interests of their students and their graduates have been found more successful compared to the traditional academies [9]. It was the first time that learning and teaching are linked directly and teaching effectiveness had been associated with the learning outcome of students. The outcome must be a measurable unit and should have some deliverable activity. The assessment criteria may vary in different institutes but it must reflect an outcome of the student's strengths or weaknesses. It can be achieved by making a rubric within a subject or maybe in terms of levels like beginner, basic, expert, etc. [10]. Asim *et al.* [11] have identified some factors influencing the design of the infrastructure of OBE in developing countries including Pakistan. He found Learning objectives, Assessment methods, Learning styles, English language competency, and Employer graduate requirements as the primary factors to be considered in OBE. Katawazai [12] has researched the implementation of OBE in Afghanistan and pointed out the difficulties there. He claimed that content-based curriculum, policies of teaching, learning, and assessment, lack of facilities, and teachers' workload are the key hindrances in adopting the OBE system in Afghanistan.

3. OTHER EDUCATIONAL REFORMS IN THE WORLD

Several countries including Australia, Malaysia, South Africa, and the majority of the European Union had adopted OBE in the past but soon removed this theory from their education infrastructure and worked on alternative reforms. The reasons for detracting from OBE are lack of evidence of its success, overburden for staff and students, dissatisfaction with the testing and assessment approach, and to some extent the admission requirements for the degree program. Thus, instead of OBE, some other reforms in the education infrastructure were made and the two most famous models namely, Competency-Based Education (CBE) and Work Based Learning (WBL) were used. These two theories are found as successful as OBE and are discussed as follows:

3.1 Competency-Based Education (CBE)

Competency-based education (CBE) is a student-centered education theory that focuses on the learning outcomes considering the interest and needs of the learner [13]. It involves the process of self-learning plans in parallel to the scheduled classes to bring out the mastery of a student's competencies. A competency can be defined as a package of knowledge, attitude, and skills and this is somewhat similar to vocational training. The basic attribute is to understand how a learner can learn the skill and performance, and much more important is to identify a competency for a student and work on its fine-tuning [14]. CBE provides students the chance to use their past experiences, skills, and knowledge to complete a course, get a degree, and/or participate in training to fulfill their goals [13].

3.2 Work-Based Learning (WBL)

Work-based learning is an educational reform that provides a student with real-life work experience from the industries. European Union in the majority is working on the WBL system and has made it mandatory to gain professional experience parallel with studies in the form of work student, internships, and part-time experiences. WBL deliberately combines theory with practice and acknowledges the intersection of clear explicit and tacit forms of knowing [15]. It has a benefit of a strong liaison between academia and industry [16], the generation of a more practical skilled pool of future employees, student awareness of career opportunities, and a reduction in pre-service training time and cost. However, it needs careful consideration and planning when imposing WBL as it consumes time to identify the key courses to be taught in degree programs.

4. OBE STRUCTURE IN PAKISTAN

Among all of the above-discussed educational reforms, Pakistan has started implementing OBE in its tertiary education system as per the policy of the Higher Education Commission (HEC). In many graduate programs including management, social and applied sciences it has opted for many years ago but engineering education was a bit lazy in this context. Pakistan Engineering Council (PEC), a statutory body to regulate the engineering profession including the mandatory education structure signed the Washington Accord in 2017 and thus instructed the HEC and affiliated institutions to make educational reforms under OBE [17]. This has been observed when Iqra National University in Peshawar started to propose a structure for Faculty Course Assessment Reports-FCAR for the assessment and monitoring of students' performance in the Department of Electrical Engineering and it was the first step toward OBE [18]. FCAR technique is a comprehensive document to assess the impact of OBE [19]. Faiz *et al.* [20] did similar research for a different institute. Manzoor *et al*. [21] discussed the transformation of the education infrastructure of Pakistan from content-based to Outcome-based technology and critically discussed the impact in terms of the success and failure of the system. This analysis was carried out typically for engineering graduate programs under the regulations implemented by PEC.

Pakistan has defined the infrastructure for OBE based on nine different criteria as shown in Table 1. Among all the nine criteria, three have gained much importance in Pakistan namely; Class Learning Objectives (CLOs), Program Learning Objectives (PLOs), and Program Educational Objectives (PEOs) [22]. PEOs are the broad statements or mission statements of the Academic Department explaining the goals and milestones which the students are achieving through a specific program. CLOs and PLOs are measurable statements from a course or activity which describe the expertise level of the students upon the completion of a degree

Table 1. Criteria for OBE Implementation in Pakistan

Criteria	Measurable statement
Criterion 1	Program Educational Objectives (PEOs)
Criterion 2	Program Learning Outcomes (PLOs)
Criterion 3	Curriculum and Learning Process/ Course Learning Outcomes (CLOs)
Criterion 4	Students
Criterion 5	Faculty and Support Staff
Criterion 6	Facilities and Infrastructure
Criterion 7	Institutional Support & Financial Resources
Criterion 8	Continuous Quality Improvement (CQI)
Criterion 9	Industrial Linkage

program. The basic difference between CLOs and PLOs is that the CLO relates to a specific course or degree program while a PLO is associated with the whole Department. PEC has defined 6 CLOs and 12 PLOs to maintain the quality of education in engineering degree programs. The details of these CLOs and PLOs are presented in Table 2 and Table 3 respectively. Keeping in mind that the CLOs and PLOs combined result in achieving the PEOs of an organization and each PLO is to be evaluated through a CLO and CLO can be evaluated by any direct and/or indirect assessment [23]. Mahmood [24] has explained very well about the infrastructure and grading system as a part of OBE and described the minimum threshold for passing criteria and the respective assessments for CLOs and PLOs. DHA Suffa University has set a well-defined framework for an OBE structure to be implemented in Pakistan [25]. This framework is shown in Figure 1.

The two direct stakeholders of the OBE system are Students and Faculty staff. Students have the benefits of clarity, flexibility, and involvement in tasks and employment opportunities and they are expected to demonstrate what they know and must accept the responsibility for what they don't know in preparation for continue achieving and reach high performance finally students have to fulfill all the PLOs to obtain their respective degrees. The faculty members are required to satisfy a

Table 2. List of all possible CLOs in OBE Pakistan

Class learning objective (CLO)	Measurable statement
CLO 1	Knowledge
CLO 2	Comprehension
CLO 3	Application
CLO 4	Analysis
CLO 5	Synthesis
CLO 6	Evaluation

Table 3. List of PLOs in OBE Pakistan

Program learning objective (PLO)	Measurable statement
PLO 1	Engineering Knowledge
PLO 2	Problem Analysis
PLO 3	Design of Solutions
PLO 4	Investigation
PLO 5	Modern Tool Usage
PLO 6	The Engineer & Society
PLO 7	Environment & Sustainability
PLO 8	Ethics
PLO 9	Individual & Teamwork
PLO 10	Communication
PLO 11	Project Management
PLO 12	Lifelong Learning

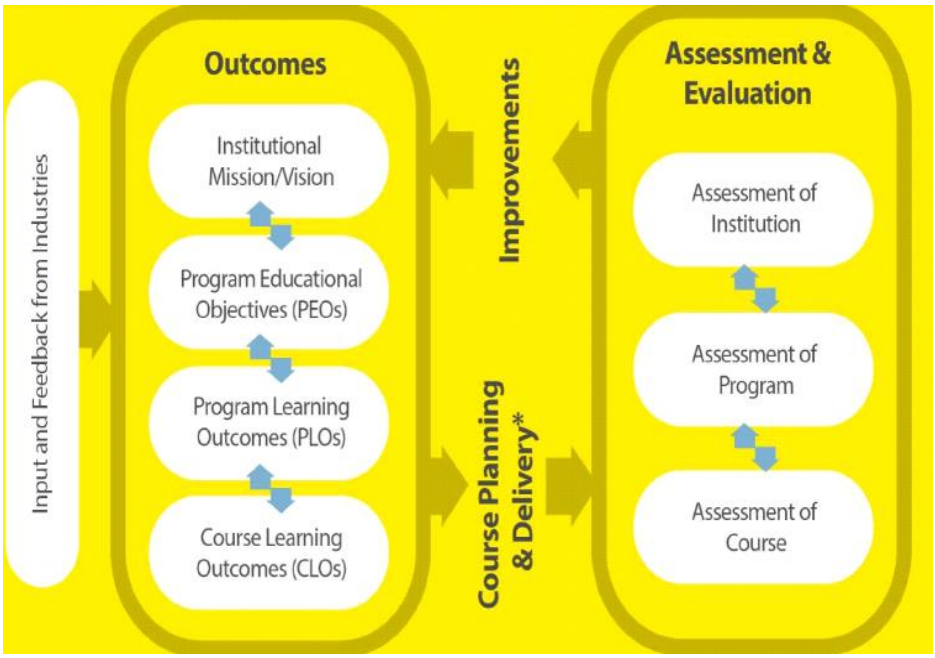

Fig 1. A typical framework for OBE in Pakistan [25]

Key Performance Indicator (KPI) evaluation for each semester. KPIs are the targets and goals defined to strengthen the Institution's ability to evaluate how well a department is going to support the students in achieving the skills, knowledge, and personal grooming. PEC has associated these KPIs with the faculty members to bring strength to the Department's ability to design a specific program in a better way. The KPIs include factors such as their regularity, punctuality, lecture delivery and knowledge, research projects and publications, conferences and seminars, and arranging site visits. The KPI ranges for the faculty members are shown in Table 4 [26].

In a small survey, students were questioned about the OBE system w.r.t. its policies, probable advantages and outcomes, and shockingly, the majority of these students were even unaware of what the OBE is. The feedback from the industry, however, seems satisfied with the implementation of OBE. Figure 2 shows the satisfaction level of employers with the performance of freshly graduated students for each PLO. The PLOs with 50 % satisfaction can be termed as successfully implemented but it shows many of the dimensions to be handled carefully in the future.

To assess the successful impact of OBE, the KPI evaluation has been made for the faculty members of different engineering disciplines from various institutes. The KPI evaluation has been made through the Department Head as well as directly from the students to analyze the more realistic and true response. A random survey has been made by Department to get the results of KPI reports confidentially and the results are presented graphically. Similarly, a group of 1000 students was questioned randomly to evaluate the KPI scores of their teaching staff, and the results are summarized graphically. The results of both surveys are shown in Figures 3 and 4 respectively.

Table 4. KPI range for faculty members [26]

KPI range	Performance level
Below 50	Under Performance
50-60	Satisfactory Performance
60-70	Good Performance
70-80	Very Good Performance
80-90	Excellent Performance
Above 90	Outstanding Performance

4.1 Advantages and Disadvantages of OBE

Compared to the traditional teacher-centered education system, OBE has provided students more importance w.r.t their fundamental rights. The PLOs have made education multifacet and the KPI evaluation has activated the working strength of the faculty members. On the other hand, it has become much more difficult to monitor the circumstances and results of OBE at such a big national level. Moreover, OBE constituted a more busy workload for faculty members and make it a bit difficult for students as well since they have to satisfy all the CLOs and PLOs to obtain their degrees. [26]

According to the PEC accreditation manual 2014, the OBE needs to be implemented in engineering degree programs in the future. In 2017, PEC became a full signatory member of the Washington Accord [27]. Therefore, since 2017, educational reforms have been made in engineering degree programs in Pakistan and engineering graduates have been introduced to the learning concept of OBE. Since, this is a newly adopted technique of learning in engineering subjects and not so many of the batches have graduated with the OBE concept therefore, it will take a few more years to assess the impact of OBE in the professional industry. Dewani et. al (2022) evaluated the impact of OBE implementation using the comparison of

Fig 2. Performance of fresh graduates with respect to PLOs

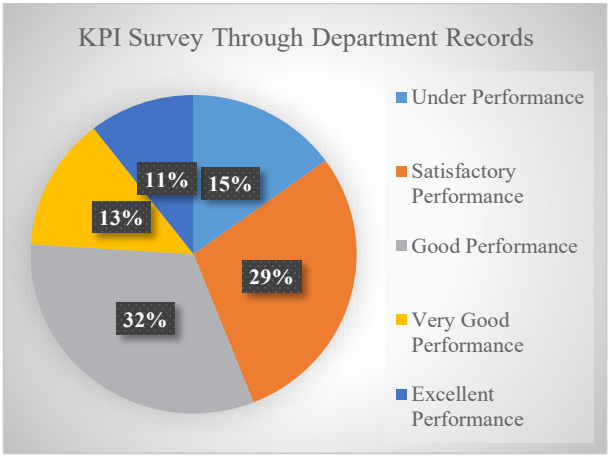

Fig 3. KPI evaluation of faculty members through daepartment records

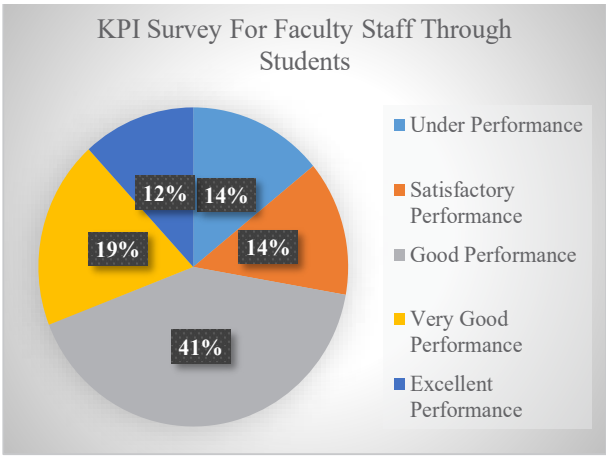

Fig 4. KPI evaluation of faculty members through students

students taught with and without the OBE system [28]. They found OBE more efficient in terms of student learning, grades, and skill competencies.

5. CONCLUSION AND RECOMMENDATIONS

Pakistan started implementing OBE in 2017 for all of the engineering degree programs under the PEC guidelines and successfully designed the PLOs and PEOs for the institutions. Unfortunately, till date, it has not been implemented completely and it will take a considerable time to get results of this educational reform. However, it has made the faculty member to be more academic since they have to present their KPIs at the end of each semester. At the current stage, OBE has kept the academic staff so busy in making policies and regulations that their workload becomes too high and this is resulting in their performance. Some Institutions involved their faculty members in the administrative work of OBE implementation and this has badly affected their academic performance. In addition, PLOs 2, 3, 4 & 7 need to be monitored with more focus as their satisfaction level has been obtained less than 50 % from the employers.

The following suggestions are highly recommended to make the education sector more strengthened:

1. The assessment of students' grades can be made in terms of excellency class rather than numeric scaling. That is *satisfactory, Fair, Good, Very Good, and Outstanding grades*. This will maintain a confidence level in a student as no one is aware of their performance and marking in exams and ultimately, it can help in their learning and communication in their tasks and completing degrees.
2. As the KPI has been implemented for the faculty members, it is suggested to announce their allowances, bonus, and increments based on the KPIs of each semester. It will make the faculty work with full pace of academic strength to participate in the competition.
3. About 15 percent of academic staff has been found under-performance and that might be because of the implementation of new system. Hence, PEC and HEC should conduct seminars and training workshops to keep the academia updated and efficient.
4. Apart from OBE, other models of education such as WBL & CBE must also be considered parallel. Especially, WBL has a more practical influence on the education of future employees.

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7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Research Article

Spectral Variability of the Symbiotic Star CH Cyg

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Abstract: On July 15, 2015, the second telescope of the Shamakhi Astrophysical Observatory (ShAO) was used to collect 14 echelle spectra of the symbiotic star CH Cyg over the course of six hours of nocturnal exposures. Along the profiles of the lines Hα and Hβ, the intensity of line HeI λ5876 Å fluctuates simultaneously with variations in the intensity ratios of the blue and red emission components. The HeI λ5876 Å line's center intensities and corresponding widths correlate with information from the blue emission component of the lines. There are certain correlations between the radial velocities of the absorption DNaI and the emission line Hα.

Keywords: Symbiotic Star, Line Profile, Line Intensity, Radial Velocity.

1. INTRODUCTION

The advantageous star CH Cyg is bizarre and varies significantly from other conventional advantageous stars based on its ghostly and photometric behavior within the "calm" and dynamic stages, as well as based on the unveiled sets of periods for the system's outspread speeds and light bends. Following the appearance of symbiotic behavior, the photometric history of the star is shown as active phases (a sequence of flashes: 1969–1970; 1977–1986; 1992–95 and 1998–1999), interrupted by "silent" intervals of varying lengths. From many minutes (flashing amid the dynamic stage) to hundreds of days (throb and revolution of M ruddy giant), and indeed 10 of a long time, changes within the CH Cyg light bend take place on different time periods (orbital moving of the components within the framework). Beginning around 2010, the star's brightness in the rays of U progressively grows until it reaches a value of around 7^m–8^m by the end of 2014. The striking spectral and photometric variability that took place in 2014–2015, along with the synchronized rise in the star's brightness in the U and V rays, prove beyond a shadow of a doubt that CH Cyg has entered its subsequent active phase [2-9]. In the active phase of the star, flickers, which are defined as a dramatic rise in brightness over a time period of few minutes to many hours with an amplitude of 0.1^m to 0.5^m, emerge in CH Cyg's optical brightness.

The interaction among the parallel framework and the near-stellar matter causes exceptionally complicated kinematics to make within the near-stellar medium amid the dynamic stages of the advantageous framework. Diverse sorts of changes within the profiles of the hydrogen Balmer lines are one way that the variable of the growth and outflow administration of matter uncovers itself. Therefore, despite thorough spectrum investigations throughout all of the CH Cyg star's active phases, there is still no single explanation that can fully account for the majority of the observable evidence [see, for example, 3, 10-12].

On the night of July 15, 2015, spectral measurements of CH Cyg were made using the

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Shamakhy Astrophysical Observatory's second telescope. Parts of the findings from these observations are described in [13, 14]. The HeI λ5876 Å lines and the NaI D1 and D2 doublet in the CH Cyg spectrum are described in detail in this work, along with a comparison to the findings of previous studies on the Hα and Hβ lines based on the same spectra [13, 14].

2. SPECTRAL OBSERVATIONS PROCEDURE

The spectra of CH Cyg within the wavelength run λλ 4700-6800 ÅÅ were gotten for one night (15.07.2015) within the Cassegrain center of the 2nd telescope of the ShAO. An Echelle spectrometer was used, assembled based on a all inclusive astrospectrograph (UAGS), employing a CCD camera of 580×530 pixels with a scattering of 10.5 Å /mm at H_α (ghastly determination R = 14,000 [15]. The observations were carried out continuously for 6 hours with an exposure of 20 minutes for each spectrum. A total of 14 Echelle spectra were obtained. Observations and processing of Echelle spectra were carried out using the DECH–20 software package developed at the SAO RAS [16].

3. OBSERVATION RESULTS

From all of the available spectra, the profiles of the lines HeI λ5876 Å, NaI D1, and NaI D2 were built, and the equivalent widths and radial velocities of the lines were determined from these profiles. Figures 1a and 1b display the profiles of the lines HeI λ5876 Å and NaI D1 and D2 in the CH Cyg star's one-night spectral analysis.

