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Pythagorean Fuzzy Nano Topological Space With (Min-Max Open Set)

Abstract

Pythagorean fuzzy set, characterized by the condition that the sum of the squares of membership and non-membership degrees does not exceed one, provide a more flexible framework for modeling uncertainty than intuitionistic fuzzy sets. In this paper, we introduce and investigate the concept of maximal open sets in Pythagorean fuzzy topological spaces. Several properties and fundamental are established, and their relationships with Pythagorean fuzzy open and closed sets are examined. Characterizations of maximal and minimal open sets are obtained through inclusion relations and intersection properties. Furthermore, illustrative examples are provided to demonstrate the applicability of the proposed concepts. The developed theory extends classical topological notions to the Pythagorean fuzzy setting and contributes to the study of generalized topological structures under uncertainty. Potential applications of the proposed framework in decision-making, information systems, and intelligent data analysis are also discussed, offering new directions for future research in fuzzy topology and soft computing.

Keywords
Pythagorean fuzzy set, Pythagorean fuzzy topology, Maximal open set, Minimal open set, Fuzzy topological space, Generalized topology, uncertainty modelling.

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1. INTRODUCTION

The concept of fuzzy minimal and maximal open sets introduced by Ittanagi and Wali in [ ] has played an important role . Swaminathan and Sivaraja [ ] discussed some properties of fuzzy minimal open and fuzzy maximal open sets. In this chapter, we have introduced the notions of Pythagorean fuzzy nano minimal (resp., δ, δ-pre, δ-semi, δα, and δβ)-open sets. Further, we have developedPythagoren fuzzy nano maximal (resp., δ, δ-pre, δ-semi, δα, and δβ-open sets and various interesting results on them.

2 .PYTHAGOREAN FUZZY NANO MINIMAL OPEN SETS

Definition 2.2.1 : Let (U,τRA) be a P𝒫Nts with respect to A where A is a P𝒫S of U. Then P𝒫s S in U is said to be Pythagorean:

(i)fuzzy nanoδα or α-open set (briefly, P𝒫Nδαos or P𝒫Naos) if S⊆P 𝒫Nint(P𝒫Ncl(P𝒫NintS)).

(ii)fuzzy nanoδβ ore∗-open set (briefly, P𝒫Nδβos or P𝒫Ne∗os) if S⊆P𝒫Ncl(P𝒫Nint(P𝒫NclS)).

The complement of P𝒫Nδαcs, P𝒫Nδβos and P𝒫Nδβcs) of U is denoted by P𝒫NδαOSU(res. P𝒫NδαCSU, P𝒫NδβOS(U) and P𝒫NδβCS(U)).

Definition 2.2.2: Let (U,τRA) be a P𝒫Nts with respect to A where A is a P𝒫S of U. Let S be a P𝒫S of U. Then Pythagorean fuzzy nano

(i)δα (resp. δβ) interior of S (briefly, P𝒫NδαintS (res. P𝒫Nδβint(S))) is defined by P𝒫Nδαint(S) (resp. P𝒫Nδβint(S))=∪{I:I⊆S & I is a P𝒫Nδαo (resp. P𝒫Nδβo) set in U}.

(ii)δα (resp. δβ) closure of S (briefly, P𝒫NδclS (res. P𝒫Nδβcl(S))) is defined by P𝒫Nδαcl(S) (resp. P𝒫Nδβcl(S))=∪{A:S⊆A & A is a P𝒫Nδαc (resp.P𝒫Nδβc) set in U}.

Definition 2.2.3: A proper nonzero P𝒫Nδβos (resp. P𝒫NPδos, P𝒫NδSos, P𝒫Nδαos and P𝒫Nδβos) E in Pythagorean fuzzy nano topological space (U,τPA) is said to be Pythagorean fuzzy nano minimal (resp., δ, δ-pre, δ-semi, δα, and δβ)-open sets (briefly, P𝒫Nminos(resp. P𝒫Nδminδos, P𝒫NminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos) if a P𝒫Nos (resp. P𝒫Nδos, P𝒫NδPos, P𝒫NδSos and P𝒫Nδβos) contained in E is 0Por E.

Example 2.2.4: Let U={s1,s2,s3,s4} be the universe set and the equivalence relation are U/R=s1,s4, s2, s3. Let A =s10.8,0.4, s20.6,0.6, s30.7,0.7, s40.5,0.7 be a Pythagorean fuzzy subsets of U.

