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StudyonOptimumModelofTemperatureandHumidityControlinGrainBulkBasedonParticleSwarmOptimizationAlgorithm

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Abstract

Temperature and moisture are the most important factors affecting the safe storage of grain. Too high or too low temperature and humidity will cause the decomposition of organic matter in grain and food security problems such as pests, diseases and mildew. The regulation of temperature and humidity in grain storage is a multi-variable coupling and multi-objective optimization problem. In this paper, by analyzing the characteristics of grain humidity and temperature regulation process, the parameters of model are optimized by using GPSO particle swarm optimization algorithm, then the model predictive control is realized, and the proposed algorithm is simulated and experimentally studied. Experiments show that the algorithm has a high degree of fitting for predicting the humidity and heat control process of large grain stacks, and has a good prediction effect for temperature and humidity trend change.

***Keywords:** Grain Bulk, Particle Swarm Optimization, Temperature and Humidity Control, Multi-objective Optimization*

1.Introduction

Grainstorageneedstoachievesafety,qualityandenergysaving.Toachievethesethreeobjectives,itneedstocontrolthetemperatureandhumidityofstoredgrain,andfurther optimizethequalityofgrainandreduceenergyconsumptionofthesystem[1].Therearetwotraditionalwaysforgrainhumidityandtemperaturetransmissioncontrolsystem,temperature-dryingandmechanicalventilation.Becausethereare manydifficultiesincontrollingthetiming,volumeanddurationofventilationaccordingtograintemperatureandhumidity,itisnecessarytomakeabreakthroughintheoptimizationmodeloftemperatureandhumidity control.

Duringtheventilationprocess,therearethreemaincharacteristics:super-largetimelag,couplingandnon-linearity.intheprocessofventilation,coolingofgrainisslowbecauseofhighwindresistancewhichleadstoslowtemperaturetransfer,andthereforetemperatureandhumidityhasgreathysteresis.Featureofcouplingandnon-linearity:intheprocessofventilation,seriousnon-linearitycanbefoundbetweeninputandoutputquantitybecauseofhighlycouplingoftemperatureandhumidity.

Itisanon-linearprocesswithlargetimelagfromthebeginningofhumidityandheatregulationtotheeffectongrainhumidityandheatparametersfartherawayfromthevent.Therefore,compensationlag,multivariablecouplingand multi-objectiveoptimizationshouldbeconsideredwhenchoosingcontrollingmethod[2-3].

Byanalyzingthefeaturesofventilationandcontrollingpr

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oblemsofventilation,particleswarmoptimizationisadoptedtooptimizeparametersofhumidityandheatregulationmodel,furthertorealizemodelpredictivecontrol[4-7].Theproposedcontrolmethodissimulatedandexperimentallystudied,atlastanalyzetheapplicationofcontrollingmethod[8].

2.Designofoftemperatureandhumiditypredictioncontrolsystemofgrainbulk

Thepredictivecontrolsystemisamulti-inputandmulti-outputmodelmechanism,asshowninFigure1.Graintemperature(T_g)andhumidity(H_g)arecontrolledobjectswhiletemperature($T_{a\text{-}in}$)andrelativehumidity($T_{a\text{-}in}$)ofairinventiscontrolobjects.

