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申请号：2023106892603
申请日：2023 年 06 月 12 日
申请人：大连理工大学
发明人：李轩衡,葛东旭,白岩浩,程思科,金灿
发明创造名称：基于强化学习的无人机智能轨迹规划和通感资源分配方法
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摘要

本发明属于通信领域中通感一体化技术的应用，针对通感一体化赋能的无人机辅助通感网络场景，提出了一种基于强化学习的无人机智能轨迹规划和通感资源分配方法，在此背景下，无人机作为空中基站同时实现对目标物体的状态感知以及为地面用户提供通信服务。针对本环境下不同区域和时段内用户通信需求动态变化与地面感知目标移动的复杂资源分配与自身轨迹规划问题，本发明基于深度强化学习算法采用历史数据或模拟数据离线训练神经网络，使无人机通过获取当前环境信息自主智能地制定最优的轨迹规划和通感资源分配联合策略，在保证感知精度的前提下实现目标感知速率和通信速率的最大化。本发明经过在目标环境中多次迭代后能够得到最优的无人机轨迹和适应环境需求的功率、带宽分配复杂耦合策略。该方法可在离线学习的基础上进行在线学习并更新权重，具有广泛的自适应性，能够被应用于无人机轨迹规划与通信感知资源分配决策相关任务。

基于强化学习的无人机智能轨迹规划和通感资源分配方法

技术领域

本发明属于6G移动通信领域，涉及到无人机和通感一体化技术，具体为利用强化学习算法实现智能的无人机轨迹规划和资源分配，提出了一种基于强化学习的无人机智能轨迹规划和通感资源分配方法。

背景技术

高速发展的信息技术驱动着5G在业务和技术两个层面向6G演进，并对6G网络提出了端到端信息处理能力与网络感知能力的更高诉求。现有网络很难同时满足通信容量和感知能力两方面的高要求，促使人们以联合的方式设计这些功能，使得通信感知一体化技术成为6G技术与业务的主导趋势之一。通信感知一体化技术简称通感一体化技术，与过去两者独立实现的方式不同，该技术基于软硬件资源或信息共享同时实现感知与通信功能，是一种新型的协同信息处理技术，可以有效提升系统频谱效率、信息处理效率和硬件效率。

近年来，得益于完全可控的机动性和强大的视距链接，无人机被视为一种有效的空中通感一体化平台，即作为空中基站对地面通信与感知进行辅助。在通感一体化赋能的无人机辅助网络中，这些空中通感一体化节点可以迅速飞到热点地区，为地面用户执行下行链路通信，同时保持与感知目标接近，以进行状态感知。与目前研究中利用地面路侧单元实现通信和感知功能相比，无人机能够更加灵活地满足动态通信需求，并及时跟踪感知目标。此外，由于其具备强大的视距链路，城市场景中常见的无线信号阻塞和散射等影响信号质量的现象可以得到很好的缓解，从而可以进一步支撑下行链路容量和感知精度。

在实际的网络中，由于感知目标运动轨迹的差异性以及地面用户通信需求的时空异构性，无人机集群如何自适应地追踪不同的目标进行感知并同时为地

面用户提供高质量通信服务是一个难题。同时，为了保障被服务用户的通信需求以及对目标运动状态的感知能力，无人机如何合理分配功率和带宽资源实现感知和通信能力间的权衡也相当重要。因此，为了解决上述问题，本发明联合制定了无人机集群轨迹和功率、带宽资源分配策略。此外，考虑到复杂动态的网络环境，本发明设计了一种基于强化学习的自适应联合策略制定方法，令无人机自主地学习网络环境，快速制定最优联合策略从而同时实现最优的通信容量和感知性能。

发明内容

本发明针对通感一体化赋能的无人机辅助通感网络场景，提出了一种新兴的智能轨迹规划和功率、带宽资源分配方法。具体来说，无人机作为空中通感一体化平台同时实现对目标物体的状态感知以及为地面用户提供通信服务，考虑到不同区域和时段内用户通信需求动态变化，且地面感知目标运动具有动态性，本发明采用深度强化学习算法，基于历史数据或模拟数据离线训练神经网络，使各无人机通过当前环境自主智能地制定最优的轨迹规划和资源分配联合策略，即在保证感知精度的前提下实现感知速率和通信速率的最大化。在实际运行中，无人机将在线执行算法并在运行中持续改进，以实现对环境的自适应。

本发明的技术方案是基于深度强化学习的无人机轨迹规划和多维资源分配方法。深度强化学习的主要框架由智能体和环境组成：无人机作为智能体从环境中观测得到状态，并根据状态选择动作，然后经评估得到一个奖励值并进入下一个状态。上述与环境交互的过程称为智能体的一个决策周期，其基本思路是指导智能体在每个状态下选择一个动作使累积奖励最大化。基于深度强化学习的联合策略制定方法建立于如下系统环境：

考虑一个单无人机通感网络环境，网络内部存在 N 个感知目标和 M 个通信

用户，不同目标的运动规律各异，此外，用户分布动态变化使得场景中用户通信需求也呈现时空异构性。为了同时实现目标感知和地面用户通信，每个决策周期内无人机将根据自己的位置$s_t=[x_t,y_t]$，选择当前的动作$a_t=\{d_t,\theta_t,\mathbf{B}_t,\mathbf{P}_t\}$，包含飞行轨迹，即以角度$\theta_t$水平飞行$d_t$距离；带宽分配决策$\mathbf{B}_t$，即给每个通信用户和感知目标分配多少带宽资源；以及功率分配决策$\mathbf{P}_t$，即为每个通信用户和感知目标分配多少功率资源。然后，无人机将执行该动作，同时得到环境反馈的奖励值，奖励值定义为:

$$r_t=\sum_{n=1}^{N}k_1R_{n,t}^{sen}-k_2(\eta_{\min}-\Gamma_{n,t}^{sen})+\sum_{m=1}^{M}k_2R_{m,t}^{com} \tag{1}$$

其中，k_1、k_2以及k_3是权重系数。$R_{n,t}^{\text{sen}}$和$R_{m,t}^{\text{com}}$分别为决策周期t内无人机感知目标n时的感知速率和服务用户m时的通信速率，两个速率性能均受到无人机分配的带宽资源与功率资源的限制。当无人机分配更多带宽资源和功率资源用于感知目标或服务用户通信时，相应的速率则更高，$\sum_{n=1}^{N}k_1R_{n,t}^{sen}$与$\sum_{m=1}^{M}k_2R_{m,t}^{com}$分别表示无人机的总感知速率与总通信速率。$\Gamma_{n,t}^{sen}$为无人机感知目标$n$时接收的雷达回波的信噪比，同样与无人机分配给目标$n$的带宽和功率资源的多少有关，为了保证对目标的状态感知精度，回波信噪比需大于阈值$\eta_{\min}$。因此，公式（1）中定义了$-k_2(\eta_{\min}-\Gamma_{n,t}^{sen})$项作为惩罚项。该奖励值的设计是为了使无人机习得最优策略，并在满足对目标物体感知精度的前提下，最大化通信速率和感知速率。得到奖励值后，无人机继续执行当前动作并更新自己的位置状态。接着，其将状态、动作、动作结束后跳转的新状态和计算得到的奖励值这四组信息存入经验元组，用于网络训练，使之能根据动态的环境信息不断改进决策，以实现最优的无人机轨迹和多维资源分配联合策略。

在对系统环境进行定义后，本发明的基于强化学习的无人机智能轨迹规划

和通感资源分配方法的具体方案设计如下：

首先，构建两个结构完全相同的神经网络，分别是主网络$Q(s_t,a_t;\mathbf{\theta})$，其网络参数为$\mathbf{\theta}$，和目标网络$\hat{Q}(s_t,a_t;\hat{\mathbf{\theta}})$，其网络参数为$\hat{\mathbf{\theta}}$。对于任意决策周期$t$，无人机首先观测当前状态$s_t$，将其输入神经网络主网络计算，网络输出当前位置状态s_t下可选动作的动作价值q_v，并基于ε-$greedy$策略选择动作，该策略以ε_t概率从所有可选动作随机选择一个用于学习探索，以$1-\varepsilon_t$概率根据主网络输出选择对应q_v值最大的动作作为当前最佳决策。接着，当无人机根据ε-greedy策略执行了动作a_t后，无人机会根据公式(1)计算奖励值r_t同时更新到下一状态s_{t+1}。然后，无人机将经验元组$(s_t,a_t,s_{t+1},r_{t+1})$存入经验池中用于网络更新。

每个决策周期，无人机都会执行上述步骤，并在经验池中随机采样一小批经验数据对主网络进行训练。具体过程是：小批量采样中的每一个经验元组的状态$\boldsymbol{s}_t$与动作$\boldsymbol{a}_t$会作为Q主网络的输入，Q主网络$Q(s_t,a_t;\mathbf{\theta})$输出对应的值称为估计$q_v$值；而$\boldsymbol{s}_{t+1}$则作为$Q$目标网络的输入，用于计算目标$q_v$值，表达式为$\arg\max_{\boldsymbol{a}\in A}\hat{Q}(\boldsymbol{s}_{t+1},\boldsymbol{a};\hat{\theta})$，其中A代表所有可能的动作组成的集合。目标$q_v$值和$r_{t+1}$组成目标值，表达式为$y_t=r_{t+1}+\gamma\arg\max_{\boldsymbol{a}\in A}\hat{Q}(\boldsymbol{s}_{t+1},\boldsymbol{a};\hat{\theta})$，其中衰减系数$\gamma\in[0,1]$。估计$q_v$值和目标$q_v$值两者之差构成损失函数$L(\theta)=Q(s_t,a_t;\theta)-y_t$，通过对损失函数求梯度来更新$Q$主网络参数，即$\theta^*=\theta-\alpha\cdot\frac{dL(\theta)}{d\theta}$，其中$\alpha$是学习率。每隔固定$J$个决策周期，$Q$主网络参数$\theta$就会复制给目标网络的参数$\hat{\theta}$。

综上，无人机将与环境不断地进行交互并储存经验数据，通过在交互过程中获得的奖励值去指导自身进行学习。在训练的初始阶段，一般设置较大的探索率ε保证对未知环境的探索，随着智能体不断与环境进行交互，探索率会逐渐下降，训练的网络也将逐渐收敛，最终找到最优的轨迹部署策略。除了上述直接进行在线训练的方法外，网络也可以是基于上述技术方案利用历史数据或者在

模拟环境中离线训练优化并保留权重，当无人机工作在实际环境中时继续进行在线更新。

本发明的效果和益处：

(1) 本发明基于深度强化学习算法，经过在目标环境中多次迭代后能够得到最优的无人机轨迹和适应环境需求的功率、带宽分配复杂耦合策略。

(2) 本发明能够在离线学习的基础上进行在线学习更新权重，具有自适应性。

具体实施方式

构建两个结构相同的神经网络，即带有网络参数θ的Q主网络和带有网络参数$\hat{\theta}$的Q目标网络，网络被设置为一个维度为128的单隐藏层的全连接网络，激活函数使用relu函数，并对网络中各类参数进行随机初始化。在每个决策周期，无人机会根据当前状态，基于ε-greedy策略制定轨迹与资源分配策略。执行决策后，无人机通过接收到的通信和感知信号的信噪比，根据公式(1)计算所得奖励值，并将经验元组信息存入经验池中。当经验池存满后无人机会从中随机采样一小批经验元组训练Q主网络，并对Q主网络网络参数进行更新。每隔J个决策周期，Q主网络的网络参数会复制给Q目标网络。最后重复上述步骤。

在算法的初始阶段，探索率ε将会被设置为一个较大值如 0.9，在算法的迭代过程中，令$\varepsilon \leftarrow 0.9\times 0.1^{t/10000}$使其指数衰减，$t$为当前决策周期。随着$\varepsilon$减小，网络的训练也将逐渐完成。当训练步数接近目标时ε的值也会衰减至 0.09，目的是让无人机对所处环境保持一定的探索能力。当训练收敛后，无人机能直接通过训练完成的网络指导其在不同状态下准确做出相应的轨迹规划和资源分配决策，以实现在保证感知质量的前提下最大化通感服务速率。

同时，无人机也可以在模拟环境中离线训练至学得最佳策略权重，并在实际使用时在此基础上在线训练更新权重，以实现适应不同环境进行优化。

基于强化学习的无人机智能轨迹规划和通感资源分配方法在此场景下的具体流程如下：

初始化：

设经验池大小G，小批量采样大小S，更新周期J，折扣因子γ，学习率α，

贪婪因子ε=0.9，Q主网络参数θ，Q目的网络参数$\hat{\theta}$，t=1，初始状态$\boldsymbol{s}_0$

重复：

无人机基于ε-greedy策略在状态$\boldsymbol{s}_t$下制定共享策略$\boldsymbol{a}_t$

转移到下一状态$\boldsymbol{s}_{t+1}$并计算奖励值r_{t+1}

收集经验元组信息：状态$\boldsymbol{s}_t$，动作$\boldsymbol{a}_t$，下一个状态$\boldsymbol{s}_{t+1}$，奖励值r_{t+1}，并将经验元组信息存入记忆单元

$t \leftarrow t+1$

$\varepsilon \leftarrow 0.9 \times 0.1^{t/10000}$

如果$\varepsilon <= 0.1$

$\varepsilon = 0.1$

如果$t > G$

更新经验元组

随机采样S个经验元组对网络进行训练

计算损失函数$L(\theta)$，执行一次梯度下降并更新Q主网络参数θ

如果 $t-G \bmod J = 0$

Q主网络参数θ复制给Q目标网络参数$\hat{\theta}$

权 利 要 求 书

1.一种基于强化学习的无人机智能轨迹规划和通感资源分配方法，其特征在于，无人机作为空中通感一体化平台同时实现对目标物体的状态感知以及为地面用户提供通信服务，考虑到不同区域和时段内用户通信需求动态变化，且地面感知目标运动具有动态性，通过深度强化学习算法建立神经网络；基于历史数据或模拟数据离线训练神经网络，使无人机通过当前环境制定最优的轨迹规划和资源分配联合策略，即在保证感知精度的前提下实现感知速率和通信速率的最大化；

建立一个单无人机通感网络环境，单无人机通感网络内部存在运动规律各异的 N 个感知目标和 M 个通信用户；每个决策周期内无人机根据自己的位置状态 $s_t=[x_t,y_t]$，选择当前的动作 $a_t=\{d_t,\theta_t,\mathbf{B}_t,\mathbf{P}_t\}$，当前的动作包括飞行轨迹、带宽分配决策 $\mathbf{B}_t$ 和功率分配决策 $\mathbf{P}_t$；所述飞行轨迹以角度 θ_t 水平飞行 d_t 距离；所述带宽分配决策 $\mathbf{B}_t$ 为给每个通信用户和感知目标分配带宽资源的决策；所述功率分配决策 $\mathbf{P}_t$ 为每个通信用户和感知目标分配功率资源的决策；

无人机执行所述当前的动作，同时得到单无人机通感网络环境反馈的奖励值，奖励值定义为：

$$r_t=\sum_{n=1}^{N}k_1R_{n,t}^{sen}-k_2(\eta_{\min}-\Gamma_{n,t}^{sen})+\sum_{m=1}^{M}k_2R_{m,t}^{com} \qquad (1)$$

其中，k_1、k_2 以及 k_3 是权重系数；$R_{n,t}^{\text{sen}}$ 为决策周期 t 内无人机同感知目标 n 的感知速率，$R_{m,t}^{\text{com}}$ 为决策周期 t 内无人机同通信用户 m 的通信速率；感知速率性能和通信速率性能均受到无人机分配的带宽资源与功率资源的限制；当无人机分配更多带宽资源和功率资源用于感知目标感知或通信用户通信时，对应速率则更高，$\sum_{n=1}^{N}k_1R_{n,t}^{sen}$ 与 $\sum_{m=1}^{M}k_2R_{m,t}^{com}$ 分别表示无人机的总感知速率与总通信速率；$\Gamma_{n,t}^{sen}$

为无人机感知感知目标n时接收的雷达回波信噪比，同样与无人机分配给感知目标n的带宽资源和功率资源有关；所述雷达回波信噪比大于阈值$\eta_{\min}$；

得到奖励值后，无人机继续执行当前动作并更新自己的位置状态；将状态、动作、动作结束后跳转的新状态和计算得到的奖励值这四组信息存入经验元组，用于神经网络训练，使神经网络能根据动态的环境信息不断改进带宽分配决策和功率资源决策，最终获得最优的无人机轨迹规划和多维资源分配联合策略。

2.根据权利要求 1 所述的基于强化学习的无人机智能轨迹规划和通感资源分配方法，其特征在于，神经网络为包括神经网络主网络$Q(s_t,a_t;\boldsymbol{\theta})$和目标网络$\hat{Q}(s_t,a_t;\hat{\boldsymbol{\theta}})$，二者结构相同；神经网络主网络的网络参数为$\boldsymbol{\theta}$，目标网络的网络参数为$\hat{\boldsymbol{\theta}}$；对于任意决策周期 t，无人机首先观测当前位置状态s_t，并将其输入神经网络主网络计算，网络输出当前状态s_t下可选动作的动作价值q_v，并基于ε-$greedy$策略选择动作，该策略以ε_t概率从所有可选动作随机选择一个用于学习探索，以$1-\varepsilon_t$概率根据神经网络主网络输出选择对应q_v值最大的动作作为当前最佳决策；当无人机根据ε-greedy策略执行了动作a_t后，无人机根据公式(1)计算奖励值r_t同时更新到下一状态s_{t+1}；无人机将经验元组$(s_t,a_t,s_{t+1},r_{t+1})$存入经验池中用于神经网络更新；

