BirdMigrationwithVisualAvianNavigation&NestNidification:TheSpatialLinearGeometriesGeoreferencing Functionality

ABSTRACT

Problem. Birdmigration(eye):Georeferencingprocedurewithclues,rules,functionalities,andrestrictions,foraviannavigationandnestnidification.

Literature knowledge. Computer vision (sensor): Robot self-referencing with the Perspective-n-Pointposeestimationtechnique.

Aim. Hypothesisintroductionandproving("Thebirdsalsofollowthesamegeoreferencingprocedurelikerobotsinaviannavigation and nestnidification").

Methodology.(a)Referencedata,images,andphotographyacquisitionand4-meanslayering(eBirddataset,Flickrimagery,CORINElandcovering,andVolunteeredGeographicInformation);
(b)Imageprocessing;and(c)GISspatialoverlayanalysis.

Results. Statistical spatial analysis using data of the GIS overlays (the 4 layers). Correlationmatrix (Avian navigation and nest nidification in low-density urban areas as these are affectedbyspatiallineargeometriesandlandcovertypes).

Conclusion. Astatisticallysatisfactoryapproachtotheintroducedhypothesis.

Potential applications. Humanspatial cognitionandmovement behavior; Children's motorcontrolandcoordination.

Keywords:Birdsvisualaviannavigation,Birdsnestnidification,Spatiallineargeometries,Georeferencing,GIS spatialoverlay.

1. INTRODUCTION

Birds and all animals on earth, including humans, live in a complex, physical world throughwhich they must move. In the last decades, the study of bird migration focused on two maintopics;thediscoveryanddescriptionofmigratoryroutesanddestinations,andtheinvestigation of the mechanisms that regulate temporal (e.g. summer) and spatial patterns (e.g.powertransmissioncables ortrain linesinbirdstraveling flywaysandpathways).

“Also, according to the bibliography (nature research/scientific reports), the magnetic “compass”(i.e.thephotochemicalmagnetoreceptionintheireye,thankstocryptochrome-basedmagnetoreceptors in birds’ retina and the bird’s eye protein Cry4) is an important biophysicaltool of birds’ avian navigation system, which allows migratory birds to solve complex geo-referencingtasksontravelinginflywaysforspringandwinteringlocations”[1,2].

In this case, the cryptochrome-based photochemical magnetoreception in birds’ eyes(locatedinthecentralpartofthe retina) isregardedtobetheprimarybiophysicalaviannavigationtool.

Also, according to bibliography and scientific reports (nature research) low-density structuredenvironmentsrichintrees, flora, andvegetation, aswell as urbanwoodlandswithroads,railways, and power lines should be regarded as the auxiliary georeferencing avian navigationtool(Fig. 1).

Figure1. BirdMigrationwithVisualAvianNavigation.Pictureby courtesyofMichelleStarr[Starr,M.,2018]

Birds’visualaviannavigation& migration

“Currently, the focus in birds’ avian migration is more on the ecological and evolutionary aspectsof bird migration, and their relevance for conservation policy. While the endogenous regulationand heritability of migration strategies have been studied in detail, their interaction with theenvironmenthasreceivedfarlessattention.Moreover,littleisknownaboutthefitness consequences,whichareultimatelyresponsibleforbirds'avionnavigationrulesandfunctionalities,birds'populationlevels,andnests'locationsinmigrationstrategies"[1,37].

"Of relevance are the relationships between the requirement and availability of resources (i.e.fuel), and the need to balance these two factors with the allocation of time between rest andflight. The optimal strategy in this will depend on many factors. Research on e.g., wheatears,godwits,andgreyploversshowsthatthesefactorscanbesuccessfullystudiedwiththecombination of field observations, field experiments, and research under controlled conditions.Theseapproaches arefurther developedwithintheInstituteofAvianResearch (IAR)"[28].

"An aspect of avian migration that has so far received little attention is its importance within thecomplete life history of an individual. The speed of migration may affect arrival time in thebreeding area, which may in turn determine the quality of the obtained breeding territory ornest site, leading to a strong cascade of effects on fitness. Only the study of migration within acompletelife-historyframeworkcanthusultimatelyexplainandpredictresponsestoachangingenvironment" [12].

Itisimportanttoemphasizethat,nowhereintheliteraturetheinfluencetobirds'aviannavigation and nest nidification, of constructions with a specific geometry of a linear form ismentioned(low-density urbanareas).

Recentliteratureknowledgeaboutvisualnavigation&georeferencing

Despite some differences, the visual process and geometric structure of the eye of humans andbirdsarebroadly thesame(theso-calledpinholemodel)[1,3,4].

The cutting-edge technology "machine vision" follows the same (geometric) structure of vision,namely the pin-hole camera model (i.e. the perspective of the pin-hole camera model). The pin-hole camera model describes the mathematical relationship between the coordinates of a pointin three-dimensional space and its projection onto the image plane of an ideal pinhole camera,wherethecameraapertureisdescribedasapointandnolensesareusedtofocuslight(Fig.2).

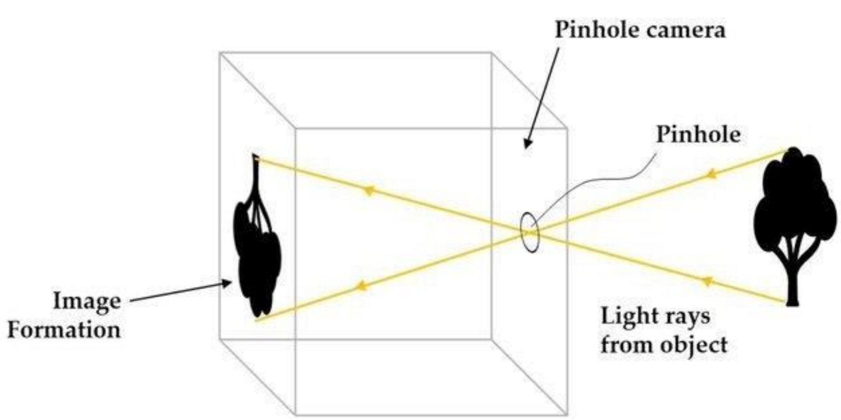

Figure2. ThePin-holeCameraModel.

Picturecredit:[StyliadisandSechidis,2011]

Evenmore,inmachinevision,therobotcomputesitsowntemporalposition(posedetermination)and navigationroutes(georeferencing)byrecognizingPnP("*Perspective-n-Point*") shapes and mutually parallel or orthogonal line pairs in observed linear or rectangularimage-geometriesusuallyfoundinnaturalimageryandnormallyoccurinlow-densityconstructedurbanenvironments (spatial lineargeometries)[5,6,7].

In the present work, first, the original concept of "*spatial (PnP) linear geometries*" is introducedanddocumentedinsub-Section2.3.Subsequentlyandforresearchtacticalpurposes,ahypothesisisstatedinsub-Section2.4(thatbirdsfollowthesamevisualprocessforgeoreferencingasrobotsinmachinevision) which isthenapproachedforstatisticalproving.

Thepaperisorganizedasfollows:InSection2("*MotorVision(Robot,Bird,Human)-Hypothesis*"),thesensor-basedmachine(robot)vision,theeyestructure,andthesimilarities/differencesin geometrybetween humans and birdsare discussed. Also, in thisSection,theinnovativeconceptisintroduced,andthehypothesisisstated.InSection3("*Methodology*"), the acquired references and imagery, as well as the in-situ field-work data(photography) for the trial birds-watching area are discussed, followed by a GIS spatial overlayof the four (4) layers involved. In Section 4 ("*Results*"), the statistically produced correlationmatrix related to birds' nest nidification and the 4-layers acquired data, is presented. Also, inthis Section, a statistically satisfactory approach, based on the correlation analysis, for theintroduced hypothesis proving is discussed. In Section 5 ("*Conclusion – Potential Applications*"),it is concluded that the visual georeferencing and nest nidification of birds (like robots) followsspatial (PnP) line geometries, shapes, and mutually detect parallel or perpendicular line pairsnormally found in low-density structured urban areas. Finally, in this Section, the study of theinfluenceofspatial(PnP)lineargeometriesgeoreferencingfunctionalityonhumanspatialcognition and movement behavior (e.g. children's motor control and coordination) could beconsideredas potentialnew applications.