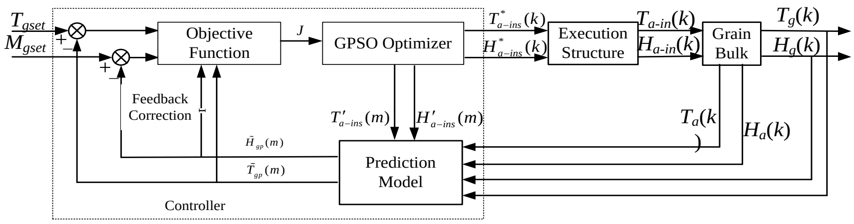

Fig.1.Predictioncontrolsystemoftemperatureandhumidityingrainbulk

Itcanbeseenfromfigure1thatcontrolleriskeytoevaluatethecontrolstructure.Controllerismadeupofoptimizerandpredictionmodel.Optimizerfirstcomputethevalueof T^*_{a-ins} and H^*_{a-ins} inthenextmomentaccordingtothevalueofTgsetandHgsetinpresentconditionbyapplyingtherulechoosenbyoptimizingcalculation.Thentemperature$T_a$andhumidity $M_a$aspredictionmodelinputbeadjustedbasedonfeedbackagainbythepredictionmodel.Nextoptimizationiscarriedoutbytheoptimizerforseveralcycles,atlastoptimizerwillcalculateoptimaloutput T^*_{a-ins} and H^*_{a-ins} whichwillbesenttoactuatorandadjustmentofgraintemperatureandhumiditywillbedonethere.

Predictionmodelisthebaseofpredictioncontrol.Fornonlinearpredictionmodel,modelfunctioniscriticalanditsbasicfunctionisbasedoninputofhistoricalinformationandpredictiveoutputofacertainperiodinacertainfuture.

Predictionmodeladoptsheatandmassmechanismmodelandismadeupofgrainhumidityequilibriumequation,airhumidityequilibriumequation,grainheatequilibriumequationandairheatequilibriumequation.

1)Grainhumidityequilibriumequation

$$\frac{\partial M_g}{\partial t} = -R_w \tag{1}$$

2)Airhumidityequilibriumequationingrainbulk

$$\rho_a \psi \frac{\partial M_a}{\partial t} = \frac{f_a}{\Delta x}\left(M_{a-m} - M_a\right) + R_w \rho_g \tag{2}$$

3)Grainheatequilibriumequationingrainbulk

$$\rho_g c_{pg} \frac{\partial T_g}{\partial t} = h_{g-a}\xi(T_a - T_g) - R_w \rho_g [(L_{vap} + c_{pv}(T_a - T_g)] \tag{3}$$

4)Airheatequilibriumequationingrainbulk

$$\rho_a c_{pa} \frac{\partial T_a}{\partial t} = \frac{f_a}{\Delta x} c_{pa}(T_{a-in} - T_a) - h_{g-a}\xi(T_a - T_g) + c_{pv} T_a R_w \rho_g \tag{4}$$

Themeaningofparametersofequilibriumequationisasfollows:tstandsfortime;$\rho_g$standsforgraindensity; h_g standsforgrainhumidity;$R_W$standsforrate-of-lossofwater; ψ standsforporosity; f_a standsforverticalairvelocity; M_{a-in} standsforairabsolutehumidityinthevent; T_g standsforgraintemperature; c_{pg} standsforspecificheatcapacity; h_{g-a}

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standsforcoefficientofconvectionandheattransferbetweengrainsurfaceandair; ξ standsforspecificsurfaceareaofwhichgraincontactwiththeair; L_{vap} standsforvaporizationheatofgrainhumiditycontent; c_{pv} standsforspecificheatcapacityofvapor; T_{a-in} standsfortemperatureinvent.

Controlvariableofsystemis$\boldsymbol{U}=[H_{a-in}T_{a-in}]^{T}$anditisaninputinthemodel.Theformula(5)isadoptedfortransformationfromrelativehumiditytoabsolutehumidityofairinthevent.

$$M_{a-in} = 0.622\frac{P_{vs}H_{a-in}}{P_{atm} - P_{vs}H_{a-in}} \tag{5}$$

Thepresentgraintemperatureandhumidityandrelativehumidityasoriginalinput,combiningtwocontrolvariablesofairtemperatureandhumidityintheventbyusingpredictionmodel,itcomesouttheformula$\boldsymbol{X}=[HgM_aT_gT_a]^{T}$,inwhich$\boldsymbol{Y}=[HgT_g]^{T}$iscontrolledvariablebythesystem.

3.Designofobjectivefunctionforoptimizingtemperatureandhumiditytransfer

Foroptimumcontrolofhumidityandtemperaturetransferoflargegrainbulk,optimizingobjectfunctioncanbeusedforobjectiveoptimization,itisabouthowtoreduceenergyconsumptiononthepremiseofguaranteeinggrainqualityintheprocessofcontrollinggraintemperatureandhumiditytransfer.Therefore,objectfunctionfocusesonhumidity,temperature,qualityandenergyconsumptionofgrain.