每个决策周期，无人机均执行上述步骤，并在经验池中随机采样一批经验数据对主网络进行训练；每一个经验元组的状态$\boldsymbol{s}_t$与动作$\boldsymbol{a}_t$作为神经网络主网络的输入，神经网络Q主网络$Q(s_t,a_t;\boldsymbol{\theta})$输出对应的值称为估计$q_v$值；$\boldsymbol{s}_{t+1}$作为神经网络目标网络的输入，用于计算目标$q_v$值，表达式为$\arg\max\limits_{\boldsymbol{a}\in A}\hat{Q}(\boldsymbol{s}_{t+1},\boldsymbol{a};\hat{\theta})$，其中 A 代表所有可能的动作组成的集合；目标$q_v$值和$r_{t+1}$组成目标值，表达式为$y_t=r_{t+1}+\gamma\arg\max\limits_{\boldsymbol{a}\in A}\hat{Q}(\boldsymbol{s}_{t+1},\boldsymbol{a};\hat{\theta})$，其中衰减系数$\gamma\in[0,1]$；估计$q_v$值和目标$q_v$值

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两者之差构成损失函数$L(\theta)=Q(s_t,a_t;\theta)-y_t$，通过对损失函数求梯度来更新神经网络主网络参数，即$\theta^{*}=\theta-\alpha\cdot\frac{dL(\theta)}{d\theta}$，其中$\alpha$是学习率；每隔固定$J$个决策周期，神经网络主网络参数$\theta$复制给目标网络的参数$\hat{\theta}$。

2022

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Zhaohuan Teng
Zhiang Xu

With Faculty Advisor

Qiuhui Pan

Of

Dalian University of Technology

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Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
E		2202576

Carbon Sequestration and Forestry Evaluation Model Based on IPCC Method and TOPSIS Evaluation

Summary

Under current threat posed by climate change, forestry ecosystems and woody products are getting indispensible in terms of carbon sequestration. To better eliminate the threat, our team developed both practical prediction and decision-making models to promote the process of carbon sequestration and to determine the selection process of forest management schemes. Our findings could help forest managers around the globe optimize their plans to achieve carbon sequestration balance in terms of water conservation, soil production, biodiversity , recreational and cultural considerations, and so on.

For question one, we proposed a carbon sequestration time model based on the improved IPCC method and an optimized carbon sequestration model based on quantum genetic algorithm to solve it. In the IPCC-based model, the increase-loss method was used to estimate carbon pool size and CO_2 storage of forestry ecosystems and woody products; additionally, FOD approximation method was put forward to describe the carbon sequestration of dynamic carbon pools with logging products (HWP) being the main inducement. In the Quantum-based model, we proposed a forestry age-area information table to describe the forest and to function constant parameters to make accurate predictions of carbon pool changes in forest biomass. Hence, a practical forest management plan was confirmed.

For question two, we developed a decision-making strategy to determine which forest management plan could best assess the ecological value of forests in a balanced manner. The strategy was divided into two parts:the ESV-TOPSIS composite model and the grey correlation degree analysis model. The former first converted various value-assessing methods to the ecological service value based on ESV value conversion method, and developed a set of forest management plans suitable for carbon sequestration based on TOPSIS assessment method; the latter then solved the gray correlation between the value of specified ecological services and other indicators, so as to prioritize value-assessing methods by ultilizing the characteristics and locations of forests to determine the transition point between plans.

For question three, we applied the above established models to the actual forest problems. Initially, based on the improved IPCC method, relevant data from a certain forest area were used as the initial conditions. The conditions for the forest to be managed were then calculated. Afterwards, we used the TOPSIS evaluation model to determine the type of forest areas. Similarly, using the grey correlation degree analysis model, forest managers could receive both the evaluation of management plans and the transition point when changing from the existing schedule to a new one in a 10-year harvest interval.

For question four, we wrote a two page newspaper article to local community explaining that harvesting should be included in the management of forests, rather than them being left untouched.

To conclude, our team gave reasonable and appropriate mathematical models according to the requirements of each problem above, which have been analyzed and verified thoroughly and have practicality and rationality for sure.

Keywords: improved IPCC method, FOD approximation, Quantum Genetic Algorithm, ESV-TOPSIS evaluation, Grey correlation analysis, Carbon Sequestration, Forestry Evaluation

Contents

1 Introduction

In recent decades, with the rapid development of human society, the great threat posed by climate change has also intensified. Forest production systems are instrumental in human efforts to mitigate the effects of climate change because of their unique function of carbon sequestration. Forest plants can absorb carbon dioxide in the atmosphere and fix it in vegetation or soil, thereby reducing the concentration of the gas in the atmosphere and achieving a good role in mitigating climate change; woody forest products are considered to be able to store and reduce carbon emissions in the form of carbon compounds such as hemicellulose and lignin throughout the life cycle, affecting forest carbon sink levels with their good carbon emission satisfaction; in addition, forest management strategies, including appropriate logging, have been regarded as good means to improve the carbon sink capacity of forestry. From this point of view, it has become a top priority for forest managers to achieve an organic and good balance between potential carbon sequestration, forest carbon sequestration, biodiversity conservation, recreational and cultural considerations, etc.

2 Restatement of the Problem

At the request of the International Carbon Management (ICM) Partnership, we aim to develop guidelines for forest managers around the world to help them figure out how to use and manage their forests. Since the composition, climate and values of different forests vary greatly around the world, we have built mathematical models and related algorithms to solve the following four problems.

- Problem 1: Develop a mathematical model of carbon sequestration in forest ecosystems with temporal variables based on the collected data. The purpose of which is to determine the change of the carbon pools of forests and their forest products over time, so as to estimate the quality of carbon dioxide that can be effectively stored. In addition, on the basis of this mathematical model, an optimization model of forest management plan with the goal of optimal carbon sequestration is established, thus outputting a management plan that is most effective in sequestration of CO_2.
- Problem 2: Develop a decision-making model whose role is to give forest managers an idea of how forests are best used. In addition, this model should identify a forest management plan that balances the various ways of assessing forests. To improve the accuracy of the decision model, issues such as the scope of its management plan, the transition point between the forest's management plan, and how to use the characteristics of a particular forest and its location to determine the transition point between the management plan need to be taken into account.
- Problem 3: Apply established models to various forests and explore the amount of carbon dioxide that the forest and its products will contain over a hundred years; develop a forest management plan for the use of the forest; and develop a strategy for transitioning from the existing schedule to the new schedule in a manner that is sensitive to the needs of forest managers and all forest users if the best management plan includes harvest intervals that are ten years longer than the current forest practice.
- Problem 4: Write a newspaper article that corrects the misconception that no tree should be harvested, explains why proper logging should be done to maximize the value of the forest, and persuades local communities that proper logging is the best option.

3 General Assumptions

When calculating biomass and carbon losses caused by disturbance using the increase-loss method based on IPCC Carbon Sequestration Model, it is assumed that all fd are released in the year in which the disturbance occurred; *In addition,* the perturbation matrix is formulated on the premise of ensuring that all carbon sink transfers are taken into account, but assuming that all biomass carbon is released in the year of soil transformation, partial transfers may be minimal or even negligible.

When proposing a model based on a first-order decay (FOD) approximation method to describe the decay process of certain biomass carbon sequestrations which is represented by HWP, the basic assumption is that true dynamic processes can be approximated by first-order attenuation, leading to exponential decay patterns; *In addition,* when applying this model into practical use, after we have derived the formula for the total carbon storage at the end of each inventory, which is done for two alternative models, representing the flow of carbon into the carbon pool, we then assume that the dynamic decay delay yields a similar result, and finally, we apply the above results to the HWP dynamic carbon pool to calculate the exact value of the HWP dynamic carbon sequestration stock.

When discussing carbon sequestration and forestry evaluation models for their respective applications, we assume that the best management plan includes harvest intervals that are ten years longer than the current forest practice. In a way that is sensitive to the needs of forest managers and all those who use forests, the discussion of the transition from existing schedules to new schedule strategies unfolds.

4 Notation Preparation

Symbol	Meaning	Unit
ΔC_B	Annual change in carbon stocks	t/a
ΔC_G	Annual gain in carbon stocks	t/a
ΔC_L	Annual loss in carbon stocks	t/a
A	The land area	ha
G_{total}	Average growth in biology	$t/ha/a$
i	A certain vegetation type	
j	A type of disturbance	
CF	Carbon fraction of dry matter	1
G_w	Average aboveground biomass growth	$t/ha/a$
R	Below-ground biomass to above-ground biomass ratio	t/a
CL	Reduction in the annual carbon pool	t/a
$BCEF_C$	The expansion factor	t/m^3
H	Merchantable round wood over bark	m^3
D	Basic wood density	t/m^3
$A_{disturbance}$	Area of disturbances	ha/a
B_w	Average above-ground biomass affected	t/ha
fd	Fraction of biomass lost in disturbance	1
$S_{cont.}$	The size of the carbon pool of the HWP	t
HL	Half-life of HWP	a

5 Model Overview

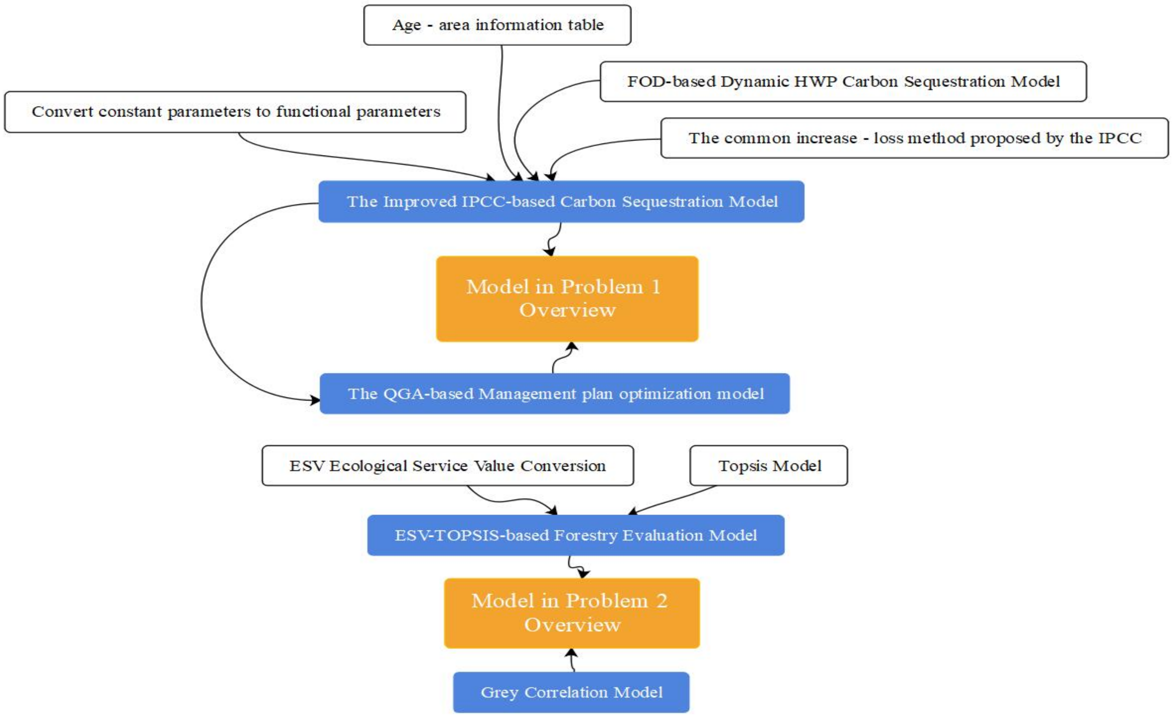


Figure 1: Model Overview of Carbon Sequestration and Forestry Evaluation

6 IPCC-based Carbon Sequestration Time Model

For the forestry industry, estimates of carbon dioxide sequestration and increase are often based on changes in ecosystem carbon pools, so we developed an IPCC-based carbon sequestration model that is able to determine the amount of carbon dioxide stored by forests and their products over time. Further, we used this model to identify one of the most effective forest management schemes for sequestration of carbon dioxide.

The sequestration of carbon dioxide depends on changes in the carbon pool of the ecosystem. Changes in carbon pools are reflected in above- and subsurface biomass, dead organic matter and soil organic matter. Just as the net increase in the total amount of carbon pools in ecosystems is used to estimate the amount of carbon dioxide in the atmosphere, the net loss of the total amount of carbon pools in ecosystems is used to estimate carbon dioxide emissions into the atmosphere. Moreover, the method focuses on the biobank changes associated with woody plants and trees, which accumulate large amounts of carbon over their lifetime, which is an important subclass due to the large carbon flows caused by management and logging, natural disturbance, natural death and forest regeneration.

We propose two methods for estimating biomass carbon loss (carbon sequestration), carbon addition and net carbon pool transition. The increase includes biomass growth in the upper and lower subsurface components, with losses divided into felling or harvesting of timber, wood burning and management of natural disturbances on land such as fires and extreme weather events.

6.1 Principle of IPCC-based Carbon Sequestration Time Model

The method subtracts biomass carbon loss from biomass carbon gain and formula is as follows:

$$\Delta C_B = \Delta C_G - \Delta C_L \tag{1}$$

6.1.1 Estimating annual carbon pool additions in biomass (increase-loss method) ΔC_G

The method calculates the annual increase in biomass by estimating the annual increase in forest use area and average biomass. The formula is as follows:

$$\Delta C_G = \sum_{i,j} (A_{i,j} \cdot G_{total_{i,j}} \cdot CF_{i,j}) \tag{2}$$

G_{total} is the total biomass growth extended from the aboveground biomass (G_w) to include the biomass growth of the underground part. According to the increase-loss method, gtolal can be obtained directly by using the default value of G_w for naturally regenerated trees or a wide range of plantations with R, and the ratio of subsurface biomass to aboveground biomass can be distinguished by woody plant category. The introduction of net annual increments (I_v) can be combined with the basic wood density (D) and biomass expansion coefficient (BEF_I) or directly using biomass conversion and expansion coefficient (BEF_I) to convert the grandmother growth of each vegetation type into aboveground biomass growth, the following transformation can be used:

$$\Delta G_{total} = \sum G_w \cdot (1 + R) \tag{3}$$

$$\Delta G_{total} = \sum I_v \cdot BCEF_I \cdot (1 + R) \tag{4}$$

$BCEF_I$ converts the annual net increase of a specific vegetation type material (including bark) into a biomass conversion and expansion factor for aboveground biomass growth, and an annual net increase in tonnes of aboveground biomass growth per unit volume. However, if the $BCEF_I$ value does not exist and the biomass expansion coefficient (BEF) and the basic wood density D value are estimated separately, the following conversion can be made:

$$BCEF_I = BEF_I \cdot D \tag{5}$$

The expansion of the biomass expansion factor (BEF_I) output volume to the entire aboveground biomass volume indicates the increase of the non-discharged part. BEF_I is dimensionless. $BCEF_I$ estimates of wood biomass in non-woodlands may not be readily available, in which case default values for $BCEF_I$ from the forest type closest to non-forest vegetation can be used to convert the yield biomass into total biomass.