2. MOTORVISION(ROBOT,BIRD,HUMAN)-HYPOTHESIS

2.1 ROBOTVISION

"Computing the position and orientation of an object (known as the object pose problem in CADandrobotics)hasimportantapplications,suchascameracalibration,determiningsensorlocation (indigitalphotogrammetry),trackingandobjectdetection(inrobotics),etc.Thiscalculationisbasedon imagesoffeaturepointsinphotographywhenthegeometricconfigurationoftheobjectis knownin advance"[6,7,8].

Thecameraposeestimation &the"Perspective-n-Point"(PnP)term

“In computer vision, the pose of an object is often estimated from camera input by the processofposeestimation.Thisinformationcanthenbeused,forexample,toallowarobottomanipula te an object or to avoid moving into the object based on its perceived position andorientation intheenvironment”[38].

“The machine visionterm*Perspective-n-Point* isreferred tothe problemof estimatingthepose of a calibrated camera given a set of n 3-D points in the world and their corresponding 2-Dprojections in the image. The camera pose consists of six (6) degrees of freedom (DOF), whichare the rotation (roll, pitch, and yaw) and the 3-D translation of the camera with respect to theworld”[8,9,38].

In Styliadis, et al. paper [8], “a technique is presented for modeling indoor scenery based ondigital images, photo-derived intra-component, geometric and topologic constraints, object-orientedgraphicdatabasescontaining3-Dparametricmodels,andarough(generic)CADmodel. This new method is based on mutually parallel or perpendicular line pairs in observedrectangularshapeimagesusuallyfoundinphotography.Inman-madeenvironments,rectangularshapescanbeseeneverywhere”.

“Itisthusconvenienttouserectangularshapesforposeandobjectdeterminationinphotogrammetric engineering(close-rangespacerejection)androbotics(robotlocation)”[10,11].

From the bibliography [8-11,38] presented above it is clear that in machine vision, the robot isgeoreferenced continuously (i.e., with a temporal functionality) by using spatial (PnP) lineargeometries.

2.2 THEEYESTRUCTURE(BIRD,HUMAN)

Birds and all animals on earth, including humans, live in a complex, physical world in which theymust navigate if they are to survive and perhaps leave some ungrateful children as a geneticlegacy. Animals must perceive the features of the physical world. This is because many of thesefeatures - such as cliffs, quicksand, predators, and sharp sticks - can lead to injury or death.Others,likefoodandwater,arenecessities thatanimalsneedtosurvive[12].

Thanks to evolution's long, brutal march through natural selection, animals have senses thatserveasimportanttoolsforsurvival.Senseshelpedancestorsgatherdataabouttheenvironment, avoiddanger,andlocatevitalresources.

“Agardenwarblerwithanattachedportabledeviceforthelocalapplicationofoscillatingmagnetic fields is displayed in Figure 3. Yellow circumference schematically shows the eyeballprojection onthepictureplane”[1].

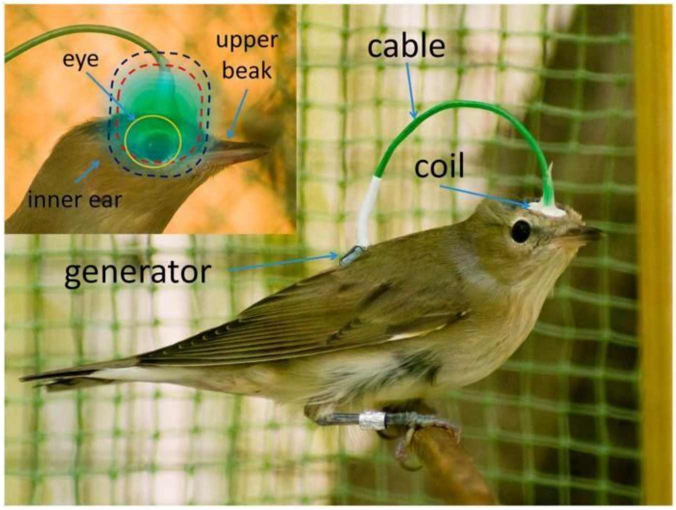

Figure 3. A garden warbler with attached portable device for local application of oscillatingmagneticfields.PicturebycourtesyofJuliaBojarinovaetal. [Bojarinova,Julia,etal.,2020].

Humaneyevs.birdeye:thesamegeometricstructure

The geometric structure of humans and birds is roughly the same [13,14]. Of course, accordingto bird vision expert Graham Martin (Emeritus Professor in the School of Biosciences at theCollege of Birmingham, UK), there are some differences that do not call into question the abovegeneralstatement[15,16].

Howisthehumaneyesimilartotheeyeofabird?

"Both birds andhumans have photoreceptive 'cones' in theretina, locatedat the backoftheeye. These cones allow us to see colored light. The human eye contains 10,000cones persquare millimeter, while songbirds, for example, have up to 12 times as many, or 120,000 conespersquaremillimeter"[17].

The retinas of birds have about three times as many sensory cells as human retinas(bothretinas are located at the back of the eye). So, like a camera with three times as many pixels,birds have much sharper vision than average humans do. Owls, in particular, have large retinasthatgivethemnocolorbutamaximumblack-and-whitevision in verylowlight.

Normal human vision is described as "20/20 level" vision, i.e. having 20/20 vision means normalor average visual acuity. Some people have a vision that's better than 20/20, like 20/15 or20/10. This means that they can see something 20 feet away (like a line on an eye chart) thatmost people can see when they're 15 feet away (the 20/15 vision case) or 10 feet away (the20/10visioncase)(Fig. 4a).

Birds devote a huge amount of space to visual processing, and they have a highly developedsenseofsightwhichallowsthemtoeasilyspotprey.Eagles,forexample,haveexcellent20/5 levelvisioncomparedtoanaveragehumanwhoonlyhas20/20vision.ThismeansEaglescanseethingsfrom20feetawaythattheaveragehumancanonlyseefrom5 feetaway.(Fig.4b).

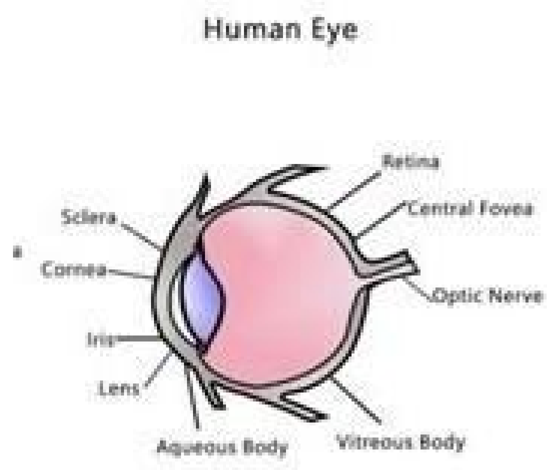

Figure4a.A20/20levelnormal(average)humanvision.Thephotoreceptive'cones'intheretinaarelocatedatthebackoftheeye.
PicturebycourtesyofIvanPhillipsen[PhillipsenI,2022].

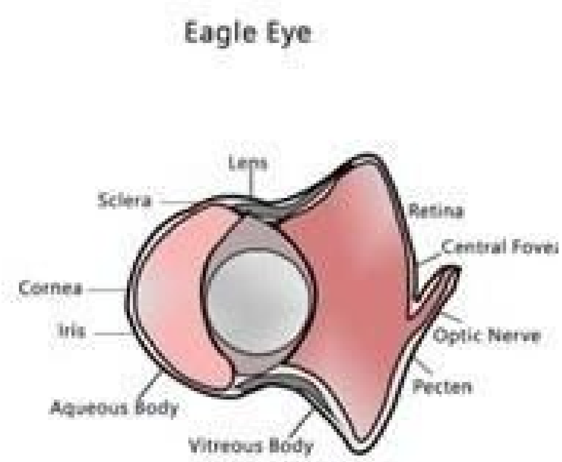

Figure4b.A20/5leveleaglevision.Thephotoreceptive'cones'in abird’sretinaarelocatedatthe back of the eye as well, having 3x sensory cells as human retinas to gather that much datathatquickly. Pictureby courtesyofIvanPhillipsen[PhillipsenI,2022].