3.1Designofoptimizingobjectfunctionofgraintemperature

Temperatureisanotherkeyfactorintheprocessofsafegrainreserve.Temperaturehasagreatinfluenceongrowthandbreedingofpestsandmicroorganism.Formostpests,thesuitabletemperatureforthemtoliveisbetween22°Cto32°C ,therefore,lowerorhighertemperaturewillhelptorestraingrowthandbreedingofpests,orevenkillthem.Formostmicroorganism,thepropertemperatureforthemtogrowandbreedisbetween28°Cto30°C.Whenitisbelow20°C ,thegrowingspeedofmostmicroorganismwillslowdownandwhenitisbelow15°C,thebreedingoffunguswillberestrained.Moreover,temperatureiscrucialtograinrespirationbecauserespirationgetsstrongerinpacewiththerisingoftemperature.Therefore,grainreservationunderlowtemperaturecanreducethelosscausedbyrespirationandguaranteegrainqualityanditisamusttokeepasuitabletemperatureinbarn.

Henceitisnecessarytosetreasonableobjectvalveofgraintemperaturecontrolandsetupoptimizingobjectfunctionofgraintemperature,andtheoptimizingobjectofgraintemperatureistheminimumvalueofthefunction.

$$J_T = (T_g - T_{gd})^2 \tag{6}$$

Inthisfunction,T_{gd}standsforthesetvalueofgraintemperature.

3.2Designofoptimizingobjectfunctionofgrainwatercontent

Grainwatercontentisoneofthemostimportantconditionsinsteadyandsafegrainreserve.Moistureisnecessarymediumforallkindsofbiochemicalreactionandallmetabolismactivitiesmustbedonewiththeexistenceofwater.Hightemperatureandhighmoistureleadstostrongerrespiration,fastermetabolismandfasterspeedofmaterialconsumption,allofwhichwilldecreasethestabilityofgrain.Higherhumidityandmoisturewillalsocutdowntheimmunityofpestsandmicroorganism.Theappropriatehumidityisintherangefrom70%to75%andmoistureisfrom13%to13.5%.Inthecaseofkeepingrelativeairhumiditybelow65%andkeepthecorrespondingmoisture,itispossibletoholdalmosttheactivitiesofallmicroorganism.Controlsystemistomakecontrolledvariablesreachtargetvaluedesigned,therefore,thelessthedeviationbetweencontrolledvalueandsettargetvalue,thebetter.Moisturetargetfunctionisasfollows:

$$J_M = (M_g - M_{gd})^2 \tag{7}$$

3.3Generaloptimizingobjectfunctionandconstrainedconditionofsystem

Asmentionedabove,generalobjectfunctionoftemperatureandhumiditytransmissioncontrolisshowninformula(8):

$$J = \alpha J_M + \beta J_T + \gamma J_E \tag{8}$$

α , β , γeachstandsforweightofmoisture,temperatureandsyst

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emenergyconsumption.Differentventilationprocessandsystemwillbepossiblebysettingdifferentvaluesandtheirvaluewillaffectinfluenceonobjectfunctioncausedbychangesofdifferentpartsoftheobjectfunction.Theminimumvalueofobjectfunctioncanbeachievedbyfindingminimizingprocessofthreedifferentphysicalquantitiesandinfluencecausedbyprocessoftemperatureandhumidityisconsideredinconstrainedconditions.

Inaccordancewithdifferentaimsoftemperatureandhumiditycontrol,therestrainedconditionshouldbecarriedoutbasedonrelativedatafromgraincondition(grainvarieties,averagetemperatureofgrainpile,maximumtemperatureofgrainpile,gradientvalueoftemperatureofgrainpile),spaceconditioninbarn(temperatureandhumidityinthebarn),environmentalcondition(airtemperatureandairhumidity).Theoptimizingobjectfunctionsandrestrainedconditionsformulatedareasfollows:

(1)Coolingandventilation

$$Hg<Hg_{div},\quad T_g \le T_{gd}$$

$$\min_{T_{a-in},H_{a-in}} J=\alpha(M_g-M_{gd})^2+\beta(T_g-T_{gd})^2+\gamma[3600P_{fan}+m_a\left|T_{a-in}-T_{am}\right|(c_{pa}-c_{pv}M_{a-in})]t'_{v2} \tag{9}$$

subjectto:

$$Hg_d\text{-}\Delta M \le Hg_e \le Hg_d$$
$$T_{DPa}<T_g$$
$$T_{min} \le T_{a\text{-}in} \le T_{max}$$
$$H_{min} \le H_{a\text{-}in} \le H_{max}$$

Amongtheabove,T_{Dpa}standsfordew-pointtemperature.Sincethemostimportantthingincoolingventilationistopreventcondensationofmoisture,restrainedconditionsofthedew-pointisaneeded.

(2)Reducinghumidityandventilation

$$\min_{T_{a-in},H_{a-in}} J=\alpha(M_g-M_{gd})^2+\beta(T_g-T_{gd})^2+\gamma[3600P_{fan}+m_a\left|T_{a-in}-T_{am}\right|(c_{pa}-c_{pv}M_{a-in})]t'_{v2} \tag{10}$$

Subjectto:

$$Hg_d\text{-}\Delta M \le Hg_e \le Hg_d$$
$$T_{DPr}<T_{a\text{-}in}$$
$$T_{min} \le T_{a\text{-}in} \le T_{max}$$
$$H_{min} \le H_{a\text{-}in} \le H_{max}$$

Amongtheabove,T_{gd}standsforoptimalobjectvalueaccordingtodifferentclimaticconditionsandgrainconditions.Thisprocesscanberegardedasthatcoolingventilationandreducinghumidityventilationarecarriedoutthesametime.Inordertopreventoverlossofmoisture,restrainedconditionsofequilibriumofmoistureareadded.ItisHg_d-$\Delta M \le Hg_e \le Hg_d$,inwhich$Hg_e$standsforafunctioncontainingairtemperatureintheventandrelativehumidity.

Thebasicpointofgraintemperatureandhumiditytransmissionprocessisaprocesswithmultipletargetsoptimization.Exceptaninitialdividingbetween*J*anditsconstraintconditionsbasedontemperatureandhumidityofgrainintheprocess,itneedstofindanothergroupofcompromisingsolutionsetstooptimizingmultipleobjectssimultaneouslyfurthertoavoidmorethanoneoptimalsolutionthatwillmakeoptimalobjectimpossibletofind.Thekeyintheoptimizingprocessisbasedonthevaluetakingofα， β， γinthefunction*j*studiedinthischapter.

4.Predictionmodelofgrainbulktemperatureandhumiditytransmissionbasedonparticleswarmoptimization

4.1Predictionprocessofgeneralizedparticleswarmoptimizationalgorithm

Theprocess of control prediction of grain temperature and humidity transmission based on particle swarm optimization is as follows:

(1)Initialization,setthepositionandspeedofparticleinparticleswarm.

$$\begin{bmatrix} x_{11} & x_{12} & v_{11} & v_{12} \\ x_{21} & x_{22} & v_{21} & v_{22} \\ \cdots & \cdots & \cdots & \cdots \\ x_{N1} & x_{N2} & v_{N1} & v_{N2} \end{bmatrix} \tag{11}$$

Amongtheabove,x_{ij}(i=1,2,...,N,j=1,2)standsforparticlepositionandv_{ij}standsfortheparticlespeed.

Computationofadaptationofeachparticle,thatischoosingobjectfunction*J*.