6.1.2 Estimating annual carbon pool reductions in biomass due to losses ΔC_L

The method uses an increase-loss method to calculate the loss estimates required to calculate changes in the biomass carbon pool. Of particular note is the need for loss estimates when using the library-differential approach to estimate biomass transferred to dead organic matter. Specifically, annual biomass losses are the sum of other losses resulting from logging, wood removal, and disruption. To indicate this relationship, the formula is as follows:

$$\Delta C_L = L_{woodremovals} + L_{fuelwood} + L_{disturbance} \tag{6}$$

- **Biomass and carbon loss due to wood removal,** $L_{woodremovals}$

  The above formula provides a methodology for estimating annual carbon sequestration of biomass caused by logging. The formula is as follows:

$$L_{woodremovals} = H \cdot BCEF_C \cdot (1 + R) \cdot CF \tag{7}$$

- **Biomass and carbon loss due to wood burning removal,** $L_{fuelwood}$

  Wood removal usually consists of two components. First, the removal of burning wood from living and some trees, such as tree roofs or branches, while the tree itself remains in the forest, will reduce the carbon in the accumulated biomass and treat it as biomass carbon loss. To estimate biomass carbon loss due to wood-burning removal, the formula is as follows:

$$L_{fuelwood} = [FG_{trees} \cdot BCEF_C \cdot (1 + R) + FG \cdot D] \cdot CF \tag{8}$$

  The Biomass Expansion Coefficient (BEF_C) extends the removal of timbered wood to the total aboveground biomass volume to account for the non-timbered parts of the tree, stand and forest. BEF_C is dimensionless.

$$BCEF_C = BEF_C \cdot D \tag{9}$$

- **Biomass and carbon loss due to disturbance,** $L_{disturbance}$
  In the specific case of loss caused by fire on the management land, the formula is as follows to estimate the change in the carbon pool caused by the disturbance:

$$L_{disturbance} = A_{disturbance} \cdot B_w \cdot (1 + R) \cdot CF \cdot fd; \tag{10}$$

6.2 Forestry age-area Information Table with Parameters Functionized

In order to further compensate for the shortcomings of the IPCC method in accurately describing forest characteristics, we collected a large amount of data to establish an age-area information table that describes the initial state of the forest area. In the model, the information table is updated annually, mainly by removing groups that exceed the upper lifespan limit, adding their area to the total area loss for the year, adding 1 to the age of each group, and adding groups with an age of 1 and an area of this year's replanted seedlings. The specific approaches are demonstrated as follows:

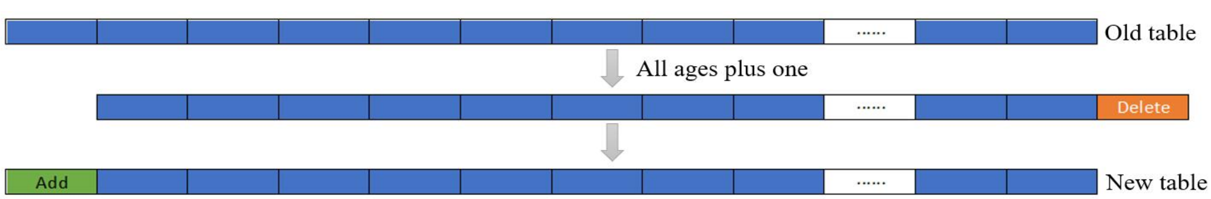


Figure 2: Process of functionization from constant parameters

In order to avoid roughly describing forest characteristics with constant parameters, we collected a large amount of data and referred to the growth curve, and established a gw function that describes the relationship between annual average biomass growth and tree age, and a gav function that describes the level of standing wood accumulation. Using functions as parameters not only refines the description of forest features, but also makes it easier to introduce temporal variables into the model.

7 FOD-based Dynamic HWP Carbon Sequestration Model

Globally, an internationally agreed methodology for estimating carbon dioxide carbon sequestration is being updated and refined. The most challenging part of the agreed inventory is estimating and reporting biomass carbon pools because of their dynamics: in order to estimate current carbon sequestrations, it is necessary to track long-term activities and associated factors, and often the processes behind the dynamics are highly uncertain or the kinetics can only be approximated. In this regard, the estimation of the carbon seal stock of the dynamic carbon pool can be converted into the estimation of the carbon seal stock of the HWP.

From this, we aim to provide a simple method of analytical solutions based on FOD differential equations that can be effectively improved on a global scale for existing carbon sequestration calculation methods. The basic assumption is that true dynamic processes can be approximated by first-order attenuation, leading to exponential decay patterns. And the model application process is as follows: first, we derive the formula for the total carbon storage at the end of each inventory, which is done for two alternative models, representing the flow of carbon into the carbon pool; second, we assume that the dynamic decay delay yields a similar result; and finally, we apply the above results to the HWP dynamic carbon pool to calculate the exact value of the HWP dynamic carbon sequestration stock.

7.1 Principle of FOD Restraints

Before modeling the dynamics of HWP in use, the first thing we need to be clear is that the lifetime of HWP in different end-uses varies: there are very short-lived products such as wood fuels or advertising papers and long-lived ones such as construction wood, whose lifetime in service can be even hundreds of years.

To obtain a more realistic description of the real process of it, we have built up a model called FOD which is accompanied with multiple-pools having different half-lives. To be more specific, in this model, solid wood products and paper products are divided into separate pools or more than two separate pools, the half-life of the paper pool is one year, the half-life of the template and sawmill ponds is several decades, and some very short-lived products can even be considered rotten.

Additionally, the only activity data that can be used globally for the purpose of national inventories on HWP in use are the historical production, export and import rates of various HWP. Such data can be used to calculate the inflows to the HWP pools of the FOD model. The inflow to the HWP pools can be approximated to be constant and evenly distributed within each year, as the activity data is only on yearly basis. Moreover, an assumption of exponential growth in past HWP consumption correlating with past roundwood production could be applied when calculating the historical inflows of the model.

7.2 Derivation of FOD-based Dynamic HWP Carbon Sequestration Model

In this part we describe the dynamics of carbon stocks that are subject to a FOD. In practice, not all the stocks in a given pool may be subject to such decay, or the decay may be delayed. It is therefore necessary to clearly distinguish the decaying carbon stock at time t, which we denote by $S(t)$, from the inert part of the stock, which we denote by $S\hat{(t)}$.The total carbon stock at any time is then the sum:

$$S_{total}(t) = S(t) + S\hat{(t)} \tag{11}$$

Let us now first discuss the dynamics of the decaying part.

7.2.1 The C-stock equation

The stock change $\frac{dS}{dt}(t)$ at time t has two components: the inflow $I(t)$ into the stock, and the outflow $O(t)$, which depends on the stock at time t:

$$\frac{dS}{dt}(t) = I(t) - O(t) = I(t) - k \cdot S(t) \tag{12}$$

Here k is the decay constant, and for zero inflow the solution of the above equation is given by the simple exponential decay:

$$S(t) = S_0 \cdot e^{-k(t-t_0)}, S(t_0 \equiv S_0) \tag{13}$$

with a half-life of $t_{1/2}$ equals to $\frac{ln2}{k}$. For non-zero inflow $I(t)$, however, the general solution of the above equation is given by

$$S(t) = (\int_{t_0}^{t} I(t') \cdot e^{-k(t-t')} dt') + S_0 \cdot e^{-k(t-t_0)} \tag{14}$$

The first term describes the contribution of the inflowing carbon to the current stock at time t, whereas the second term describes the remainder at time t of the initial stock at time t_0. For general $I(t)$ the integral in the above equation can be solved numerically; in the following we discuss important special cases in which it can also be solved analytically.

7.2.2 Simple flow models

The carbon inflow function I(t) is a function that represents the actual amount of carbon that flows into the carbon stock over time. The inflow may depend on a number of parameters and its exact form may be difficult to determine. It is therefore useful to take a pragmatic view and use simplified approximations to the actual inflow function. Two of such approximations are presented here, these two approximations differ in the representation of the timing of the inflow.

- **Continuous constant inflow**
  For the continuous constant inflow model it is assumed that the inflow rate does not change over time and its value is determined by dividing the total amount of inflow by the time period during which the inflow occured. In this case the above equation simplifies to

  $$S_{cont.}(t) = \frac{I}{k} \cdot (1 - e^{-k(t-t_0)}) + S_0 \cdot e^{-l(t-t_0)} \tag{15}$$

  If the inflow rate is constant only within an interval, say one year, but changes over the years, then the above equation can be wrriten for t equals to T_{n+1}, i.e. the end of year n:

  $$S_{cont.}(T_{n+1}) = \sum_{i=0}^{n} I_i \cdot \frac{e^k - 1}{k} \cdot e^{-k(T_n - T_i)} + S_0 \cdot e^{-k(T_{n+1} - T_0)} \tag{16}$$

  where we have performed the integration over exponentials and used the fact that T_{i+1} equals to $T_i + 1$. The above equation is rather useful in the context of annual stock or emission inventories because typically the total inflow in each year is can be estimated, even though the actual inflow rate at each point in time is not known. Dividing the total inflow by the inflow period (here: one year) results in the average inflow rate for one year. The same applies to statistics of harvested

wood products: only yearly production rates are compiled. Thus it is reasonable to assume that the production and input flow into the HWP pool is evenly distributed over the year.
The above equation can also be presented in recursive form in which the stock at the beginning of year n+1 can be expressed as a function of stock at the beginning of year n and the constant inflow during year n:

$$S_{cont.}(T_{n+1}) = e^{-k} \cdot S_{cont.}(T_n) + \frac{1-e^{-k}}{k} \cdot I_n \tag{17}$$

This equation is especially practicable as it gives a simple updating rule for subsequent inventories.

- **Instantaneous inflow**
  In contrast to the constant inflow model above, for the instantaneous inflow model it is assumed that the total inflow occurs at a single point in time.
  Mathematically the instantaneous inflow is represented by a so-called delta-function $\delta(x)$ which has the property

$$\delta(x) = 0, x \neq 0, \int f(x)\delta(x-x_0)dx = f(x_0) \tag{18}$$

If x_0 lies in the integration domain. The delta function essentially peels off the integral and leaves the integrand with the appropriate argument. In order to avoid double counting the integration domain needs to be defined carefully.
For example, here the convention is used that T_i belongs to year i (T_i being 1 January of year i), and consequently T_{i+1} does not (being 1 January of the following year). In particular it follows that for the integral over year i

$$\int_{T_i} T_{i+1}\delta(t'-T_{i+1})dt' = 0 \tag{19}$$

Because T_{i+1} does not lie inside the integration domain.
If the instantaneous inflow I occurs at $t \geqslant T_0$, the above equation becomes

$$S_{inst.}(T_{n+1}) = I \cdot e^{-k(T_{n+1}-t)} + S_0 \cdot e^{-k(T_{n+1}-T_0)} \tag{20}$$

i.e. S_0 is decaying since T_0 and I is decaying only since the time when the inflow occured. In the complication of an annual inventory it is necessary for consistency to assume that each year the instantaneous inflow of I_i occurs on the same date. If a denotes the inflow date, then the inflow in year i can be expressed as

$$I(t) = I_i \cdot \delta(t-(T_i+a)) \tag{21}$$

Hence the annualized version of the above equation becomes

$$S_{inst.}(T_{n+1}) = \sum_{i=0}^{n} I_i \cdot e^{-k(T_{n+1}-T_i-a)} + S_0 \cdot e^{-k(T_{n+1}-T_0)} \tag{22}$$

And describes the stock at time the end of the inventory year (t equals to T_{n+1}) assuming an instantaneous inflow of carbon each year on a date a (the value a equalling to 0 corresponds to 1 January, a equals to $\frac{1}{2}$ to 1 July, etc.).

Again, the stock at the end of each year can be expressed as a function of the stock at the beginning of the year (end of the previous year) and the total inflow into the stock

$$S_{inst.}(T_{n+1}) = e^{-k} \cdot S_{inst.}(T_n) + I_n \cdot e^{-k(1-a)} \tag{23}$$

It can easily be seen that the above equations coincide if and only if

$$a = a^* = \frac{1}{k} ln(\frac{e^k - 1}{k}) \tag{24}$$

The Figure below illustrates the dependency of a^* on $t_{1/2}$. It can be seen that a^* approximately equals to 1/2, so that the instantaneous inflow model with a equals to 1/2 (1 July) is a fairly good approximation for a half life of more than 1 year. For a half life less than half a year the instantaneous inflow model with a equals to 1/2 is no longer a good approximation.

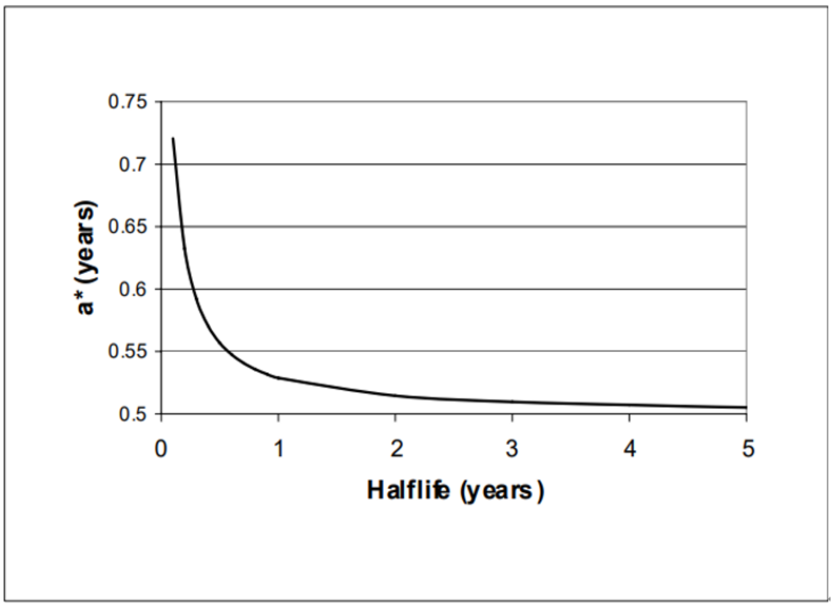


Figure 3: Value of a equals to a^* for which the results serve as a function of half-life of the decay.

7.3 Application of FOD-based Dynamic HWP Carbon Sequestration Model

Under the above deprivations the carbon dynamics of a HWP pool can be described recursively by the following equation (for a derivation of the formula, see next subsection):

$$S_{cont.}(T_{n+1}) = e^{-k} \cdot S_{cont.}(T_n) + \frac{1 - e^{-k}}{k} \cdot I_n \tag{25}$$

which means that having the stock estimate for 1 January of year n the corresponding estimate for the next year n+1 can be generated. Further, the stock change during year n is simply given by

$$S_{cont.}(T_{n+1}) - S_{cont.}(T_n) = \frac{1 - e^{-k}}{k} \cdot I_n + (e^{-k} - 1) \cdot S_{cont.}(T_n) \tag{26}$$

8 Optimization of Carbon Sequestration based on QuantumGA

In the design and optimization of the carbon sequestration management scheme of forests and their forest products, the core content is to formulate a plan on when to harvest, what tree species are selected for logging, how much is harvested and how to restore after harvesting, and the scientific and effective management plan will greatly improve the carbon storage of forests and their forest products. Due to the large number of variables that need to be optimized and the need to consider the time factor, it is more complicated to design an optimization management scheme. After studying the characteristics of the model and the basic genetic algorithm, we propose to use the quantum genetic algorithm to solve the above problems.

8.1 Advantages of Quantum Genetic Algorithm

Quantum genetic algorithm is a relatively novel intelligent optimization algorithm, which differs from genetic algorithm mainly in population coding methods and evolutionary strategies. The core of the quantum genetic algorithm population coding method is to use qubits and quantum superposition states to encode chromosomes, so that a chromosome represents information of multiple states at the same time, which greatly enriches the diversity of the population; at the same time, the quantum revolving gate is used to update the population, and the current optimal individual information is used as the guide for evolution. Of particular note is that quantum states are a way to preserve information, namely qubits and qubits and quantum gates that transform quantum information through the following formula:

- In quantum computing, qubits $|0\rangle$ and $|1\rangle$ represent two fundamental states of microscopic particles, and according to the superposition principle, the superposition of quantum information can be expressed as a linear combination of these two fundamental states, i.e $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$, in this equation α and β are complex numbers, representing the amplitude of probabilities in the state of a qubit, with $|\psi\rangle$ representing quantum state, which collapse to the state of $|0\rangle$ and the probability of $|1\rangle$ due to measurement and the normalization condition is met.

- In quantum genetic algorithms, chromosomes are encoded using the probability amplitude of qubits. For example, if a chromosome with 3 qubits has a probability amplitude of three pairs:

$$\left[\begin{array}{c|c|c} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & \frac{\sqrt{3}}{2} \end{array}\right] \tag{27}$$

They can be described as:

$$\frac{1}{4}|000\rangle + \frac{\sqrt{3}}{4}|001\rangle - \frac{1}{4}|010\rangle + -\frac{\sqrt{3}}{4}|011\rangle + \frac{\sqrt{1}}{4}|100\rangle + \frac{\sqrt{3}}{4}|101\rangle + -\frac{1}{4}|110\rangle + \frac{-\sqrt{3}}{4}|111\rangle$$

Then the probability value of eight coming superpositions $|000\rangle$, $|001\rangle$, $|010\rangle$, $|011\rangle$, $|100\rangle$, $|101\rangle$, $|110\rangle$, $|111\rangle$ are described as: 1/16, 3/16, 1/16, 3/16, 1/16, 3/16, 1/16, 3/16.

- In the quantum genetic algorithm, the quantum revolving gate is used to change the qubit phase to update the probability amplitude of the qubit, thereby achieving the effect of genetic mutation.

8.2 Data Preparation for Quantum Genetic Algorithm

In this paper, the time function of carbon pool accumulation in the carbon sequestration model is embedded in the quantum genetic algorithm as the objective function.

The annual harvesting of each tree species, the amount of replanting seedlings of each tree species per year, and the proportion of various HWP production are used as variables.

The upper limit of the life of each tree species and the Growth Curve of Sigmoid in the limited resource environment are used as constraints.