Thebird’seyeanatomy

ThefollowingFigure5displaysthebird’seyeanatomyandstructure.

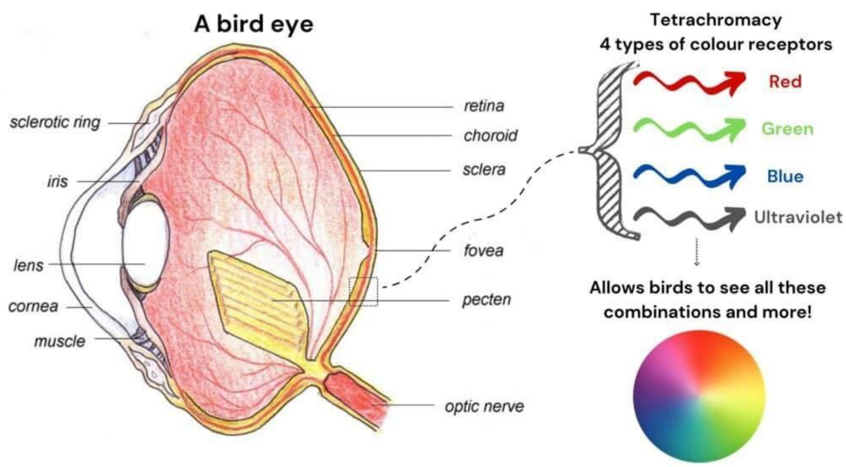

Figure5. Bird’sEyeAnatomy.
PicturebycourtesyofIvanPhillipsen[PhillipsenI,2022].

2.3 INTRODUCINGANINNOVATIVECONCEPT

In the present work, first, the original concept of "*spatial (PnP) linear geometries*" is introducedand documented to describe the PnP shapes and the detected line pairs that are parallel orperpendicular to each other in observed on-images geometries with rectangular shapes, usuallyfound inurbanenvironments(sub-Section2.3).

Subsequently,ahypothesisisstated(thatbirdsfollowthesamevisualprocessforgeoreferencing as robots in machine vision) which is then approached for proving (a statisticallysatisfactoryproving approach based on a synthesis of evidence from eBirddatasets, Flickrimages,CORINElandcovertypes,in-situphotography,andstatisticalanalysis/correlationmatrix).

2.4 INTRODUCINGAHYPOTHESIS

Forresearchtacticalpurposesahypothesisisintroducedinsub-Section2.4.Thestatedhypothesisassumes thatbirdsfollowthesamevisual processin georeferencingasrobots(machine vision, pose determination). Then, according to correlation matrix analysis in sub-Section4.1,itis“proved”asastatisticallysatisfactoryapproachthatbirdsintheir aviannavigation and in nest nidification also follow the same visual process in georeferencing asrobots. A “proof” based on a synthesis of evidence (eBird datasets, Flickr images, CORINE landcovertypes,and in-situphotography)andastatisticalanalysis/correlationmatrix.

Hence,thepaperreasoningthatbirds,apartfromtheirprimarybiophysicalmagnetic“compass”andtheauxiliarygeoreferencingaviannavigationtools(low-densitystructured environmentsrichintrees, flora, andvegetation, aswell as urbanwoodlandswithroads,railways, and power lines), also follow for georeferencing the same as robots’ visual aviannavigationprocess basedon"spatial(PnP)lineargeometries".

3. METHODOLOGY

In this Section the data acquisition is discussed in sub-Section 3.1 while in sub-Section 3.2 a GISoverlayanalysis forthesedatais presented.

3.1 FIELD EXPERIMENTS IN BIRDS WATCHING AREA (eBIRD, FLICKR, CORINE, IN-SITU &VGI)

Thestudyarea

Thetrialbirds-watchingareaislocatedatPossidi,Chalkidiki,NorthernGreece) (Fig.6).

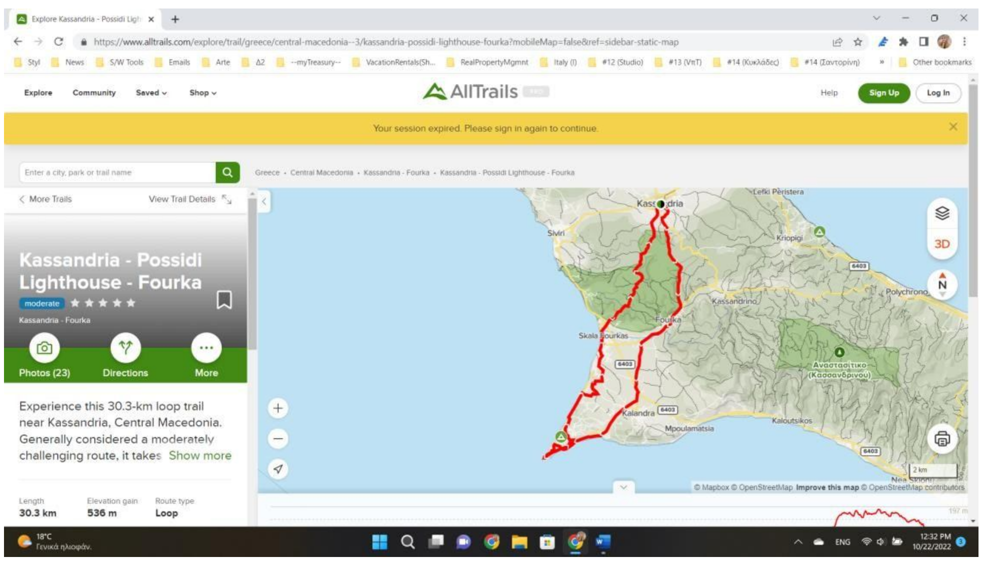

Figure6. Birds’watchingarea–The boundingbox (Possidi/Chalkidiki,Greece). Printscreencredit:AllTrails.comapp,SanFrancisco,CA.

The data acquisition channels (eBird datasets, Flickr imagery, CORINE land cover types, in-situ&VGIphotography)

The data acquisition procedure is related to geo-tagged raster imagery and photography, wasperformed between August – September 2022and it is based on the following fourinputchannels.

(a) **eBirdbasicdataset(EBD):“**TheEBDisthecoredatasetforaccessingallraweBirdobservationsandassociatedmetadata.TheEBDisupdatedmonthly(15thofeachmonth)andisavailablebydirectdownloadthroughhttps://science.eBird.orgtoanylogged-inuserafter completion of a data request form" [20]. "eBird provides open data access in several formats tologged-in users, ranging from raw data to processed datasets geared toward more rigorousscientificmodeling"[21].

(b) **Flickr sharing application:** The Flickr is an online photo management and imagery-sharingapplication for uploading, downloading, sharing, and organizing content [22]. For the trial case,birds' route distributions in Flickr imagery were compared to available eBird data as references.Hence,Flickrimagerycanbeapossiblecomplementarydatasource forgeoreferencingscience.

Flickr as one of the largest photo-sharing platforms has been used in various environmentalanalyses from natural disaster prediction to wildlife monitoring. In this article, bird photos fromFlickr have been downloaded and used to illustrate the spatial distribution of bird locations inPossidi area / Chalkidiki / Greece, and most importantly to see the correlation between thelocationofbirds' nests,thecovertypes,andthespatial(PnP)lineargeometries.

(c) **CORINE land cover types / Copernicus Land Monitoring Service** (part of the CopernicusProgramme)**.** Copernicus is a European programme for monitoring the Earth, in which data iscollected byEarthobservation satellites and combined with observation datafromsensornetworksontheearth's surface.

"Once collected the data is then processed, providing reliable and up-to-date information withinsix thematic areas. These areas are: land, marine, atmosphere, climate change, emergencymanagement,andsecurity.Variousorganizationsmanageanddeliverthesesixthematicin formationservices"[23].