Particletraining,computethevalueofposition$\boldsymbol{P}_{bi}(m)$,inwhichtheparticlehasbestadaptationeverexperiencedtil

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lcurrentoptimizingmomentm.

$$\boldsymbol{P}_{bi}(m)=\begin{cases}\boldsymbol{P}_{bi}(m-1) & J(\boldsymbol{x}_i(m))>J(\boldsymbol{P}_{bi}(m))\\ \boldsymbol{x}_i(m) & J(\boldsymbol{x}_i(m))\le J(\boldsymbol{P}_{bi}(m))\end{cases} \quad (12)$$

$$\boldsymbol{P}_{bi}(m-1)=[x_{i1}(m-1)\quad x_{i2}(m-1)\quad \cdots \quad x_{in}(m-1)] \quad (13)$$

$$\boldsymbol{x}_i(m)=[x_{i1}(m)\quad x_{i2}(m)\quad \cdots \quad x_{in}(m)] \quad (14)$$

(4)Optimizationinoverallsituation,trainoptimalpositionthatallparticlesintheswarmhaveexperienced.

$$G_{bi}(m)=\min\left\{J(\boldsymbol{P}_{bi}(m))\right\} \quad (15)$$

(5)Updateoptimalparticlespeedandpositon.

$$v_{ij}(m+1)=v_{ij}(m)+c_1r_1(P_{bij}(m)-x_{ij}(m))+c_2r_2(G_{bi}(m)-x_{ij}(m)) \quad (16)$$

$$x_{ij}(m+1)=x_{ij}(m)+v_{ij}(m+1) \quad (17)$$

Amongtheabove,$c_1$and$c_2$standforlearningrates,$r_1$and$r_2$arerandomnumberuniformdistributedinthevaluesrange[0,1].

Inordertoimprovetheconvergencefunctionofthecomputation,theconceptofinertiaweightisintroducedintoShiandothers[107],therenewedformulaofspeedandpositonisasfollows:

$$v_{ij}(m+1)=wv_{ij}(m)+c_1r_1(P_{bij}(m)-x_{ij}(m))+c_2r_2(G_{bi}(m)-x_{ij}(m)) \quad (18)$$

$$x_{ij}(m+1)=x_{ij}(m)+v_{ij}(m+1) \quad (19)$$

$w$standsforinertiaweight,andcandecidetowhatextentithasofthecurrentspeed.Reasonablechoiseofwmakeparticleshavetheabilityofbalancedexplorationanddevelopment.Theexpressionofnertiaweightadoptslineargraduallydecreasingweithtingstrategyperposedby Shi[107]thatcanbeseenasfollows:

$$w=w_{\max}-(w_{\max}-w_{\min})\times\frac{t}{T_{\max}} \quad (20)$$

Amongtheabove,T_{max}standsformaximumevolutionalgebra;w_{max}standsforinitialinertiaweight;w_{min}standsforinertiaweightinthecaseofmaximumevolutionalgebra. Usuallyw_{min}takesthevalueof0.4,andw_{max}0.9.

(6)Makejudgementandcomparisonofadaptabilityofobjectfunctiontoseeifitmeetstherequirementoradvancedtoiterationssetbefore,ifnot,backtostep(2).

4.2Objectdescriptionandparametersdetermination

4.2.1.Experimentenvironment

Theexperimentenvironmentadoptsexperimentplatformofnationalgrainengineeringcontrollaboratory.Theexperimentalsubjectiswheatandoverallsizeofgraincropinexperimentbarnis12meterslong,8meterswideand5metershigh.Thesensorsofgraintemperatureandhumidityinsidethegrainbulkarearrangedaccordingthatspacebetweenthethermometriccableisnomorethan5meters,andverticaldotpitchisnomorethan2meters,andthermometriclocationsupanddownandallaroundshouldbesetunderthegrain,againstthewall,30cmto50cmabovethefloor.Arrangementofsensorsisdetailedasfollows:

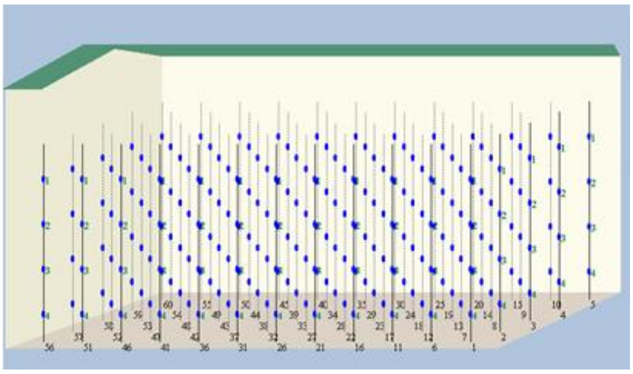

Fig.2.Diagrammaticsketchofarrangementofsensors

4.2.2.Parameterssetting

Aboutparameterssettingofcontrolpredictionofgraintemperatureandhumiditytransmission,basedontheamountofcalculation,accuracyandoptimizationcombinationofmodelparameters,particleswithgroupsize20,maximumiterativetimes50andparticledimensionissetas2(reducinghumidity)and1(cooling)accordingtodifferentamountofvariables.Inertialweightwadoptslinearlydec