As observed in Figure 1a, there are significant variations to the center intensity of the HeI λ5876 Å line profiles over a period of roughly 20 minutes that are almost coincident with changes to the Ib/Ir ratios of the Hα and Hβ lines. As mentioned in, the variation in the intensity of the blue emission

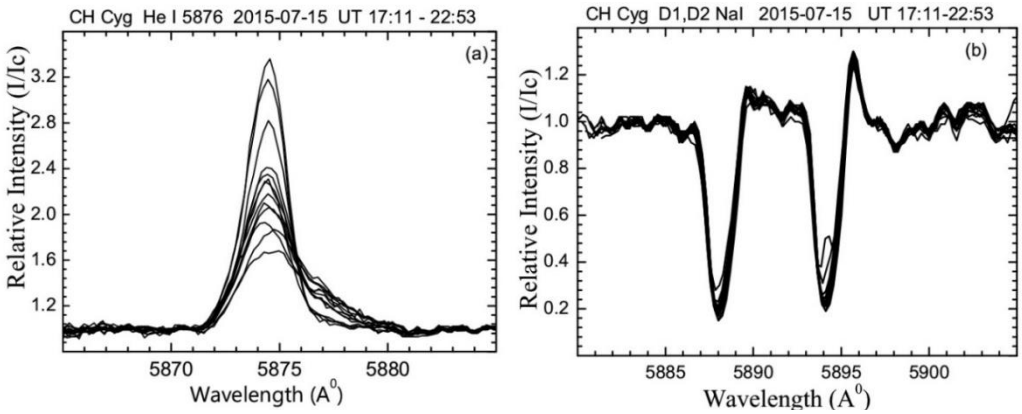

Fig. 1. (a, b). Profiles of HeI λ5876 and NaI D1.2 lines in the spectra of the symbiotic star CH Cyg observed for one night (2015-07-05 UT 17:11 – 22:53).

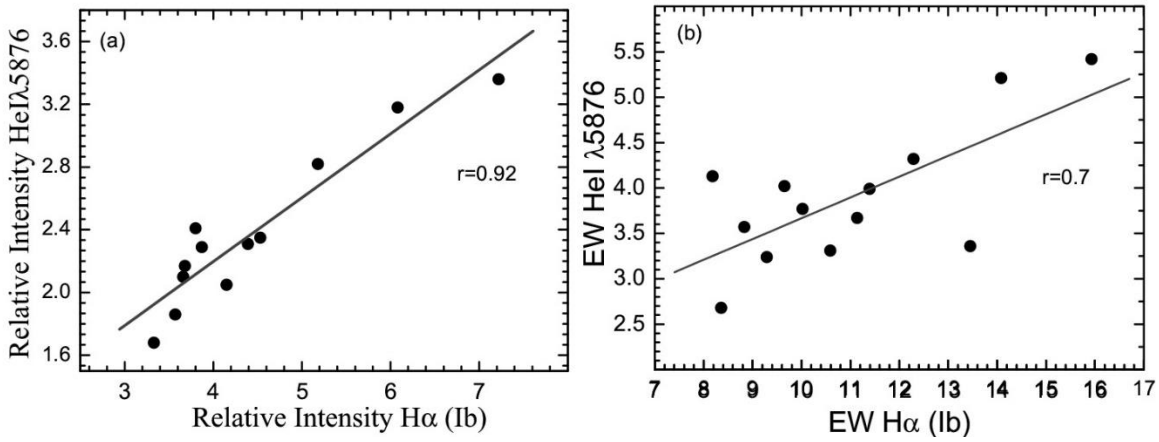

Fig. 2. (a, b). Dependences of the profile parameters of the blue component of the Hα lines on HeI 5876

component is the major cause of the change in the Ib/Ir ratio [13, 14]. Therefore, it can be inferred indirectly that the HeI λ5876 Å and Ib emission lines' intensities shift about at the same time. The HeI λ5876 Å line's relative intensity was 1.93 at the start of the observations; at the conclusion, it had climbed by around twice and was at a value of 3.36. The blue component of the Hα and HeI λ5876 Å lines' profile characteristics exhibit strong correlations. Correlation values of 0.92 and 0.70, respectively, are found between the relative intensities and equivalent widths of these lines (see Figure 2a and 2b). The antiphase is when the HeI λ5876 Å line's center intensity and half-width alter (Figure 3a and 3b).

The NaI D1 and D2 lines, particularly NaI D1, have a profile of type P Cyg, as seen in Figure 1b. The outspread speed of the emanation component of the line NaI D1 is close to the speed of the ruddy component (Vre) of the emanation lines Hα and Hβ, and the spiral speed of the assimilation component of the line NaI D1 generally compares to the outspread speed of the blue component (Vbe) of the outflow lines Hα and Hβ (roughly -100 km/s) [14].

Although the absorption core exhibits significant fluctuation, particularly in the NaI D1 line, the residual intensity of the NaI D1 and D2 lines do not exhibit abrupt shifts. For the observation period, the emission component NaI D1 does not exhibit fluctuation. A second absorption component shows at the NaI D1 line on one spectrum (UT 22:37) with a speed of 68 km/s, which is comparable to the Hα line's core absorption rate [14]. On this spectrum, the HeI λ5876 line's intensity reaches a maximum.

4. DISCUSSION

We found the dependences of the escalated of the HeI λ5876 emanation line, the proportionate width of the blue outflow component, and the leftover escalated of the high-speed retention components on the Ib/Ir proportions of the twofold profiles of the emanation Hα and Hβ lines utilizing spectra from one night for a time interim of approximately 6 hours.

Outspread speeds of the outflow line Hα and the D NaI assimilation line have a few association, as seen in Figure 4. This shows up to infer that sodium lines create in a especially hot and thick gas within the line's creation zone. Such circumstances are achieved in exceptionally minor segments of the disk or wind, but the root of the emanation line creation is much bigger, for illustration, see [17].

It appears that the white dwarf's activity levels and orbital location have a significant impact on the profiles' shapes and intensity ratios of the emission lines. The phase that corresponds to our spectral measurements was computed for the orbital period of 5689.2 days using the ephemeris from [18]: φ= 0.028.

JD (periastre)=2445681 (±192) + 5689.2 (±47.0) x E

where JD –Julian date and E is an integer number of cycles. The hot component was virtually periastric at the time of our spectral measurements. It may be

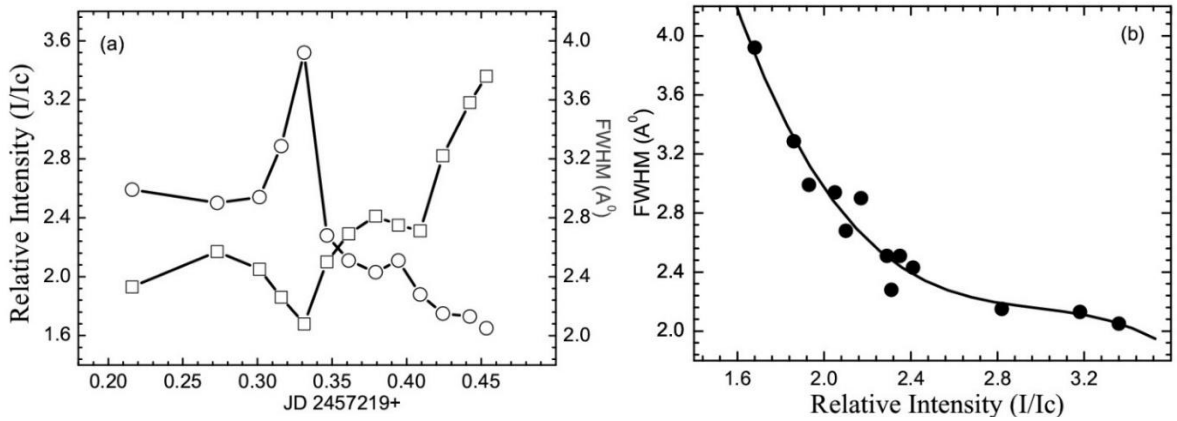

Fig. 3. (a, b). The change in the central intensity (y–axis scale on the left scale) and the half–width (y-axis scale on the right scale) - (a) and the dependence between the central intensity of the half-width - (b) - line HeI λ5876 on a time scale of regarding 6 hours during the night in the spectrum of the symbiotic star CH Cyg.

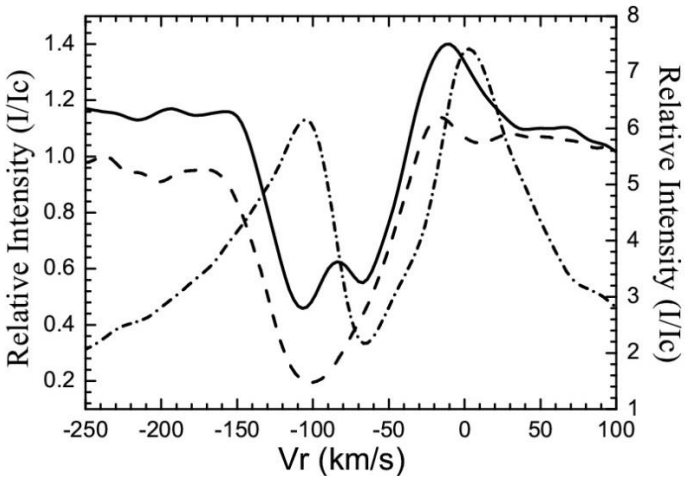

Fig. 4. Profiles of the lines NaI D1 (solid line), NaI D2 (dashed line) - scale on the y axis on the left scale and the emission line Hα (dashed line) - scale on the y axis on the right scale, according to the spectrum obtained in 2015-07-05 (UT 22:37).

believed that the hot star in 2014-2015 was situated close to the periaster due to the enormous size of the orbital period. The mass exchange process is activated when the system components have reached their maximum convergence, and this is followed by a large increase in spectral variability.

Rapid photometric variability was seen in the active phase of the symbiotic star CH Cyg system in 2014-2015 with amplitudes of $0.^{m}1$-$0.^{m}3$ and ~$0.^{m}5$ over typical times of 7–15 minutes and 4 hours, respectively [6,7]. Combining the aforementioned observational data, it can be said that the CH Cyg system exhibits fast photometric variability (flickering) in 2014-2015 and in earlier active phases, with characteristic timings that are similar to those of spectral variability. Evidently, the star's optical brightness is flickering in conjunction with the quick spectral shifts we have observed in the CH Cyg spectrum.

5. CONCLUSION

1. It was discovered that Hα and Hβ simultaneously occur with variations in the Ib/Ir ratios of the emission lines' blue emission component.
   a. variations in the line HeI λ5876 's intensity. The HeI λ5876 line's center intensities and comparable widths correlate with information from the H lines' blue emission component.
   b. changes in the corresponding lengths of the Hα and Hβ lines' blue emission components.
   c. the intensity of the Hβ line's blue wing's high-speed broad absorption components. During the observations, the intensity of the absorption components increased for 2.5 hours when the Ib/Ir ratio decreased, then decreased for the following 3 hours when the Ib/Ir ratio increased.
2. The outspread speed of the emanation component of the line NaI D1 is close to the speed of the ruddy component (Vre) of the emanation lines Hα and Hβ, and the spiral speed of the assimilation component of the line NaI D1 generally compares to the outspread speed of the blue component (Vbe) of the outflow lines Hα and Hβ (roughly -100 km/s) [14].
3. Our quick spectral variations in the CH Cyg spectrum are likely caused by the star's optical brightness flickering, which is typical of the active phase of the system.

6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Research Article

Temperature-Properties Relationships of Martensitic Stainless Steel for Improved Utilization in Surgical Tools

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Abstract: Sintering temperature and environment plays a very important role in strengthening powder particles of compacting surgical parts by cold powder metallurgy technique. Powder metallurgy is a process of producing components/tools by compacting finely metallic or nonmetallic powders. Generally, in the last decade, these tools were produced by conventional casting techniques but now first time in Pakistan this technique is introduced to develop surgical tools/parts. In this study, the effect of sintering behavior by varying temperatures and environments was studied. The AISI 420 Stainless steel compacted surgical parts (Scalpel and scissor) were sintered at 1000 °C to 1300 °C for 30 minutes in a vacuum and an inert environment in the presence of Argon. The compact density, microstructure and mechanical properties were studied. Microstructural characteristics like porosity, and crystalline size were studied by optical microscope. The hardness values and density of the final parts were also measured through the Rockwell hardness machine and by the Archimedes principle. Decreasing the porosity in the final parts will increase the mechanical properties of sintered parts. Adopting the present process for the development of surgical tools after further refining, the process will prove beneficial in the cost-effectiveness, time and energy saving of the present product.

Keywords: Sintering Temperature, Sintering Environment, Surgical Parts, Stainless Steel, Powder Metallurgy.

1. INTRODUCTION

Powder metallurgy (PM) offers a great advantage when the required criteria for manufacturing are small components in large series with intricate and net shapes [1-3]. PM of martensitic stainless steel is reported to vary on a limited scale due to its difficult processability as compared to other PM of stainless steel [4]. Martensitic starless steel (MSS) and Austenitic stainless steel (ASS) are ordinarily utilized for manufacturing parts with remarkable mechanical and optimum corrosion resistance properties to be worked in different conditions [5, 6]. Their properties can be modified by the heat treatment process, unlike other stainless-steel products [7]. As such, these are widely utilized in dental and surgical instruments, pressure vessels, steam generators, moulds and dies, cutting tools manufacturing as well as automotive sector [8-11].

The PM stainless steel shows limitation in its applications due to low mechanical and corrosion properties as compared to other non-porous materials equivalent to them. Therefore, there is always a primary concern to improve such properties[12, 13]. Enhanced densification by super-solidus liquid phase was attempted by sintering in hydrogen atmosphere for austenitic stainless steel or to increase the mechanical properties such as tensile and fatigue strength by sintering in nitrogen environment and eventually, densification rate was boosted by micro addition of other elements such as silicon. In addition, elements which spark sintering and increase densification such as copper and boron were added to the duplex stainless steel in order to minimize residual porosity and enhancing ductility, so as to improve mechanical behavior of the final samples [12].

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It is proven that sintering-cooling rates have high impact on microstructure of materials [4, 13]. Decrease in corrosion resistance by the presence of brittle phases in austenitic and ferrite stainless steel samples sintered in vacuum and followed by slow cooling. Powder Injection molded austenitic stainless steel (316 L) exhibits improved mechanical and corrosion properties sintered in vacuum with a cooling rate of 10 °C per min, as compared to those cooled at 5 °C per min [14].

Pakistan is one of the major exporters of hand-held surgical instruments throughout the world [15-17]. Owing to the quality of Pakistan's surgical instruments as compared to its cost, various international brands are reported to have shut down their manufacturing units. The surgical industry plays a crucial role as it contributes 1.6 % to overall exports of Pakistan. It has among highly potential items to enhance its contribution to country's overall exports. If proper policymaking is provided, this industry can easily achieve its full potential which will allow it to compete with its global competitors, according to the major industry's players [18, 19].

On the other side of coin, the manufacturers of surgical products in Pakistan are facing several problems. The major problems include lack of adaption of new technology and modernization, continuously decreasing skilled labors and lack of proper R & D for innovation. The industry will face a new and emerging challenge as the European Union is going to introduce Medical Device Regulation (MDR) in the beginning of 2024. According to this law, the surgical instruments will have to be compliant with the new European regulations on biocompatibility. The growing markets of China and Mexico are also posing a major competition for Pakistan's exporter as their innovation sides are more advanced [19-21].

Manufacturing of various engineering products by the use of PM is an emerging field in developing countries. A recent advent 3D printing manufacturing technology, which can be considered as modern shape of Powder Metallurgy is set to revolutionize many industries. 3D printing manufacturing technology has the ability to manufacture any engineering design/parts at a fraction of the present cost. It is expected that this manufacturing technology will change the face of today industries. 3D printing plays a major and important role in the field of medical devices manufacturing [22-24].

Due to the advantage of low labor cost of Pakistani industries, it remains competitive in the international market. The 3D printing manufacturing technology is presently utilized for prototyping only in developed countries, while Pakistan is still sticking to the conventional machining process which uses high energy and human resources. If commercial application of 3D printing started its operation for batch production, our industry might face existential risk in the near future. Therefore, serious steps need to be taken to counter the recent challenges [19].

In the present research, microstructure, density, porosity and mechanical properties of AISI 420 martensitic stainless steel sintered in Argon environment were investigated as a function of temperature for making surgical tools by powder metallurgy, a step way forward to strengthen the manufacturing quality of said tools in Pakistan.

2. MATERIALS AND METHODS

A commercially available AISI 420 martensitic stainless-steel SP-112 grade powder with a mesh size of -200 and zinc stearate as a binder were selected as the base material to prepare surgical tool samples in this research. Powder-binder mixture with different weight percentages of zinc stearate ranges from 0.90 weight % to 4 weight % was prepared in tubular mixer for 30 min. After mixing, zinc stearate powder was homogenously distributed within the stainless-steel powder and hydraulic press of 250 ton's capacity at ~2500 psi for ~8 sec's. Zinc stearate was also used as a die lubricant. Green compact specimens were sintered in Argon atmosphere with a flow rate of Argon gas is 1.5 normal liters per min at different sets of temperature ranges from 1000 °C to 1250 °C, and then cooled in a water-cooled chamber as shown in Table 1. The chemical composition of AISI 420 stainless steel powder is given in Table 2. The schematic representation of the PM process adopted for the present study is shown in Figure 1.