P𝒫NA= s10.5,0.7, s20.6,0.6, s30.7,0.7,

P𝒫NA= s10.8,0.4, s20.6,0.6, s30.7,0.7,

ℬP𝒫N(A) = s10.7,0.5, s20.6,0.6, s30.7,0.7.

Now τPA={0P, 1P, P𝒫NA1, P𝒫NA1, ℬP𝒫NA1}

Here (i) P𝒫NA is P𝒫Nminδo, P𝒫NδSo and P𝒫Nδαo set,

(ii) (P𝒫N(A))c is a P𝒫NminδPo and P𝒫Nminδβo set.

Lemma 2.2.5: Let (U,τPA) be a Pythagorean fuzzy nano topological space.

(i)If E1 is P𝒫Nminos (resp.P𝒫Nminos, P𝒫NminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos) and E2 is P𝒫Nos (resp. P𝒫Nos, P𝒫Nδos,P𝒫NδSos, P𝒫Nδαos) in U, τPA, then E1∩E2=0P or E1⊂E2.

(ii)If E1 and E2 are P𝒫Nminos (resp. P𝒫Nminδos, P𝒫NδminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos), then E1∩E2=0P or E1=E2.

Proof:

(i)Let us assume that E2is P𝒫Nδβos in U,τPA such that E1∩E2≠0P. Since E1 is P𝒫Nminδβos, and E1∩E2⊂E1, then E1∩E2=E1 implies E1⊂E2.

(ii)Suppose that E1⊂E2≠0P, then clearly from (i), E1⊂E2 and E2⊂E1 as E1 and E2 are P𝒫Nminδβos. Hence E1=E2.The proof of the others are similar.

Theorem 2.2.6: Let E and Ei are P𝒫Nminos (resp. P𝒫Nminδos, P𝒫NδminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos) for any i∈M. If E⊆i∈MEi,then E=Ej for any j∈M.

Proof: Suppose E⊆i∈MEi, then E=E∩(i∈MEi)=i∈M (E∩Ei).By Lemma 2.2.5(ii), E∩Ei=0P or E=Ei as E and Ei are P𝒫Nminδβos's. If E∩Ei=0P, then E=0P which contradicts that E is a P𝒫Nminδβos. Hence if E∩Ei≠0P then E=Ej for any j∈M. The proof of the others are similar.

Theorem 2.2.7: If E and Ei are P𝒫Nminos (resp.P𝒫Nminδos, P𝒫NδminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos) for any i∈M and E≠Ei, then E∩(i∈MEi)=0P for any i∈M.

Proof: Let E∩(i∈MEi)≠0P, then E∩Ei≠0P for any i∈M. By Lemma 2.2.5(ii), E=Ei contradictory to E≠Ei. Hence E=E∩(i∈MEi)=0P.

Theorem 2.2.8: If Ei is a P𝒫Nminos P𝒫N δminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos) for any i∈M(M≥2) and Ei≠Ej for any distinct i,j∈M, then ((i∈M/{j}Ei)∩Ej=0P) for any j∈M.

Proof: Let (i∈M/{j}Ei)∩Ej≠0P. Then i∈M/{j}(Ei∩Ej)≠0P⟹Ei∩Ej≠0P.By Lemma 2.2.5 (ii), Ei=Ej, a contradiction. Hence (i∈M/{j}Ei)∩Ej=0P for any j∈M.

Theorem 2.2.9: If Ei is a P𝒫Nminos (resp. P𝒫N δminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos) for any i∈M(M≥2) and Ei≠Ej for any distinct i,j∈M. If K is a nonempty proper subset of M then (i∈M/KEi)(j∈KEj)=0P.

Proof: If (i∈M/KEi)(j∈KEj)≠0P. It implies that (Ei∩Ej)≠0Pfor i∈M\K and s∈K implies that Ei∩Es≠0P for some i∈M and j∈K. By Lemma 2.2.5 (ii), Ei=Ej, which is a contradiction. Hence (i∈M/KEi)(j∈KEj)=0P.

Theorem 2.2.10: If Ei and Ek are P𝒫Nminos (resp. P𝒫N δminδPos, P𝒫NminδSos, P𝒫Nminδαos and P𝒫Nminδβos) for any i∈M and k∈S and if there exists an n∈S such that Ei≠Ej for any i∈M, then n∈KEn⊆[i∈MEi].