In order to ensure the accuracy and practical significance of the designed and optimized forest management plan, we collected relevant data on the Daxinganling forest area in China. Some of the data is displayed as follows:

Symbol	Xing'an Larch	Birch	Source
R	0.28	0.23	[3]
Harvtime	60 years	50 years	[3]
Lifespan	250years	150years	[3]
CF	0.4893	0.4872	[3]

The Greater Khingan Range forestry area belongs to the northern Eurasian leaf forest, the main species are Xing'an larch and birch [3], and the average annual rate of aboveground biomass G_w is 0.1-0.2[2], the biomass conversion expansion coefficient is 0.85[2]. Moreover, Common forest product logs and cardboard have half-lives of 30 and 20 years, respectively [1]. As is shown below:

	Xing'an Larch		Birch	
Age Group	**Area ($\times 10^5$ hm^2)**	**Accumulation Volume ($\times 10^7$ m^3)**	**Area ($\times 10^5$ hm^2)**	**Accumulation Volume ($\times 10^7$ m^3)**
Juvenile Forest	2.55	1.31	1.43	0.34
Middle-aged Forest	27.08	22.82	9.71	7.29
Nearlyripe Forest	3.35	3.27	7.22	6.83
Mature Forest	9.47	10.74	4.57	5.05
Overripe Forest	3.20	3.86	1.41	1.56
Subtotal	45.65	42.00	24.34	21.07

Figure 4: Statistics of natural forests

Using the collected data, forestry age-area information table and function gw, function gav are established As is shown below:

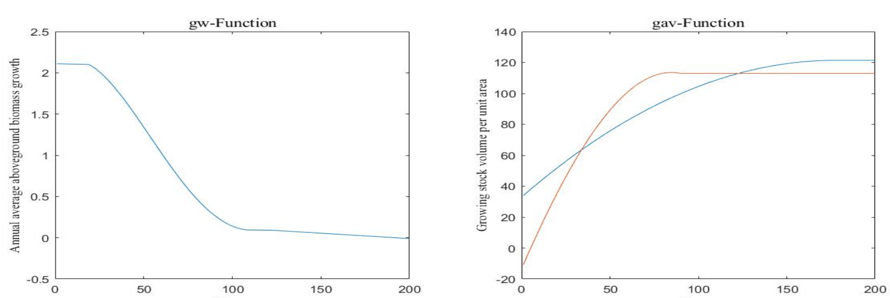
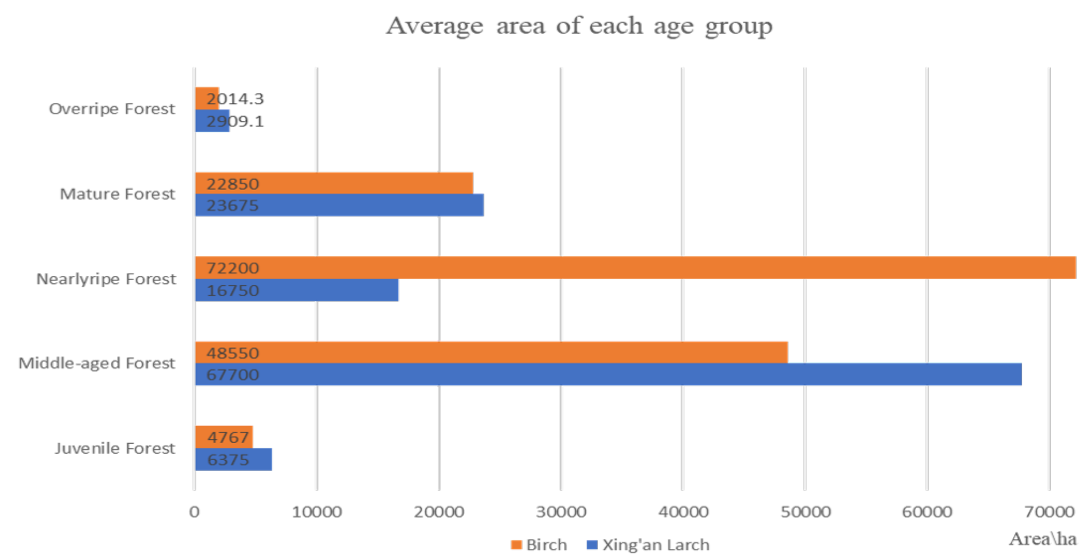


Figure 5: Function gw and function gav



8.3 Optimization of Quantum Genetic Algorithm

According to the carbon sequestration model and the quantum genetic algorithm, an optimization algorithm with the goal of carbon sequestration can be obtained the next page.

Algorithm 1 Manage plan optimization algorithms

Require: Initial age-area information table, Related parameters, GQA setting parameters, Target year
Ensure: Harvesting volume of each tree species in each year, Proportion of replanting in each year of each tree species, Proportion of each HWP, Carbon dioxide sealing stock in the target year

```
for n=1 to Target year do
    The gav function and gw function were used to obtain the biomass growth of each age tree in each
    year G_W and standing woody accumulation level Rou
    Use (G, Rou) to get (ΔC, L)
    Use (ΔC, dC, L) to get the total carbon pool net increase for the year dC
    for m=1 to HWP number of different kinds do
        Use FOD Carbon Sequestration Model to get the amount of change in HWP carbon pool C
    end for
    Update the Age-Area Information Table
    Summing dC to get the carbon pool size for that year and converts it to carbon dioxide absorption
end for
```

8.4 Results of Optimized Carbon Sequestration based on QuantumGA

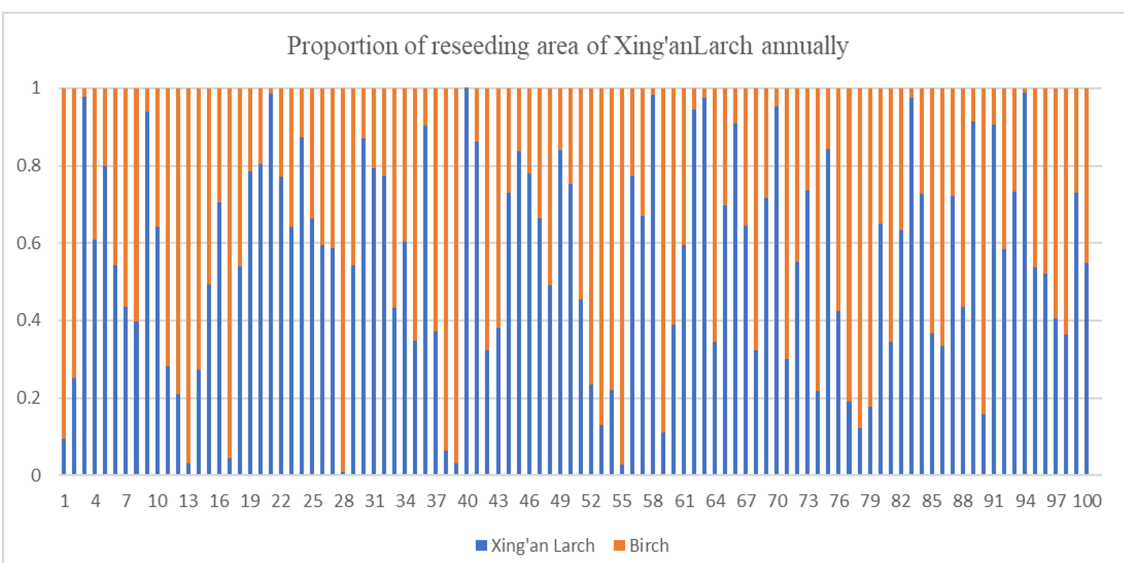
The forest management scheme output by the above algorithm consists of four parts: Annual harvesting of larch and birch in Xing'an, proportion of replanting of larch and birch in Xing'an per year, proportion of production of two forest products (logs and cardboard), and total carbon dioxide uptake in 100 years.

- **In terms of annual harvesting:**
  In the management plan, the harvesting volume of birch is generally higher than that of Xing'an larch, and the initial accumulation and area of birch is lower than that of Xing'an larch, which is due to the shorter life of birch. Because the model sets the age of trees and the penalty for annual biomass growth after reaching lifespan, harvesting forest products from trees that are about to reach their lifespan will increase the size of the carbon pool to some extent.
  In the management plan, the annual harvesting of birch and Xing'an larch is gradually increasing with the year, which is because in the initial setting of the area and accumulation of the two kinds of forests in various ages, the proportion of middle-aged forests and near-mature forests is relatively large. Over time, these larger stands gradually reach the upper limit of lifespan, resulting in a positive correlation between annual harvest and year.

- **In terms of annual replanting ratio:**
  In the management plan, the average annual tonic ratio of Xing'an larch is 0.5559, while the average annual proportion of birch replanting is 0.4441, and the proportion of Xing'an larch is slightly more. This is because, despite the penalties for annual biomass growth due to tree age, stored in forest carbon pools is still better stored in forest carbon pools than in forest products for most of the time. And because the life of Xing'an larch is longer, it is more inclined to make the area and accumulation of Xing'an larch larger when designing the scheme, so the proportion of replanting is also higher.

- **In terms of proportion of forest products produced:**
  In the management plan, the production of logs accounted for 0.988.The harvested part of the forest carbon pool in the model is converted into a carbon pool in the forest product, due to the oxidation of forest products, the carbon pool will continue to decay during the effective period of forest products, and the effective period of logs is longer than that of paperboard, so the proportion of production of logs is more inclined in the management scheme.

Since the amount of data is large a not intuitive, we directly visualize some of the data for display, as is shown in the following two figures:



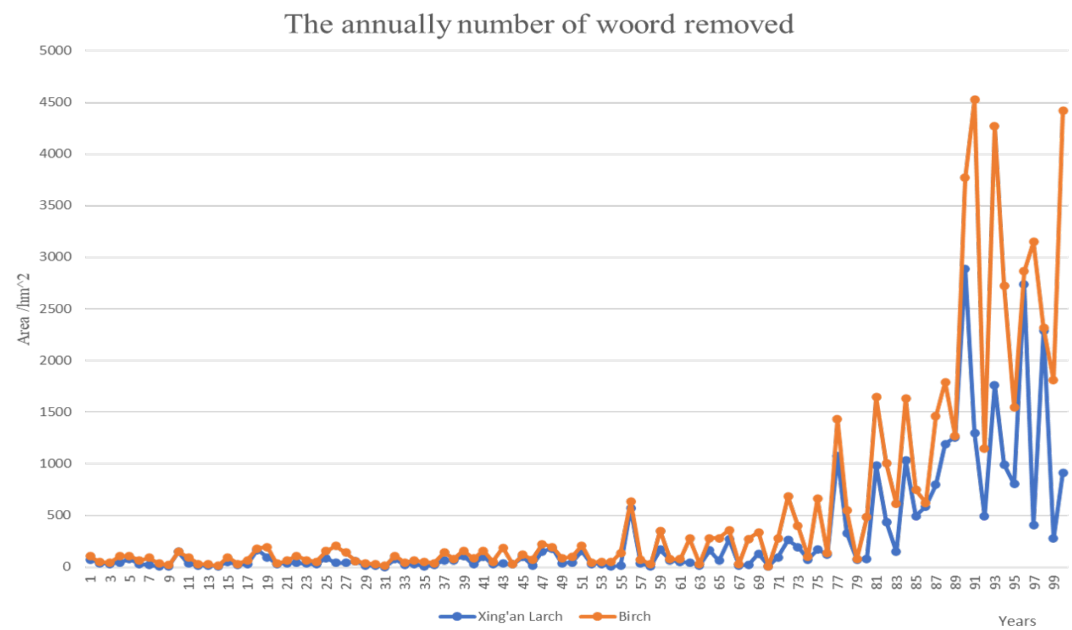


Figure 6: Visualized data

8.5 Applications of Optimized Carbon Sequestration based on QuantumGA

Here we assume that the types of forests considered are special forest (including defense forest, experimental forest, landscape forest and nature reserve forest, etc.), charcoal forest and timber forest. Different forest management schemes are adopted for these three types of forests:

-*Special forest is not harvested.* The annual harvest for forest products and the amount harvested for burning wood are zero, taking into account only the loss of death due to the age of the trees reaching the upper limit, and replanting new seedlings of the corresponding area.

-*Charcoal forests are only harvested for wood burning*. The annual harvesting for wood burning is 10 cubic meters per hectare, while the harvesting for forest products is 0.

-*Timber forests are harvested only to make forestry products.* The annual harvesting for forestry products is 10 cubic meters per hectare, while the harvesting for forest products is 0.

After calculation, under the condition that the forest is managed as a special forest, 6.29241t carbon dioxide will be stored within hundred years; under the condition that the forest is managed as a charcoal forest, 4.47694t carbon dioxide will be stored within hundred years; under the condition that the forest is managed as a timber forest, 5.61277t carbon dioxide will be stored within hundred years.

It can be seen that because the forest is not harvested, under the condition of using special forest as a forest management policy, the most carbon dioxide is stored in hundred years; while the charcoal forest needs to be harvested for burning wood all year round, and a large number of new seedlings are replanted, resulting in a weakening of the ability to seal carbon dioxide, and the amount of carbon dioxide stored in hundred years is the least; and the difference between the amount of carbon dioxide stored in timber forests and special forest in hundred years is not large, this is because the age of special forest trees is generally large, and the annual biomass growth is not as good as that of timber forests. Moreover, timber forests transfer a part of the carbon pool to forest products, which to a certain extent increases the carbon dioxide storage stock.

9 ESV-TOPSIS-based Forestry Evaluation Model

Considering that forests have various kinds of value in addition to carbon sequestration and forest products, such as potential carbon sequestration, conservation and biodiversity aspects, recreational uses and cultural considerations. We first unified the value conversion of various value-assessing methods of forests based on the ESV value conversion method, and then developed a set of forest management decision-making models that are most suitable for carbon sequestration based on the TOPSIS evaluation strategy, which can balance the diverse means of evaluating forests so that forest managers can make the best forest management decisions.

The value modalities of forests, such as carbon sequestration, recreation culture, biodiversity, production and life, and soil and water conservation, are incorporated into our decision-making model. That is, the management plan scope of the forest management plan decision model based on the ESV value conversion method and the TOPSIS evaluation strategy is the above five value methods.

9.1 Principle of ESV Value Conversion Method

The evolution of forest pattern is an important basis for studying the economic development and human activities in the area where the forest is located; forest ecosystem services are the natural environment and human living conditions formed by forest ecosystems and ecological processes, and the value of ecosystem services is the basis for quantifying and analyzing the functional strength of the service system and further formulating decision-making models.

The above two elements restrict and interact with each other. The change of forest pattern will inevitably lead to strong changes in the composition, structure and ecological processes of the ecosystem and biodiversity, which will have a significant impact on the value of forest services; the loss and degradation of ecosystem services affect the structure and efficiency of forest pattern changes, seriously affect human security and health, and directly threaten regional and even global ecological economy and ecological security.

Therefore, based on the mathematical model of forest service value, the response of forest pattern changes and forest service value is quantitatively analyzed, and the reliability of the results is verified by the sensitivity index, and the conversion results obtained based on the ESV value conversion method can be used as a unified standard for further decision-making.

9.1.1 ESV value conversion

Initially the value coefficient of forest ecological services is calculated:

$$VC_0 = \frac{1}{7} \cdot P \cdot \frac{1}{n} \sum_{i=1}^{n} Q_i \tag{28}$$

In this equation,

VC_0=The value amount of the ESV equivalence factor, yuan per area;

P=Average forest product price, yuan/kg;

Q=Average forest product yield, yuan/kg;

n=The number of years;

The value equivalent multiplied by the economic value of forest product yield can quantify the ecological value per unit area of the forest utilization type, and the ESV-based formula is as follows:

$$ESV = \sum_{k=1}^{n}(A_k \cdot VC_k) \tag{29}$$

$$ESV_f = \sum(A_k \cdot VC_{fk}) \tag{30}$$

In this equation,
ESV=Forest ecosystem service value, yuan;
A_k=The area of forest utilization type K, the are;
VC_k=ESV coefficient, yuan per area;
ESV_f=Service functional value of forest system f, yuan;
VC_{fk}=Functional value coefficient of the f service of forest utilization type k, yuan per area;

9.1.2 Sensitivity validation

In order to verify whether the selected VCs are suitable for this study area, the sensitivity index is selected for analysis. Sensitivity analysis means that after obtaining the optimal solution of the model, no matter how many parameters in the model change, the conditions of the original optimal solution can still be maintained. The dependence of ESV and VC over time can be determined by the sensitivity index. The sensitivity index (CS) means that a 1% change in VS will cause a 1% change in the ESV: if the CS is greater than 1, it indicates that the ESV is resilient to the VC, and the lower the accuracy of the result, the less accurate the VC cited; less than 1, it indicates that the ESV is inelastic to the VC, and the VC introduction is appropriate and the result is credible. The calculation formula of CS is as follows:

$$CS = |\frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} = VC_{ik})/VC_{ik}}| \tag{31}$$

In this eqaution,
CS=Sensitivity refers to changes in ESV caused by 1% VC change;
VC=Forest value coefficient;
i, j=Initial value coefficients and adjusted coefficient;
k=Types of forest utilization;

9.1.3 Results of value conversion and sensitivity validation

The change of ESV is closely related to the change of forest pattern, and the change of forest pattern affects the value trend of ESV and determines the value of ecological services in the area where the forest is located.

With the intervention of human activities, the forest body in the forest area is severely fragmented and the whole is fully utilized, the diversity, uniformity and connectivity of forest utilization types are improved, and the forest pattern is evenly distributed. Therefore, in the case of qualitative analysis considering maximizing the value of forests, there is no condition that the forest will not be deforested.

In addition, the sensitivity verification formula shows that the ESV is inelastic to VC, and the value factors of the five forest use types used, namely carbon sequestration, recreation culture, biodiversity, production and life, and soil and water conservation are applicable to the actual situation, and the ESV obtained is accurate and credible, indicating that forest utilization tends to be stable and standardized, and the value of forests is maximized.