2.1 Characterization Technique

The samples for microstructure evaluation were prepared by cutting the specimen from different parts of surgical tools followed by grinding and polishing. Electrochemical etching using Oxalic acid (10 gram) and distilled water (90 %) was used in order to reveal the microstructure. Density of sintered samples was measured by water

Table 1. Experimental conditions used for sintering of AISI420 stainless steel compacted surgical tools

Sample ID	Base Powder	Binder	Sintering Temperature	Soaking Time	Sintering Environment
Sample 1	420 SS	Zinc stearate	1000 °C	30 min	Argon, Vacuum
Sample 2	420 SS	Zinc stearate	1100 °C	30 min	Argon, Vacuum
Sample 3	420 SS	Zinc stearate	1120 °C	30 min	Argon, Vacuum
Sample 4	420 SS	Zinc stearate	1140 °C	30 min	Argon, Vacuum
Sample 5	420 SS	Zinc stearate	1150 °C	30 min	Argon, Vacuum
Sample 6	420 SS	Zinc stearate	1200 °C	30 min	Argon
Sample 7	420 SS	Zinc stearate	1220 °C	30 min	Argon
Sample 8	420 SS	Zinc stearate	1250 °C	30 min	Argon

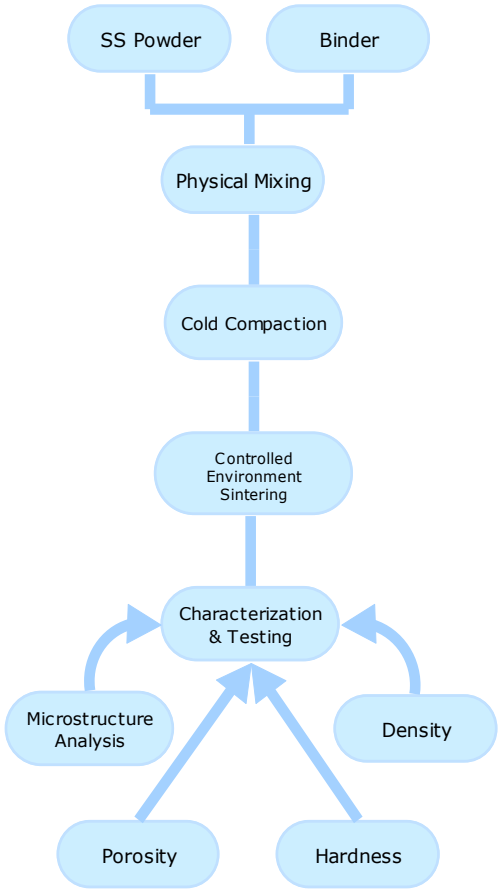

Fig. 1. Schematic representation of Powder Metallurgy Process adopted for present study

Table 2. Composition of AISI 420 martensitic stainless steel as received

Cr	Ni	C	Mo	Mn	Si	Fe
12/14	3/5	0.25-0.35	2/3	≤1	≤1	Balance

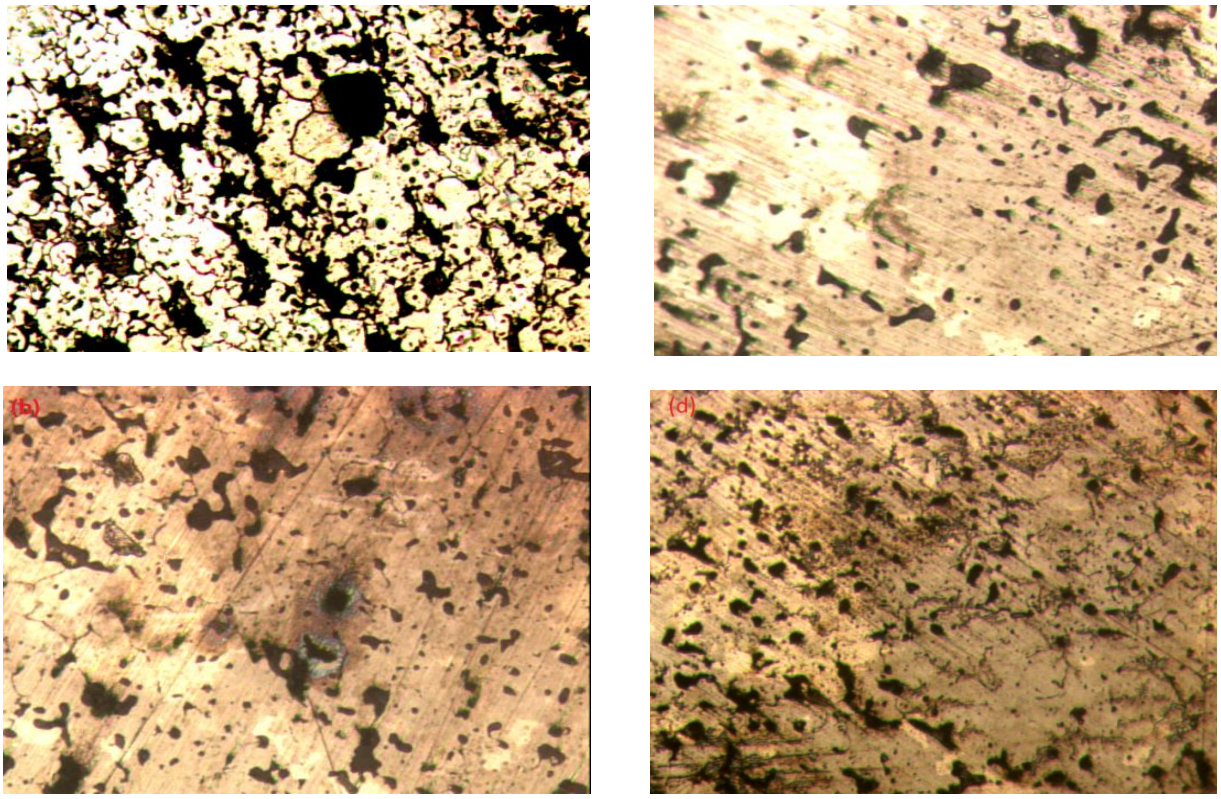

Fig. 2. Optical micrographs of 420 martensitic stainless steel samples sintered at different temperatures (a) 1000 °C, (b) 1150 °C (c) 1200 °C, and (d) 1250 °C

displacement method based on the Archimedes principle in accordance with the ASTM B328-03 standard. Mechanical properties of sintered samples were evaluated using Vickers hardness test. Image J software was utilized to find out the porosity of sintered samples.

3. RESULTS AND DISCUSSION

Microscopic images were obtained in order to examine the porosity of sintered samples shown in Figure 2(a-d). As the samples were sintered within a temperature range of 1000 °C up till 1250 °C under a controlled environment, it was observed that the samples sintered at 1000 °C exhibited higher porosity due to low solid diffusion rate, whereas with the rise in temperature up till 1250 °C, total porosity levels started to decrease. As we know, porosity level can be reduced by two methods in powder metallurgy. The first method is to increase the compaction pressure in order to raise densification of green bodies. The other method is to increase the sintering temperature. At 1100 °C, the porosity level decreases as compared to that of lower temperatures. Upon reaching 1200 °C, the changes in total porosity level becomes prominent, which means proper sintering of green samples has been completed at this temperature, minor or almost negligible changes observed after the temperature at 1250 °C [5, 12] as shown in Figure 3. Moreover, as the sintering temperature increases to around 1200 °C, pore sizes are getting smaller and smaller due to the effect of solid-state diffusion within the samples.

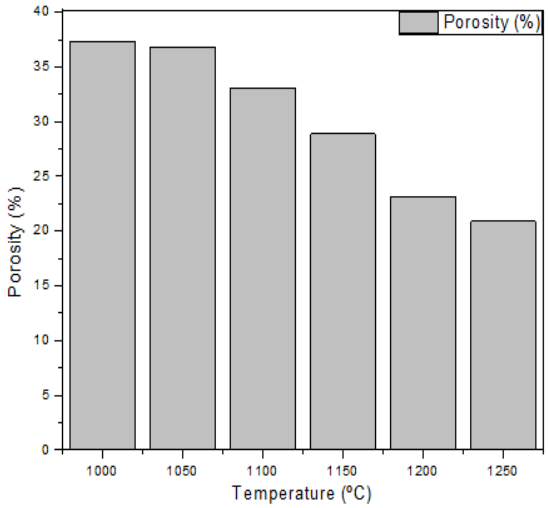

Fig. 3. Percentage/Volume of porosity determined for 420 martensitic stainless steel obtained by Image J

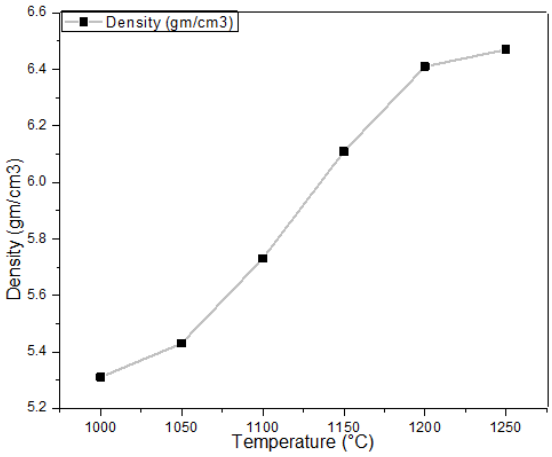

Fig. 4. Density changes with respect to sintering

The sintering process is actually based on diffusion phenomena. The micrographs (Figure 2) clearly show that half of the pores are so small at higher sintering temperature that they act as closed pores as compared to open ones, which are dominant in lower sintering temperature. Relative density of sintered samples was measured by the Archimedes principle. It is clear from Figure 4 that density increases by increasing sintering temperature [25]. As previously discussed, diffusion phenomenon is dominant at higher temperatures, so we obtained dense samples at those temperatures [5]. Hardness of any sintered material strongly depends upon the porosity level percentage. The main idea of our research is to replace surgical tools manufacturing through forging and machining by production through sintering via powder metallurgy. Hardness of sintered samples is always lower compared to those of forged ones. Hardness values (HV) of samples sintered at 1000 °C are about 85 HV, but,

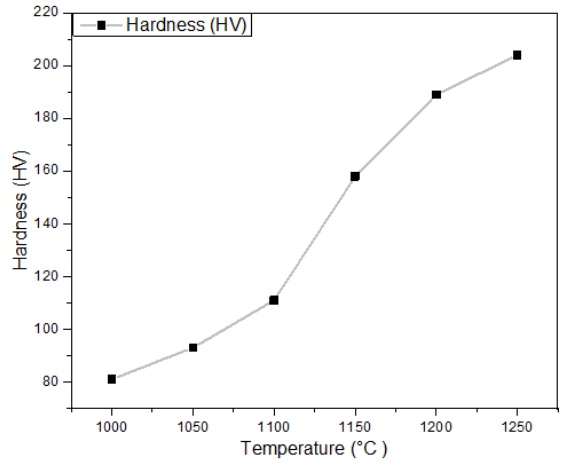

Fig. 5. Comparison of hardness values for different samples

Fig. 6. Surgical tools prepared via powder metallurgy temperature calculated by Archimedes principle

at higher sintering temperature, hardness values start to increase up to 205 HV at 1250 °C as shown in Figure 5. Compaction force and cooling rate also affects hardness values and it is very important factor for stainless steel products [26]. Consequently, in this research, cooling of sintered samples in a water-cooled furnace is responsible for increment in hardness values. The final surgical tools developed as a result of present study are presented in Figure 6.

4. CONCLUSION AND RECOMMENDATION

For PM stainless steel, the hardness, pore size and density were found improved by the application of proper sintering temperature and compaction pressure. At high temperature, the diffusion phenomenon becomes high as compared to that at lower temperatures, and it is the main concept behind good mechanical properties and density of the sintered samples. In the present research, unfortunately, we didn't achieve the optimum mechanical properties necessary for commercial surgical tools. However, it was a first step/struggle towards upgradation of aforementioned tools manufacturing process in Pakistan. The present study will open new doors for researchers to work for the betterment in the said field.

Mechanical properties, density and porosity will expectedly increase by sintering of surgical tools in nitrogen and hydrogen environment and we are further working on similar sintering environment. Enhancement of overall properties can expectedly be done by using additive manufacturing process or the novel 3D printing process.

5. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Research Article

Modeling and Robust Fractional Order Fuzzy Sliding Mode Two Time Scale Controller Design for Synchronous Generator of ACP1000 Nuclear Power Plant in LabVIEW

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Abstract: A state-of-the-art higher-order model of a synchronous generator is developed for ACP1000 nuclear power plant in the present research. The model is transformed into state space form. The state space model is decomposed into the two-time-scale framework. Based on the dynamics of the synchronous generator, fast and slow states are identified. The reduced order slow model is identified by neglecting the fast dynamics. A closed-loop model is developed in the frequency domain incorporating coupled and decoupled dynamics as separate transfer functions. The closed-loop model is configured as input-output pairs and two controllers are synthesized using a hybrid fraction order proportional integral derivative sliding surface oriented adaptive fuzzy two-time-scale control algorithm. The simulation model is developed in the graphical programming environment LabVIEW. The open and closed loop dynamics of the synchronous generator is simulated and analyzed in frequency and time domain separately. The proposed closed-loop framework is robust in performance, results are accurate and stable well within robust performance bounds.

Keywords: Synchronous Generator, Fractional Order, Adaptive Fuzzy Logic, Sliding Mode Control, ACP-1000, Nuclear Power Plant, LabVIEW.

1. INTRODUCTION

The synchronous generator of the Advanced Chinese Pressurized Water Reactor (ACP1000) type nuclear power plant is addressed in the present study for modeling, model reduction, control design, analysis and simulation purposes in the LabVIEW environment. The theoretical modeling aspects of the synchronous generator are discussed by Ernesto *et al.* [1]. A real-time experimental facility for synchronous generator is developed and simulation is performed by Helmy *et al.* [2]. A detailed first principle model is developed and simulated by Brazovac *et al.* [3] for the synchronous generator. A large industrial model of a 500 MWe power plant is analyzed and a PI controller is designed for the synchronous generator by Daphadar *et al.* [4]. A large industrial model of a 1000 MWe power plant is analyzed and the PI controller is designed for the synchronous generator by Fodor *et al.* [5]. Modeling and fault detection for the synchronous generator is performed by Karnavas *et al.* [6] in LabVIEW. The phase diagram and capacity curve for the synchronous generator is analyzed by Sardar *et al.* [7] in LabVIEW. Experimental parametric model estimation is performed in the LabVIEW environment by Szabo *et al.* [8]. A comprehensive model of a synchronous generator is developed and simulated in LabVIEW and its performance is compared with the model developed in MATLAB for a 1000 MWe power plant by Dume [9]. A synchronous generator model is synthesized in a two-time scale framework by Mahmoud [10]. Research is further explored in the area of artificial

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intelligence. A fuzzy logic controller is designed for synchronous generators by Sumina *et al.* [11]. The nonlinear sliding mode controller is established for an analytical model of a synchronous generator by Chang and Wen [12]. A nonlinear fractional order controller is designed for synchronous generator by Asadollahi *et al.* [13]. Further research is addressed for a hybrid fuzzy logic and two-time scale controller design for a robot arm manipulator by Lin and Lewis [14]. An investigation is performed for hybrid fractional order sliding mode controller synthesis for permanent magnet type synchronous generator by Xiong *et al.* [15]. Research is further expanded for the study of adaptive fractional order sliding mode controller design for the permanent magnet-type synchronous generator by Aghazamani and Delavari [16]. A most modern algorithm is developed for adaptive fractional order sliding mode fuzzy logic switching controllers for uncertain dynamics of the nuclear reactor of ACP1000 nuclear power plant by Malik *et al.* [17].

In this research work, a novel non-integer hybrid approach is adopted using a state-of-the-art algorithm developed in a graphical programming environment LabVIEW. The proposed algorithm encompasses new fractional order proportional integral derivative sliding surface, intelligent adaptive fuzzy logic and continuous two-time-scale (FO-PIDSMC-AFL-TTS) framework for closed-loop dynamics of the synchronous generator of the most sophisticated third-generation ACP1000 nuclear power plant. The proposed framework is the novel algorithm which is designed for the first time in LabVIEW for the nuclear industry.

2. MATERIALS AND METHODS

2.1 Synchronous Generator

The generator is a directly driven, three-phase, 50 Hz, 1500 rpm, 4-pole synchronous generator with a Hydrogen-cooled stator core and rotor, and water-cooled stator coils. The generator auxiliary system comprises of sealing oil system, hydrogen and carbon dioxide control system and stator coil cooling water system. The generator is cooled by circulating hydrogen, which transfers heat to hydrogen-cooler. The cold gas is forced to the rotor ventilation channel by the fan, and through the ventilation hole to the stator core around. The stator coil is cooled by water. Cooling water enters from one end of the coil and exits from the other end after absorbing heat. Rotor coils are cooled by the internal axial duct by gas which back to the air gap after absorption heat. The gas flows through the generator and returns to the hydrogen-cooler. The stator is made with an inner frame and outer frame construction.

The generator is equipped with four hydrogen coolers. During installation, the coolers will be lowered into the generator through openings at the top of the generator frame. The magnetic core consists of stacking together cold-rolled, sheet metal magnetic segments with high permeability and low specific losses. The rotor shaft is machined from single steel forging free from injurious flaws and defects. The rotor shaft is mechanically coupled to the turbine. Floating-type retaining rings prevent straining of coil insulation. The retaining rings are made from forged 18Mn18Cr non-magnetic material.

The seal oil system is a double-ring type sealing oil system, used to seal the hydrogen with the frame of the generator, forming a hydrogen seal at the junction of the generator shaft. The seal oil system provides sealing oil to the sealing rings of the generator to prevent the escape of hydrogen from the generator, but also to prevent the outside air and moisture into the generator. The seal oil system ensures the stability of the differential pressure between the generator gas pressure and the seal oil pressure. Hydrogen is the cooling medium of the generator. The hydrogen and carbon dioxide gas system provides means for safely putting hydrogen in or taking hydrogen out of the generator by using carbon dioxide as a scavenging medium to prevent the air and hydrogen mixture and maintaining the gas pressure in the generator at the desired value. Hydrogen and carbon dioxide gas are supplied from the gas storage system. For cooling the generator stator coil by using the cooling water, the heat produced by the generator stator coil is taken away by the circulating high-purity water flowing through the stator hollow conductor (stator cooling water). The circulating high-purity water is cooled by closed-cycle cooling water in a water-water heat exchanger. The stator cooling water system provides circulating high-purity demineralized water to the generator stator coil.

Brushless excitation is adopted for the generator. The system contains an exciter, pilot and AVR (Automatic Voltage Regulator). The AVR contains the voltage regulator function together with limiters and other control circuits. The voltage regulator controls the output voltage of a power converter. The resulting DC voltage is supplied through field suppression equipment to the exciter field.

2.2 Synchronous Generator Modeling

The large-scale industrial synchronous generator is an electro-mechanical system. Various parameters/ symbols and variables used hereafter in the process of synchronous generator modelling are defined as follows:

α_i = Variable Fraction Orders
D_t = Time Derivative
ω_m = Rotor Mechanical Frequency
ω_e = Electrical Frequency
τ_e = Electrical Torque
R = Diagonal Matrix of Winding Resistances
L = Symmetric Inductance Matrix
L_m = Mutual Inductance between
J = Rotor Moment of Inertia
I_d = Generator Current d-axis System
I_q = Generator Current q-axis System
I_f = Field Current
V_q = q-axis Winding Voltage
ε = Separation Parameter
S = Sliding Surface
K_p = Proportional Gain
K_I = Integral Gain
K_D = Derivative Gain
K_{SMC} = SMC Gain
u(t) = Control Input Signal
u^F = Fractional Order Control Signal
F= Fractional
FO = Fractional Order
PID = Proportional Integral Derivative
SMC= Sliding Mode Control
AFLC= Adaptive Fuzzy Logic Controller
TTS = Two Time Scale
V_1 = Reference Input 1
V_2 = Reference Input 2
Y_1 = Cross Coupled Controlled Output 1
Y_2 = Cross Coupled Controlled Output 2
G_{11} = Transfer Function of Paired Input 1 and Output 1
G_{12} = Transfer Function of Paired Input 1 and Output 2
G_{21} = Transfer Function of Paired Input 2 and Output 1
G_{22} = Transfer Function of Paired Input 2 and Output 2
Cx = Product of Output Matrix and State Vector
Du = Product of Direct Transmission Matrix and Control Input
Bu = Product of Input Matrix and Control Input
$X_f(t)$ = Fast State Vector
Xs(t) = Slow State Vector
λ_d = Flux Linkage along *d*-axis
λ_q = Flux Linkage along *q*-axis
λ_{abf} = Three Phase Flux Linkages in Stationary Frame
N = Number of Turns
θ = Rotor Angle
T = Transpose of Matrix

If α_i are the variable fractional orders of time domain differential operators $D_t^{\alpha_i}$ then the electrical dynamics of the synchronous generator are computed by the two-phase stator model as [3]:

$$D_t^{\alpha_1}\lambda_{abf} = -RL(\theta)^{-1}\lambda_{abf} + V_{abf} \quad (1)$$

The electrical torque is computed as:

$$\tau_e = D_\theta^{\alpha_2}\left(\frac{1}{2}\lambda_{abf}^T L(\theta)^{-1}\lambda_{abf}\right) \quad (2)$$

The mechanical speed of the rotor is computed as:

$$D_t^{\alpha_3}\omega_m = \frac{1}{J}(\tau_e - B\omega_m) \quad (3)$$

Now, transform the above equations into a synchronous reference frame and the electrical dynamics is computed as [6]:

$$D_t^{\alpha_4}\lambda_d = -\frac{R}{L}\lambda_d + \omega_e\lambda_q + \frac{RL_m}{L}i_f \cos\theta \quad (4)$$

$$D_t^{\alpha_5}\lambda_q = -\omega_e\lambda_d - \frac{R}{L}\lambda_q - \frac{RL_m}{L}\lambda_q i_f \sin\theta + V_q \quad (5)$$

$$D_t^{\alpha_6}\theta = \omega_e - \frac{N}{2}\omega_m \quad (6)$$

The output equations are computed as:

$$i_d(t) = \frac{1}{L}\lambda_d - \frac{L_m}{L} i_f \cos\theta \quad (7)$$

$$i_q(t) = \frac{1}{L}\lambda_q + \frac{L_m}{L} i_f \sin\theta \quad (8)$$

Now, equations (4) to (8) are linearized and transformed into fractional order state-space form as:

$$D_t^{\alpha_i} x(t) = Ax(t) + Bu(t) \quad (9)$$

$$y(t) = Cx(t) + Du(t) \quad (10)$$

2.3 Fractional Order Two-Time Scale Modeling of Synchronous Generator

The electrical dynamics of a synchronous generator are fast while mechanical dynamics are slow. The fast and slow states of fractional order two-time scale state-space model of the synchronous generator are given as:

$$x_f(t) = \begin{bmatrix} \lambda_d & \lambda_q & \theta \end{bmatrix}^T \quad (11)$$

$$x_s(t) = \begin{bmatrix} \omega_m \end{bmatrix} \quad (12)$$

These states are associated with slow and fast subsystem equations responsible for the dynamics of synchronous generators.