Copernicus Land Monitoring Service (CLMS) provides geographical informationon thelandcover to a broad range of users in the field of environmental terrestrial applications.Thisincludes land use, land cover characteristics and changes, vegetation state, water cycle, andearthsurfaceenergyvariables.CLMSproductsaredividedintofivecategories:
Systematic biophysical monitoring, Land cover & land use mapping, Thematic hotspot mapping,Referencedata,andGroundmotionservice.Thesecategoriesenableapplicationstobedevel opedinawiderangeofareas.Theseincludespatialandurbanplanning,Forestmanagement, Watermanagement, Agricultureandfoodsecurity,Natureconservationandrestoration,Ecosystemaccounting,andMitiga tionofclimatechange.

(d) In-situphotography&VGI(VolunteeredGeographicInformation)

In-situclose-rangephotographywasperformedinthetrialareaoncetheFlickrimageryindicated sufficient density in bird flocks, nests, and spatial (PnP) linear geometries. Even more,andforadditionaldataacquisition,aVGI survey wascarriedout.

"Also, social media data are becoming potential sources of the called "passive" VGI (VolunteeredGeographic Information) and citizen science" [18]. "VGI refers to georeferenced data created bycitizen volunteers. VGI has proliferated in recent years due to the advancement

of
technologiesthatenablethepublictocontributegeographicdata.VGIisnotonlyaninnovativemechan
ism

forgeographicdataproductionandsharingbutalsomaygreatlyinfluenceGIScienceandgeography and its relationship to society. Despite the advantages of VGI, VGI data quality isunder constant scrutiny as quality assessment is the basis for users to evaluate its fitness forusing it in applications. Several general approaches have been proposed to assure VGI dataqualitybutonlyafew methodshavebeendevelopedtotackleVGIbiases"[18].

In the discussed trial, VGI [18] and location-based environmental monitoring [19] have beenapplied in in-situ field surveys in the birds' observation area for spatial (PnP) linear geometriesspatial and visual documentation, land cover types recording, and birds' nests' georeferencedphotography.

Chi-square(orχ^2)testofindependence

The chi-square test of independence is an inferential statistical test, meaning that it allowsdrawing conclusions about a population based on a sample. Specifically, it allows concludingwhether two or more variables are related in the population. It is a statistical hypothesis testthatisvalidtoperformwhentheteststatisticischi-squareddistributedunderthenullhypothesis, specifically Pearson's chi-squared test and variants thereof. Pearson's chi-squaredtest is used to determine whether there is a statistically significant difference between theexpected frequencies and the observed frequencies in one or more categories of a contingencytable.

In the standard applications of this test, the observations are classified into mutually exclusiveclasses.Ifthenullhypothesisthattherearenodifferencesbetweentheclassesinthepopulation is true, the test statistic computed from the observations follows a $\chi2$ frequencydistribution. The purpose of the test is to evaluate how likely the observed frequencies wouldbe assuming the null hypothesis is true. Test statistics that follow a $\chi2$ distribution occur whenthe observations are independent. There are also $\chi2$ tests for testing the null hypothesis ofindependenceofapair of randomvariables based on observations ofthepairs.

Chi-squared tests often refer to tests for which the distribution of the test statistic approachesthe $\chi2$ distribution asymptotically, meaning that the sampling distribution (if the null hypothesisis true) of the test statistic approximates a chi-squared distribution more and more closely assamplesizes increase [https://en.wikipedia.org/wiki/Chi-squared_test].

In the presented trial four (4) chi-square tests of independence have been applied to illustratethe association between birds' nest nidification and the contrast pixel gray coloring (split inthree categories >80%, 40-80%, <40%) detected in (i) the raster eBird datasets, (ii) the rasterFlickr images; (iii) the CORINE land cover classes; and (iv) the raster in-situ and VGI photographyofspatial(PnP)lineargeometries.Thestatisticallysignificantassociationbetweennestnidificationandthesefourvariablesisdescribedin Section4("Results").

(A) Rasterimagesacquisition(eBirddatasets,Flickrimagery,CORINElandcovertypes)

ThenextfiveFigurespresentthe study area aswellasthe datapointsthatindicatethe positionofthecollectedFlickrimages(Figs. 7-11).

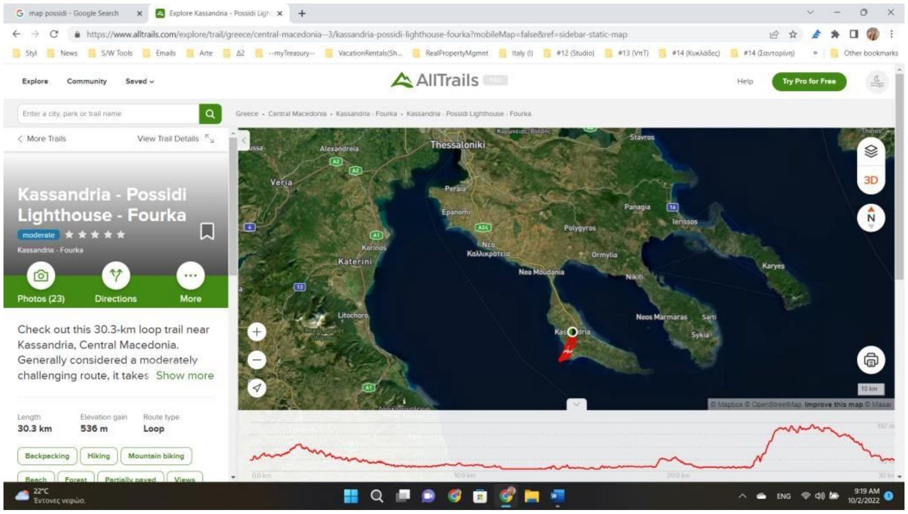

Figure7.eBird datasets&Flickr imagery:PeninsulaofChalkidiki,Greece. Theoverlayimagewascomposedbyebird(www.ebird.org),andFlickr(www.flickr.com)layer images and created on September 28, 2022. Print screen credit: AllTrails.com app,SanFrancisco, CA.

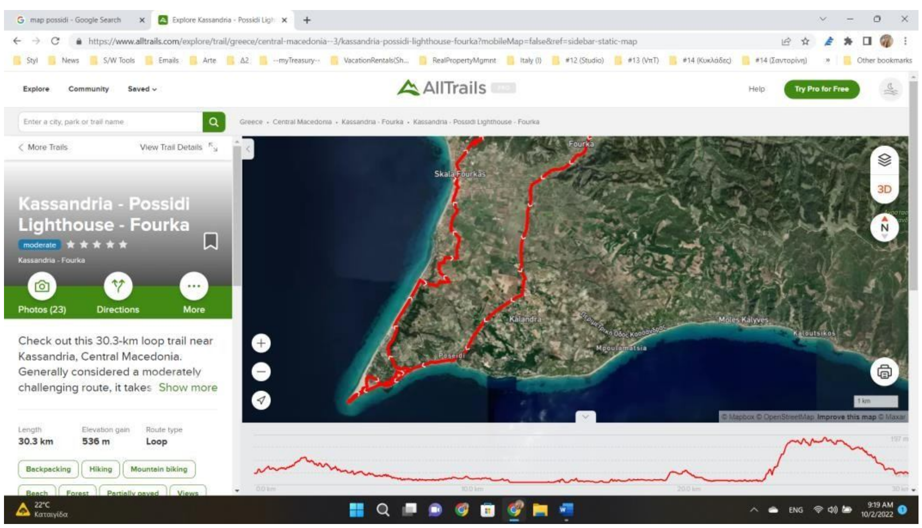

Figure8.eBird datasets&Flickr imageryforthebirds’watchingarea. The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com),andCORINE(https://land.copernicus.eu)layer images andcreatedonSeptember28,2022.Printscreencredit:AllTrails.comapp,SanFrancisco,CA.