9.2 Principle of TOPSIS Evaluation Strategy

The TOPSIS evaluation strategy, all know as technique for order preference by similarity to ideal solution, as a commonly used comprehensive evaluation method, can make full use of the information of the original data and accurately reflect the gap between the evaluation schemes. Since the TOPSIS evaluation strategy does not have strict restrictions on data distribution and sample content, data calculation is simple and easy.

Above we have first based on the ESV value conversion method to unify the various value methods of the forest after the value conversion, the following is based on the TOPSIS evaluation strategy developed a set of forest management plan decision model that is most suitable for carbon sequestration, to balance the various ways of assessing the forest, so that the forest manager understands the best use of the forest The basic process is: Firstly, the original data matrix after the unified standard is forward-oriented processing to obtain its corresponding positive matrix. Secondly, the positive matrix is standardized to eliminate the influence of each index program, and find the optimal scheme and the worst scheme in the limited scheme, and finally calculate the distance between each evaluation object and the optimal scheme and the worst scheme respectively, and obtain the relative proximity of each evaluation object to the optimal scheme, as the basis for evaluating the advantages and disadvantages.

9.2.1 Forward the original matrix

First we must make it clear that there are four kinds of indicators that we commonly use: very large indicators, also known as benefit indicators, the larger the indicators, the better; the very small indicators, also known as cost indicators, the smaller the indicators, the better; the intermediate indicators, the closer the indicators are to a certain value, the better; the interval indicators, the indicators fall in a range the best. To forward the original matrix is to unify all indicator types into very large indicators.

To convert a very small indicator into a very large indicator, apply the following formula:

$$max - x \tag{32}$$

Of particular note is that $\frac{1}{x}$ can also be used if all elements are positive.

To convert an intermediate indicator to a very large indicator, apply the following formula:

$$M = max\{|x_i - x_{best}|\}, \hat{x} = 1 - \frac{|x_i - x_{best}|}{M} \tag{33}$$

In this equation,
$\{x_i\}$=A set of intermediate indicator sequences ;
x_{best}=The best value in the sequence;

To convert an interval indicator into a very large indicator, apply the following formula:

$$M = max\{a - minx_i, maxx_i - b\}, \hat{x} = \begin{cases} 1 - \frac{a-x_i}{M}, x_i < a \\ 1 - \frac{x_i-b}{M}, x_i > b \\ 1, else \end{cases} \tag{34}$$

In this equation,
$\{x_i\}$=A set of interval-type indicator sequences;
$[a, b]$=The best interval in the sequence;

9.2.2 Normalize the forwardization matrix

The purpose of standardizing the forward matrix is to eliminate the effects of different indicator schemas. Suppose there are n objects to be evaluated, and the positive matrix composed of m positive evaluation indicators is shown in the following figure:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}$$

Figure 7: The positive matrix composed of m positive evaluation indicators

Then the matrix normalized to it is denoted Z, and the formula for each element in Z is as follows:

$$z_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} {x_{ij}}^2} \tag{35}$$

In this equation,
x_{ij}=Each element;
$x_{ij} / \sqrt{\sum_{i=1}^{n} {x_{ij}}^2}$=The sum of the squares of the column in which the element resides;

9.2.3 Calculate scores and normalize such scores

The purpose of normalization is to make the result easier to interpret, that is, to give us a clearer and more intuitive impression of the result. Suppose there are n objects to be evaluated, and a standardized matrix of m evaluation indicators is similar to the above matrix.
Here we define the distance of the evaluation object i from the max and the min value repectively as:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} w_j (Z_j^+ - z_{ij})^2}, D_i^- = \sqrt{\sum_{j=1}^{m} w_j (Z_j^- - z_{ij})^2} \tag{36}$$

9.2.4 Results of evaluation strategy

Under above discussions, we can calculate the unmerited score of the evaluation object i:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{37}$$

From this, we can conclude that with the increase of S_i,the value of D_i^+ gets bigger and thus, the normalized the scores are demonstrated as follows:

$$\hat{S}_i = S_i / \sum_{i=1}^{n} S_i, \sum_{i=1}^{n} \hat{S}_i = 1 \tag{38}$$

9.3 Applications of ESV-TOPSIS-based Forestry Evaluation Model

9.3.1 Discussion on which forestry management plan outstands

In order to solve the problem of what kind of forest plan to use for forests, six different management methods of A-F are given as shown in the following figure (Unit: ESV):

Management Methods	Recreation and Culture	Biodiversity Issues	Production of Products	Climate Regulation	Water Conservation	Carbon Sequestration	Soil Formation	Production of Food
A	123.86	206.765	144.883	186.79	228.56	179.318	274.106	44.883
B	73.96	206.247	43.876	183.488	228.804	183.848	284.507	40.19
C	74.81	317.477	142.345	179.318	211.436	186.062	218.55	38.675
D	75.641	214.075	139.176	286.062	215.405	185.79	232.445	48.435
E	69.659	213.892	133.129	185.79	232.389	184.804	254.98	61.781
F	74.82	207.784	141.962	186.081	203.104	199.457	234.076	31.229

Figure 8: Six different management methods of forests

Based on ESV-TOPSIS Forestry Evaluation Model, the following specific examples are given to discuss the specific application of the evaluation model.

-Urban forest areas are daily life areas of residents, mainly building leisure and entertainment types of parks, and the ecological value of forests is more reflected in cultural tourism, so the method of entertainment culture weight is chosen.

-Economic forest areas are generally located in areas far from towns. According to edge theory and biodiversity, such forest areas are areas with high production capacity, so more logging activities are generally carried out to obtain greater product or food production.

-Timber forest areas are generally located in areas with good climatic conditions and water source conditions, so the tree species are complete and forestry resources are abundant. Therefore, in the development of such forest areas, in addition to achieving the economic indicators related to the production of wood products, it is also necessary to appropriately take into account the protection of natural ecological values such as climate regulation, water conservation, and carbon sequestration.

Urban forest area

Recreation and Culture				
			P Weights: 0.20, 0.24, 0.05, 0.21	
			N Weights: 0.08, 0.06 , 0.1, 0.06	
Index	Positive distance	Negative distance	Composite score index	Sort
A	0.24915378	0.58947825	0.70290452	1
B	0.5602973	0.27651366	0.33043742	6
C	0.52292732	0.33439525	0.39004601	4
D	0.4689776	0.35915297	0.43369124	3
E	0.46130708	0.49592865	0.51808414	2
F	0.59670373	0.29882018	0.33368197	5

Best Solution: A

Economic forest area

Production and life				
			Positive Weights: 0.40, 0.40	
		Negative Weights:	*0.03, 0.05, 0.04, 0.02, 0.01, 0.04*	
Index	Positive distance	Negative distance	Composite score index	Sort
A	0.32351283	0.39823545	0.55176502	3
B	0.4872891	0.21556951	0.30670395	6
C	0.37968575	0.38011743	0.50028407	4
D	0.24300672	0.4317401	0.63985496	2
E	0.12797872	0.58455859	0.82039014	1
F	0.50437443	0.34976408	0.4094934	5

Best Solution: E

Timber forest area

Ecological protection				
		Positive Weights:	*0.25, 0.25, 0.10, 0.13, 0.24, 0.1*	
			Negative Weights: 0.01, 0.02	
Index	Positive distance	Negative distance	Composite score index	Sort
A	0.56858081	0.38143168	0.40150175	3
B	0.63829685	0.31391911	0.32967218	5
C	0.60528137	0.391041	0.392484411	4
D	0.38757556	0.56237546	0.59200469	1
E	0.52916405	0.48204543	0.47670185	2
F	0.69395318	0.23326547	0.25160261	6

Best Solution: D

9.3.2 Discussion on transition from an existing shedule to a new timesheet

We assume that the best management plan includes harvest intervals that are ten years longer than the current forest practice. In a way that is sensitive to the needs of forest managers and all those who use forests, the following discussion of the transition from existing schedules to new ones unfolds. Over time, we need to adjust and replace new management plans, which often includes a harvest interval of ten years longer than the current forest practice, so that the transition from the existing schedules to the new ones can be better completed, and grey correlation model is used here to analyze.

Of particular note is the fact that the degree of correlation indicates the degree of similar correlation between each evaluation item and the reference value (parent sequence), which is calculated by the correlation coefficient to calculate the average value. The larger the value is, the stronger the correlation between the evaluation item and the reference value (parent sequence) will be. Combined with the correlation value, all evaluation items are sorted to obtain the ranking of each evaluation item.

In addition, combined with the above correlation coefficient results weighting processing, the correlation degree value is finally obtained, and the correlation degree value is used to evaluate and sort the 7 evaluation objects; the correlation degree value is between 0 and 1, and the larger the value, the stronger the correlation between it and the reference value (parent sequence).

9.3.3 Results of forestry management plan and transition strategy

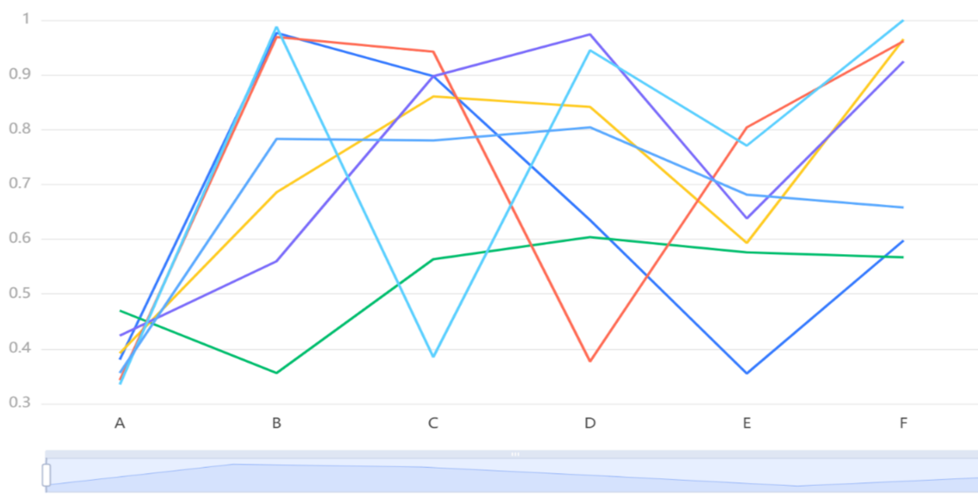


Figure 9: Relationship coefficient results

As can be seen above, the correlation between 7 evaluation items (food production, product production, water conservation, climate regulation, soil formation, biodiversity conservation, carbon sequestration) and 6 data was analyzed, and the correlation between 7 evaluation items (food production, product production, water conservation, climate regulation, soil formation, biodiversity conservation, carbon sequestration) and entertainment culture was studied with entertainment culture as the reference value (parent sequence), and the analysis reference was provided based on the correlation degree.

When using the gray correlation degree analysis, the resolution coefficient is 0.5, and the correlation value is calculated according to the correlation coefficient calculation formula, and then the correlation value is calculated for evaluation and judgment according to the correlation value.

Evaluation Projects	Biodiversity Protection	Process of Soil Formation	Climate Regulation	Watersource Nourishment	Carbon Sequestration	Productivity of Food	Productivity of Products
Relevance	0.737	0.736	0.733	0.723	0.677	0.640	0.523
Rank	1	2	3	4	5	6	7

Figure 10: Relevance results

To conclude, as is demonstrated on the above lable and the Figure, for the seven evaluation items, biodiversity conservation evaluation was the highest, with a correlation degree of 0.737, followed by soil formation, with a correlation degree of 0.736.

10 Strengths and Weaknesses

10.1 IPCC Improvement as Means of Carbon Sequestration

- Strengths:The improved IPCC model provides forest-related parameters for each temperature zone and climate domain around the world, such as the average annual growth of biomass, carbon coefficient, rhizome ratio, etc. Overcoming the fact that the data are difficult to describe the forest at the level of the forest area; and the fact that these data are mostly constants makes it impossible to consider the change of time in the model.
- Weaknesses:The traditional IPCC model has a limited lifespan, with slow annual biomass growth at a certain age and death after reaching the upper limit of lifespan. Some forest products may outspire the trees that produce them, and these products also serve as a barrier to carbon dioxide during their lifetime. This does not meet the requirements of the topic to establish a model of carbon sequestration and time relationship.

10.2 ESV-TOPSIS Evaluation Strategy as Means of Foresty Evaluation

- Strengths:As for the TOPSIS evaluation strategy with weights, the weights of the default indicators are not the same, but the weights are calculated for each element in the standardized matrix, and then the score is calculated directly with the normalized matrix with weights, and the weight w_j is added to the equation that defines the distance between the evaluation object i and the maximum value D_i^+.
- Weaknesses:As for the TOPSIS evaluation strategy with weights, the application of analytic hierarchy method is too subjective when determining the weight of m evaluation indicators, which is inferior to the objective assignment of entropy weight method. The ESV estimation model still needs to be improved in terms of accuracy and timeliness, which is suitable for estimating the value of forest ecosystem services in long-term sequences, different forest ecological service systems have their own different functional quantitative estimation formulas, and different forest service function estimation formulas are applicable to different forest utilization types.

11 References and Sources of Data

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12 Appendix- MATLAB Code

QuantumMain

```
trace=zeros(1,MAXGEN);
best=struct('fitness',0,'X',[],'binary',[],'chrom',[]);
chrom=InitPop(sizepop*2,sum(lenchrom));
binary=collapse(chrom);
best.binary=binary(bestindex,:);
best.chrom=chrom([2*bestindex-1:2*bestindex],:);
best.X=X(bestindex,:);
trace(1)=best.fitness;
for gen=2:MAXGEN
binary=collapse(chrom);
chrom=Qgate(chrom,fitness,best,binary);
if newbestfitness>best.fitness
best.fitness=newbestfitness;
best.binary=binary(newbestindex,:);
best.X=X(newbestindex,:);
end
trace(gen)=best.fitness;
end
plot(1:MAXGEN,trace);
title('Evolutionary process');
xlabel('Evolution algebra');
ylabel('Optimum fitness per generation');
disp('The best solution X: ',num2str(best.X))
disp('The maximum value Y: ',num2str(best.fitness));
```

FitnessFunction

```
function (fitness,X)=FitnessFunction(binary,lenchrom)
sizepop=size(binary,1);
fitness=zeros(1,sizepop);
num=size(lenchrom,2);
X=zeros(sizepop,num);
for i=1:sizepop
(fitness(i),X(i,:))=Objfunction(binary(i,:),lenchrom);
end
```

ObjFunction

```
function (Y,X)=Objfunction(x,lenchrom)
bound=(zeros(301,1) (5000.*ones(200,1);ones(101,1)));
X=bin2decFun(x,lenchrom,bound);
C=sum(dC_1)+sum(dC_2);
CO2=C/12*44;
Y=CO2;
display('error1')
display('error2')
```

Why harvesting in management of forests rather than them being left untouched is superior

ICM Team
Newspaper Article Sheet

We, the ICM team, are tasked with helping you local community develop a set of methods to convince your local residents that harvesting should be included in forests' management plan rather than it being left untouched in terms of improving carbon sink capacity of their forests.

As is known to all, climate change now poses a huge threat to human life. Under current circumstances, forest production systems are crucial in terms of mitigating the effects of climate change. To better decrease the influences of such change, reducing greenhouse gas emissions never tends to be effective enough. We need to work together to increase the amount of carbon dioxide sequestered from the atmosphere through the biosphere or mechanical means. In this process, forest plants absorb carbon dioxide from the atmosphere and fix it in vegetation or soil, thereby reducing the concentration of this particular gas in the atmosphere. Thus, forests are playing an indispensable role in mitigating climate change.

Forests mitigate climate change mainly in their important role in achieving carbon sequestration. In addition to the tactics of afforestation and reforestation, reduction of deforestation and forest degradation, such as holding large-scale afforestation activities and increasing forest stock to enhance forest carbon sink capacity, forest management, carbon sequestration of woody forest products and their substitution effects play an indelible positive impact on forest carbon sequestration.

In terms of carbon sequestration and the substitution effects of woody forest products, due to the impact of related human activities, including proper harvesting, products made from trees are insulated from carbon dioxide over their life cycles, and some products may exceed the lifespan of the trees that produce them. Compared to the carbon sequestration gains of deforestation only, the carbon sequestered in certain forest products combined with the carbon sequestration due to the regeneration of young forests has the potential to allow for more carbon sequestration over time. According to the theory of life cycle correlation, the growth of wood is the process of carbon sequestration, because the formation of wood is the tree absorbing carbon dioxide from the atmosphere during the growth process, relying on solar energy in the tree body in the form of cellulose, hemicellulose, lignin and other carbon compounds fixed storage. Through harvesting, such fixed carbon in the forest can be transferred to the woody forest products, and the whole life cycle of the woody forest products can be stored and reduced, and it has good carbon emission satisfaction, and can reverse the forest management behavior through consumption, affecting the level of forest carbon sinks. To conclude, forests are an important carbon storage reservoir for terrestrial ecosystems, and woody forest products, as the main component of this carbon reservoir, play an important role in improving the carbon sink capacity of forests.