The input and output vectors are defined as:

$$u(t) = \begin{bmatrix} I_f & \omega_e \end{bmatrix}^T$$

$$y(t) = \begin{bmatrix} I_d & I_q \end{bmatrix}^T$$

If ε is the separation parameter between the fast and slow sub-systems then the fractional order two-time scale state-space model of synchronous generator is given as:

$$\varepsilon D_t^{\alpha_i} x_f(t) = A_{11} x_f(t) + A_{12} x_s(t) + B_1 u(t) \quad (13)$$

$$D_t^{\alpha_i} x_s(t) = A_{21} x_f(t) + A_{22} x_s(t) + B_2 u(t) \quad (14)$$

$$y(t) = C_1 x_f(t) + C_2 x_s(t) + Du(t) \quad (15)$$

If the dynamics of the fast system are neglected then the reduced order slow system is derived as:

$$\begin{bmatrix} I_d(s) \\ I_q(s) \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} I_f(s) \\ W_e(s) \end{bmatrix} \quad (16)$$

If K_{11}(s) and K_{22}(s) are two controllers the closed loop dynamics corresponding to diagon input-output pairs as reference input signa output pairs then input-output pairs are derive as:

$$\frac{Y_1(s)}{V_1(s)} = G_{11}(s)_{Decoupled}\, G_{11}(s)_{Coupled} \quad (17)$$

$$\frac{Y_1(s)}{V_2(s)} = G_{12}(s)_{Decoupled}\, G_{12}(s)_{Coupled} \quad (18)$$

$$\frac{Y_2(s)}{V_1(s)} = G_{21}(s)_{Decoupled}\, G_{21}(s)_{Coupled} \quad (19)$$

$$\frac{Y_2(s)}{V_2(s)} = G_{22}(s)_{Decoupled}\, G_{22}(s)_{Coupled} \quad (20)$$

2.4 Hybrid Controller Modeling

Now, in this section, a hybrid control algorithm is developed based on fractional order PID sliding surface and adaptive fuzzy logic using the concept of algorithm developed in [18].

The fractional order PID sliding surfaces for K_{11}(s) and K_{22}(s) controllers are designed as:

$$S_{11} = K_{P_{11}} e_1(t) + K_{I_{11}} D_t^{-\alpha_{11}} e_1(t) + K_{D_{11}} D_t^{\alpha_{11}} e_1(t) \quad (21)$$

$$S_{22} = K_{P_{22}} e_2(t) + K_{I_{22}} D_t^{-\alpha_{22}} e_2(t) + K_{D_{22}} D_t^{\alpha_{22}} e_2(t) \quad (22)$$

The hybrid fractional order sliding mode adaptive fuzzy two-time scale controllers corresponding to these sliding surfaces are designed based on algorithm formulated in [18] as:

$$u_{11}(t) = u_{eq_{11}}^F(t) + K_{SMC_{11}}(D^{\alpha_{11}} e_1(t) + u_{AFLC_{11}} e_1(t) \quad (23)$$

$$u_{22}(t) = u_{eq_{22}}^F(t) + K_{SMC_{22}}(D^{\alpha_{22}} e_2(t) + u_{AFLC_{22}} e_2(t) \quad (24)$$

2.5 Graphical User Interface Development for Model Parameters in LabVIEW

The state space model of the synchronous generator is constructed by inputting model

generator is constructed by inputting model parameters using a graphical user interface (GUI) developed in LabVIEW. The GUI for the design parameters of the synchronous generator is shown in Figure 1 while, the symbolic representation of state space model matrices is shown in Figures 2 and 3.

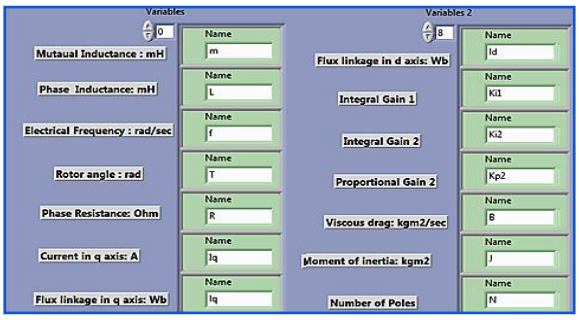

Fig. 1. GUI for design parameters of synchronous generator

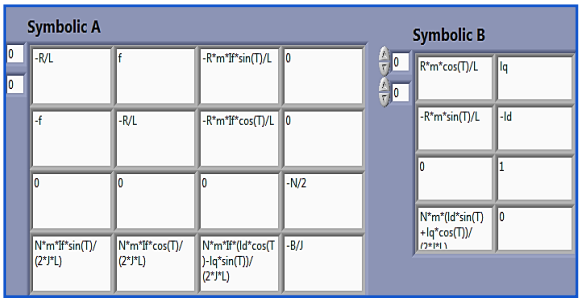

Fig. 2. Symbolic representation of linear model state space matrices A and B

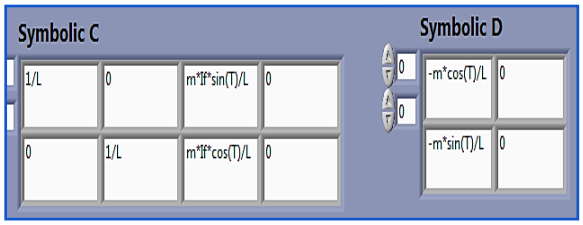

Fig. 3. Symbolic representation of linear model state space matrices C and D

2.6 Synthesis of Reduced Order Synchronous Generator Model

Now, in this section, the reduced order synchronous generator model is developed using equations (9) to (16). The synthesized automated model is developed in LabVIEW as shown in Figures 4 and 5.

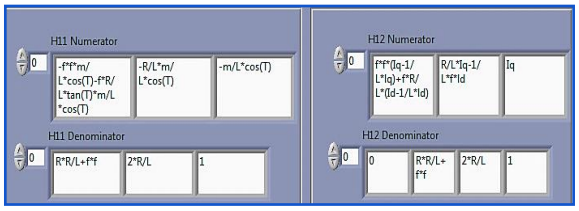

Fig. 4. Symbolic representation of reduced order transfer function elements H_{11} and H_{12}

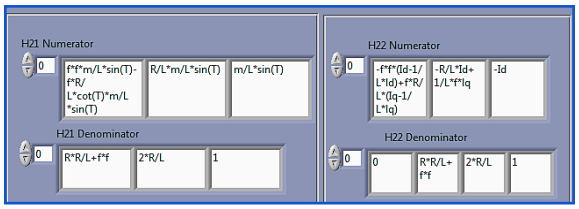

Fig. 5. Symbolic representation of reduced order transfer function elements H_{21} and H_{22}

3. RESULTS AND DISCUSSION

The design, analysis and simulation of synchronous generator is carried out in open loop and closed loop. The design analysis and performance evaluation is carried out in frequency domain and time domain in order to assess the robustness of synthesized model.

3.1.Evaluation of Synthesized Open Loop Framework in Frequency Domain

The reduced order model developed for synchronous generator as shown in Figures 4 and 5 is used for the open loop analysis of transfer function elements in the frequency domain using a Bode plot.

The magnitude and phase plots are designed and analyzed for transfer function elements in LabVIEW as shown in Figures 6 and 7. The frequency response proves that open loop reduced-order dynamics are guaranteed stable as there is not any unstable pole in the transfer functions.

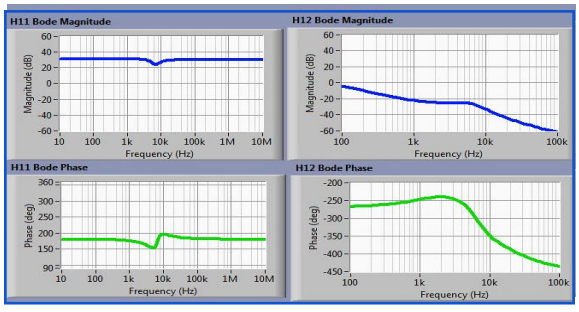

Fig. 6. Open loop frequency response of reduced order system H_{11} and H_{12}

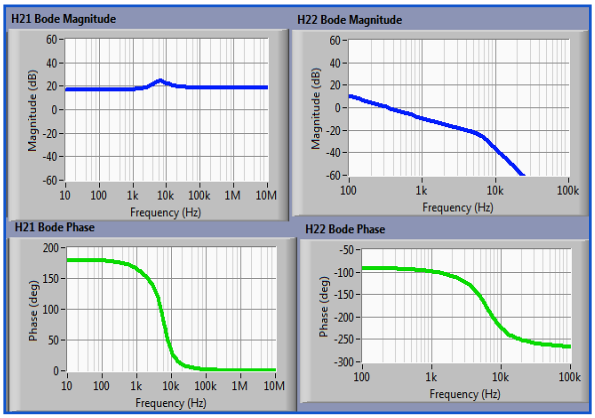

Fig. 7. Open loop frequency response of reduced order system H_{21} and H_{22}

3.2. Evaluation of Synthesized Closed Loop Framework in Frequency Domain

The input-output pairs are configured through a reduced order model with controllers $K_{11}(s)$ and $K_{22}(s)$ as shown in Figure 8. The reduced order model developed for the synchronous generator as shown in Figures 4 and 5 is used for the closed-loop analysis of transfer function elements in the frequency domain using a Bode plot. The magnitude and phase plots are designed and analyzed for transfer function elements in LabVIEW as shown in Figures 9 and 10.

3.3. Evaluation of Synthesized Closed Loop Framework in the Time Domain

The input-output pairs are configured in a closed-loop time domain. The time domain dynamics of internal states are shown in Figure 11. The dynamics of mechanical frequency due to slow and fast sub-systems are shown in Figures 12 and 13. Now, the closed-loop dynamics of the full-order system are analyzed and the behaviour of output parameters is shown in Figure 14. The output parameters are

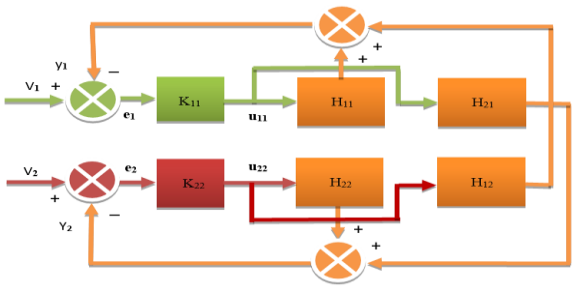

Fig. 8. Closed loop framework of FO-PIDSMC-AFL-TTS control system

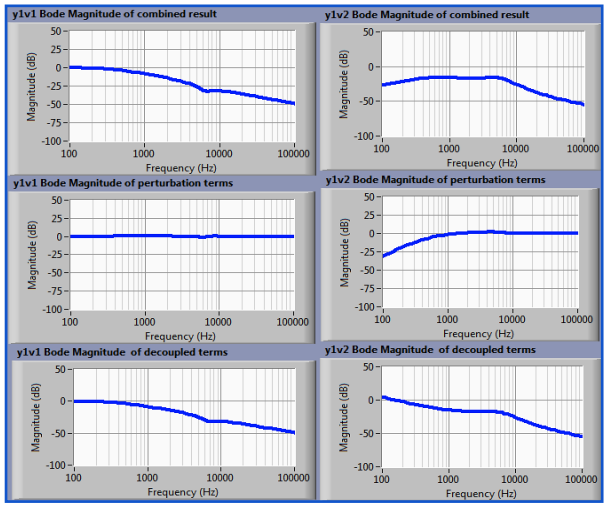

Fig. 9. Closed loop frequency response of decoupled system Y_1V_1 and Y_1V_2

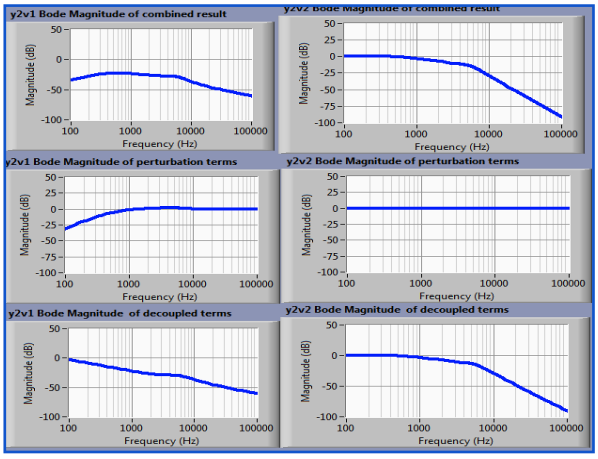

Fig. 10. Closed loop frequency response of decoupled system Y_2V_1 and Y_2V_2

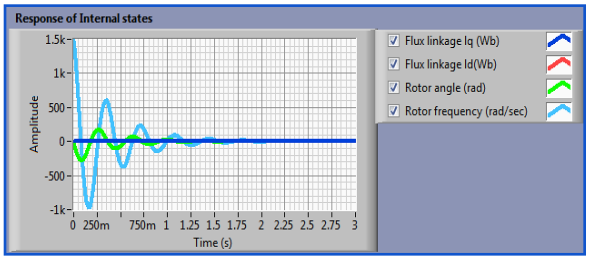

Fig. 11. Time response dynamics of internal states

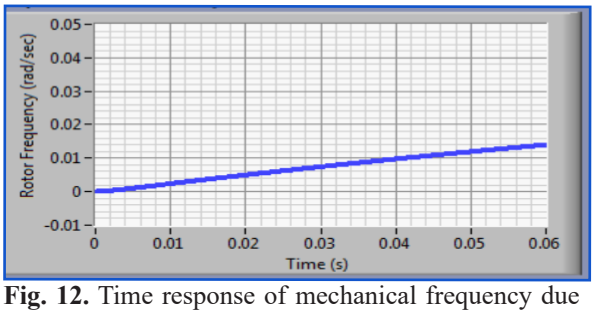

Fig. 12. Time response of mechanical frequency due to slow subsystem

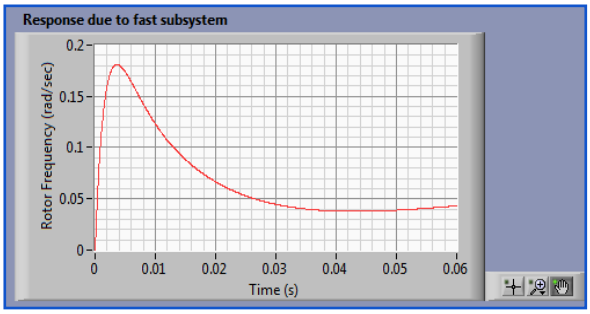

Fig. 13. Time response of mechanical frequency due to fast subsystem

visualized on a per-unit scale.

The inter-comparison of linear, linear fast and nonlinear model responses is assessed in Figure 15 and it is observed that the dynamics of Id due to the fast system model are fastest and nonlinear and fast linear model dynamics have almost no steady-state error.

The optimized design parameters of model and controllers' framework are obtained using Particle Swam Optimization (PSO) method. The optimized parameters are tabulated in Table 1.

4. CONCLUSION

The synchronous generator is the main electrical equipment on the conventional side of the ACP1000 nuclear power plant. A higher order two-time-scale state-space model of synchronous generator is developed in this research work. The stiff two-time-scale model is bifurcated into slow and fast sub-systems. Model reduction is accomplished using a time-scale design philosophy. Two separate controllers are designed for input-output pairs. Controllers are designed using a novel hybrid control design algorithm based on non-linear non-integer sliding mode and intelligent fuzzy logic for a two-time-scale framework in LabVIEW. The design approach is the first step towards two-time-scale and multi-time-scale dynamics of ACP1000 nuclear power plant systems.

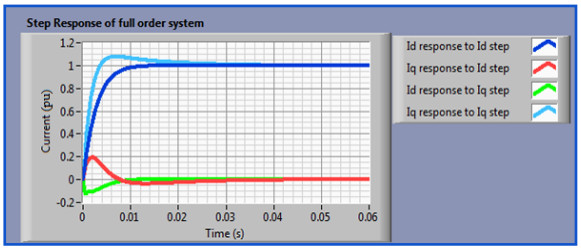

Fig. 14. Closed loop step response of full order feedback model

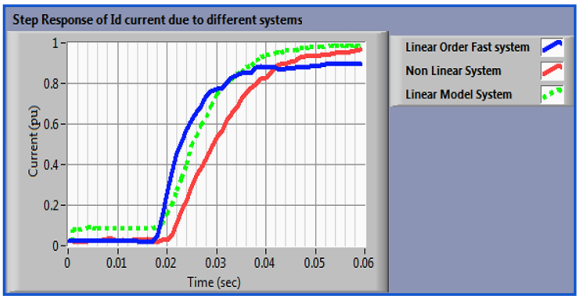

Fig. 15. Closed loop step response comparison of different system models

Table 1. Optimal design parameters of model and controllers

Optimal design parameters	Design values
α_3	0.91
α_4	1.12
α_5	1.22
α_6	0.98
α_{11}	1.40
α_{22}	1.35
K_{SMC11}	1.7
K_{SMC22}	3.4
Number of membership functions for $K_{11}(s)$	14
Number of membership functions for $K_{22}(s)$	18
Scalar design parameters of $K_{11}(s)$	28
Scalar design parameters of $K_{22}(s)$	36

5. ACKNOWLEDGEMENTS

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6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Research Article

An Efficient Class of Repeated Measurements Designs to Control the Residual Effects Using Periods of Three Different Sizes

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Abstract: Repeated measurements designs (RMDs) are always economical but with the use of these designs, there may arise residual effects. Minimal strongly balanced RMDs are well known to estimate the treatment effects and residual effects independently. In the situation, where these designs cannot be constructed, minimal nearly strongly balanced RMDs are used which is an efficient class of RMDs to control the residual effects. In this article, efficient minimal circular nearly strongly balanced RMDs are constructed in periods of three different sizes.

Key Words: Repeated Measurements Design, Carry Over Effects, Residual Effects, Strongly Balanced RMDs, Minimal Designs.