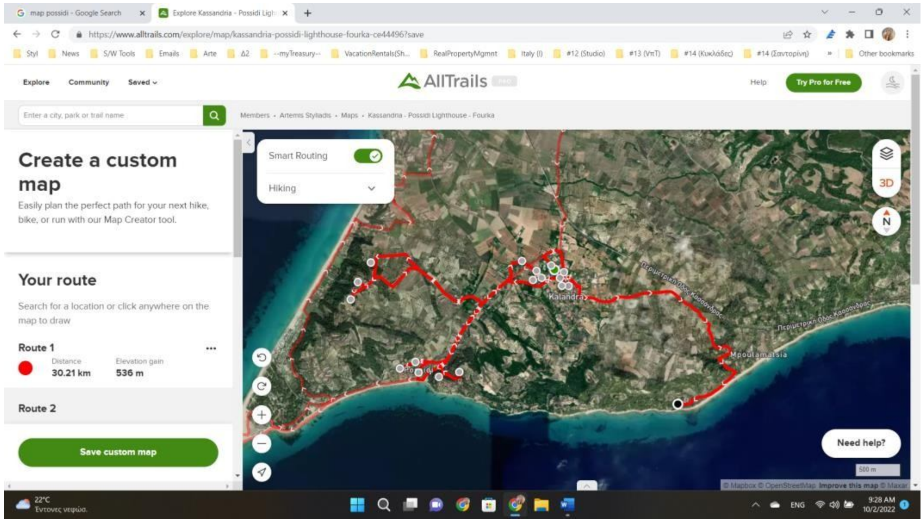

Figure9. Birdmigration:The Temporaldimension(Summer2022imagery). TheoverlayimagewascomposedbyeBird(www.ebird.org),andFlickr(www.flickr.com),layer imagesandcreatedonSeptember30,2022. Printscreencredit:AllTrails.comapp,SanFrancisco,CA.

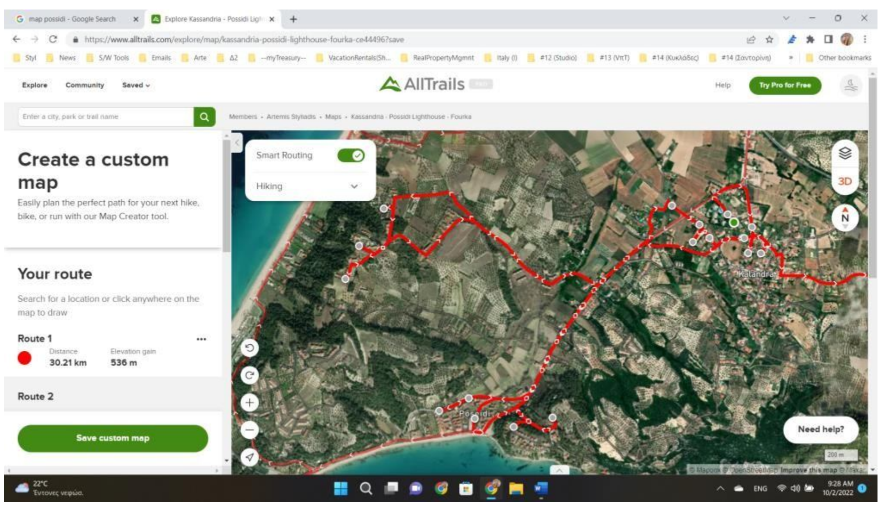

Figure 10. Bird migration: The Spatial patterns dimension(Birds'travelingflywaysinPossidiarea/Chalkidiki,Greece).
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com),andCORINE(https://land.copernicus.eu)layer images andcreatedonSeptember30,2022.Printscreen credit:AllTrails.comapp,SanFrancisco, CA.

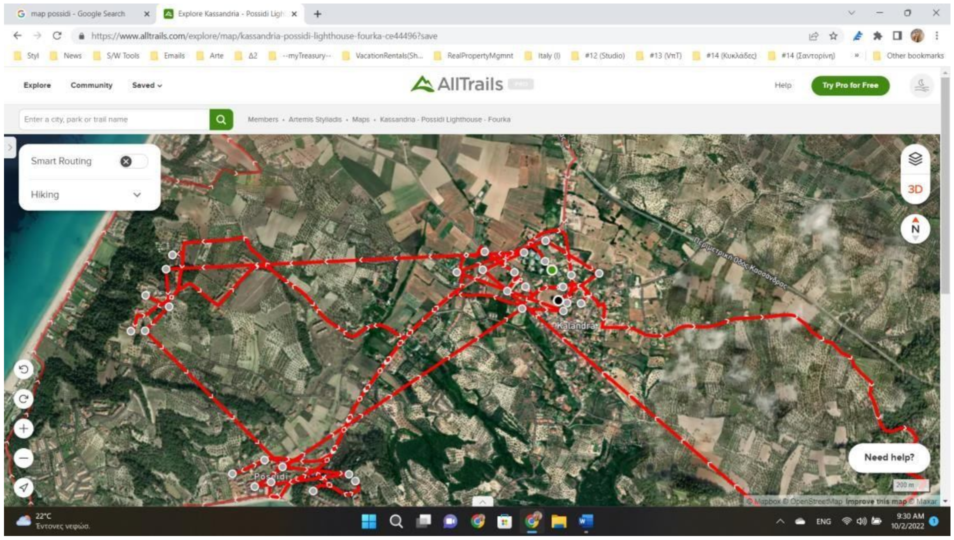

Figure 11. Bird migration: Demonstrating both, Temporal and Spatial patterns(Birds'travelingpathwaysinPossidiareainSummer2022/Chalkidiki,Greece).
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com),andCORINE(https://land.copernicus.eu)layer images andcreatedonSeptember30,2022.Printscreencredit:AllTrails.comapp,SanFrancisco,CA.

Flickrimageryfiltering

The first step was to download the images and then to apply filters to them in order to obtainclean data for image processing analysis. On the Flickr API the following four requirements weresetjust beforebeginningtherasterimagedownloading:

- Themediawassettodownloadonlyimagesandnotvideos.
- ThestartingdatewassetasthefirstofAugust2022.
- Onlyraster imageswithgeo-locationweredownloaded.
- Inordertofindonlyimageswithflocksofbirds,thecorrecttag(birds)hadtobeidentified.

"Flickr has two types of tags: user-generated tags, which are added by Flickr contributors, andmachine-generated tags, which are added to images using Flickr's artificial intelligence. So, themachine-generated tags were set as any, and the user-generated tags were set as bird" [19].As a result, the rasterimages as well as their metadatawere obtained (geo-location, date,imageURL, imageID,andalistofalltagsforeachimage).

Following the raster images downloading, two major filters were applied to the dataset: (i)imagefiltering;and(ii)tag filtering(Fig. 12).

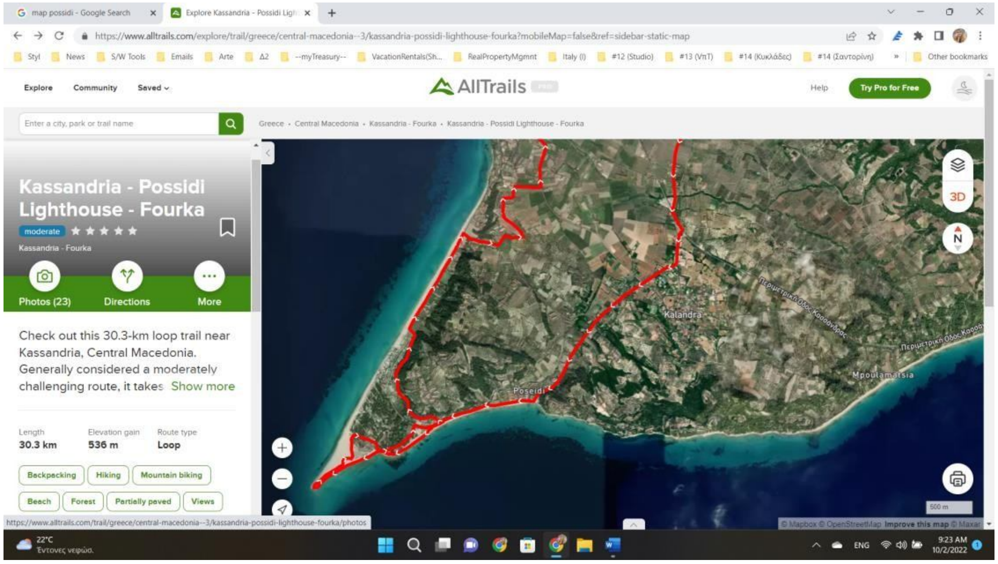

Figure12.eBirddatasets&Flickrimagery:FilteringtheBirds'watchingarea(Fourka,Possidi,PossidiLighthouse/Chalkidiki,Greece).
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com),andCORINE(https://land.copernicus.eu)layer images andcreatedonSeptember28,2022.Printscreencredit:AllTrails.comapp,SanFrancisco,CA.