Proof: Assume that there exists an n∈S such that Ei≠En for any i∈M, then n∈KEn⊄[i∈MEi].

⇒En⊂[i∈MEi] for some n∈K.

⇒Ei≠En for any i∈M, by Theorem 2.2.6, which is a contradiction. Hence n∈KEn⊄[i∈MEi].

Theorem 2.2.11: If Ei is a P𝒻Nminos (resp. P𝒻Nminδos, P𝒻N δminδPos, P𝒻NminδSos, P𝒻Nminδαos and P𝒻Nminδβos) for any i∈M such that Ei≠Ej for any distinct i,j∈M, then

(i)Ej⊂[i∈M/{j}Ei] for some j∈M.

(ii)i∈M/{j}Ei≠1P for any j∈M.

Proof:

(i)By hypothesis, Ei≠Ej fore any distinct i,j∈M. By Theorem 2.2.7, i∈MEi∩Ej=0P which is true for any j∈M.⇒i∈M[Ei∩Ej]=0P
⇒Ei∩Ej=0P(By Lemma 2.2.5(ii))
⇒Ei⊂Ejc
⇒i∈M/{j}Ei⊂Ejc. Hence proved.

(ii)Let j∈M such that i∈M/{j}=1P
⇒Ei=0P
⇒Ei is not a P𝒻Nminδβos set, a contradiction. Hence i∈M/{j}≠1P for any j∈M. The proof of others are similar.

Corollary 2.2.12: If Ei is a P𝒻Nminos (resp. P𝒻Nminδos, P𝒻N δminδPos, P𝒻NminδSos, P𝒻Nminδαos and P𝒻Nminδβos) for any i∈M such that Ei≠Ej for any distinct i,j∈M, thenEi∪Ej≠1P for any distinct i,j∈M.
Proof: Similar to the proof of Theorem 2.2.12 (ii).

Theorem 2.2.13: If Ei is a P𝒻Nminos (resp. P𝒻Nminδos, P𝒻N δminδPos, P𝒻NminδSos, P𝒻Nminδαos and P𝒻Nminδβos) for any i∈M such that Ei≠Ej for any distinct i,j∈M, then Ej=[i∈MEi]∩[i∈M/{j}Ei]c for any j∈M.
Proof: For any j∈M⇒[i∈MEi]∩[i∈M/{j}Ei]c = [i∈M/{j}Ei∪Ej]∩[i∈M/{j}Ei∪Ej]c
= [(i∈MEi)∩(i∈M/{j}Ei)c]∪[Ej∩(Ej∩(i∈M/{j}Ei)c]
= 0P∪Ej
= Ej for any j∈M.

Proposition 2.2.14: Let G be a P𝒻Nminos(resp. P𝒻Nminδos, P𝒻N δminδPos, P𝒻NminδSos, P𝒻Nminδαos and P𝒻Nminδβos) set in U,τPA. If xα∈G, then G⊂G1 for any P𝒻Ne-open neighbourhood of xα for any xα∈G.
Proof: Let G1 be an P𝒻Ne-open neighbourhood of xα such that G⊄G1⊊G and G∩G1≠0P. This implies that G is a P𝒻Nminδβos set which is contradiction. The proof of others are similar.

Proposition 2.2.15: Let G be a P𝒻Nminδβos(resp. P𝒻Nminδos, P𝒻N δminδPos, P𝒻NminδSos, P𝒻Nminδαos and P𝒻Nminδβos). Then G=∩{G1:G1P𝒻Nδ (resp. P𝒻N δP, P𝒻NδS, P𝒻Nδα and P𝒻Nδβ)-open neighbourhood of xα for any xα∈G}.
Proof: By Proposition 2.2.14 and as G is an P𝒻Nδβ-open neighbourhood of xα, we have G=∩{G1:G1 P𝒻Nδβ-open neighbourhood of xα⊂G}. This completes the proof. The proof of others are similar.

Theorem 2.2.16: Let G be a P𝒻Nminos(resp. P𝒻Nminδos, P𝒻N δminδPos, P𝒻NminδSos, P𝒻Nminδαos and P𝒻Nminδβos). Then the following conditions are equivalent.

(i)G is P𝒻Nminos(resp. P𝒻Nminδos, P𝒻N δminδPos, P𝒻NminδSos, P𝒻Nminδαos and P𝒻Nminδβos) set.