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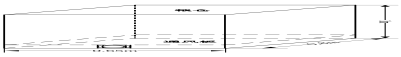
reasingweightstrategyandlearningfactorbothc1andc2takethevalueof2,r1andr20.65.

Forparticlegroup,thereisaneedtodecidebasedontherangeofairtemperatureandhumidityforventilation.Assumethejcontrolofparticleiisx_{ij}:


(21)

Intheformula,$x_{j\max}$and$x_{j\min}$standformaximumandminimumvalueofcontrolvariable$j$respectively,randstandsforrandomnumberuniformlydistributedintherangeof[0,1].Normaltemperatureforreservationinsidegrainbulkisnohigherthan45°C,thusvariationrangeofairtemperatureintheventare$x_{1\min}$=10°C，$x_{1\max}$=40°C.

Initializationofspeedofcomponentjofparticleicanbeachievedasfollows:

$$v_{ij} = V_{j\min} + \mathrm{rand} \times (V_{j\max} - V_{j\min}) \qquad (22)$$

Intheformula,$V_{j\min}$and$V_{j\max}$eachstandsformaximumandminimumspeedofcomponent$j$ofparticle.Alsointheregulationofgrainreservation,toavoidbigeffectongrain,moistureofgrainisrequirednottovarygreatlyandhumidityisusuallysettobeofplusorminusof20%.

Forthedeterminationofweightcoefficient,αshouldtakethevalueasmuchaspossibleandassumeα=4×10^4tokeep$J_M$intheorderrangeof0~10^2withsettingβ=1,γ=0.01,ΔM=1%.Simulationhasprovedthatthevaluesoftheseparametersareproperlychosenandabletoachievethegoaloftemperatureandhumiditycontrolandoptimalenergyconsumption.

Innaturalreservationcondition,changesofgrainpiletemperatureandhumidityhappenslowly.Therefore,terminationconditionscanbesetwithinallowanceerrortopreventtheproblemsofunstablesystemandovershoot.Controlterminationconditionisasfollows:Hg_d-0.5%≤Hg≤Hg_d+0.5%，T_g≤T_{gd}.

4.3Experimentalresultsanddiscussionandanalysis

(1)Experimentalresultsandanalysis

Simulationandexperimentdataisfromgrainpiledata,45thermometriccablewith3testingdotsoneachcablewhichbeganatoneo'clockof6_{th},9,2017andtimeintervaloftemperatureandhumidityacquisitionis15minutes.

Theheightofgrainbulkis6meters.Thetemperaturesensordividestheheightofgrainbulkintofourlayers,eachwithadistanceof1.5meters,thatis,thefirstlayer,thesecondlayer,thethirdlayerandthefourthlayer.Inthepredictionstudyoftemperature,thecorrespondingpredictionstudyismadeonthefourlayersofgraintemperature.ThepredictionsforthefourlayersareshowninFig.3toFig.6,respectively.