In terms of forest management, at the global level, forest management strategies, including appropriate harvesting, favor carbon sequestration. Forest managers tend to make clear choices between the value resulted from deforestation only when forests serve as living trees, and that from carbon sequestration of properly harvested forest products. If the former is considered, the age and type of trees, geography and topography need to be taken into account, because the composition, climate, benefits and values of forests vary greatly around the globe, then one-size-fits-all guidance is simply not possible; plus, forest carbon sequestration presupposes a healthy life cycle, and once the forest lacks effective management, such as fires, insect infestations, or as the carbon released by the decomposition of the forest's aging, decaying, and dead organic matter gradually increases, it is possible to change from a carbon sink to a carbon source. As you can see, in order to achieve long-term carbon sequestration of forests, forest operators should manage forests with sustainable management concepts and rationally harvest and utilize them. After the tree is converted into a woody forest product, the carbon sequestration cycle of it can exist with the same life cycle as the product or even beyond the life cycle of it. Even if a woody forest product exceeds its lifespan, it can still be recycled. In short, still, forests are an important carbon storage reservoir for terrestrial ecosystems, and forest management strategies with appropriate harvesting play an indispensable role in improving the carbon sink capacity of forests.

To conclude, in recent years, the concept of green development and low-carbon development has put forward higher requirements for improving carbon sink capacity of forests. By means of conducting proper harvesting for more efficient processing and utilization of woody forest products for carbon sequestration and enhanced forest management, forest ecology and economic benefits can be increased, and is an effective solution to improve carbon sink capacity of forests. The scientific and rational use of timber through appropriate harvesting can, on the one hand, encourage technological innovation and promote the research and development and application of manufacturing technologies for high-performance, multi-functional and longer-life cycle woody forest products; on the other hand, the relevant management strategies of appropriate harvesting priorities can be implemented, and the preferential use of wood as the main way to sequestration forest in community projects can be encouraged, and the benefits of forestry production can be brought into play. The forest cultivation and rational harvesting can also be organically combined to maximize carbon sink capacity of forests.

ICM Team
2022-02-18

2021

Mathematical Contest In Modeling®

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Be It Known That The Team Of

Xinyi Yuan
Yanhao Bai
Jiaxin Zhong

With Faculty Advisor

Qiuhui Pan

Of

Dalian University of Technology

Was Designated As

Honorable Mention

Steven B. Horton, Contest Director

Administered by COMAP

With support from

David H. Olwell, Head Judge

Problem Chosen	2021 MCM/ICM Summary Sheet	Team Control Number
C		# 2107042

Interpolation Fitting and Hornet Recognition Model Based on Convolutional Neural Network

Summary

The presence of the Vespa mandarinia was discovered on Vancouver Island in 2019. Since then, there have been several pest sighting events in neighboring Washington state, many of which have been identified as mistaken sightings. Aimed at eliminating the Vespa pest, our team predicts their spreading areas based on the Interpolation Fitting Model. Meanwhile, a Vespa Hornet Recognition Model is established based on thesis of Convolutional Neural Network (CNN) to identify whether pictures with unknown results are wrongly classified by means of cluster analysis.

Based on Interpolation Fitting Model, we first filter out all the Global IDs marked with Positive from certified sighting reports and, call its valid information such as detection date, latitude, longitude to realize the conduct of 3D interpolation with the help of MATLAB and a polynomial-fitted image to predict the propagation of Vespa hornets. The residuals appearing in the fitting process are then analyzed and evaluated to determine its feasibility.

Additionally, owing to numerous reports' being classified wrongly, a Hornet Recognition Model is established based on CNN to check the sighting pictures. We classify and conduct a data set called Statistic Library to train the recognition system. In face of possessing too few positive ones, we enrich the data set by various means. Sliding-window algorithms enables the settings of four parameters to realize the construction of the layers used in our model to realize the want that positive and negative pictures compose of a training set to be used for model-learning, so as to offer the test set made up of unverified and unprocessed pictures chances to determine whether the sighting results are true.

The recoginiton model's ability to predict unverified pictures' possibility to be positive is feasible. If that percentage predicted is more than 50%, the corresponding picture would be classified as positive. We filtered out these sightings and put them into the Interpolation Fitting Model to evaluate how well the model fits and it's considered reliable to guide the subsequent investigations.

We then study the living habits, reproduction and predatory features of the Vespa hornets and those of other hornets' as well as the species relations among them. Changes in terms of the population of the Vespa hornets in the light of biological species relations and self-ethnic development are estimated to realize the formulation of reasonable model-updating frequencies.

To conclude, combined with the latest endangered species rating standards established by the International Union for the Conservation of Nature (IUCN) and the Species Survival Commission (SSC), all the unverified sightings are determined positive or not via the hornet ecognition model. And all the reports identified as positive are interpolated and fitted with certified reports to estimate the number of the Vespa species that may exist and their domination areas. Vespa pests will then be eliminated after being informed the longitude and latitude of the sightings to better ensure the safety of local people.

Keywords: 3D interpolation fitting model, the Convolutional Neural Network (CNN), cluster analysis, the construction of a Statistic Library, the Vespa species relations, endangered species rating standards

1 Introduction

The Vespa mandarinia (also known as the Asian giant hornet) is a kind of wasp from East Asia regions with potentially biological invasive characteristic. For the duration of September 2019, the Vespa hornets' nests discovered on Vancouver Island, British Columbia were eradicated. This specific creature is rather destructive to the local ecological environment and, as the largest wasp species around the globe, it's the predator of European bees. Bee nests across Europe can be destroyed within a short period of time just by several Vespa hornets. Also, they are fierce predators to kinds of pests. It's been a top priority for relevant governments to find out the habitats of the Vespa hornets, thus eradicating their nests in a timely manner. The specific wasp sightings occurred in Washington State has been affirmed till now, but this matter of thing has been accompanied by a large number of mistaken sightings. The Vespa hornet is similar in appearance to European hornets and cicada killers, and on many occasions the wrongly-identified incidents increase the workload of government personnel. How to interpret the relevant data in public reports and what strategies to use to analyze these reports are all the pressing problems to solve.

2 Restatement of the problem

As the Vespa hornet sightings increase year by year, relevant supporting documents regarding different forms from various regions is involved. Based on more than 4000 sighting reports in recent years and Penn State's background information on the Vespa hornets, mathematical models and relevant algorithms are established to solve the five problems listed as follows:

- Problem 1: Apply the relevant predictive models to make predictions upon the spread of the Vespa hornets over a specific period of time on account of the global IDs, detection time, laboratory status, longitude and latitude listed in the sighting reports, and to determine the feasibility and the possibility of predictions based on the model's accuracy.
- Problem 2: Owing to the appearance similarity, the Vespa hornets are prone to being mistaken for European hornets or cicada killers. So models created based on the sighting reports provided are of great necessity to analyze the possibility of a mistaken classification.
- Problem 3: Figure out ways to analyze how to confirm the picture posed a Positive ID or a Negative ID using the model created above.
- Problem 4: How often the model is supposed to be updated should be takin into consideration using reasonable explanations and illustrate how it should be updated.
- Problem 5: Determine under what evidence or standards does the Washington State has eliminated the Vespa hornets.

3 Modeling Assumptions

The changing habits of predatory Vespa hornets are ignored and a consensus is reached that Vespa hornets' annual reproducing breeds keep the same in parallel with last year's ones. Also assume that the Vespa hornets spread only near Vancouver Island, and there is no second nest place in the United States far from Washington state. Moreover, the state of the sighting reports given classified as positive, negative, unverified, unprocessed is the same as the objective fact, and the data provided by the witness is authentic.

4 Modeling the Hornet Diffusion

The Vespa mandarinia incident at the beginning of Vancouver Island has attracted much attention, and the pest is a great threat to local life. Predictions of its spread over time have become an urgent issue. At the same time, it is possible to analyze and study the accuracy of the prediction model to judge its feasibility.

4.1 Principle of the Hornet Diffusion Prediction Model

For each information in the sighting report list, we filter out valid detection date, latitude, longitude and have built up a 3D interpolation fitting model to predict the future migration of the Vespa pests. As is shown in Diagram 1, we set longitude to x-coordinates, latitude to y-coordinates, and detection date to z-coordinates. After the prediction function is developed, the positive information is filtered out in more than 4,000 reports and fitted in the model. The 3D diagram established by our team with the appliance of MATLAB is:

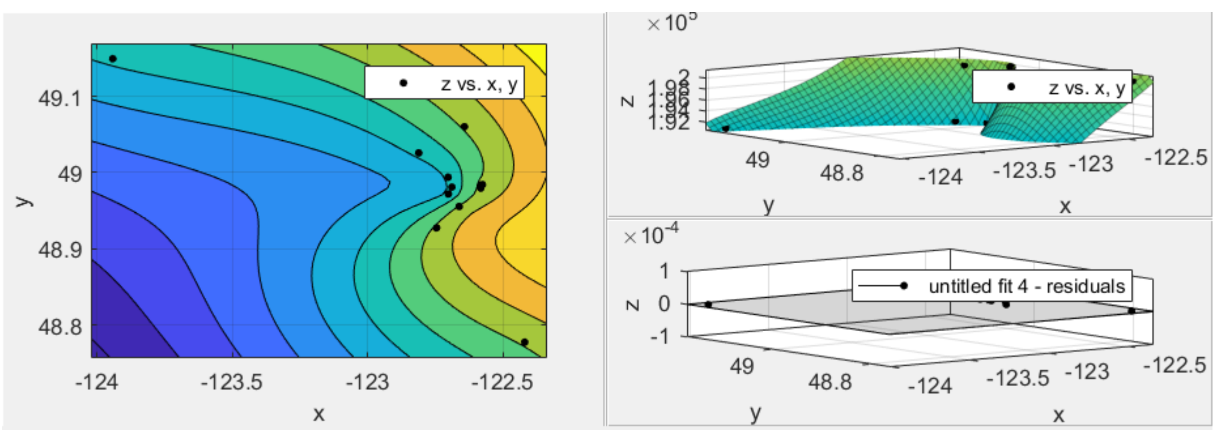

Figure 1: The three-dimensional Vespa diffusion-prediction function diagram

4.2 Results of the Hornet Diffusion Prediction Model

Because the positive reports are directly charted and fluctuate too much, it is difficult to find patterns to predict. After multiple screening, we have selected the interpolant fitting method, adopting the interpolation by using the thin-plate-spline function, to find a smooth surface with the smallest bending of all control points, thus drawing a 3D image to predict pest diffusion. At the same time, the residuals are analyzed. The empirical prediction model has certain feasibility. The Vespa pest will spread towards the yellow area as shown in Figure 1.

5 Modeling the Hornet Recognition

Because of too many reports' being classified wrongly, a Hornet Recognition Model is established by us based on CNN to check the sighting pictures. We classify and conduct a data set called Statistic Library to train the recognition system. When faced with problem of possessing too few positive pictures, we enrich the data set by various means of means of continuous rotating, perspective transforming, zooming, filling, reversing and as well panning the pictures both horizontally and vertically. Sliding-window algorithms are also put into use to enable the settings of four parameters to realize the construction of the three layers used in our model to realize the want that positive and negative pictures compose of a training set to be used for model-learning, so as to offer the test set made up of unverified and unprocessed pictures chances to determine whether the sighting results are true.

5.1 Principle of the Hornet Recognition Model

In order to solve the hornet-sighting classification problem, we establish a Vespa hornet recognition model based on Convolutional Neural Network (CNN), the general principle of which is to find commonality among the same type of pictures through an incipient study of a large number of various types of pictures through the thesis of neural network, thus applying the acknowledged commonality to the field of picturing classification. Suppose we regard the model's picturing classification as the sighting-events' classification, then we're able to indirectly classify the sighting events using this model.

5.2 Structure of the Hornet Recognition Model

The neural network part of this model consists mainly of three layers: Convolution, Pooling, and the Fully-connected layer. The Convolution layer: The function is to extract the characteristics of each small part of the picture. And through constantly changing the convolution kernel, the network can determine which kernels have the feasible use in terms of signify the characteristic of the picture. A matrix multiplied by the particular convolution kernel is thus produced. The Pooling layer: The function is to take down the number of the training process mentioned above. Additionally, reducing the dimension of the feature vector produced by the Convolution layer, the overfitting process and the transmission of noisy sounds is also the edges of Pooling layer. The Full-connected layer: The function is to generate a classifier.

5.3 Basic Settings of the Hornet Recognition Model

5.3.1 The construction of the Statistic Library

To create a data set extensively applied in our model, a Statistic Library is meant to be produced following the listed steps. First and foremost, the images provided by the sighting events are classified into four categories according to the classification of the sighting event itself: positive, negative, unverified, unprocessed. Secondly, all the pictures of Positive ID are placed into the Positive folder and pictures of the Negative ID alike. Take the name of relative folders as the classification label for these two types of pictures. And one-shot the labels. What's worth noticing is that the size of the picture might affect the classification process of pictures, so it's necessary to set all the pictures to the same size. Lastly, in order to realize an effective prediction of the neural network created, we separate the data set (also the Statistic Library) into two parts, that is, the training set and the test set. Wherein the training set accounts for 70% of all the statistics in the data set, and the test set take the rest 30% (the training set is not supposed to be too small, otherwise the neural network cannot get the effective study). The purpose of the training set aims at training the neural network to obtain the corresponding characteristics from the picture, while the test set is used to test whether the network could make reasonable predictions. It's also worth mentioning that because too few pictures are provided by sighting events, in order to avoid the circumstance that the neural network cannot actually study the characteristics of the picture owing to the small training set, all the pictures in training set are due to be enhanced for the duration of the data set's setting process. Specifically speaking, we enrich the data set by means of continuous rotating, perspective transforming, zooming, filling, reversing and as well panning the pictures both horizontally and vertically. Till now, the construction of the data set (also the Statistics Library) is finished.

5.3.2 The construction of the Convolutional Neural Network (CNN)

The convolutional neural network can roughly be divided into two parts: three convolution layers and one fully-connected layer. Each convolution layer consists of one pooling layer, and the fully-connected one serves as the output layer of the convolution layers.

The construction of the convolution layer uses sliding window algorithms to convolute the two-dimensional input and is selected from the Conv2D (a type of two-dimensional convolution layer, i.e. the empty convolutional fields of the picture) in the Keras package (a system package used in Python Deep Learning fields). So the construction of the convolution layer mainly is by changing the parameters in Conv2D-as follows is the method of setting the parameters.

Setting 1: Input-shape Input-shape contains three parameters, the first two are the size of the input picture. As is known from the process of creating the data set, we set all the pictures to the same size and the specific number is 64*64 pixels. The third parameter represents the number of the input channels. Due to the fact that this neural network is generally applied in fields of picture recognition, i.e. the file type of the input documents falls into the RGB type, the number of channels is set to 3. To conclude, in this neural network the input-shape equals to (64,64,3).

Setting 2: Kernel-size The width and length of a convolutional kernel, originating from the list/tuple constructed by a single integer or two is defined to be kernel-size. If it's the case of one single integer, the size represents the same length in each spatial dimension. First and foremost, calculate last-layer picture's perceived domain, the same size as the convolutional kernel, with the help of the convolution layer's kernel, and arrives at a value. After the scanning process dominated by the kernel, the resulting values are combined into a featuring picture. Similarly, all the following kernels repeat the same work. What's worth mentioning is that the commonly used kernels' sizes are 3*3, 5*5, 7*7. Then, in order to obtain a point of pixels, the task completed by a 7*7 kernel can be done by three 3*3 kernels. The 7*7 kernel owns 49 weights, while three layers, each layer conducting tasks by a 3*3 kernel, covers a deduction of 27 weights. So the calculation complexity can be reduced by splitting the convolutional kernels and increasing the number of convolution layers. Lastly, the calculation complexity is defined as a cost function and so this model prioritizes calculating the computational complexity by setting the convolutional kernel to 3*3.

Setting 3: Filters Filters stands for convolutional kernels' number in the convolution layer, i.e. the output's dimension. With the increase of convolution layers' number, the number of the corresponding kernels multiplies as well (i.e. when setting first layer's convolutional kernel number to 32, the feature value is supposed to be set to 64). The conduct of increasing convolutional kernel's number layer by layer results in the network's studying the characteristics displayed in the training set layer by layer. However, the current setting of filters has not yet attained supports from sound theoretical basis, different data set calls for different values of filters. Also, as for various neural networks, the type of filters is never the same and except for all these things, the size of the convolutional kernel mentioned in 2.1.2 counts as well when figuring out the precise values for setting particular filters. Therefore, the filters can only be through constant adjustments to acquire an approximate value so, our model sets first layer's filters to 32, the second 64, the third 128.

Setting 4: Activation When it comes to neurons in the case of biological sense, the subsequent neurons are activated only when the weighted sum outweighs a certain specific threshold. In a nutshell, the significance of the activation function lies in determining whether the output of each neuron has reached a threshold, while in the picture-recongnitioning convolution layer, the significance of the which lies in determining whether the featuring strength in one particular area has reached a certain standard. If the answer is no, the output will be the figure 0, implicating that this kind of feature extraction method (of convolutional kernel) can no longer extract characteristics from this range of area, meaning the areas unrelated to this featuring area will not affect the training of the feature extraction method. The activation functions currently commonly used for bipartite Convolutional Neural Network (CNN) are Sigmoid and ReLU. Every convolution layer in our convolutional neural network apply ReLU to serve as its activation function and, the definition of which is:

$$ReLU(x) = max(0, x) \tag{1}$$

The linear graph of the function is available in Figure 2.