(ii) G⊂P𝒻NCl(K) (resp. G⊂P𝒻NδClK, ⊂P𝒻NδPClK⊂P𝒻NδSClK,⊂P𝒻NδαClKand ⊂P𝒻NδβCl(K) for any nonzero P𝒻S of K of G.

(iii) P𝒻NClG=P𝒻NClK(resp. P𝒻NδClG=P𝒻NδClK, P𝒻Nδ PClG=P𝒻Nδ PClK, P𝒻NδSClG= P𝒻NδSClK,P𝒻NδαClG=P𝒻NδαClK and P𝒻NδβClG=P𝒻NδβCl(K) for any nonzero P𝒻SK⊆G.

Proof: (i) ⟹(ii): By Proposition 2.2.14 for any xα⊂G and P𝒻Nδβ open neighbourhood M of xα, we have K=G∩K⊂(M∩K) for any proper nonzero P𝒻NK⊂G. Therefore, we have (M∩K)≠0P and xα⊂ P𝒻NδβClK. It follows that G⊂P𝒻NδβClK.
(ii) ⟹(iii): For any P𝒻S K of G, P𝒻NδβClG⊂P𝒻NδβClK. Also by (iii) P𝒻NδβClG⊂P𝒻NδβCl P𝒻NδβClK=⊂P𝒻NδβClK. Hence proved.
(iii)⟹(i): Let us assume that G is not P𝒻Nminδβos. Then there exists a proper P𝒻Nminδβos D such that D⊂G. Then there exists yα∈G such that yα∉G.Then P𝒻NδβCl(yα)∈Dc implies that P𝒻NδβClyα≠P𝒻NδβClG, a contradiction. This completes proof. The proof of others are similar.

2.3 PYTHAGOREAN FUZZY NANO MAXIMAL OPEN SETS AND ITS PROPERTIES

Definition 2.3.1: A proper nonzero Pythagorean fuzzy nano (resp. δ, δpre, δ semi, δα and δβ)- open set (briefly, P𝒻Nos(resp. P𝒻Nos, P𝒻NδPos, P𝒻NδSos, P𝒻Nδαos and P𝒻Nδβos) F of a Pythagorean fuzzy nano topological space U,τPA is said to Pythagorean fuzzy nano Maximal (resp. P𝒻Nmaxδos, P𝒻NmaxδPos, P𝒻NmaxδSos, P𝒻Nmaxδαos and P𝒻Nmaxδβos)) if any P𝒻Nos (resp. P𝒻δos, P𝒻NδPos, P𝒻NδSos, P𝒻Nδαos and P𝒻Nδβos) which contains F is either F or 1P.

Example 2.3.2: In Example 2.2.4, the set (i)BP𝒻N(A) is P𝒻Nmaxδo and P𝒻NmaxδSo, (ii) P𝒻N (A) is P𝒻NmaxδPo, P𝒻Nmaxδαo and P𝒻Nmaxδβo set.

Lemma 2.3.3 : Let U,τPA be a Pythagorean fuzzy nano topological space. Then

(i)If F1 is a P𝒻Nmaxos (resp. P𝒻Nmaxδos, P𝒻NmaxδPos, P𝒻NmaxδSos, P𝒻NδSos, P𝒻Nδαos and P𝒻Nδβos) in U, then F1UF2=1P or F2⊂F1.

(ii)If F1 and F3 are P𝒻Nmaxos (resp. P𝒻Nmaxδos, P𝒻NmaxδPos, P𝒻NmaxδSos, P𝒻NδSos,P𝒻Nδαos and P𝒻Nδβos) then either F1UF3=1P or F1=F3.

Proof: (i)Assume that F2⊄F1. Clearly , F1⊂F1∪F2 a contrary to F1 is a P𝒻Nmaxδβos if F1∪F2≠1P. Hence , F1∪F2=1P.
(ii)Let F1 and F3 are P𝒻Nmaxδβos's. Then form (i) F3⊂F1 and F1⊂F3 implies that F1=F3. The proof of others are similar.

Theorem 2.3.4: If F1,F2 and F3 are P𝒫Nmaxos (resp. P𝒫Nmaxδos, P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos) such that F1≠F2 and (F1∩F2)⊂F3, then their F1=F3 or F2=F3.