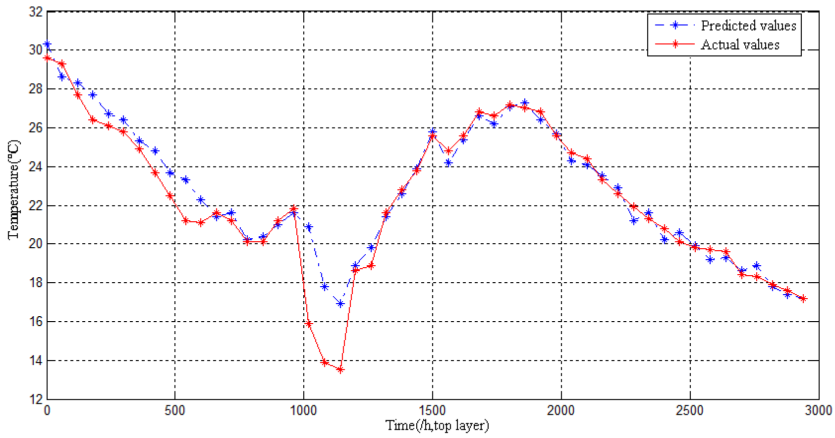


Fig.3.FirstlayerPredictionandPredictionCurve

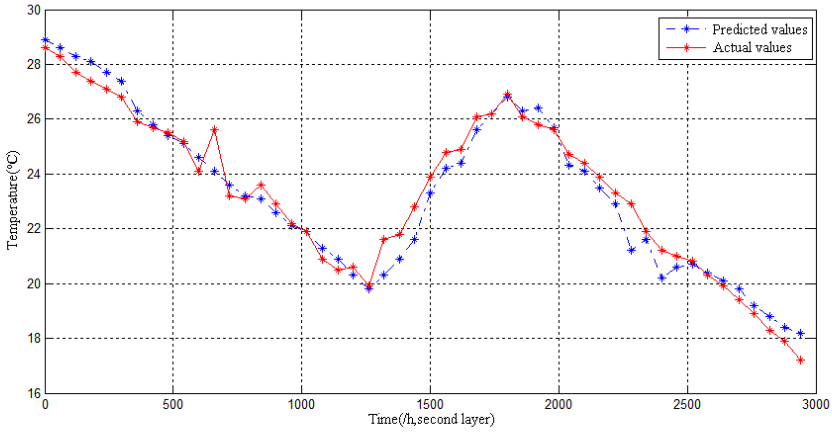


Fig.4.Secondlayerpredictionandpredictioncurve

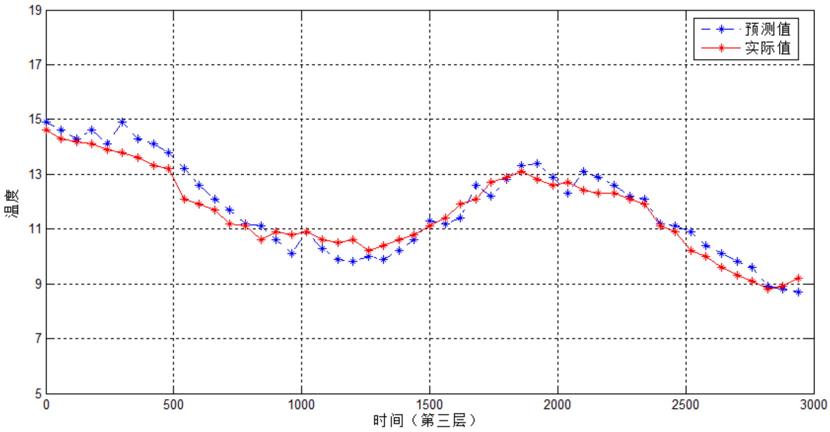


Fig.5.Thirdlayerpredictionandpredictioncurve

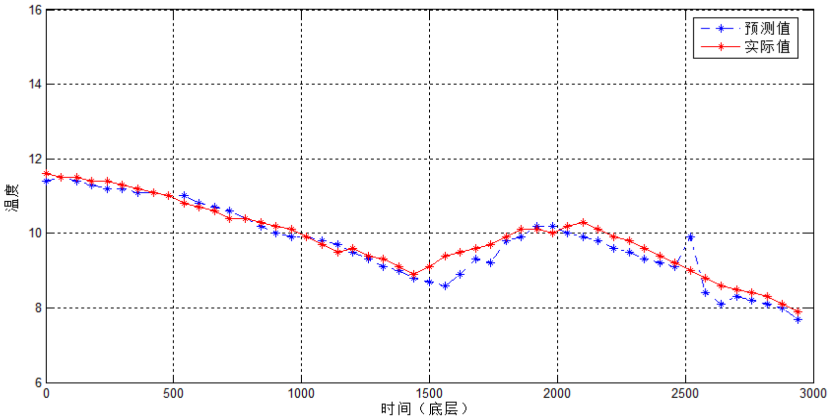


Fig.6.Forthlayerpredictionandpredictioncurve

FromFig.2.5toFig.2.8,itcanbeseenthatalthoughthereis asuddenchangepointabout1200hoursinFig.2.5,about700hoursinFig.2.6,andFig.about2500hoursinFig.2.8,thesensordrifthasbeenverifiedonsite,andthepredictedvaluehasbeenprovedcorrectaftermaintenance.Therefore,usingtheimprovedGPSOalgorithm,thetemperatureandhumiditypredictionoflargegrainbulkhasgoodresults,andthefittingdegreeofpredictionisveryhigh.

5.Conclusion

Itcanbeseenfromthetestingresult,predictivecontrolalg orithm studied in this paper can carry out effective control over grain bulk, not only to control grain humidity and temperature effectively but also to optimize energy consumption at the same time. Compared with traditional control method, predictive control algorithm proposedbythispaperischaracterisedbythefollowing:

(1)Inpredictivecontrolalgorithm,byadjustingcropcoolerandusingairtemperatureandhumidityinthevent,automaticallyadjustcontrolledvariablestocontrolgraintemperatureandhumidity.

(2)Inpredictivecontrolalgorithm,ittakestheprocessoftemperatureandhumiditycontrolasanoptimizationprocesstomakegraintemperatureandhumiditychangeaccordingtocurvilinearpathformedafteroptimization.

(3)Simultaneouscontrolovergraintemperatureandhumiditytoguaranteegrainqualityandrealizeoptimizationofenergyconsumption.

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Reference