1. INTRODUCTION

Repeated measurements designs (RMDs) are popular in experiments of psychology, pharmacology, medicine, and animal sciences, but residual effects may arise in RMDs. Effect which a treatment has during its period of application (treatment effect) may persist into the preceding period. Such effect is called residual effect or carry over effect. Balanced or strongly balanced RMDs control these effects efficiently. RMD is minimal balanced (MBRMD) with respect to the residual effects if each treatment is immediately preceded once by all other treatments (excluding itself). RMD is minimal strongly balanced (MSBRMD) if each treatment is immediately preceded once by all other treatments (including itself). Using method of cyclic shifts, minimal circular strongly balanced RMDs (MCSBRMDs) can only be constructed through its Rule I which provides constructions of these designs for some specific cases of number of treatments (v) and period size (p). For most of the remaining cases, Rule II provides construction of minimal circular nearly strongly balanced RMDs (MCNSBRMDs). If each treatment is immediately preceded once with all other treatments (including itself) except v-1 which is not preceded with itself then it is MCNSBRMD. If experimental subjects are human or animals, they may die or recover during the experiments. In such cases, proposed designs should be used in unequal period sizes.

Williams [1-2] constructed MBRMDs for v even with $p = v$, where p is the period size and v is the number of treatments. Pearce [3] used RMDs in experiments in biology. The application of RMDs with unequal period sizes in experiments of industry and agriculture was described by the Kageyman [4]. Magda [5] gave the idea of a circular balanced RMD (CBRMD). Constantine and Hedayat [6], and Afsarinejad [7-8] constructed MBRMDs for $p < v$. Afsarinejad [9] also introduced a simple method to obtain MBRMDs and MSBRMDs in periods of unequal sizes. Using cyclic shifts, Iqbal and Jones [10], and Sharma *et al.* [11] constructed efficient RMDs in equal and two distinct periods. Iqbal and Tahir [12,14], and Sharma *et al.* [13] presented some CSBRMDs through cyclic shifts. Bailey *et al.* [15]

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constructed universally optimal weakly balanced RMDs for $p = v$. Bashir *et al.* [16], and Rajab *et al.* [17] generated some CBRMDs in equal period sizes. Rasheed *et al.* [18] generated MCSBRMDs for even p_1, $3 \le p_2 \le 10$ and $2 \le p_2 \le 9$. Daniyal *et al.* [19], Ahmed *et al.* [20], and Rasheed *et al.* [21] constructed some MCSBRMDs. Khan *et al.* [22] generated some minimal circular weakly BRMDs in equal period sizes. Some infinite series of minimal circular strongly partially BRMDs are developed by Jabeen *et al.* [23]. Using Rule I, recently, Rasheed *et al.* [24] constructed MCNSBRMDs in periods of three different sizes with smallest of size two. MCNSBRMDs are efficient designs but these are not available for $p_3 = 3$. Construction of MCNSBRMDs in three distinct period sizes with smallest of size three will be an innovational work. In this article, therefore, MCNSBRMDs are constructed in periods of three different sizes for $v \le 100$, $4 \le p_1$ (odd) ≤ 9, $4 \le p_2 \le 8$ and $p_3 = 3$.

Our proposed designs are highly efficient (i) to estimate the residual effects and treatment effects independently, (ii) to control the residual effects. Proposed designs have their application in the field of medicine, agriculture and animal sciences.

2. MATERIALS AND METHODS

Procedures are explained to find the efficiency for residual effects and efficiency of separability in the following sections.

2.1 Efficiency for Residual Effects

The canonical efficiency factors are the harmonic mean of non-zero Eigen values of their respective C^* (information matrix) are expressed by James and Wilkinson [25], and Pearce *et al.* [26]. Design possessing high value of E_r will be efficient to estimate the residual effects.

2.2 Efficiency of Separability (ES)

The following relation is given by Divecha and Gondaliya [27] for Es.

$$Es = \left[1 - \left\{\frac{(l_1 + 4l_2)v - (l_1 + 2l_2)^2}{(v-1)(l_1 + 2l_2)^2}\right\}^{\frac{1}{2}}\right] \times 100\%,$$

where

l_1 : No. of treatments preceded once by other treatment.

l_2 : No. of treatments preceded twice by other treatment.

3. CONSTRUCTION OF EFFICIENT MCNSBRMDS IN THREE DISTINCT PERIOD SIZES

In this Section, using the method of cyclic shifts (Rule II) introduced by Iqbal [28], MCNSBRMDs are constructed from the following sets of shifts in three distinct period sizes for $v = ri+s+2$, here $p_1 = r$ (odd), $p_2 = s$, and $p_3 = 3$. In these designs, only one pair (v-1, v-1) do not appear while all others appear once which means v-1 does not appear as its own preceded treatment.

$S_u = [q_{u1}, q_{u2}, \ldots, q_{u(r-1)}]$; $\quad u = 1, 2, \ldots, i.$
$S_{u+1} = [q_{(u+1)1}, q_{(u+1)2}, \ldots, q_{(u+1)(s-1)}]$,
$S_{u+2} = [q_{(u+2)1}]t.$

Here,

- Each element of sets lies between 0 and v-2.
- In S*, all of 0, 1, 2, …, v-2 appear once.

Here, S* contains (i) each element of all sets, (ii) complement of the sum of elements in each set except the last set with single element, where complement of 'a' is v-1-a.

Example 3.1: $S_1 = [1, 2, 3, 4]$, $S_2 = [6, 7, 8]$ and $S_3 = [5]t$ provides following MCNSBRMD for $v = 11$ in $p_1 = 5$, $p_2 = 4$ and $p_3 = 3$.

Here, S* = [1, 2, 3, 4, 0, 6, 7, 8, 9, 5] contains each of 0, 1,…,9 exactly once. Hence given sets of shifts provide MCNSBRMD. The complete design is obtained through Rule II from the given sets of shifts in the following manners, see Table 1, 2, and 3.

Table 1: Blocks generated from $S_1 = [1, 2, 3, 4]$

Periods	Subjects									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0	1	2	3	4	5	6	7	8	9
2	1	2	3	4	5	6	7	8	9	0
3	3	4	5	6	7	8	9	0	1	2
4	6	7	8	9	0	1	2	3	4	5
5	0	1	2	3	4	5	6	7	8	9

Table 2: Blocks generated from $S_2 = [6, 7, 8]$

Periods	Subjects									
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	0	1	2	3	4	5	6	7	8	9
2	6	7	8	9	0	1	2	3	4	5
3	3	4	5	6	7	8	9	0	1	2
4	1	2	3	4	5	6	7	8	9	0

Table 3: Blocks generated from $S_3 = [5]t$

Periods	Subjects									
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
1	0	1	2	3	4	5	6	7	8	9
2	5	6	7	8	9	0	1	2	3	4
3	10	10	10	10	10	10	10	10	10	10

Tables 1, 2, & 3 jointly present the MCNSBND for $v = 11$ in $p_1 = 5$, $p_2 = 4$ and $p_3 = 3$.

Catalogues of MCNSBRMDs are presented in Appendix for $v \leq 100$, $5 \leq p_1 \leq 9$, $4 \leq p_2 \leq 8$ and $p_3 = 3$.

4. RESULTS AND DISCUSSION

To estimate the treatment and residual effects independently, MCSBRMDs are 100 % effective but these are not available for all combinations of v and p. Our proposed MCNSBRMDs have at least (i) 97 percent efficiency of Separability, making them the best alternatives to MCSBRMDs for independently estimating residual effects and treatment effects, and (ii) 81 percent efficiency of residual effects, making them effective to control residual effects. As a future work, a catalogue of efficient MCNSBRMDs will be constructed in three distinct sizes with $p_3 > 3$.

5. CONCLUSION

In the present study, minimal circular nearly strongly balanced RMDs (MCNSBRMDs) have been constructed to control the residual effects. These designs are the best alternatives of minimal circular strongly balanced RMDs (MCSBRMDs) which are useful in the field of medical, agriculture and animal sciences.

6. ACKNOWLEDGEMENT

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7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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APPENDİX

MCNSBRMDs for $v \leq 100$, $5 \leq p_1$ (odd) ≤ 9, $4 \leq p_2 \leq 8$ and $p_3 = 3$, where $p_1 > p_2$.

v	p_1	p_2	p_3	Sets of Shifts	Es	Er
11	5	4	3	[1,2,3,4]+[6,7,8]+[5]t	0.97	0.87
21	5	4	3	[12,2,3,4]+[5,7,9,8]+[15,1,13,14]+[16,6,18]+[10]t	0.98	0.83
31	5	4	3	[1,2,3,4]+[13,7,8,18]+[11,12,6,5]+[16,17,9,19]+[21,22,23,24]+ [10,27,28]+[15]t	0.99	0.82
41	5	4	3	[1,2,3,12]+[19,6,7,8]+[26,4,9,5]+[15,16,17,18]+[21,13,23,24]+ [11,27,28,29]+[30,31,32,33]+[35,37,38]+[20]t	0.99	0.82
51	5	4	3	[1,2,3,4]+[5,6,7,8]+[10,11,48,22]+[16,17,18,19]+ [13,21,23,14]+[26,27,28,20]+[36,32,33,34]+[42,37,38,39]+ [41,35,43,31]+[45,46,47]+[25]t	0.99	0.81
61	5	4	3	[1,2,3,5]+[4,7,8,10]+[11,12,13,15]+[14,17,18,20]+ [19,32,23,24]+[26,58,28,29]+[6,48,33,34]+[45,37,25,38]+ [50,47,43,44]+[40,42,21,41]+[16,57,53,54]+[46,52,27]+[30]t	0.99	0.81
71	5	4	3	[11,18,3,48]+[6,7,8,9]+[20,38,13,14]+[16,17,2,1]+ [21,22,23,24]+[25,27,28,29]+[26,61,33,15]+[36,37,49,19] + [30,42,43,44]+[45,46,47,68]+[41,52,53,54]+[39,56,57,58]+ [32,62,63,64]+[65,66,67]+[35]t	0.99	0.81
81	5	4	3	[1,2,3,4]+[5,7,8,9]+[56,17,13,14]+[15,16,18,19]+ [34,39,23,35]+[26,27,33,49]+[31,38,47,48]+[24,36,37,41]+ [32,42,43,44]+[46,28,21,20]+[65,52,53,64]+[11,57,58,59]+ [61,62,63,54]+[66,67,68,69]+[71,72,73,74]+[75,77,78]+[40]t	0.99	0.81
91	5	4	3	[1,2,3,4]+[28,67,8,17]+[11,12,13,14]+[20,24,18,19]+ [21,22,23,26]+[16,27,6,76]+[31,32,33,34]+[36,37,38,75]+ [41,42,43,44]+[89,46,86,49]+[69,5,53,58]+[66,65,68,64]+ [61,62,63,59]+[57,56,52,54]+[71,72,73,74]+[39,29,77,78]+ [79,81,82,83]+[87,48,30]+[45]t	0.99	0.81
13	7	4	3	[1,3,2,4,5,9]+[7,8,11]+[6]t	0.97	0.90
27	7	4	3	[1,2,3,4,5,11]+[9,8,10,14,25,20]+[6,16,15,17,19,24]+ [21,22,23]+[13]t	0.99	0.88
41	7	4	3	[1,2,3,4,5,25]+[7,8,9,10,11,12]+[15,16,17,18,19,39]+ [34,22,13,6,26,27]+[28,29,30,31,24,37]+[14,33,38]+[20]t	0.99	0.87
55	7	4	3	[1,2,3,4,5,39]+[8,9,48,11,12,13]+[14,15,17,18,37,19]+ [21,23,24,25,26,53]+[47,43,31,32,33,34]+[35,36,20,38,40,41]+ [16,30,22,45,46,29]+[10,51,52]+[27]t	0.99	0.87
69	7	4	3	[1,2,3,4,5,6]+[7,8,9,10,11,25]+[14,15,16,17,18,19]+ [22,23,13,24,26,29]+[28,20,31,32,21,33]+[30,36,38,27,40,41]+ [42,43,44,45,46,52]+[49,50,51,48,53,54]+[57,58,59,55,61,62]+ [63,64,65]+[34]t	0.99	0.86
83	7	4	3	[1,2,3,4,5,6]+[7,9,10,11,12,13]+[14,15,16,17,18,19]+ [60,23,24,25,26,54]+[29,42,31,32,33,81]+[35,36,37,51,39,27]+ [43,44,45,46,47,48]+[28,38,52,53,30,77]+[56,57,58,59,22,76]+ [63,64,8,66,67,68]+[70,71,72,73,69,75]+[40,78,79]+[41]t	0.99	0.86
97	7	4	3	[1,2,3,4,5,6]+[7,8,9,11,12,53]+[15,16,17,18,19,52]+ [21,22,23,24,25,50]+[29,30,60,32,49,34]+[35,37,38,39,14,41]+ [43,44,45,46,47,95]+[33,26,36,20,69,76]+[56,57,58,59,61,62]+ [63,42,65,66,67,68]+[70,71,72,73,74,80]+[77,78,79,81,82,83]+ [85,86,87,88,89,90]+[91,93,94]+[48]t	0.99	0.86
15	9	4	3	[3,2,1,4,6,5,8,13]+[10,11,12]+[7]t	0.98	0.91

v	p_1	p_2	p_3	**Sets of Shifts**	Es	Er
33	9	4	3	[1,2,3,4,5,6,7,8]+[10,11,12,13,14,21,30,17]+ [19,20,15,22,23,24,25,26]+[27,29,31]+[16]t	0.99	0.90
51	9	4	3	[1,2,3,4,5,6,7,22]+[10,11,48,21,14,28,16,17]+ [18,19,20,13,8,23,24,49]+[27,15,29,30,31,32,33,44]+ [36,38,37,40,39,41,42,43]+[45,46,47]+[25]t	0.99	0.90
69	9	4	3	[1,2,3,4,5,6,7,40]+[9,10,11,12,13,14,15,16]+ [18,19,20,21,22,23,24,25]+[28,29,30,31,26,33,67,35]+ [48,37,38,39,41,42,43,44]+[46,47,49,66,62,51,52,58]+ [54,55,56,57,53,64,60,50]+[63,59,65]+[34]t	0.99	0.87
87	9	4	3	[1,2,3,4,5,6,7,8]+[9,10,11,12,13,14,15,16]+ [18,19,21,22,23,24,25,26]+[44,28,29,31,32,33,34,35]+ [81,37,38,39,40,41,42,85]+[45,46,47,48,49,83,52,60]+ [54,56,55,57,58,59,53,61]+[62,64,65,66,67,68,69,70]+ [36,73,82,75,76,77,79,84]+[17,74,50]+[43]t	0.97	0.89
21	7	5	3	[1,2,3,4,5,6]+[7,8,9,11,12,13]+[15,16,17,18]+[10]t	0.98	0.66
35	7	5	3	[1,2,3,4,5,6]+[7,8,9,21,11,12]+[15,30,33,26,19,20]+ [22,23,24,25,18,14]+[29,16,31,32]+[17]t	0.99	0.87
49	7	5	3	[1,2,3,4,5,6]+[8,9,10,11,12,13]+[15,16,18,17,19,20]+ [22,23,47,25,26,28]+ [44,45,31,32,7,35]+ [36,37,38,14,40,41]+[42,43,29,30]+[24]t	0.99	0.87
63	7	5	3	[1,2,3,4,5,6]+[8,9,10,11,12,13]+[15,16,18,17,19,25]+ [22,23,24,20,26,27]+ [29,30,55,32,34,40]+ [36,37,38,39,56,7]+[42,43,21,45,46,51]+ [58,47,52,5 3,54,48]+[57,50,59,49]+[31]t	0.99	0.87
77	7	5	3	[1,2,3,4,5,6]+[14,9,10,11,12,13]+[15,28,30,40,19,74]+ [41,23,24,25,26,27] +[29,37,47,32,33,34]+ [36,17,75,39,18,8]+[43,44,45,46,31,53]+ [49,50,51 ,52,48,54]+[57,58,59,60,61,21]+ [56,65,66,67,70,69]+[71,72,73,20]+[38]t	0.99	0.87
91	7	5	3	[1,2,3,4,5,6]+[8,70,10,11,12,13]+[27,36,17,18,19,20]+ [22,23,28,25,26,35] +[29,63,31,32,33,58]+ [16,37,38,39,84,41]+[52,44,89,46,47,40]+ [50,51,49,53,54,55]+[77,59,34, 60,61,62]+ [30,64,65,66,67,68]+[71,72,73,74,75,76]+ [78,79,80,81,82,83]+[85,86,87,88]+[45]t	0.99	0.84
25	9	5	3	[1,3,2,16,5,6,7,8]+[10,11,23,13,18,15,4,17]+ [19,20,21,22]+[12]t	0.99	0.91
43	9	5	3	[1,2,3,4,5,6,7,14]+[9,11,12,13,8,15,17,16]+ [18,19,20,41,22,23,24,33]+[28,29,39,31,32,26,34,35]+ [36,37,38,30]+[21]t	0.99	0.90
61	9	5	3	[1,2,3,4,5,6,7,8]+[10,11,12,13,15,14,16,20]+ [18,17,19,21,22,25,23,35]+[54,58,29,59,31,32,33,38]+ [37,39,34,40,41,42,43,48]+[46,47,44,49,50,51,52,53]+ [27,55,56,57]+[30]t	0.99	0.90
79	9	5	3	[1,2,3,4,5,6,7,8]+[10,11,12,13,14,15,16,17]+ [19,56,21,22,23,24,25,26]+[27,29,28,30,31,32,34,35]+ [36,37,38,77,74,41,43,44]+[62,9,47,49,73,51,52,54]+ [53,55,20,57,58,59,61,60]+[72,50,65,33,67,68,69,76]+ [63,64,40,75]+[39]t	0.99	0.89
97	9	5	3	[1,2,15,88,5,6,7,8]+[9,10,11,12,13,14,3,28]+ [34,78,21,22,23,24,25,26]+[16,29,71,31,44,33,18,19]+ [36,37,38,39,64,53,42,43]+[46,47,95,49,87,63,52,41]+ [51,55,56,57,58,90,61,74]+[80,40,65,66,67,68,69,76]+ [20,4,86,75,54,77,30,79]+[82,83,84,85,62,50,73,72]+ [91,17,93,94]+[48]t	0.97	0.89