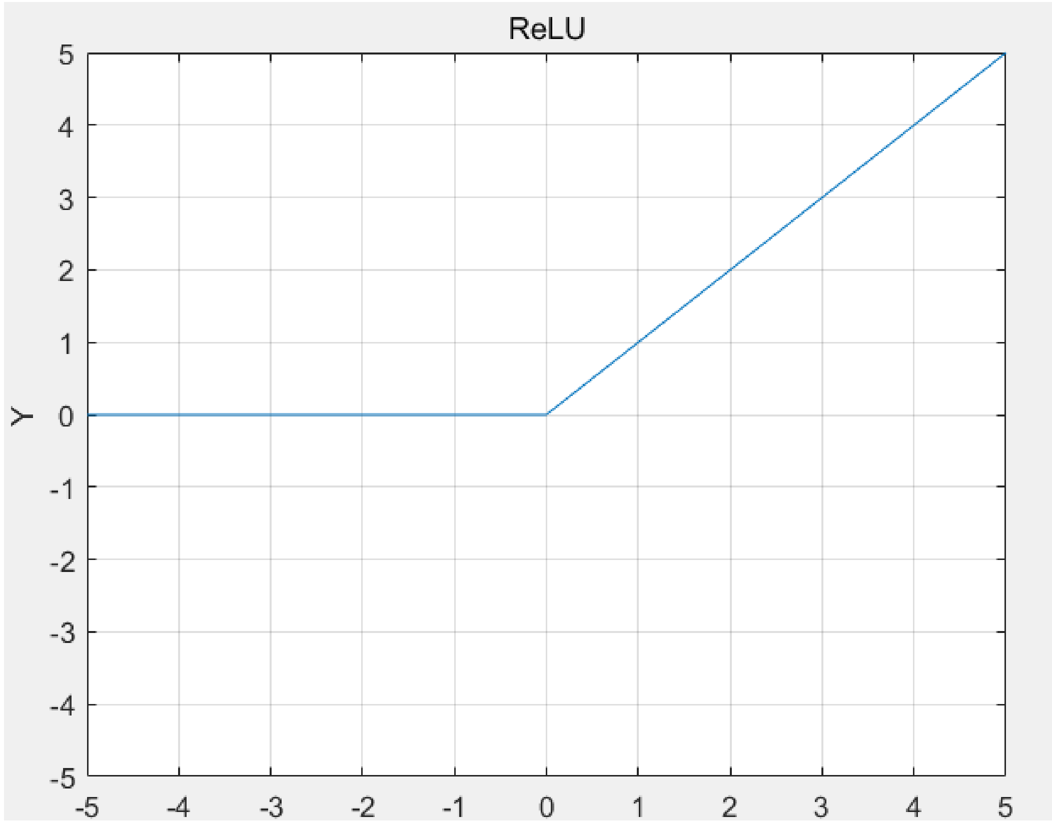

Figure 2: The linear graph of activation function ReLU

As we can see from Figure 2, when Signal (x-axis) <0, the output (y-axis) = 0. When Signal >0, the output >0 and equals to input. The reasons why we choose ReLU as our activation function are listed as follows.

Sum of ReLU's Sparsity is small and it offers a smaller possibility to cause problems like Vanishing Gradient. This advantage of ReLU allows us to train deep neural network directly in a supervised manner without relying on unsupervised layer-by-layer pre-training.
ReLU serves as a linear function, is born with a low calculational complexity, thus offering itself the feasible use of improving the learning efficiency of the convolutional neural network.

However, due to the fact that the ReLU function is fragile in retraining so, even a little carelessness can lead to damaging neurons 'necrosis'. For example, since the ReLU has a gradient of 0 at x<0, thus causing the negative gradient to be zeroed in this ReLU, and the neuron may never be activated by any data again. If this happens, then the gradient after the neuron is always 0, i.e. the ReLU neuron is dead and no longer responds to any data. Therefore, subsequent improvement of this convolutional neural network can be focused on optimizing the network by means of improving the ReLU function.

Setting 5: Selection of the pooling layer In this model we chose to build a pooled layer using MaxPooling2D in Keras package. Maximizing pooling is the most common and the mostly used pooling operation. Using the maximum value in the image area as the pooled value for this region, and through such a down-sampling effect of confluence operation, the purpose of spatially dimension reduction is sure to be achieved, thus resulting in CNN's extracting a wider range of features and, reducing the figure of next layer's input, thereby reducing the amount of calculation and the number of the parameters so that the model could realize a deduction in terms of computational complexity.

To conclude, the convolution layer is roughly built up through the settings of the above parameters. In order to avoid the phenomenon of Convolutional Neural Network (CNN) overfitting cases, Dropout can be added to the convolution layer. Besides, if the want of a much faster and more steadily-trained CNN is required, it can be fully realized by adding the BN (Batch Normalization) layer while inputting the distribution changes in the process of training to reduce the internal co-variance offset.

The construction of Full-connected layer is supported by the Flatten layer which tends to be primarily used to down-dimensionalize the results of the convolution layer, i.e. one-dimensionalize the multi-dimensional inputs in the convolution layer. And this theory is applied in fields of the transition of the convolution layer and the full-connected layer. After the process of down-dimensionalizing, the Flatten layer will create a full-connected layer consisting of 512 hidden units with the help of Keras package, and conduct the process of done down-dimensionalizing convolution layer signals' featuring strength. At last, because of the whole network's picturing binary classification, the output results consist of only one hidden unit, which is used to classify the predictionary values for the pictures being diagnosed by activation function Sigmoid, the definition of which is:

$$log\ sig(x) = \frac{1}{1 + (1/e)^x} \tag{2}$$

The linear graph of the function is available in Figure 3.

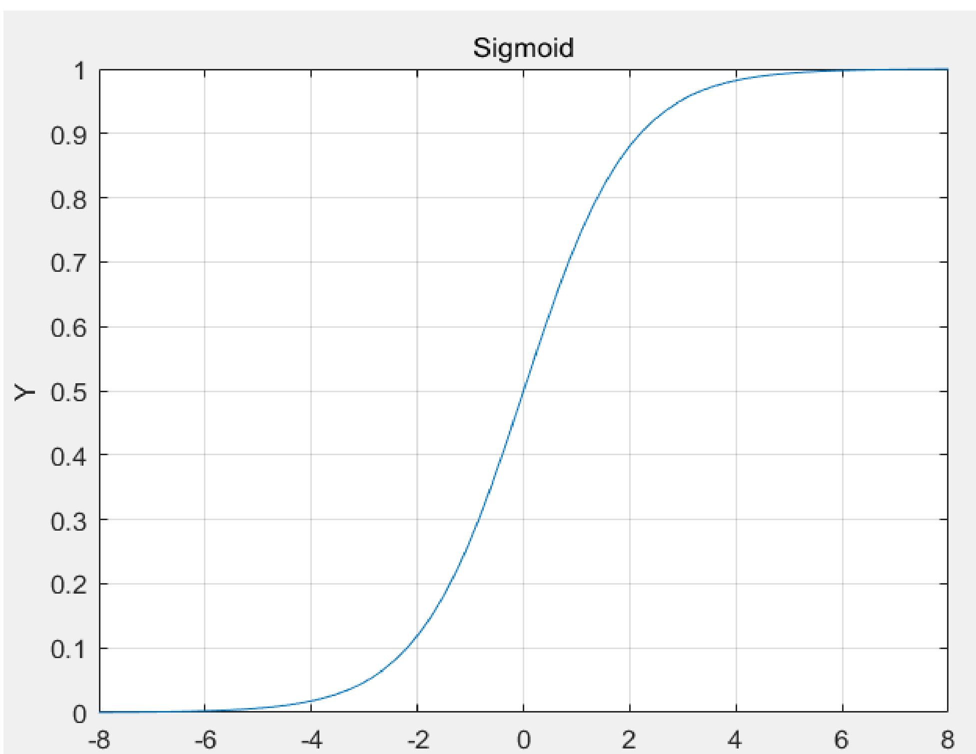

Figure 3: The linear graph of activation function Sigmoid

5.3.3 The training of the Neural Network

The training process of the convolutional neural network is divided into two phases of stages. The first stage is the phase of data transmission from a lower level to a higher level, that is, forward propagation stage. Another stage is that when the result of the forward propagation varies from the expected outcome, this stage will be the phase of data transmission from an upper level to a lower level, that is, backward propagation stage. During the training process, the neural network first initializes the weight values. For the construction of the data set, 70% of the picture will be used as a training set, and this part of the data is plunged into the neural network. The possibility of the done-input data being classified as positive through the convolution layer, pooling layer, and full-connected layer during the forward propagation is meant to be attained. If the possibility is larger than 50% then the picture will be classified as positive and otherwise negative. Since we already know the classification of a given picture, i.e. the label of the picture, if the network's output classification is consistent with the label, the classification then is proved to be correct and vice versa. The incorrect classification at the same time is the residual between the network's output value and the target value. When the residual is beyond our expectations, the residual will be transmitted back to the network, and in turn to find the residuals of the full-connected layer, pooling layer and the convolution layer. The residuals at each layer can be acknowledged as the total error for the network, and when the error is equal to or less than our expectations, one circle of training is due to be done. The neural network's weights' being reinitialized according to the residuals after the past training will start a new training.

Parameters for Neural Network Training are needed to conduct the setting of parameters, and the parameter sets are listed as follows.

Parameter 1: Learning rate The higher the learning rate is, the faster the model learning will be. But a too fast learning is easy to result in a large loss, thus the accuracy will produce shocks. The smaller the learning rate is, the slower the model learning will be. But a convergence speed will be slow, too. Therefore, a more often conduct is by setting a dynamically changing learning rate. In our model, we adopt the method of fractional mitigation (also known as decay) to achieve the dynamic change of the learning rate. And the model is defined as:

$$a = \frac{a_0}{1 + kt} \tag{3}$$

In this model, a stands for the learning rate, k stands for the mitigation range, t stands for the rounds of the training conduct. We set the initial learning rate to 0.005, and the k to 0.0005. The a image resulting from different k values are displayed in Figure 4. Wherein the blue line is the a image at k=0.0005, the red line is the a image at k=0.005. Apparently the greater the k value is, the faster the a value decreases. Therefore, preventing the phenomenon of overtraining resulting from the overfitting can be achieved through the conduct of lifting initial learning rate or taking down the value of k.

The linear graph of the function is available in Figure 4.

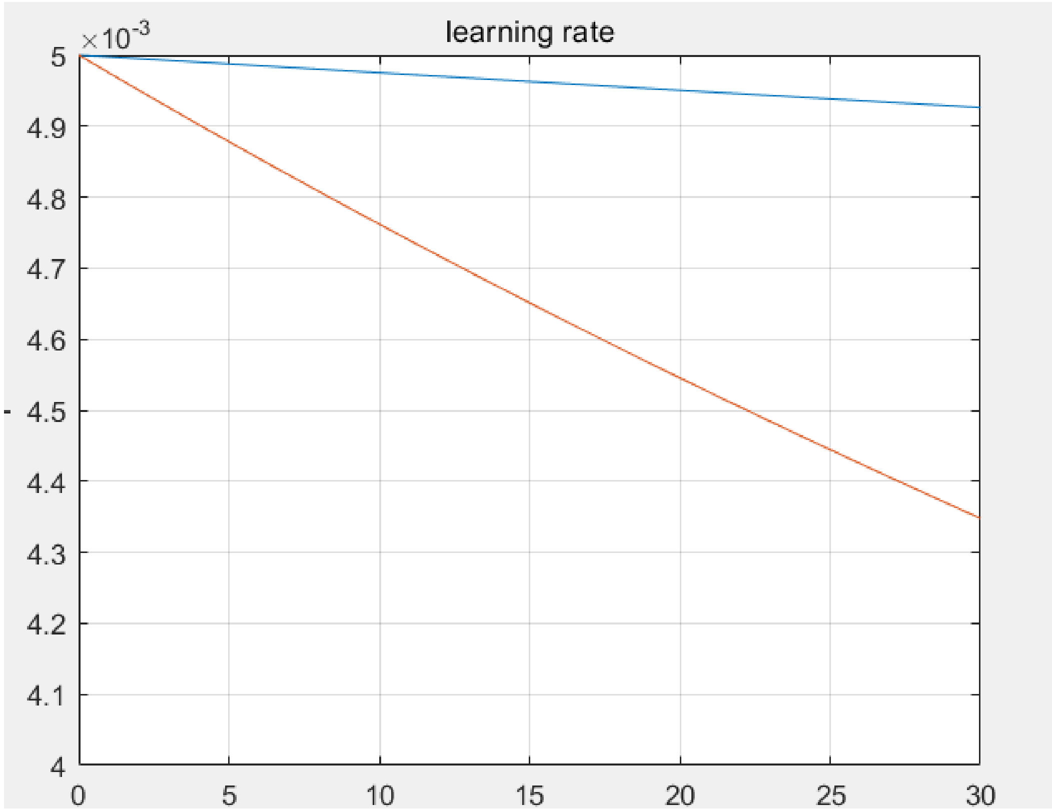

Figure 4: The a image resulting from different k values

Parameter 2: Epochs Epochs, i.e. the round of the training process, if is too large, means that too many rounds of training are conducted. Then numerous extra trainings might be done. On the contrary, too few trainings may lead to the convolutional neural network's inadequate practices. In the training process of the neural network, we find that within a certain range with the continuous increase of the number of training, the network's residual will continue to decrease, but after achieving a certain number of training times, the network's error no longer changes widely. So how to determine the correct setting times of training is particularly influenced by taking what standard of training stoppage. In this model, the following two values are used primarily as criteria for determining whether follow-up training is necessary.

- **Value 1: The loss value of the training set**
  In this model, we use the function binary coross-entropy, which is commonly used for calculating classifier loss values as our tool, the definition of which is:

$$H_p(q) = -\frac{1}{N}\sum_{i=1}^{N} y_i \cdot log(p(y_i)) + (1 - y_i) \cdot log(1 - p(y_i)) \tag{4}$$

In this function, y equaling 1 or 0 stands for the classification category of the binary category. The loss value calculated by this method quantifies how well a given predictor classifies the input datapoints from the data set. The smaller the loss is, the better the classifier will work between the input data and the output target. So we can improve the accuracy of the model by reducing loss as much as possible if loss no longer reduces the overfitting phenomenon caused by the presence of too tight training data. At this point, the subsequent training will be considered ineffective.

- **Value 2: The loss value of the test set**
  Using the same calculation function as the training set's, the difference between these two's loss values of the training set is measured during each training session, and the loss of the validation set is measured after each epoch, which means that the loss of the validation set is 0.5 epochs later than the loss of the training set. You can analyze training problems by analyzing loss changes in training sets and test sets. If the training set loss continues to decline, and the test set loss continues to decline, the network is proved to be still learning and the training is still effective. If the training set loss continues to decline and the test set loss tends to remain the same, the network is proved to be overfitted, which can be addressed by appropriately increasing the learning rate. If the training set loss tends to change and the test set loss continues to decline, there is a problem with the data set. If both the training set and the test set loss are on the rise, there is a problem with the network structure. If both tend to remain the same, it means that the model learning is experiencing bottlenecks and needs to be reduced, But if the accuracy of the test set is high enough, no continuing training is required.

5.4 Evaluation of the Hornet Recognition Model

The general part of this model is the convolutional neural network, so the model can be evaluated by evaluating the training of the network. And due to the fact that the test set is built in the construction of the model, so the training of the network is evaluated mainly by the prediction results of the test set. As the training progresses, the convolutional neural network will gradually be perfected, and theoretically the accuracy value of the test set will approach 1 as the training progresses (not if there is a problem with the network structure), so in order to evaluate the training of the model we have constructed a functional relationship between the test wheel and the training set, the test set, functional relation between loss and accuracy, which is clearly showed in Figure 5.

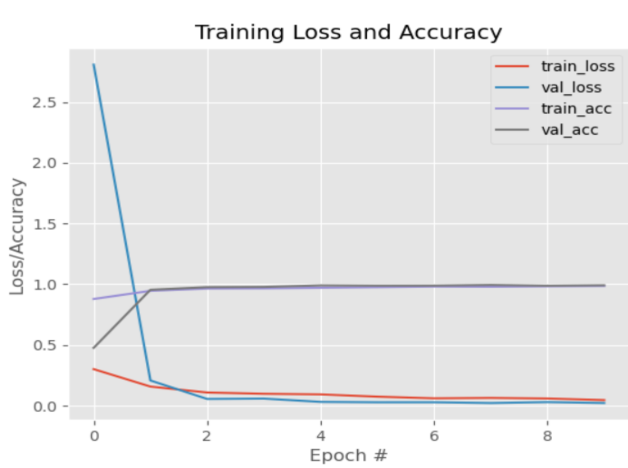

Figure 5: The relation between training loss and accuracy

As we can see from the figure above, after several trainings, the accuracy of the test set will be closer to 1, and both the loss of the test set and the loss of the training set will be effective for this convolutional neural network so this model will be extremely effective in the binary classification of Vespa hornets through pictures.