1. WuJianjun,ZhenTong.AnimprovedGPSOalgorithmofgrainstoragemicroenvironmentoriented.JournaloftheChineseCerealsandOilsAssociation,2015(12):101-105
2. Bilgaiyan,S.Sagnika.Amulti-objectivecatswarmoptimizationalgorithmforworkflowschedulingincloudcomputingenvironment.Intelligentcomputing,communicationanddevices,Springer(2015),pp.73-84
3. Q.Lin,J.Li,Z.Du,J.Chen,Z.Ming.Anovelmulti-objectiveparticleswarmoptimizationwithmultiplesearchstrategies.EuropeanJournalofOperationalResearch,2015(247),pp.732-744
4. MarcoS.Nobile,PaoloCazzaniga.FuzzySelf-TuningPSO:Asettings-freealgorithmforglobaloptimization,SwarmandEvolutionaryComputation,2018(39):70-85
5. M.Hu,T.-F.Wu,J.D.WeirAnadaptiveparticleswarmoptimizationwithmultipleadaptivemethods.IEEETrans.Evolut.Comput.,17(5)(2013),705-720
6. H.Meslouba,M.T.Benchouiaa.DesignandimplementationofDTCbasedonAFLCandPSOofaPMSM.MathematicsandComputersinSimulation,May2018,1-16
7. BouallegueS.,Hagg_egeJ.,AyadinM.,BenrejebM.PID-typefuzzylogiccontrollertuningbasedonparticleswarmoptimization,Eng.Appl.Artif.Intell.,25(2012),pp.484-493
8. BourogaouiJ.M.,BenAttiaSethomH.,SlamaBelkhodjaI.Real-timeencoderfaultsdetectionandrotorpositionestimationforpermanentmagnetsynchronousmotordrivesfaulttolerantsensorlesscontrolusingdigitalsignalcontroller.Math.Comput.Simulation,131(2017),pp.253-267
9. BingHanaXiaoqiangBian.AhybridPSO-SVM-basedmodelfordeterminationofoilrecoveryfactorinthelow-permeabilityreservoir.Petroleum,Volume4,Issue1,March2018,Pages43-49
10. DjaafarZouache,YahyaOuldArby.Multi-objectivechickenswarmoptimization:Anovelalgorithmforsolvingmulti-objectiveoptimizationproblems.Computers&IndustrialEngineering,Volume129,March2019,Pages377-391