v	p_1	p_2	p_3	**Sets of Shifts**	Es	Er
15	7	6	3	[2,1,3,4,5,13]+[9,8,10,11,12]+[7]t	0.98	0.91
29	7	6	3	[1,2,3,4,5,6]+[8,9,10,11,12,13]+[27,15,16,17,18,19]+ [20,22,23,24,25]+[14]t	0.99	0.88
43	7	6	3	[1,2,24,4,5,6]+[7,8,10,11,12,13]+[14,15,16,17,18,19]+ [29,9,3,25,26,35]+[30,22,31,32,33,34]+[36,37,38,39,40]+[21]t	0.99	0.87
57	7	6	3	[1,2,3,4,5,6]+[8,9,10,11,12,13]+[14,15,16,17,18,25]+ [22,23,24,19,26,33]+[48,37,47,32,27,34]+[36,30,38,39,40,41]+ [42,43,44,45,46,31]+[50,51,52,53,54]+[28]t	0.99	0.87
71	7	6	3	[1,2,3,4,5,6]+[8,9,10,11,12,13]+[16,14,17,18,19,20]+ [52,62,24,25,26,27]+[22,30,31,32,33,34]+[15,37,38,39,40,42]+ [41,61,44,46,47,56]+[50,51,29,53,54,43]+[48,57,58,59,60,45]+ [21,65,66,67,68]+[35]t	0.99	0.87
85	7	6	3	[1,2,3,4,5,6]+[21,8,9,11,12,46]+[14,16,17,18,20,19]+ [22,80,24,25,26,27]+[29,65,31,32,33,34]+[62,37,38,43,39,41]+ [50,44,45,13,47,54]+[7,49,40,51,52,53]+[57,58,59,60,10,36]+ [55,15,30,66,67,68]+[70,71,72,73,74,75]+[78,79,23,81,82]+ [42]t	0.99	0.87
99	7	6	3	[1,2,3,4,5,6]+[8,9,10,11,12,13]+[14,15,16,17,18,19]+ [23,29,24,25,26,27]+[62,30,31,89,33,57]+[36,37,38,39,40,41]+ [43,44,45,46,47,48]+[56,51,52,53,54,55]+[34,58,59,60,61,22]+ [64,65,66,67,68,69]+[72,70,73,74,75,76]+[0,78,79,81,82,83]+ [85,86,87,88,32,28]+[92,93,94,95,96]+[49]t	0.97	0.84
17	9	6	3	[1,2,3,4,5,6,7,12]+[10,11,7,13,14]+[8]t	0.88	.99
35	9	6	3	[1,2,3,4,5,6,7,8]+[10,11,12,13,14,15,33,19]+ [18,20,16,30,42,22,23,26]+[27,28,29,21,31]+[17]t	0.94	0.90
53	9	6	3	[1,2,3,4,5,6,7,8]+[9,10,11,12,13,14,15,20]+ [34,17,21,22,23,32,25,51]+[27,50,30,31,24,33,18,19]+ [37,38,39,40,41,42,43,48]+[45,46,47,44,49]+[26]t	0.99	0.90
71	9	6	3	[1,2,3,4,5,6,7,8]+[9,10,12,11,13,14,15,16]+ [19,20,21,22,23,24,25,38]+[53,28,29,62,31,32,46,69]+ [37,26,39,17,66,42,43,44]+[45,33,47,48,49,68,51,52]+ [54,55,56,57,59,58,60,61]+[63,64,65,41,67]+[35]t	0.99	0.90
89	9	6	3	[1,2,3,4,5,6,7,8]+[9,11,12,13,14,15,16,17]+ [18,19,21,22,23,24,25,26]+[28,29,30,31,32,33,34,48]+ [36,37,38,39,40,41,27,43]+[80,46,47,35,49,78,42,53]+ [55,56,57,58,59,60,61,68]+[63,64,65,66,67,62,70,71]+ [20,85,82,75,76,77,50,79]+[81,74,83,84,73]+[44]t	0.99	0.90
27	9	7	3	[1,2,3,5,4,6,7,8]+[24,10,11,12,25,14,15,19]+ [18,17,20,21,22,23]+[13]t	0.99	0.92
45	9	7	3	[1,3,43,4,5,6,7,8]+[2,9,12,13,14,15,16,17]+ [19,20,18,21,24,23,25,26]+[28,29,27,39,31,33,32,35]+ [37,38,30,40,41,42]+[22]t	0.99	0.90
63	9	7	3	[1,2,3,4,5,6,7,8]+[9,10,11,12,13,61,15,38]+ [18,19,20,21,22,23,24,25]+[27,28,29,30,32,33,34,35]+ [36,57,60,55,56,41,42,43]+[45,46,48,49,50,51,52,53]+ [39,54,47,37,58,59]+[31]t	0.99	0.81
81	9	7	3	[1,2,3,4,5,6,7,8]+[50,11,12,53,14,15,16,17]+ [19,67,21,22,23,24,25,26]+[28,29,30,72,32,33,34,35]+ [37,38,39,79,41,42,43,45]+[46,47,48,49,10,51,9,60]+ [55,56,57,58,59,18,61,62]+[64,65,66,20,68,69,74,71]+ [73,70,75,76,77,78]+[40]t	0.99	0.90

v	p_1	p_2	p_3	**Sets of Shifts**	Es	Er
99	9	7	3	[1,2,3,4,5,6,7,8]+[10,11,12,13,14,15,18,17]+ [19,20,21,23,22,24,25,26]+[28,39,30,71,32,33,34,35]+ [36,37,38,61,40,41,42,53]+[46,47,48,97,50,51,52,54]+ [43,57,55,58,59,60,29,31]+[63,64,65,66,67,69,70,56]+ [72,73,74,76,75,77,78,79]+[81,80,83,84,85,87,89,88]+ [91,92,93,94,95,96]+[49]t	0.99	0.90
19	9	8	3	[1,3,2,4,5,6,8,7]+[11,10,12,13,14,16,15]+[9]t	0.98	0.93
37	9	8	3	[9,2,3,4,5,6,8,7]+[11,10,12,13,14,15,16,17]+ [19,20,21,22,23,24,27,25]+[26,29,30,31,32,33,34]+[18]t	0.99	0.91
55	9	8	3	[1,2,3,4,5,6,7,8]+[10,11,12,13,14,16,15,17]+ [53,20,21,34,23,24,25,26]+[28,29,41,31,32,33,35,22]+ [46,37,38,39,40,30,42,43]+[36,47,48,49,50,51,52]+[27]t	0.99	0.90
73	9	8	3	[1,2,3,4,5,6,7,11]+[23,8,12,13,14,15,16,17]+ [18,19,20,21,22,10,25,9]+[28,29,30,31,32,42,34,35]+ [46,38,39,68,59,24,43,44]+[47,37,48,49,50,51,52,53]+ [55,56,57,58,41,60,61,62]+[63,64,65,66,67,69,70]+[36]t	0.99	0.87
91	9	8	3	[1,2,3,4,5,6,54,16]+[9,11,12,21,14,15,8,17]+ [63,48,13,22,23,24,25,34]+[28,29,58,31,32,33,7,81]+ [37,38,39,40,41,42,43,44]+[60,47,62,49,50,51,52,53]+ [55,57,56,20,59,46,27,30]+[64,65,66,67,68,69,70,71]+ [72,74,75,76,77,78,79,80]+[82,83,84,85,86,87,88]+[45]t	0.99	0.83

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Research Article

Strengthening Pedestrian Safety: An Evaluation of Signals at Major Intersections in Lahore, Pakistan

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Abstract: Pedestrians' safe mobility at intersections is associated with the facilities provided at the crossings. Lahore is one of the most populous cities in Pakistan. Too many road accidents occur daily at various areas of Lahore in which pedestrian-vehicle collision has a major ratio. To reduce the pedestrian-vehicle collisions, pedestrian signals are installed at major intersections of Lahore city. This paper examines the relationship between pedestrian signals and Level of Service (LOS), with a focus on enhancing awareness of pedestrian signal operation and investigates the impact of pedestrian signals on the LOS of intersections in Lahore in terms of pedestrian movement. Research shows that the poor level of awareness about how pedestrian signals work contributes to the inadequate level of service of intersections in terms of pedestrian movement. The results also provide valuable insights for policymakers and practitioners in developing effective strategies to improve the pedestrian experience and reduce pedestrian-vehicle collisions at intersections.

Keywords: Pedestrian-Vehicle Collision, Pedestrian Signals, Pedestrians Awareness, Pedestrian Safety.

1. INTRODUCTION

Road safety with respect to pedestrian movement, is an important issue in cities around the world. Pedestrians are among the most vulnerable road users, and ensuring their safety is crucial for creating a comfortable and sustainable urban environment. Lahore, one of the most populous cities in Pakistan, is reportedly facing many road accidents on daily basis at various areas of the city. Among these, the pedestrian-vehicle collision has a major ratio. In view of high volume of traffic and increasing number of pedestrian-vehicle collisions at major intersections and saturated roads of Lahore, the Punjab Safe Cities Authority (PSCA) has installed pedestrian signals at major intersections of the city. PSCA is an autonomous government body that aims to improve road users' safety and traffic management in the province of Punjab, Pakistan. The main purpose of these signals was the safety and facilitation of pedestrians at crossings. Safe walking environments especially, along roadside encourage physical activities of people [1]. Occasionally, it is noticed that individuals feel greater ease when walking or crossing in areas equipped with suitable amenities. Govinda *et al.* [2] performed a comparative study of pedestrian crossing behaviour at uncontrolled intersection and midblock locations in medium size cities (Warangal and Thiruvananthapuram in India) under mixed traffic conditions and noted that the minimum crossing speed observed at the intersection is higher than the midblock. In low and middle income countries (LMICs) walking is still under consideration by majority of travellers. In LMICs, pedestrians' safety and security are an important public health objective with regard to injury control, as pedestrians suffer most of the road traffic fatalities and injuries. Compared to low and middle income countries (LMICs), high income countries (HIC) with crossing facilities have documented a decrease in pedestrian fatalities [3]. A Global burden of disease study states that there were half a million of pedestrian fatalities

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in the year 2010 [4]. Pedestrian fatalities usually occurred at the time of road crossing. Being a road user, pedestrians often get injured or even die during interaction with intersecting vehicles [5].

Some researchers have studied pedestrian non-compliance behavior at signalized intersections for the purpose of developing pedestrian speed flow relations [6] and also delay models [7]. Pedestrian crossing behaviors are important to know in order to examine the working of pedestrian signals. Factors affecting pedestrian crossing behaviors were identified for the improvement of pedestrian safety at signalized intersections [8]. Pedestrians exhibited increased confidence and ease when crossing in the presence of traffic signals. Conversely, at locations without a traffic signal, pedestrians had to exert nearly twice as much effort in determining appropriate gaps in traffic and making crossing attempts [9].

Pedestrians using crosswalk during pedestrian green phase were considered as compliance pedestrians while those who were using crosswalk during non-green phase were considered as non-compliance pedestrians. The percentage of pedestrian compliance was defined as the ratio between the number of pedestrians using the crosswalk during green phase and total number of pedestrians that arrived at crosswalks. Similarly, Marisamynathan and Perumal studied that during pedestrian non-green phases, pedestrians are prohibited to enter the intersection that is important for their safety [10]. Whereas, during pedestrian green phase, pedestrian-vehicle interactions might have occurred due to driver's negligence, that needs to be controlled for the safe movement of pedestrians on the crossings. Pedestrians' two stage crossing behavior is of great significance to enhance safety and efficiency for pedestrians at signalized intersections. A research shows that pedestrians in the two directions present different preferences in terms of route choice, waiting position, directional change and route type. Two-stage crossing is an effective measure to increase the pedestrian flow rate and the intersection capacity [11]. Pedestrians' walking speed is also an important parameter for designing traffic signals at signalized intersections [12]. Varsha and Bindhu have examined some factors affecting pedestrian crossing speed which are important for the improvement of pedestrian safety at intersections. Their field study shows that the crossing speed of pedestrians varies mostly from the expected constant value of 1.2 ms^{-1} [13]. Moreover, to predict vulnerable pedestrians' behavior there is a need for the highest level of development in the field of pedestrian safety. In this regard, Yang *et al.* [14], have introduced a groundbreaking neural network architecture that combines distinct spatio-temporal features in order to predict pedestrian crossing intentions.

In Pakistan, a large number of road accidents occur on daily basis at various sections/intersections of major roads in meteropolitan/most populus cities such as Lahore, Karachi etc in which pedestrian-vehicle collision has a major ratio. To reduce the pedestrian-vehicle collisions, the road authorities has installed pedestrian signals at major road intersections in these cities which has resulted in a fair decrease in the road traffic colloisons/crashes. As an example a prominent trend of decrease in road traffic crashes (RTC) in the city of Lahore has been observed during the year 2019 [15]. The data publicized by Punjab Emergency Service (PES) mentioned that in 2017, almost 443 people were killed in road accidents, whereas, in year 2019 the figure was reduced to 350 showing a clear decline in casualties. With the aim to provide safe and convenient crossing for pedestrians as well as vehicles PSCA has installed pedestrian signals at 65 intersections of Lahore. The main objective of present investigation is the evaluation of pedestrian signals at 4 major intersections of Lahore with respect to activation, working, effectiveness, awareness and users' satisfaction. Furthermore, evaluation of Level of Service (LOS) of intersections with respect to pedestrians' movement is also analyzed using SIDRA intersection tool. LOS is usually ranked by two parameters E (unstable flow) and F (forced traffic flow). The unstable flow (E) refers to the condition when the flow becomes irregular and speed varies rapidly because there are virtually no usable gaps to maneuver in the traffic stream and speeds rarely reach the posted limit. On the other hand, the forced traffic flow (F) refers to the condition when the amount of traffic approaching a point exceeds the amount that can be served. Accordingly, this type of LOS represents stop-and-go waves, increased accident exposure, low comfort and convenience, and poor travel times.

2. STUDY AREA

Lahore, the capital of the Punjab province Pakistan, has been selected for evaluation of signals at major road intersections in the city. The city of Lahore is a bustling metropolis with mixed traffic conditions that require careful consideration for pedestrian safety. There are a total of 6 towns in Lahore where pedestrian signals are installed, i.e., Model Town, Civil Lines, Saddar, Cantt, Iqbal Town and Walled city. The study area chosen for this research is Mall road in Civil Lines Town. Mall road is one of the major roads in Lahore. This historic road was built by the British on a route leading to governor house. Mall road is a wide, major traffic thoroughfare which has enough space to run along most sections of the road. Mall road Lahore is the one which is totally equipped with most of the technologies of Intelligent Transportation System under PSCA that is why this road is selected as study area. This road has 12 intersections in total among which only 4 four intersections namely, Faisal intersection, Regal intersection, GPO intersection and High Court intersection shown in Figure 1, on which pedestrian signals are fully operative have been selected for the analysis. These are the major intersections of Lahore having a minimum of 3 lanes road and a maximum of four lanes road with a greater volume of pedestrians.

3. RESEARCH METHODOLOGY

Current research has analyzed several pedestrian crossing behaviors at 4 selected signalized intersections on Mall road Lahore to provide insights for improving pedestrian safety. Figure 2 highlights the schematics/research methodology used in the present investigation.

The primary data about pedestrians crossing facility design, pedestrians' volume and signal control were obtained from field through pedestrians countdown survey. The pedestrian count surveys were conducted for peak hours in a single day. This data was used to evaluate the working of the pedestrian signals. Moreover, the data about awareness level, pedestrians' priority to cross the road, frequency of crossing, impact and effectiveness of pedestrian signals were also obtained from questionnaire survey. The questionnaire survey was divided into five sections i.e. socioeconomic factors, awareness level, usage/non-usage of signals, impact of signals on pedestrian accidents and effectiveness. The sample size comprised of 600 questionnaires. SPSS and SIDRA intersection tools were used for data analysis.

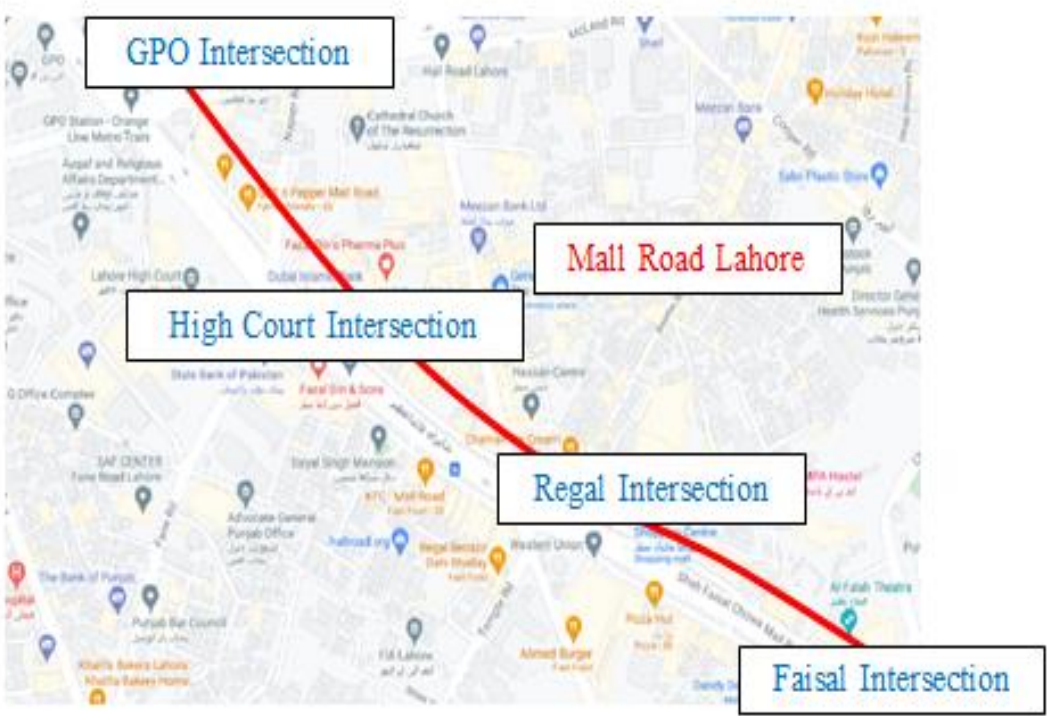

Fig.1. Map of study area/selected intersections on Mall road, Lahore

4. RESULTS AND DISCUSSION

4.1 Descriptive Analysis

Table 1 presents descriptive analysis with respect to various statistical parameters such as; (i) socioeconomic characteristics (age), (ii) awareness level of pedestrian signals, (iii) effectiveness of pedestrian signals (obeyance to follow pedestrian signals or otherwise, (iv) safety: reasons of pedestrian vehicles collisions, decrease in pedestrian vehicle collisions. The descriptive results shows that 30 % of respondents were females and 70 % were males. Maximum participants were of age between 20-35 years. Descriptive statistics show that 21 % of participants thought that pedestrians should cross the road whenever get a chance, while 41 % thought that pedestrians should cross the road when traffic light is red which is a safer option for the pedestrians. Moreover, 25 % of participants stated that they should watch the traffic flow before crossing the street while, 13 % suggested that pedestrians should not interrupt the flow of traffic if there is no urgency. Regarding the awareness of the pedestrian signals, only 44 % of pedestrians were aware of these signals but they were not fully aware about the working and usage of the signal. Furthermore, 34 % of participants said that they do not follow the signals. Some of the reasons were that they cannot wait much as it is time taking and sometimes crossing at intersection is not feasible as it is away from their destination. 51 % of users mentioned that awareness of pedestrian signals should be increased among people and 31 % stated that law enforcement should also be implemented to increase the effectiveness of these signals. Result shows that according to users' perspective 49 % of pedestrian vehicle collisions were due to the irresponsibility of drivers as well as pedestrians. Moreover, 55 % statistics shows that accidents take place due to the pedestrians who do no follow

Table 1. Descriptive statisctics

Variables	**Description**	**Distribution (%)**	**Frequency**
Socioeconomic characteristics			
Gender	Male	70	421
	Female	30	179
Age	<20	23	138
	20-35	63	375
	36-50	11	66
	51-65	2	17
	>65	1	4
Awareness level			
Awareness of pedestrian signals	Fully aware	21	126
	Aware	44	262
	Somewhat aware	29	176
	Not Know	6	36
Effectiveness of pedestrian signals (PS)			
Effectiveness of pedestrian signal	Very effective	17	103
Do you follow pedestrian signals?	Effective	57	344
	Neutral	21	124
	Not ffective	5	29
Reasons of not following the pedestrian signal	Always	39	234
	Sometimes	40	242
	Rarely	16	97
	Never	5	27
Reasons of pedestrian vehicle collisions	Time taking	34	206
	Away from destination	26	155
	Pedestrian Bridge is Provided	20	120
	Other	20	119
Safety			
	People donot follow signals	55	332
	High traffic volume	20	118
	High traffic speed	14	82
	Existing signals are not working	9	57
	Other	2	11
Decrease in pedestrian vehicle collisions	Increase in number of pedestrian crossing locations	12	73
	Raise awareness	51	306
	Law enforcement	31	183
	Increase speed bumps	6	38

the signals. According to users' perspective there was decrease in pedestrian-vehicle collision after the installation of pedestrian signals. Almost there was 51 % decrease is the accidents by raising the awareness about the installation and working of pedestrian signals which shows the effectiveness of pedestrian signals in reducing the pedestrian-vehicle collision. Moreover, 57 % of respondents mentioned that it is effective as per safety of the pedestrians if followed properly.