6 Application and Combination of the Models

Vespa Mandarinia's report, which is given to the information, determines whether a sighting is real by the image itself, detection date, latitude and longitude that the report contains. We set up a classifier above to classify images by the Convolutional Neural Network and can use this model to classify the images of the sighting reports thus making a preliminary judgment on whether they are correct by sorting the results. We'll provide a more intuitive example of how our model guides agencies to prioritize incidents that are most likely to be correct sightings by using the example of an incident that has a status of unverified in the report provided.

6.1 Application of Hornet Recognition Model

Our model will first need to sizing-process and scaling-process the pre-predicted picture to ensure that it's the same size as our neural network data set. After the processing procedure, we will use a trained model to classify the picture, and give the probability that it is positive, because we are using the Sigmoid function as a classifier, so theoretically the prediction value above of 0.5 pictures will be classified as positive. During the process of our model prediction, we consider the picture in Table 1 as positive.

Filename	Positive Possibility
ATT1678_hornet.jpg	88.23%
ATT2253_8184D704-622B-41F6-A201-A511C069FEBA.jpg	73.72%
ATT3009_0B71F9E2-435D-47F2-BCFA-9AD9592A68AD.jpg	68.77%
ATT3262_hornet.jpg	69.72%
ATT3302_tmp-cam-4811883243317525499.jpg	63.56%
ATT647_F4F331AE-CAA2-438D-915D-AAC15DBC8C2.jpg	52.93%
ATT74_image0 (27).jpg	52.66%

Table 1: Considered positive files with the prediction value above of 50%

6.2 Application of Hornet Diffusion Prediction Model

We use the image's correspondence with the global ID to find the sightings to which the images belong and filter out the detection date, longitude, and latitude information found in Table 2. Then we add the detection date and longitude and latitude data for each sighting event in the table into the model of Hornet Diffusion Prediction Model to arrive at the sum of the residual squares and SSE for each sighting's basic information added for interpolation fitting.

Filename	Detection Date	Latitude	Longitude	SSE
ATT1678_hornet.jpg	2020-08-02	46.706048	-120.481003	1.46E-14
ATT2253_8184D704-622B-41F6-A201-A5 11C069FEBA.jpg	2020-08-16	47.24486	-122.312704	6.60E-16
ATT3009_0B71F9E2-435D-47F2-BCFA-9AD 9592A68AD.jpg	2020-09-20	47.491153	-121.716577	4.28E-15
ATT3262_hornet.jpg	2020-10-16	45.651467	-122.514675	8.47E-22
ATT3302_tmp-cam-48118832433175254 99.jpg	2020-08-29	48.997938	-122.72989	6.18E-17
ATT647_F4F331AE-CA A2-438D-915D-AAC 15DBC8C2.jpg	2020-05-02	48.910234	-122.357076	6.71E-17
ATT74_image0 (27).jpg	2020-04-21	47.586052	-122.007302	2.55E-15

Table 2: Basic information combined with Hornet Diffusion Prediction Model

6.3 Combination of the Two Models

In the process of Modeling the Hornet Diffusion, we have fitted the basic information of all the 14 sighting reports certified as Positive IDs in 3D Interpolation Fitting to produce the following results:

Thin-plate spline interpolant:
  f(x, y) = thin-plate spline computed from p
  where x is normalized by mean -122.7 and std 0.3624
  and where y is normalized by mean 48.98 and std 0.07932
Coefficients:
  p = coefficient structure
Goodness of fit:
  SSE: 4.877e-17
  R-square: 1
  Adjusted R-square: NaN
  RMSE: NaN

The sum of the residual squares after the error analysis is 4.877e-17. We judge by twice that number. If the positive probability in the Hornet Recognition Model based on CNN's determination is over 0.5, the sighting's sum of the residual squares will be in fitted well with 14 certified-positive IDs within this range, we then confirm that they fit well and are certified as Positive ID.

The brief filenames identified as a Positive ID after these two model filters are as follows:
  ATT3262_hornet;
  ATT3302_tmp-cam-4811883243317525499;
  ATT647_F4F331AE-CAA2-438D-915D-AAC15DBC8C2.

The three certified sighting reports obtained from the Hornet Recognition Model based on CNN and the 3D Interpolation Fitting Model have strong credibility and should be given priority investigation.

7 Future Work

Under our underlying hypothesis attributing to the results of the model using, that is, consensus that the annual reproducing breeds keep the same in parallel with last year's ones has been reached, two factors are taken into consideration when it comes to how often the update should occur. The two factors are the relationship between the breeding and predatory features of the Vespa hornet and those of other hornets within one single year and Vespa hornets' features alone.

7.1 The breeding and predatory features of the Vespa hornet chronologically

When winter arrives, the current seasons' nests die out and the only individuals that survive are overwintering queens. When overwintering queens emerge in the spring, they begin a new colony preparing for the breeds. The nests grow slowly through the spring and summer until they reach a peak population in autumn and so the males and queens leave the nest to mate and wait for the colony's falling into disarray until it eventually dies off with the coming winter.

7.2 The relationship between the Vespa hornets and other hornets

7.2.1 Predatory and Coevolutionary relations

Due to the size of the colony or the production of reproductive queens and workers, the Vespa hornets switch from other prey sources to honey bees beginning in and peaking in autumn. Most yellowjackets, especially the European hornets, are sometimes confused for the Vespa hornets when they are active in the spring and often the colonies of them will remain until autumn.

7.2.2 Competitive relations

Baldfaced hornets re native wasps that are competitive predators on caterpillars, flies, and other soft bodied insects versus the Vespa hornets. Early in spring and summer, protein in the form of live prey is the usual diet consisting of many other types of insects which is ought to be the diet of the Vespa hornets'. Most of the colony, other than newly fertilized potential queens that will overwinter, will die before or shortly after the first hard frost in winter.

7.3 The qualitative conclusion upon how often the updates should occur

Firstly, the number of the Vespa hornets in spring and in summer will decrease due to the increase of that of the competitive hornets, thus causing less updates. Secondly, the number in autumn will increase due to its own increase and that of its prey hornets' increase, thus causing more updates. Lastly, the number in winter will decrease mainly due to its own decrease despite of its competitive hornets' decrease either, thus causing less updates. Additionally, the increase of the Vespa hornets' coevolutionary hornets in spring, summer, and autumn adds to the higher frequency of the updates because more mistaken classifications are likely to occur during these seasons. Also, that means a lower frequency in winter. To conclude qualitatively, considering the joint efforts mentioned above, updates should occur monthly in autumn and quarterly in spring, summer and winter.

8 Policy Recommendations

Since 1989, the Steering Committee of the International Union for the Conservation of Nature (IUCN) and Species Survival Commission (SSC) has proposed the establishment of new endangered species rating standards so that the conservation community can make a case for future planning. The establishment of the new endangered species rating standards has been through years of discussion and, finally a latest version of the endangered species rating standards is realized.

On ground of the above thesis, local government employees in Washington State could have access to determine whether this annoying Vespa species has been eliminated with the help of our model. To be specific, the number of the positive Vespa hornets can be roughly calculated using our model and the state governors just have to submit the statistics of the positive reports to local labs to reach an ulterior confirmation to see if the Vespa hornets reach the eradicative standards.

The detailed information of the latest endangered species rating standards is listed as follows.

8.1 Standard 1: The distribution of the Vespa species

If the distribution area of the positive Vespa species is less than 100 square kilometers or the Vespa species dominates an area of less than 10 square kilometers in the local place.

8.2 Standard 2: The number of the Vespa population

Three judgement criteria attribute to the numbering factor.

8.2.1 Judgement criterion 1:

According to the roughly estimated statistics following the model, over the past 10 years or three generations, the population is expected to continuously reduce by 80%.

8.2.2 Judgement criterion 2:

According to the roughly estimated statistics following the model, the number of the Vespa species is less than 250 and meets the following criteria, that is, over the past 3 years or one generation, the population is expected to continuously reduce by 25%.

8.2.3 Judgement criterion 3:

According to the roughly estimated statistics following the model, the number of the Vespa species is less than 50.

9 Strengths and Weeknesses

9.1 ReLU as an activation function for convolution layer

Sum of ReLU's Sparsity is small and it offers a smaller possibility to cause problems like Vanishing Gradient. This advantage of ReLU allows us to train deep neural network directly in a supervised manner without relying on unsupervised layer-by-layer pre-training.ReLU serves as a linear function, is born with a low calculational complexity, thus offering itself the feasible use of improving the learning efficiency of the convolutional neural network. However, due to the fact that the ReLU function is fragile in retraining so, even a little carelessness can lead to damaging neurons 'necrosis'. For example, since the ReLU has a gradient of 0 at x<0, thus causing the negative gradient to be zeroed in this ReLU, and the neuron may never be activated by any data again. If this happens, then the gradient after the neuron is always 0, i.e. the ReLU neuron is dead and no longer responds to any data. Therefore, subsequent improvement of this convolutional neural network can be focused on optimizing the network by means of improving the ReLU function.

9.1.1 ReLU Strengths

- ReLU makes some neurons' output 0, which causes the sparseness of the network, and reduces the interdependence of parameters, which alleviates the occurrence of overfitting problems.
- ReLU mainly accounts for the linear relationship so the calculation is small.
- ReLU will not have saturation tendencies, there will be no particularly small gradient.

9.1.2 ReLU Weeknesses

- ReLU is too fragile, and neurons are no longer active after network parameters are updated due to the large function ladder of the input.

9.2 Sigmoid as an activation function for full-connected layer

Since Sigmoid has widely been used in the binary classification algorithm, the principle of its classification will not be repeated here. At this time, the output value of the Sigmoid function can be considered to be the conditional possibility corresponding to the input positive pictures.

9.2.1 Sigmoid Strengths

- The output of the Sigmoid function is between (0,1), i.e. the output range is limited. Additionally, the optimization is stable and can be used as the output layer.
- Because of Sigmoid's continuous function, it's easy to derive.

9.2.2 Sigmoid Weeknesses

- The Sigmoid function saturates when a variable has a very large positive or negative value, which means that the function becomes flat and insensitive to small changes in the input. In reverse propagation, when the gradient is close to 0, the weight is basically not updated, it is easy for the gradient to disappear, thus unable to complete the training of the deep network.
- The output of the Sigmoid function is not a 0-means signal, which causes the input of the neurons in the rear layer to be a signal of a non-0-means, which affects the gradient.
- The calculation is highly complex because the sigmoid function is exponential.

9.3 Binary coross-entropy as a loss function

The function binary coross-entropy is commonly used for calculating classifier loss values as our tool. The loss value calculated by this function quantifies how well a given predictor classifies the input datapoints from the data set. The smaller the loss is, the better the classifier will work between the input data and the output target. So we can improve the accuracy of the model by reducing loss as much as possible if loss no longer reduces the overfitting phenomenon caused by the presence of too tight training data. At this point, the subsequent training will be considered ineffective.

9.3.1 Binary Coross-entropy Strengths

- Binary coross-entropy can measure subtle differences.
- Binary coross-entropy is a kind of convex optimization function so it's easy to use the gradient drop method to find the optimal solution.

9.3.2 Binary Coross-entropy Weeknesses

- Binary Coross-entropy can only be applied to the binary ones when it comes to the loss value calculation.

10 References and Sources of Data

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D. Cire¸san, U. Meier, J. Schmidhube *Multi-column deep neural networks for classifying images Arxiv preprint arXiv:1202.2745* 2012.

Han, Jun, Morag, Claudio *The influence of the sigmoid function parameters on the speed of backpropagation learning 195–201* 1995.

Michael Nielsen *Neural Network and Deep Learning chapter 3*.

L. E. Papet. *The Reliable Detection Dog: A Manual to Naturally Train*.

Software:MATLAB, LaTeX, Python, Microsoft Excel

11 Appendix-Python Code

```
from keras.models import Sequential
from keras.layers.normalization import BatchNormalization
from keras.layers.convolutional import Conv2D
from keras.layers.convolutional import MaxPooling2D
from keras.initializers import TruncatedNormal
from keras.layers.core import Activation
from keras.layers.core import Flatten
from keras.layers.core import Dropout
from keras.layers.core import Dense
from keras import backend as K
class SimpleVGGNet:
@staticmethod
def build(width, height, depth,classes):
model = Sequential()
inputShape = (height, width, depth)
chanDim = -1
if K.image_data_format() == "channels_first":
inputShape = (depth, height, width)
chanDim = 1
model.add(Conv2D(32, (3, 3), padding="same",
input_shape=inputShape,kernel_initializer=TruncatedNormal(mean=0.0, stddev=0.01)))
model.add(Activation("relu"))
model.add(BatchNormalization(axis=chanDim))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Conv2D(64, (3, 3), padding="same",kernel_initializer=TruncatedNormal(mean=0.0, std-
dev=0.01)))
model.add(Activation("relu"))
model.add(BatchNormalization(axis=chanDim))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Conv2D(128, (3, 3), padding="same",kernel_initializer=TruncatedNormal(mean=0.0, std-
dev=0.01)))
model.add(Activation("relu"))
model.add(BatchNormalization(axis=chanDim))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Flatten())
model.add(Dense(512))
model.add(Activation("relu"))
model.add(BatchNormalization())
model.add(Dense(1))
model.add(Activation("sigmoid"))
return model
```

Memorandum recording the contribution to the Washington State Department of Agriculture

MCM Team
Memorandum Sheet

We, the MCM team, are tasked with helping the Washington State Department of Agriculture develop a set of methods to pick out the mistaken sightings involved in relevant supporting documents concerning the Vespa mandarinia sightings.

Through the creation of a Vespa hornet recognition model based on convolutional neural network to interpret the relevant data in public reports and to explore what strategies to use to analyze these reports, the Washington State Department of Agriculture are equipped with both effective and efficient tools to find out the habitats of the Vespa hornets, thus eliminating their nests in time. Furthermore, though the particular Vespa sightings occurred in Washington State has been affirmed till now, numerous mistaken sightings have put a heavy workload on the government employees because of the alike appearance among Vespa hornets and European hornets accompanied with cicada killers. So apart from applying the relevant predictive models to make predictions upon the spread of the Vespa hornets over a specific period of time on account of the global IDs, detection time, laboratory status, longitude and latitude listed in the sighting reports, we create the model to analyze the possibility of a mistaken classification, figure out ways to analyze how to confirm the picture posed a Positive ID or a Negative ID using the model created above. Also, in order to make our model more feasible, we figure out ways to decide how often the model is supposed to be updated using reasonable explanations and illustrate how it should be updated.

In order to achieve our primary goal of interpreting the data provided by the public reports, we ignore the changing habits of predatory Vespa hornets and reach a consensus that the annual reproducing breeds keep the same in parallel with last year's ones.

Additionally, we display the two- and the three- dimensional distribution of the Vespa hornet using the mathematical model and relevant algorithms. For the problem what strategies we can use to prioritize the public reports for additional investigation given the limited resources of government agencies, we propose the verification of the unverified pictures posed by hornet-sighting viewers, by means of running a Statistics Library System perfected by us with the assistance of Python and apply our model into this process. More specifically, to assess the calculation of the possibility of a mistaken classification of the Vespa mandarinia, the Statistic Library we create consists of numerous pictures of the Vespa hornets with both Positive ID and Negative ID based on Python Imaging Library thesis and the theory of convolutional neural network. In our library, after inputting the picture, if there are characteristic points featuring several specific parts of the Vespa hornet's body, the picture will fall into the positive or negative category, while in the meantime, displaying a graph depicting statistics of training loss and accuracy, another description of the word possibility itself under our specific circumstance. We simulate the human brain's performance of determining whether the hornet is the Vespa mandarinia or just a kind of European hornets or cicada killers, as we call it, thus classifying the picture into a particular category, providing choices between positive or negative ID. In the forehead, that is, during the incipient phases of our model-creating process, we input Vespa hornets' along with many other look-alike hornets' pictures provided by the person submitting the sighting report, who might be a person of the street, or occasionally a state employee. Then the python system itself trains on its own and provide a specific arithmetic to perform the following steps.

Under our underlying hypothesis attributing to the results of the model using, that is, consensus that the annual reproducing breeds keep the same in parallel with last year's ones has been reached, two factors are taken into consideration when it comes to how often the update should occur. The two factors are the relationship between the breeding and predatory features of the Vespa hornet and those of other hornets within one single year and Vespa hornets' features alone.

On ground of the thesis about endangered species rating standards established by the Steering Committee of the International Union for the Conservation of Nature and Natural Resources Species Survival Committee, local government employees in Washington State could have access to determine whether this annoying Vespa species has been eliminated with the help of our model. To be specific, the number of the positive Vespa hornets can be roughly calculated using our model and the state governors just have to submit the statistics of the positive reports to local labs to reach an ulterior confirmation to see if the Vespa hornets reach the eradicative standards. To conclude, as the Vespa hornet sightings increase year by year, effectively and efficiently determining under what evidence or standards does the Washington State has eliminated the Vespa hornets will mean that on top of precluding the deadly predatory behaviors of the Vespa hornet on terms of the alarming invasion and destruction of European honeybees' nests or even the whole colony, we have the very access to prioritize public reports for additional investigation given the limited resources of government agencies and thus maximizing the safety of local people.

MCM Team
2021-02-08