The final dataset includes the Flickr tag, image ID, and the geo-locations for the raster imagefrom the Institute of Avian Research (IAR), the German Ornithological Society (DO-G), and thejournalVogelwarte [28](Figs.13,14).

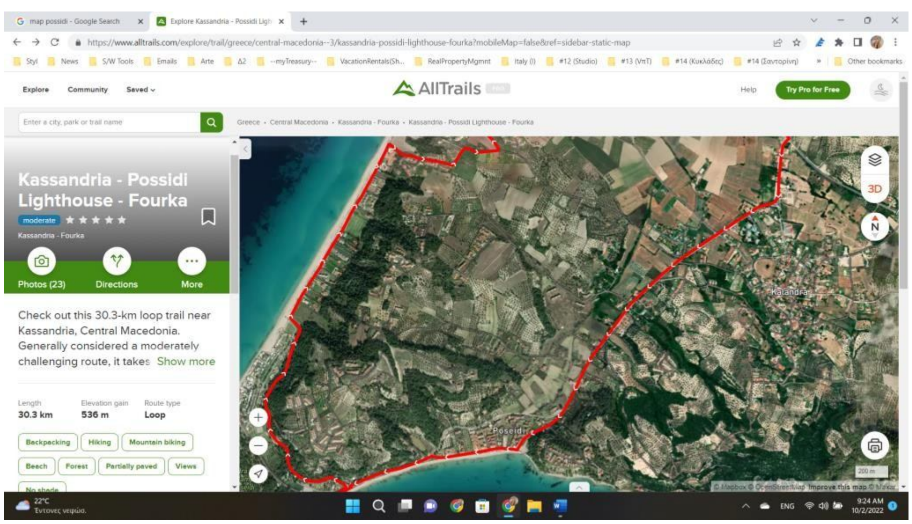

Figure13.eBirddatasets&Flickr imagery:TheFlickrtagandtheImageID.
The overlay image was composed by eBird (www.ebird.org), Flickr (www.flickr.com),andCORINE(https://land.copernicus.eu)layer images andcreatedonSeptember29,2022.Printscreen credit:AllTrails.comapp,SanFrancisco,CA.

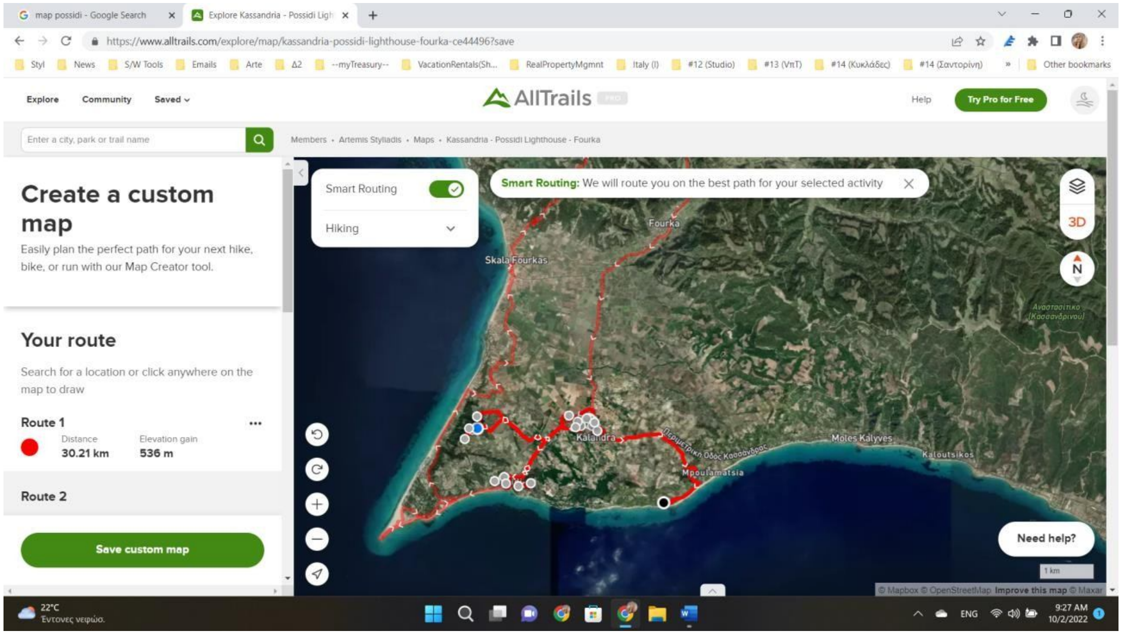

Figure14.eBirddatasets&Flickrimagery:Thegeo-locationsfortheimage. Theoverlayimagewascomposedbyebird(www.ebird.org),andFlickr(www.flickr.com)layerimagesandcreatedonSeptember29, 2022. Printscreencredit:AllTrails.comapp,SanFrancisco,CA.

Birdsdistribution&imageprocessinganalysis

"After obtaining the filtered dataset, in order to visualize the density (expressed in contrast graycoloring) of distribution of bird observations in the study area, image processing techniques andkernel density analysis (KDE) were used" [33,34]. "Kernel Density Estimation (KDE)is a non-parametric technique for density estimation in which a known density function (the kernel) isaveragedacrosstheobserveddatapoints tocreateasmoothapproximation"[34].

Moreover, to explore thedistributionofthedatainlocal low-density areas enjoyinghighdensity gray coloring indicating birds presence, two additional datasets were created: (i) theCORINE land cover values for each observation point within various land cover classes; and (ii)thein-situandVGI rasterphotography.

"Thus, the frequency of birds' observations within different land cover types was observed, andfour chi-square test of independence were performed to explore the association between (i)birds' nest nidification and eBird metadata and references; (ii) birds' nest nidification and rasterFlickr images; (iii) birds' nest nidification and land cover classes; and (iv) birds' nests nidificationandspatial (PnP)lineargeometries" [29,30,31]

(B) Rasterimagesacquisition(In-situphotography,VGIphotography)

An in-situ photography campaign was performed on October 8, 2022 in local low-density areasenjoying high density gray coloring indicating birds presence according the eBird datasets, Flickrimagery,andCORINElandcoverclassesanalysis.

Intheobservationarea(Possidi/Chalkidiki),therearemanyconstructions(e.g.,houses,maisonettes, and villas) rich in “spatial (PnP) linear geometries” structures in a low-densitystructured environment richin trees, flora, andvegetation. In the performed photographycampaign many birds’ nests and manybirds’ travelingflyways, routes, and pathways werephoto-caught(Figs.15,16,17).

Figure15. Birds’nestsona low-densitystructuredenvironmentrichintrees,flora,andvegetationandwithmany“spatial (PnP)lineargeometries”.

Figure16. Birds'nestsona low-densitystructuredenvironmentrichintrees,flora,andvegetationandwithmany "spatial(PnP)lineargeometries".

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Figure17. Birds'nestsona low-densitystructuredenvironmentrichintrees,flora,andvegetationandwithmany "spatial(PnP)lineargeometries".

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On the other hand, in the same environment (Possidi / Chalkidiki, rich in trees, flora, andvegetation) butin constructions without "spatial (PnP)linear geometries"birds' nests didn'tfind (Fig. 18).

Figure18. NoBirds'nestsonalow-densitystructuredenvironmentrichintrees,flora,andvegetationbutpoorin"spatial(PnP)lineargeometries".

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In the same observation area (Possidi/Chalkidiki), there are also constructions (e.g., churches)with non-linear structures in environments poor in trees and flora. In these constructions nobirds'nestsandnobirds'travelingflyways,routes,andpathways werenoticed(Figs.19,20).