4.2 Intersection Analysis (SIDRA)

Faisal intersection, Regal intersection, GPO intersection and High Court intersection are located at mall road. All four intersections are four legged intersections with maximum of four lanes in each direction. Analysis was done using SIDRA intersection tool to check the level of service (LOS) and delays of these intersections with respect to pedestrians movement. The pedestrian volumes of Faisal intersection, Regal intersection, GPO intersection and High Court intersection were collected for peak hour of a day. Hourly average pedestrian volume at each intersection is given in Table 2.

A summary of the overall statistical analysis with regards to pedestrian characteristics (i.e., travel speed, travel distance, travel time, demand flow and control delay at intersections along with LOS of the intersection with respect to pedestrians' movement) for the four selected intersections on the Mall road (Table 3) is disscused in the following sections.

Table 2. Average pedestrian volume/hour

Cross walk location	Average pedestrians (volume/hour)
Faisal intersection	255
Regal intersection	268
GPO intersection	368
High Court intersection	208

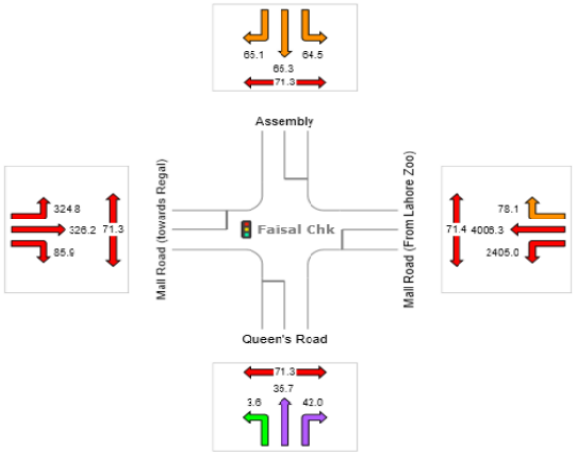

Fig. 3. LOS of Faisal Intersection Mall Road

4.2.1 Faisal Intersection

Table 3 shows that at Faisal intersection, the pedestrians were walking at an average speed of 1.9 km/h with total distance travelled of 17.6 pedestrian-km/hr. The delay time that the pedestrians were facing at this intersection was 7 1sec with a total hourly flow rate of 268 pedestrians/hour. Based on these values the overall pedestrian LOS at Faisal intersection (Figure 3) is ranked as "F" which means that all walking speeds were severly restricted and that there was frequent unavoidable contact with other pedestrians.

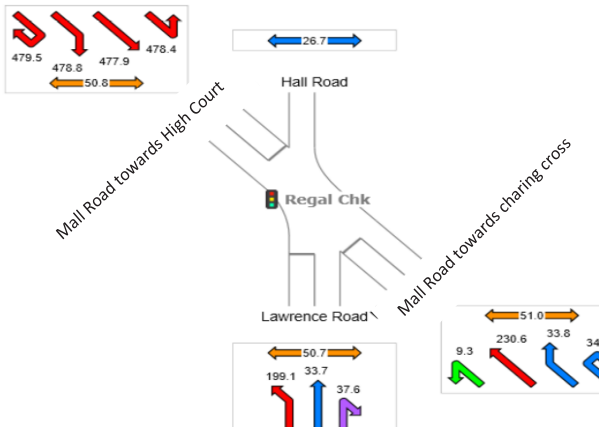

Fig. 4. LOS of Regal Intersection Mall road

Table 3. Intersection summary for pedestrians

Intersections	Travel speed (km/h)	Travel distance (Ped-km/h)	Travel time (Ped/h)	Demand flow (Ped/h)	Control delay (sec)	LOS
Faisal	1.9	17.6	9.1	268	71	F
Regal	1.8	11	6.1	272	50	E
GPO	1.4	16.6	12.3	387	81	F
High Court	2	8.6	4.4	219	42	E

4.2.2 Regal Intersection

Table 3 shows that at Regal intersection, the pedestrians were walking at an average speed of 1.8 km/h with a total distance travelled of 11 pedestrian-km/hr. The delay time that the pedestrians were facing at this intersection was 50 seconds with a total hourly flow rate of 272 pedestrians/hour. Based on these values the overall pedestrian LOS at Regal intersection (Figure 4) is classified as E which means that nearly all pedestrians restricted their normal walking speed and that space was not sufficient for passing slower pedestrians.

4.2.3 GPO Intersection

Table 3 shows that at GPO intersection, the pedestrians were walking at an average speed of 1.4 km/h with a total travelled distance of 16.6 pedestrians-km/hr. The delay time that the pedestrians were facing at this intersection was 81 sec with total hourly flow rate of 387 pedestrians/hr which results in pedestrian LOS F as shown in Figure 5.

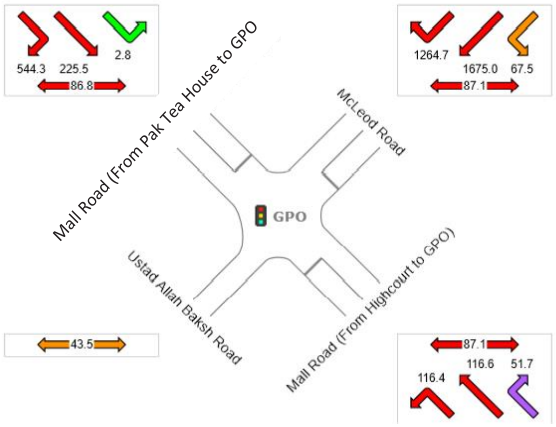

Fig. 5. LOS of GPO Intersection Mall Road

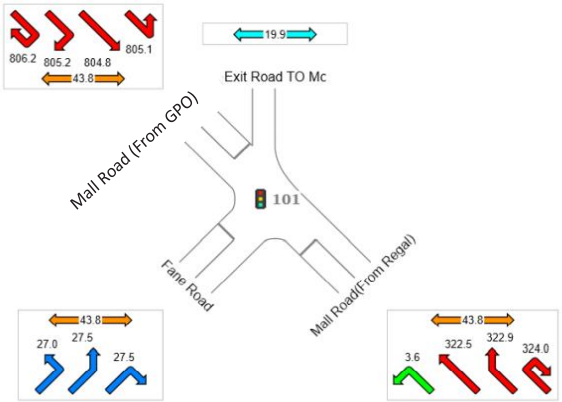

Fig. 6. LOS of High Court Intersection Mall Road

4.2.4 High Court Intersection

At High Court intersection in Table 3 shows the pedestrians were walking at an average speed of 2.0 km/h with the total distance travelled by pedestrian was 8.6 ped-km/hr. The delay time that the pedestrians were facing at the intersection was 42 sec with a total hourly flow rate of 219 ped/hour. Based on these values the overall pedestrian LOS at High Court intersection (Figure 6) is classified as E. The analysis shows that overall working of pedestrian signal at the intersection was not good enough in terms of delays and user satisfaction, which needs to be improved. This may be because of the lack of awareness about the usage and importance of the pedestrian signals which needs to be disseminated among masses travelling through this intersection. Figure 3 and figure 5 shows that pedestrians' LOS at Faisal intersection and GPO intersection was "F" which means that all walking speeds were severely restricted, and forward progress was made only by shuffling. There was frequent unavoidable contact with other pedestrians. Cross-and reverse-flow movements were virtually impossible which made the flow irregular and unstable. Space is a property of queued pedestrians than of moving pedestrians. On the other hand, figure 4 and figure 6 shows that pedestrians' LOS at Regal intersection and High Court intersection was E which means that nearly all pedestrians restricted their normal walking speed. Forward movement was possible only by shuffling. Space was not sufficient for passing slower pedestrians. Cross or reverse-flow movements were possible only with extreme difficulties. Design volumes approached the limit of walkway capacity which caused interruption of flow and difficulty in crossing.

5. CONCLUSION

The deployment and execution of the pedestrians' signals within the Lahore city has developed a great sense of responsibility among the road users. With this system, road users understand the value of road safety in true sense and meaning, which indeed guides them to follow the traffic rules. The present study has analysed the response of the pedestrians to the signals that are in use at various

road intersections within the Lahore city as a part of the transportation system. The pedestrian-vehicular interaction and the influencing factors on intersection LOS, providing an in-depth understanding of the factors that affect pedestrian safety has also been analyzed.

The study found that only 44 % of participants were aware of pedestrian signals at the intersection, while 34 % did not follow the signals due to inconvenience. To reduce pedestrian-vehicle collisions, 51 % suggested awareness campaigns, 31 % favored law enforcement and 57 % found pedestrian signals effective. The analysis of pedestrian signals reveals that working of pedestrian signals with respect to pedestrian movement was not perfect. At Faisal intersection the delay time that the pedestrians were facing was 71sec with a total hourly flow rate of 268 ped/hour. Based on these values the overall LOS of intersection was F. At Regal intersection the delay time was 50 seconds with a total hourly flow rate of 272 ped/hour. In addition, the overall LOS of intersection was E. Furthermore, analysis shows that at GPO intersection, the delay that the pedestrians were facing at this intersection was 81 seconds with total hourly flow rate of 387 ped/hour which results in overall intersection LOS as F. At High Court intersection, the delay time that the pedestrians were facing was 42 seconds with a total hourly flow rate of 219 ped/hour which results the LOS as E. The analysis shows that overall working of pedestrian signal at the intersection was not good enough in terms of delays and user satisfaction, which needs to be improved.

It is envisaged that the present studies will help to develop pedestrian delay models and pedestrian LOS (level of service) models at signalized intersections, which can be used by concerned authorities and policymakers to make informed decisions and who strive to make signalized intersections safer for all road users.

6. RECOMMENDATIONS

The following recommendations are made to improve pedestrian safety and to reduce pedestrian vehicle collisions:

- Conduct awareness campaigns to educate the public about pedestrian signals.
- Optimize pedestrian signal placement and timing to reduce delays and improve convenience.
- Coordinate pedestrian signals with traffic signals to improve safety.
- Increase law enforcement to ensure compliance with traffic rules.
- Regularly evaluate and improve pedestrian signals.

By implementing these recommendations, pedestrian safety can be improved, collisions reduced, and a better user experience may be provided for pedestrians.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Research Article

Exploring the Complexities of Urbanization and Socio-Ecological Challenges in the High Mountainous Region of Chitral, Khyber Pakhtunkhwa (KPK), Pakistan

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Abstract: Rapid urbanization is not only an issue in plain areas but also in mountainous regions. However, urbanization affects the socio-ecological pattern of mountainous regions especially depleting natural resources, e.g., traditional agricultural practices. Although urban sprawl impinges on such fertile productive lands, it also positively affects trade activities, and high-income opportunities, and the region will have high spatial interaction. This paper presents the results of an attempt to gain insight into the mechanisms for the urban growth of district Chitral (Chitral Town) located in the Hindu Kush range north of KPK Pakistan. Over the last few decades, the urban agglomeration has become attractive among migrants from within and beyond the district, further accelerating urban growth in the surrounding area. The landscape transformation phenomenon in Chitral town was investigated with the following objectives: (i) Detection of spatiotemporal change in the study area over the last two decades, (ii) Identification of existing landscape patterns i.e. land-use assessment by analysing the acquired high-resolution remote satellite imageries for the years 2003 and 2020, (iii) Empirical analysis of data within the framework of an object-based approach. Land-use transformations like spatiotemporal change, loss of agriculture, and infrastructure patterns of urban growth were estimated for the past 17 years. This study reveals that the agricultural Land-use has declined by 348 m^2 while the Built-up area has increased by 318 m^2. The research offers practical recommendations for sustainable town planning and management. As such, this study has the potential to propose future strategies and it may be helpful to the policy/decision-makers in the development of future town planning in the similar mountainous regions of Pakistan or elsewhere.

Keywords: Land-use (LU)/Land-cover (LC) Pattern, Urbanization, Mountainous Regions of Chitral, Spatio-Temporal Changes, Socio-Ecological Patterns, Town Planning.

1. INTRODUCTION

Urbanization is a worldwide phenomenon resulting from the industrial revolution and the advancement of contemporary industry and technology [1]. More than half of the globe's population is living in metropolises, urbanization is worldwide in progress, and the city population is predicted to rise reaching 60 % by 2030. Of these, residents living in township areas, approximately 1.2 billion are precarious informal settlement residents [2]. Suitable human use is very limited in mountainous areas, valley floors are usually occupied by settlements, mass transit routes, and economic and social set-ups e.g., educational, health-related, power, and industry-based facilities are usually at risk on one hand while inadequate agriculturally productive land resources on the other hand [3]. Rapid urbanization has not halted the footprint of mountainous areas, gradually affecting small

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and medium-sized communities negatively in mountain regions, posing special socio-ecological concerns such as diminishing natural resources and increasing natural hazard risk which received the least amount of scientific attention [4]. If Land-use planning strategies will be implemented, any urban area could be improved [5]. At the urban margins, there is a lack of availability of appropriate microdata for residential development therefore; as a result, there is diminutive analysis for the vacant lands, which is evident in the introduction of urban growth boundaries (UGB's) [6]. In mountains, urban settlements are mesmerizing locations although modernization is obvious due to cities and towns and mountains are the last sites that preserve wilderness and rural customs [7]. Therefore, rustic livelihood in mountainous sites is taking its last breaths in the existing era.

For waged communities mountainous towns provide an adequate environment of want and demand and the creation of capital and market conditions also provide ample opportunities to the neighboring regions, while geographical research mostly focused on megacities and small towns were given less attention, to the meaning of small and medium towns in the modern urbanization process has constantly grown [8]. However, these mountainous towns have constantly grown and paved the way for urban problems and ecological changes like open space shrinkage, irregular land use, environmental pollution, dwelling problem, increase in land coast, etc. Therefore, a research approach acts as a bridge between the natural environment and the social forces in finding a way to a satisfying environment for the future [9]. The complexities of urbanization in mountainous areas are debatable.

Pakistan has a widespread high-rise mountain zone of the Himalayas and Hindukush. Almost 61 % of the geographical area of Pakistan is covered by mountainous areas out of a total of 26.5 % of the world's continental land surface [10]. The high mountain zone of the Himalayas and Hindukush is divided into Northwest Frontier Hills & sub-montane Indus and Himalaya-Karakorum [11, 12]. The Hindukush Range in the North extends Northwest; The Karakoram Range passes through The Himalayas in the center [13]. The estimation in the population resided at mountains rely upon the definition of World Conservation Monitoring Centre (WCMC) [14]. In the mountains and highlands agricultural sites are mostly practiced on the terraces, and in some areas, it is practiced as historical traditions and fragment of cultural ecologies amenities [15]. Among the 17 Sustainable development goals, 15th goal is related to life on land and it is based on protection, restoration and promotion of sustainable use of Earth's ecosystem in which prime most is stop and inverse the land degradation [16]. For centuries diverse and locally adapted agricultural systems developed, managed, trial and tested by people involved in primary activities, a vital combination of cultural, social, economic and ecological of such practices have been induced to men [17].

In Pakistan, all localities, which are metropolitan corporations, municipal corporations, municipal committee, or cantonments at the time of the census, were treated as urban [18]. The present investigation in mountainous regions of Chitral locayed in Khyber Pakhtunkhwa (KPK), Pakistan focuses on analyzing the reasons and consequences of mountain urbanization from a broader and more integrative perspective by addressing questions like: What are the spatiotemporal characteristics of the urbanization process in a high mountain town? What determines the pace and form of urbanization? Which challenges for sustainable urban governance appear? The main objective of this study is to provide insight into the mechanisms for the urban growth of district Chitral (Chitral Town) located in the Hindu Kush range north of KPK Pakistan. To investigate the landscape transformation phenomenon, attempts have been made to detect the spatio-temporal change in the study area over the last two decades, and to identify existing landscape patterns i.e., land-use assessment by analyzing the acquired high-resolution remote satellite imageries for the years 2003 and 2020.

2. MATERIALS AND METHODS

2.1 Study Area

The study area namely Chitral Town (Figure 1) is located in Chitral district; a Northern most districts of Khyber Pakhtoon Khawah (KPK), and Chitral River originates from the Chiantar Glacier located in along with its tributaries and numerous springs,

drained the valley and after draining the region, it enters into Arandu-Afghanistan [19]. Chitral Town is approximately 35.9 km^2 area coverage which is 0.24 % of the total Chitral district's area. Study comprises on three union councils (UC's) namely UC Chitral-1, UC Chitral-2 and UC Broze with the population selected urban area is 49,780 [20].

Chitral is the valley bounded by Hindu Kush Range on the North West, Karakoram Range on the North East and Hindu Raj Range on the South, the famous Lawari tunnels is located there which connect the district to upper Dir. The physiography of Chitral; a diverse mountainous area with glaciers including snow cover mountains, and unembellished rock and sterile ground covered approximately 28.5 % of land while pasture and sparse vegetation spread over 62 % of land [21]. Climatic condition of the region is experiencing cold winter with mid-summer. Since, the area is surrounded by mountains, it does not receive the monsoon rains [21]. Mean rainfall at Drosh meteorological station located at Chitral towns of Lower Chitral ranges 500-650 mm per year [22].

2.2 Study Plan

To assess the urbanization trends, data have been collected through the detection of Spatio-temporal change at town scale over the past two decades. High resolution quick bird 10 meter resolution Satellites images from the SaaS planet have been downloaded for the year 2020, DEM 30 meter from Earth Explorer and High-resolution image for the year 2003 from Google Earth pro (Figure 2).

To detect spatio-temporal change and identify spread patterns of built-up land expansion from the urban core to associated landscape from 2003 to 2020, the acquired images have been processed in ArcGIS in order to get raster data for further analyzing, the manual digitization process is applied through the steps mentioned in (Figure 3). After editing all the raster data, which have been processed through the images, attribute tables have been analyzed further. Object based (manual) analysis [5, 23] have been conducted for creating all the vector data. Finally, the data have been tabulated.