Proof: Suppose that F1,F2and F3 are P𝒫Nmaxδβos's with F1≠F2,F1∩F2⊂F3, and if F1≠F3, then

F2∩F3= F2∩F3∩1P

=F2∩[F3∩(F1∪F2], by Lemma 2.3.3 (ii)

= F2∩F3∩F1)∪(F3∩F2

= [F2∩F3∩F1]∪[F2∩F3∩F2]

=[(F2∩F1)]∪[F2∩F3)]

=F2∩[F1∪F3)]

=F2∩1P

=F2

F2∩F3=F2⇒F2⊂F3. As F2 and F3 are P𝒫Nmaxδβos's, F3⊂F2. Hence F2=F3.

Theorem 2.3.5: For any distinct P𝒫Nmaxos (resp. P𝒫Nmaxδos, P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos) such that F1, F2 and F3 we have F1∩F2⊄F1∩F3.

Proof: Consider F1∩F2⊂F1∩F3 for any distinct P𝒫Nmaxδβos's F1, F2 and F3. Then F1∩F2∪F2∩F3⊂F1∩F3∪F2∩F3=F1∩F3∩F2⊂F1∪F2∩F3=1P∩F2⊂1P∩F3=F2 is contained in F3 a contradiction to F1,F2 and F3 are distinct. Hence F1∩F2≠F1∩F3.

Theorem 2.3.7: If Fi is a P𝒫Nmaxos (resp. P𝒫Nmaxδos, P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos)'s for any i∈M, M is a finite set and Fi≠Fj for any distinct i,j∈M, then

(i)[i∈MjFi]c⊂Fj for any j∈M.

(ii)i∈M{j}Fi≠0Pfor any j∈M.

Corollary 2.3.8: If Fi is a P𝒫Nmaxos (resp. P𝒫Nmaxδos, P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos)'s for any i∈M, M is a finite set and Fi≠Fj for any distinct i,j∈M, then Fi∩Fj≠0P for any distinct i,j∈M.

Remark 2.3.9 : If Fi is a P𝒫Nmaxos (resp. P𝒫Nmaxδos, P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos)'s for any i∈M, M is a finite set and Fi≠Fj for any distinct i,j∈M, and if K is a proper nonzero fuzzy subset of M, then i∈MFi⊄k∈KFK.

Theorem 2.3.10: If Fiis a P𝒫Nmaxos (resp. P𝒫Nmaxδos, P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos)'s for any i∈M, M is a finite set and Fi≠Fj for any distinct i,j∈M, and if i∈MFi is a fuzzy subset, then Fj is a fuzzy subset for any j∈M.

Proof: By theorem 2.3.9, we have Fj=i∈MFi∪[i∈M/{j}Fi]c for any j∈M, Fj=[i∈MFi∪[i∈M/{j}Fi]c .

Since M is finite i∈M/{j}Fic is a P𝒫Nmaxδβ-closed. Hence Fj is P𝒫Nmaxδβ-closed for any j∈M.

Similarly proof the remaining theorem.

Theorem 2.3.11: If Fi is a P𝒫Nmaxos (resp. P𝒫Nmaxδos, P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos)'s for any i∈M, M is a finite set and Fi≠Fj for any distinct i,j∈M, and if i∈MFi=0P, then Fi/i∈M is the set of all P𝒫Nmaxδos (resp. P𝒫NmaxδPos, P𝒫NmaxδSos, P𝒫Nδαos and P𝒫Nmaxδβos)'s of Pythagorean fuzzy nano topological space U,τPA.

Proof: Suppose that there exists another P𝒫Nmaxδβos Fk of a Pythagorean fuzzy nano topological space U,τPA such that Fk≠Fi, ∀i∈M. Clearly, 0P=i∈MFi=i∈(M∩K)/{k}Fi≠0P,by Theorem 2.3.7(ii), a contradiction. Hence Fi/i∈M is the family of all P𝒫Nmaxδβos's of Pythagorean fuzzy nano topological.

Conclusion:

In this topic, the concept of Pythagorean fuzzy nano (resp. δ, δpre, δ semi, δα and δβ)- minimal and Pythagorean fuzzy nano (resp. δ, δpre, δ semi, δα and δβ)-maximal open sets are introduced and some properties of Pythagorean fuzzy nano (resp. δ, δpre, δ semi, δα and δβ)-minimal open and Pythagorean fuzzy nano(resp. δ, δpre, δ semi, δα and δβ)-maximal open are discussed.

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