Figure19.A Non-linearstructure(Church)inanaturalenvironmentwithouttreesandwithoutPnPlineargeometries→ NoBirds'nests found.

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Figure20.ANon-linear structure(Church)inanaturalenvironmentwithfewtreesandwithoutPnPlineargeometries→NoBirds'nests found.

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3.2 THE4-LAYERSGISOVERLAYSPATIALANALYSIS

"The adapted overlay methodology was the operation of comparing variables among the threemultiplecoverages(EBDreferencedata,Flickrimagery,andCORINElandcover).Intheperformed overlay analysis new spatial data sets were created by merging the data from thesethree input data layers (EBD, Flickr, and CORINE). Overlay analysis is one of the most commonandpowerful GIStechnique"[26].

"For the birds' watching area located in Chalkidiki / Northern Greece (Fig. 6), nine (9) geo-taggedFlickr imagery -which was downloaded using the Flickr API (Application Programming Interface)"[19]- was acquired, analyzed (image processing following by field/on-situ measurements andobservations), and used as the geo-data layer; in conjunction with four (4) eBird datasets usedas the reference-data layer; and three (3) CORINE land cover types related to trees, flora, andvegetationusedas theenvironmental/natural-datalayer[23].

Then,theESRI'sGISclientsoftware(ArcGIS;providedbytheInternationalHellenicUniversity/Department of Forest & Natural Environment Sciences/GIS laboratory) and spatialanalytics technology [24], as well as the AllTrails.com app [25] were used for an overlay spatial(GIS) analysis for gathering and analyzing the following data: nests location (spatial intelligencefunctionality), birds presence density, low-density (or high-density) constructed urban (or ruralareas), spatial linear (or curved) geometries, and land cover types) from all of these three layersandusedlateras inputinthepaper's Section 4("Results").

3.3 QUANTIFYINGTHEACQUIREDFROM THE GISOVERLAYSPATIALANALYSISDATA

The GIS overlay spatial analysis produces raster imagery data that must be quantified to beuseful for statistical spatial analysis purposes (sub-Section 4.1). For this purpose, and with animage-to-ground scaling 1:1.000, the recognized gray darkness areas (with 1-pixel accuracy) areclassifiedintothefollowingthree(3)categories(Table1):

Table1. Classificationsettings fortheGISoverlayspatialanalysis.

Category	Percentage of graydarkness/squared inch onthe raster image (Scale1:1.000)	Number of nestnidification spera100m^2 ground (onaverage)	Local areas(about10acres)
A	80+%-100%	0.. 0.5	Without natureand PnPgeometries
B	40+%-80%	0.5.. 1	Richjustin nature
C	0%-40%	>1	Rich both innatureandPnPgeometries

LocalareasclassifiedasCategoryAhavethelowestdetectedbirds'presence,whileaCategoryC classification referred to the highest ones. The classification settings were defined accordingtoreal-worldon-groundobservations.

The overlay analysis is used to combine the characteristics of the four datasets (layer I: eBirdmetadata and references; layer II: raster Flickr images; layer III: land cover classes; and layer IV:spatial(PnP)lineargeometries)intoone.

Then specific locations or areas that have a certain set of attribute values should be defined,thatis,matchthecriteriaspecifiedinTable1.Obviously,andforaccuracyreasons,thecombined layer should be tested against layer V: nest nidification (raster images from in-situsurveysandVGI photography).

"This approachisoftenused tofindlocations that aresuitablefora particularuseoraresusceptible to some risk. For example, some GIS spatial analysis projectsoverlay layers ofvegetation type, slope, aspect, soil moisture, and so on, to find areassusceptible to wildfire"[24].

In raster GIS overlays, each cell of each layer references the same geographic location. Thatmakes it well suited to combining characteristics for numerous layers into a single layer. In thepresentedtrialcase,numericvalueswereassignedtoeachcharacteristic,allowingmathematically combinationoftheinvolvedlayersandassignmentofanewvaluetoeachcellintheoutputlayer.

Below is an example of the raster GIS overlay applied to the trial case. Three raster layers (Flickrimage, nature, and PnP geometries) are ranked for development suitability on a scale of 1(image) to 1.000 (ground). When the layers are added, each cell is ranked on a scale of 3 (birdsnestnidification/acre)to 21(birdsnestnidification/acre)(Fig.21).

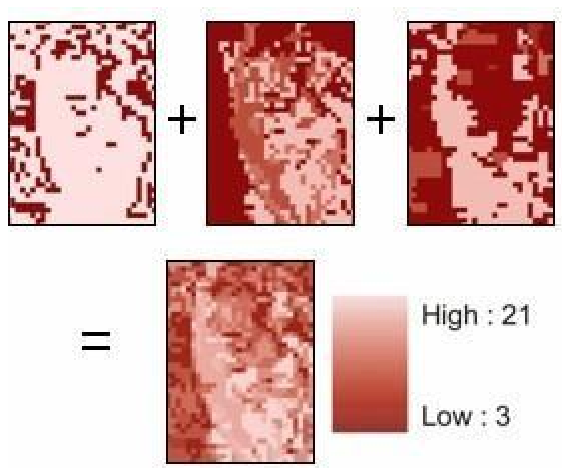

Figure21.A rasterGISoverlayexampleforthebirdswatchingarea(Possidi/Chalkidiki/Greece).

4. RESULTS AND DISCUSSION

4.1 STATISTICAL SPATIAL ANALYSIS – NEST NIDIFICATION (FIVE VARIABLESCORRELATION)

In this Section the input data for performing a statistical spatial analysis are: nests location(spatial intelligence functionality), birds routes tracking, birds presence density, low-density (orhigh-density) constructed urban (or rural areas), spatial linear (or curved) geometries, and landcover types; from all of the three layers (i.e. eBird dataset, Flickr imagery, and CORINE landtypes).

“Correlation is a statistical term describing the degree to which two or more variables move incoordinationwithoneanother”[32].Iinthetrialcasethevariablesarefive:(i)thenest nidifications; (ii) in eBirds datasets/flock of birds detected in traveling paths or pathways; (iii) inFlickr images/flock of birds detected in traveling paths or pathways; (iv) in CORINE imagery/theclassified land cover classes, and (v) In in-situ photography/the spotted spatial (PnP) lineargeometries.

"Forthetrialcasefourchi-squaretestofindependencewereperformedtoexploretheassociation between (i) birds' nest nidification and eBird metadata and references; (ii) birds'nestnidificationandraster Flickrimages;(iii)birds'nestnidificationandlandcoverclasses; and (iv)birds'nestsnidificationandspatial(PnP)lineargeometries[29,30,31].FollowingtheCramer'sVmetric wascomputedas aresultofthetest"[35].

"In statistics, Cramér's V (sometimes referred to as Cramér's *phi* and denoted as ϕ_c) is a measureof association between two nominal variables, giving a value between 0 and +1 (inclusive). It isbased on Pearson's chi-squared statistic and was published by Harald Cramér in 1946" [36]."Cramer's V is a metric to measure the strength of association between two variables. It rangesbetween 0 to 1, which values above 0.5 indicating a strong association. In the trial case, theresult of the chi-square test illustrated a statistically significant association between birds' nestsandlandcovertypes(withCramer'sV=0.5209andp-value<0.0001);andaverystrongstatistically significant associationbetween birds' nests and spatial (PnP)linear geometries(withCramer'sV=0.6312andp-value<0.0001)"[32].

"Table2illustratestheStatisticalSpatialCorrelationoftheBirds'Nestsdistribution(eBirddatasets, Flickr imagery, CORINE land cover types, and PnP photography from in-situ and VGIsurveys).Moreover,informingthecontributorsaboutthevalueoftheirdatainhelpingscientificprojectscanmotivatethemtocontributehigher-qualitydata"[19].