3. RESULTS AND DISCUSSION

The change detection of land-use/land cover of the study area (Figure 4) has been mentioned. There is shrinking of agricultural land-use can easily be identified. In contrast, the extension of built-up land-use has been identified in different places. In many places, extension of built-up towards the city's fringes may be viewed. Around the cities, there is a high demand for land-use for residential purposes and it was estimated that by the year 2025 if the estimated trend continued, then 70 %

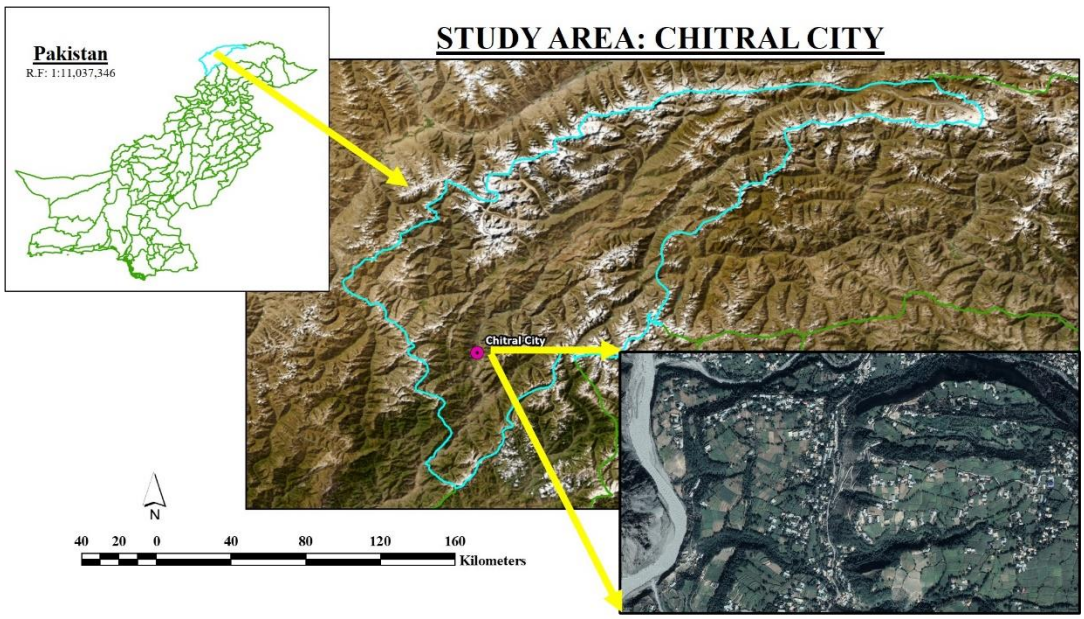

Fig. 1. Study area map of Chitral Town-Khyber Paktunkhwa (KPK)

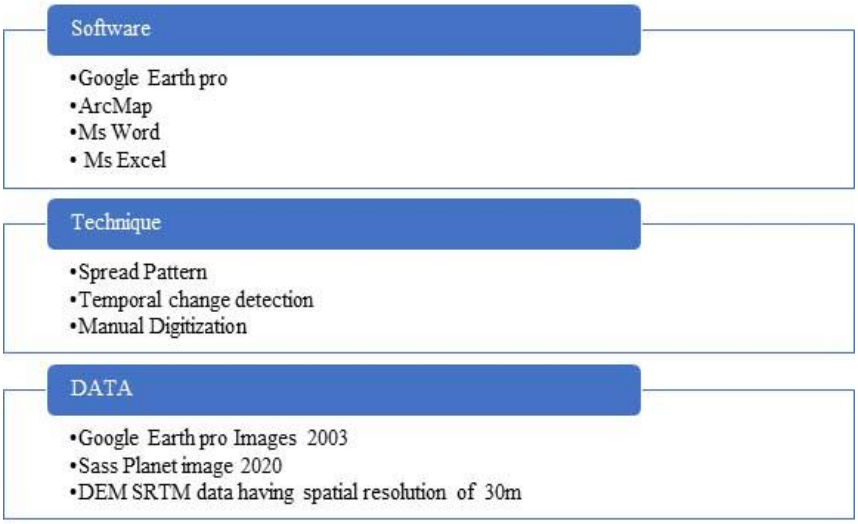

Fig. 2. Data acquisition and processing

of the population would reside in cities. In the year 2003, agricultural land-use was 766 m^2, which was shrinked up to 418 m^2 in the year 2020 (Table 1). Therefore, loss of 348 m^2 of agricultural area has been recorded during a period of 17 years. Kiambu County, the peripheries of Nairobi have lost forty percent of productive agricultural land to city expansion since 1995 [24]. In the year 2003, built-up area mostly for residential purposes was 371 m^2 (Table 1) in the study area, in contrast in year 2020 it expanded to 689 m^2 (Table 1). Therefore, in the study area, the expansion of 318 m^2 of the area have been recorded. Road networks and associated infrastructure remain the prominent sign of arbitrating urbanization, Chitral city resonances the urbanization in a true sense, where in the year 2003, road network was 360,432 meters and it increased by 594,171 meters by the year 2020 (Table 1), therefore in 17 years 233,739 meters roads have been paved. Nevertheless, it is the fact that mountainous areas are mostly unhabituated and Chitral city was also located over the mountainous range, which has been considered the highest mountainous range of the world i.e., The Great Himalayas. One out of ten world's population lives in mountainous areas and these mountainous areas hold 25 % of the land surface of Earth [25]. Number of settlements increased from 3015 (Year 2003) to 4091 (Year 2020) in the study area (Table 1), therefore 1,076 new settlements have developed. Hu et al. [26] stated that Pakistan's Land-use (LU)/Land-cover (LC) patterns have endured huge variations since

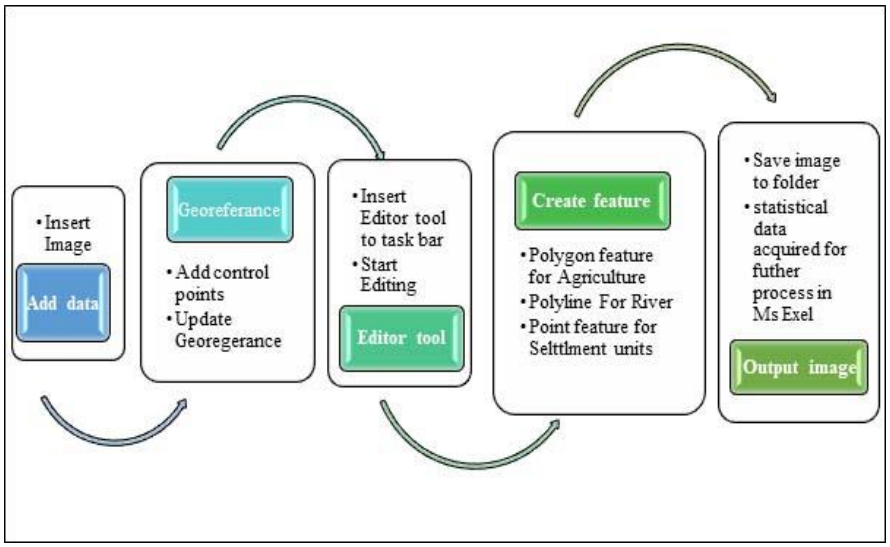

Fig. 3. Image acquisition and process

the 1900s, with no clear modified plan.

3.1 Change Detection of Land-Use for the Year 2003 and 2020

Build-up area included the build-up land and other infrastructure e.g. residential, commercial, or industiral land-use etc. By the comparison of two decade change in build-up land in the study area (Figure 5), it is observed that during the year 2020, the total number of further built-up land-use have been constructed at the fringes of cultivated land stretched to 4091 m^2 which was 3015 m^2 during the year 2003. It is, therefore, evident that the number of settlments in the period of two decades has become two-fold. Through the observation based survey and interviews of respondents were conducted from 8 locations within the study area, it has been detected that the dominant factors are modernization in central area of town, administative infrastructre and residential land-uses have increased with the rapid rate. Kausar *et al.* [5, 23] conducted a research on urban areas of Karachi; the largest metropolitan of Pakistan and suggested that there is a dire need to adapt suitable planning strateiges to gear up the urban sprawl.

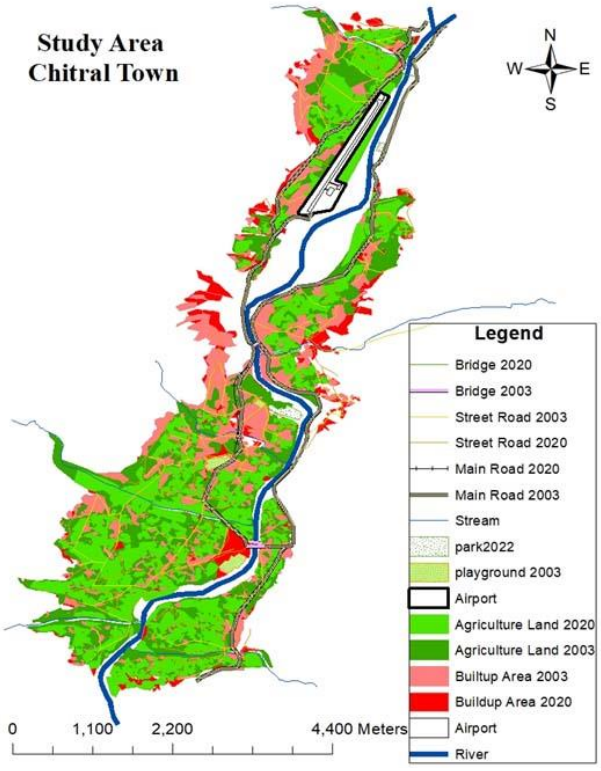

Fig. 4. Land-use of study area

3.2 Shrinking of Agriculture Land-Use

The comparison of agricultural land-use data for the period 2003-2020 (Figure 6) shows that there is a clear decline in agricultural land-use. In the year 2003, the total agricultural land-use was 766 m^2, which educed to 418 m^2 in the year 2020. It is evident that during two decades, the agriculture land-use has declined by 54.6 % which is about half of the area. This decrease is attributed to the direct impact of unplanned and irregular development of fast-growing urbanization. It is evident that the rapid urbanization is the main cause of agricultural land-use decline (Table 1). In contrast, during a study of the LU/LC change detection in Western Nile data in Egypt, Abd El-Kawy *et al.* [27] reported that nearly 28, 14, and 9 % of infertile land was transformed to agricultural land in the periods 1984–1999, 1999–2005, and 2005–2009, respectively.

3.3 The Most Affected Area

As compared to other areas, two highlighted areas (Figure 7) are found more affected in terms of build-up areas. In these areas, primarily the areas having slope topographical feature, the infrastructure and buildup area are observed to be developed very fast. Topographically, both areas are on slope and these slopes were having wilderness. Later, both the areas experienced rapid development of build-up infrastructure. It was observed that these areas became developed in infrastructure and service sector. During the last decade, the provision of basic facilities e.g., frequent supply of drinking water, accessibility in terms of road networks, electricity made the areas more accessible. Such facilities led the area towards fast growing with an irregular settlement pattern. Our results are in-line with Yang [28] who observed major variations in conversion of arable land and grassland into construction land during the period 1990–2020.

4. CONCLUSION AND RECOMMENDATIONS

An object-based approach, combination of high-resolution remote sensing imagery and Geographic Information System (GIS) contribute to the determination of the urbanization pattern in high mountainous towns such as the Chitral Town. This was an attempt to reach deep inside the mechanism of rapid and random development in the small town

Table 1. Temporal change of land-use

Land-Use	Year	
	2003	**2020**
Built-up Area	371 m^2	689 m^2
Agriculture Land	766 m^2	418 m^2
Road Network	360,432 meters	594,171 meters
Main Road	204,755 meters	11,749 meters
Numbers of Settlement	3015	4091

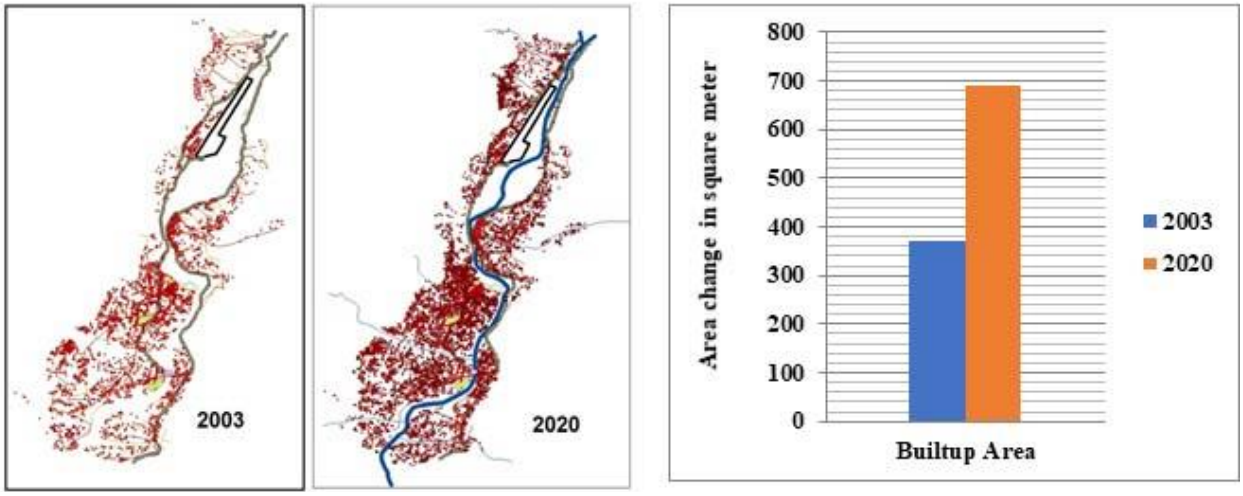

Fig. 5. Change detection of build-up area

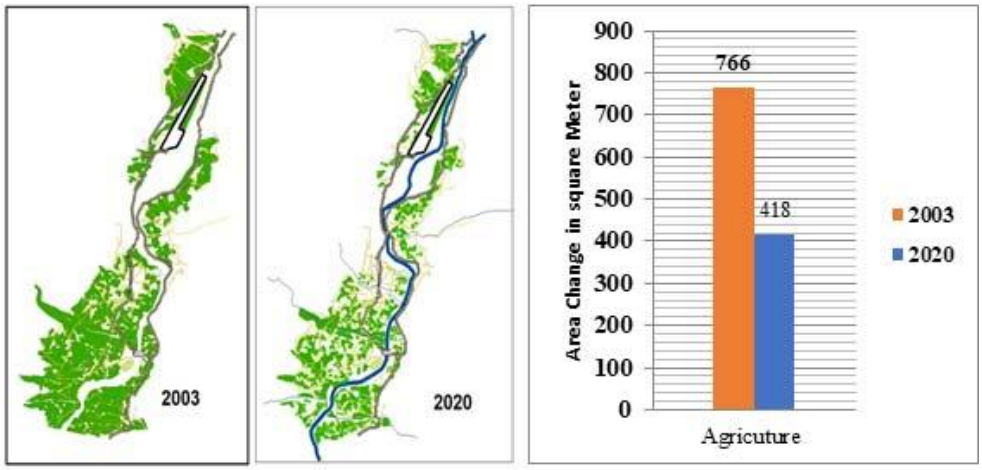

Fig. 6. Change detection of agricultural land-use in the study area (Chitral Town)

of Chitral, which has ultimately resulted in serious planning glitches today, and near future. Following results have been concluded from the present investigations in Chitral Town:

(i) Agricultural Land-use has declined by 348 sq-meters in Chitral city since 2003;
(ii) Built-up area has increased by 318 m^2 since 2003;
(iii) The number of settlments has become two-fold since 2003;
(iv) During the 17 years, 2,33,739 meters roads was surfaced.

The present investigations suggest that there is an urgent need to develop policies and adapt land-use planning strategies to alleviate the negative

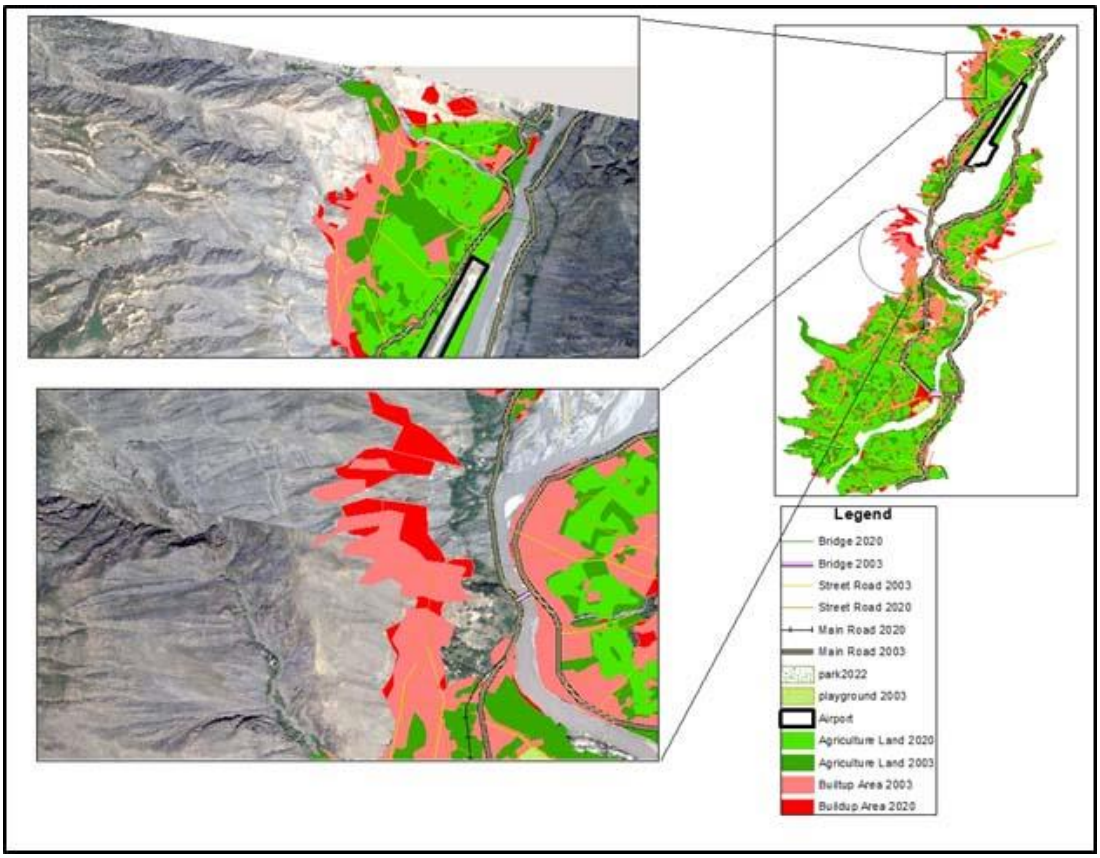

Fig. 7. Most affected areas in Chitral Town (KPK, Pakistan)

effects of rapid growth in build-up land in the study area. There should be implementation of "smart growth" strategies, especially the transfer of development rights and implementation of urban growth boundaries. Smart growth concentrates on compact development, and redevelopment of built-up area in the town, therefore inventive and efficient management is required to control the negative impact. On the Government level, the Municipal Committee (Chitral Town) has already divided the whole Bazar (market) into three zones, but it is not implemented yet and there is a dire need for micro-scale planning for the future growth of the town to avoid urban sprawl. There is future need for land-use planning at both; the government and private level to stear for the right direction of urban development in the study area.

5. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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2. W. Bialek, and S. Setayeshgar. Cooperative sensitivity and noise in biochemical signaling. *Physical Review Letters* 100: 258–263 (2008).
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5. W.R. Luellen. Fine-Tuning Your Writing. *Wise Owl Publishing Company, Madison, WI, USA* (2001).
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d. Reports

9. M.D. Sobsey, and F.K. Pfaender. Evaluation of the H2S method for Detection of Fecal Contamination of Drinking Water, Report WHO/SDE/WSH/02.08, *Water Sanitation and Health Programme, WHO, Geneva, Switzerland* (2002).

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