Table 2. Statistical Spatial Correlation of the Birds' nest nidification distribution(eBirddatasets,Flickrimagery,CORINElandcovertypes,In-Situ& VGIphotography)

Layer	Min	Max	Mean	Std
SDM_eBird datasets	0.0920	1.0000	0.2145	0.2090
SDM_Flickr imagery	0.4283	1.0000	0.5332	0.1337
CORINE landcovertypes	0.4509	1.0000	0.5512	0.1308
PnP photographyfrom In-Situ&VGI surveys	0.5677	1.0000	0.6244	0.1212

Table3presentstheCovarianceMatrixasithasbeengeneratedfrom(i)Table's1data(Statistical Correlation of theBirds' Nests distribution: eBird datasets & Flickr imagery); (ii)Birds' Nests locations and traveling routes, paths, and pathways; (iii) Land cover types; and (iv)Spatial(PnP)lineargeometries.

Table3. TheCovarianceMatrix

Layer	SDM_eBird datasets	SDM_Flickr imagery	**Birds' Nestnidificationl ocations andFlying/Traveli ngflyways, routes &paths**	CORINE landcover types(Natur alenvironme ntwith water,trees, andplants)	PnP Lineargeomet ries(Mutually parallel orperpendicu larline pairs inobservedre ctangular shapeimages)
SDM_eBird datasets	0.00848	0.01224	0.01230	0.01212	0.01242
SDM_Flickr imagery	0.01224	0.02075	0.01220	0.01207	0.01262
Birds' Nestslocations andFlying/Traveli ngflyways,routes & paths	0.01230	0.01220	0.00790	0.01273	0.01263
CORINE landcover types(Naturalenvi ronment withwater,trees,a nd plants)	0.01212	0.01207	0.01273	0.00809	-
PnP Lineargeometries (Mutually parallelor perpendicularline pairs inobserved rectangular shapeimages)	0.01242	0.01262	0.01263	-	0.00786

"Finally,Table4demonstratestheCorrelationMatrix.Actually,thePearsoncorrelationcoefficient is used to examine the strength and direction of the linear relationship betweenthese three continuous variables: (i) Birds' Nests locations and traveling routes, paths, andpathways; (ii) Land cover types; and (iii) PnP linear geometries. The correlation coefficient canrange in value from −1 to +1. The larger the absolute value of the coefficient, the stronger therelationship betweenthevariables"[31].

Table4. TheCorrelationMatrix
(Birds' nests' locations and flying/traveling routes, paths, and pathways; Land cover types;SpatialPnPlineargeometries)

Layer	Birds' Nestslocations andFlying/Traveli ngflyways, routes &paths	Land Covertypes(Naturalenvir onmentwith water,trees, andplants)	PnP Lineargeometr ies(Mutuallyp arallel orperpendicul arline pairs inobservedrec tangular shapeimages)	Rich NaturalLand s withtrees &Man yPnP Lineargeo metries
Birds' Nestslocations andFlying/Trav eling flyways, routesandpaths	1.00000	0.66732	0.73655	**0.90703**
Land Cover types(Naturalenvi ronment withwater,trees,a nd plants)	0.66732	1.00000	0	0.50448
PnP Lineargeometries (Mutually parallelor perpendicularline pairs inobservedrectan gularshape images)	0.73655	0	1.00000	0.51087
RichNaturalLand withtrees & Many PnP Lineargeometries	**0.90703**	0.50448	0.51087	1.00000

A very strong positive correlation relationship (r = 0.90703) has been found between the layers"*Birds' Nests locations and Flying/Traveling routes & paths*" and "*Rich Natural Lands with trees&ManySpatial(PnP)Lineargeometries*".Obviously,thebirdsprefertotravelinroutes/paths/pathways and to build up nests in constructed natural environments rich in trees,flora,andvegetation,aswellaswithmanyspatial (PnP)lineargeometries (Table3).

4.2 HYPOTHESIS–ASTATISTICALLYSATISFACTORYAPPROACH

Hence, this very strong correlation relationship (r = 0.90703) should be interpreted as a greatgeoreferencing utility and functionality in birds' migration procedure [30]. Hence, this should beregarded as a statistically satisfactory approach of confirmation for the case introduced in sub-Section 2.4 (Hypothesizes that birds follow the same visual process for georeferencing as robotsinmachinevision).

Theconfirmation ("proof")isbased ona synthesisof evidencefrom eBirddatasets, Flickrimages,CORINElandcoverclasses,in-situandVGIphotography,andstatisticalanalysis/correlation matrix, that birds also follow the same visual process for georeferencingbasedon"spatial(PnP)lineargeometries"as robots.

5. CONCLUSION–POTENTIALAPPLICATIONS

Conclusion.Thebirds,apartfromtheirprimarybiophysicalmagnetic"compass"andtheauxiliary georeferencing avian navigation tool,also follow the same visual avian navigationprocessforgeoreferencingbasedon"spatial(PnP)lineargeometries"asrobots.

In this paper, after introducing and documenting the innovative concept "*spatial (PnP) lineargeometries*", a statistically satisfactory approach is reasoning that birds' visual georeferencingprocedure follows (like robots) the PnP closed forms and georeferencing functionalities derivedfrom several detected mutually parallel or perpendicular line pairs in observed rectangularshape images usually found in natural and low-density structured environments. The presentedresearchisbasedonavailablerecent(AugustandSeptember2022)eBirddatasets,Flickrimagery, and CORINE land cover reference layer data, as well as in-situ and VGI photography(October 2022)fromthePossiditrialareainChalkidiki,NorthernGreece.

Actually, the proposed methodology observes the temporal and spatial distribution in acquiredraster images of both, the birds' traveling pathways and the birds' nest nidification, as well as todetermineswhetherornotthereisanyassociation(correlation)between(i)thisspatialdistribution (ii) the land cover types (natural environment with or without trees, flora, andvegetation),and(iii)thespatial(PnP)lineargeometries.

The results illustrated that the data are more concentrated near natural environments withtrees and water pockets inlow-density urban areas with many constructionsrich inspatial(PnP) linear geometries. A very strong positive correlation relationship (r = 0.90703) has beenfoundbetweenthelayers“*Birds’NestslocationsandFlying/Travelingflyways,routes&paths*”

and “*Rich Natural Lands with trees & Many spatial (PnP) Linear geometries*”. Obviously, thebirdsprefertotravelinroutes/paths/pathwaysandtonidificatenestsinlow-densityconstructed natural environments rich in trees, flora, and vegetation, as well as with many PnPlinear geometries(Section4,Table3).

Moreover, a statistically significant association was observed between birds’ traveling pathways(spatial patterns of observations/data from Flickr imagery); birds’ observers’ behavior; landcovertypes;andspatial(PnP)lineargeometries.

Finally, in this paper, it was stated that birds, apart from their primary biophysical magnetic“compass”(cryptochrome-basedmagnetoreceptors)andanyauxiliarygeoreferencingaviannavigation tools (low-density structured environments), also followfor georeferencingsimilartorobots’visualmotorprocess basedon"spatial(PnP)lineargeometries".

PotentialApplications

Aspotentialfutureapplicationsshouldbeexaminedthestudyoftheinfluenceoftheintroduced “spatial (PnP) linear geometries” georeferencingfunctionalityon human spatialcognitionandmovementbehavior(andparticularlyonchildrenwithmotorcontrolandcoordination disorders).

Openresearchissues

Infutureresearchonbirdavianmigration,thestudyofmetabolicphysiologyandthebiochemical basis of migratory behavior should be examined. Technological advancement inphysiological and biochemical analyses -in particular- has contributed to this, as it now allows tostudyoftheseaspects.Obviously,thescopeofthisresearchworkextendsbeyondbirdsbecauseits biophysicalcontext.

DataAvailability

All data generated or analyzed during this study are included in this published article (and itsSupplementaryInformationfiles)andtheyareavailablefromtheauthoronreasonablerequest.

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ACKNOWLEDGEMENTS

I am grateful to my doctoral supervisor committee for their helpful advice, and to the Instituteof AvianResearch "VogelwarteHelgoland"(IAR), anon-universityresearchinstituteintheportfolio of the Lower Saxonian Ministry of Science and Cultural Affairs (Germany), for helpingmy research with data and advice on using eBird datasets and Flickr imagery. The work wassupported by the Department of Forest and Natural Environment Sciences / The InternationalHellenicUniversity,Greece.