**Supplementary materials**

**Table A1.** Types of crop diseases and pests detection methods.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Categorize** | **Methods** | **Reference** |
|
| Crop diseases and pests damages | Coffee | ELM, RF, MLR | (Kouadio et al., 2018) |
| Maize | RF, ANN | (Pineda et al., 2018) |
| Recognition of 10 tomato plant diseases and pests | CNN | (Fuentes et al., 2018) |
| Avocando iron deficiencies | DT, MLP | (Abdulridha et al., 2018) |
| Identification of six plant leaft diseases | RBFN | (Chouhan et al., 2018) |
| Identification of tea red scab, tea leaf blight and tea red leaf spot diseases | SVM, DT, RF, CNN | (Dhingra et al., 2019) |

**Table A2.** Vegetation indices derived from RGB and multispectral images.

|  |  |  |
| --- | --- | --- |
| **Vegetation indices** | **Formula** | **References** |
| **RGB-** **Colour vegetation index** |
| visible-band difference vegetation index, VDVI | $$VDVI=(2G-R-B)/(2G+R+B)$$ | (Hunt et al., 2013) |
| visible atmospherically resistant index, VARI | $$VARI=(G-R)/(G+R-B)$$ | (Gitelson et al., 2002a) |
| normalized green-red difference index, NGRDI | $$NGRDI=(G-R)/(G+R)$$ | (Motohka et al., 2010; Gitelson et al., 2002a) |
| normalized green-blue difference index, NGBDI | $$NGBDI=(G-B)/(G+B)$$ | (Du & Noguchi, 2017) |
| red-green ratio index, RGRI | $$RGRI=R/G$$ | (Verrelst et al., 2008) |
| green-red ratio index, GRRI | $$GRRI=G/R$$ | (Du & Noguchi, 2017) |
| modified green red vegetation index, MGRVI | $$MGRVI=(G^{2}-R^{2})/(G^{2}+R^{2})$$ | (Bendig et al., 2015) |
| excess green index, ExG | $$ExG=2G-R-B$$ | (Woebbecke et al., 1995) |
| color index of vegetation, CIVE | $$CIVE=0.441R-0.881G+0.385B+18.78745$$ | (Torres-Sánchez et al., 2014) |
| vegetativen, VEG | $$VEG=G/(R^{a}×B^{(1-a)})，a=0.667$$ | (Hague et al., 2006) |
| excess green minus excess red, ExGR | $$ExGR=ExG-ExR=ExG-1.4R-G$$ | (Meyer & Neto, 2008) |
| woebbecke index, WI | $$WI=(G-B)/(R-G)$$ | (Woebbecke et al., 1995) |
| combination, COM | $$COM=0.25ExG+0.3ExGR+0.33CIVE+0.12VEG$$ | (Guijarro et al., 2011) |
| combination 2, COM2 | $COM2=$0.36ExG+0.47CIVE+0.17VEG | (Guerrero et al., 2012) |

**Table A2. (continued).**

|  |  |  |
| --- | --- | --- |
| **Vegetation indices** | **Formula** | **References** |
| **Multispectral narrow-band vegetation index** |
| simple ratio index, SRI | $$SRI=R\_{λ1}/R\_{λ2}$$ | (Jordan, 1969; Pearson & Miller, 1972) |
| normalized difference vegetation index, NDVI | $$NDVI=(R\_{λ1}-R\_{λ2})/(R\_{λ1}+R\_{λ2})$$ | (Rouse et al., 1974) |
| enhanced vegetation index, EVI2 | $$EVI2=2.5×{(R\_{λ1}-R\_{λ2})}/{(1+R\_{λ1}+2.4R\_{λ2})}$$ | (Jiang et al., 2008) |
| optimized soil-adjusted vegetation index, OSAVI | $$OSAVI=1.16×(R\_{λ1}-R\_{λ2})/(R\_{λ1}+R\_{λ2}+0.16)$$ | (Rondeaux et al., 1996) |
| soil-adjusted vegetation index, SAVI | $$SAVI=1.5×(R\_{λ1}-R\_{λ2})/(R\_{λ1}+R\_{λ2}+0.5)$$ | (Huete, 1988) |
| difference vegetation index, DVI | $$DVI=R\_{λ1}-R\_{λ2}$$ | (Jordan, 1969) |
| renormalized difference vegetation index, RDVI | $$RDVI=(R\_{λ1}-R\_{λ2})/\sqrt{(R\_{λ1}+R\_{λ2})}$$ | (Roujean & Breon, 1995) |
| modified simple ratio, MSR | $$MSR=\frac{{R\_{λ1}}/{R\_{λ2}}-1}{\left(\sqrt{{R\_{λ1}}/{R\_{λ2}}}-1\right)}$$ | (Chen, 1996) |
| modified soil-adjusted vegetation index, MSAVI | $$MSAVI=0.5×\left(2R\_{λ1}+1-\sqrt{\left(2R\_{λ1}+1\right)^{2}-8×\left(R\_{λ1}-R\_{λ2}\right)}\right)$$ | (Qi et al., 1994) |
| NDSI | $$NDSI\_{(D\_{λ1}, D\_{λ2})}=(D\_{λ1}-D\_{λ2})/(D\_{λ1}+D\_{λ2})$$ | (Inoue et al., 2012) |
| RSI | $$RSI\_{(D\_{λ1}, D\_{λ2})}=D\_{λ1}/D\_{λ2}$$ | (Inoue et al., 2012; Zarco-Tejada et al., 2009) |

Note: *R*, *G*, *B* denotes the radiometric normalized pixel values of each orthomosaic images’ red, green, and blue band, respectively. *Rλ1* or *Rλ2* represents the reflectance of a variable band in the spectral range of 600-1000 nm. *Dλ1* and *Dλ2* are the first derivative values at *λ1* and *λ2* nm over the whole spectra.

**Table A3.** The 68 common vegetation indices.

|  |  |  |
| --- | --- | --- |
| **Vegetation indices** | **Formula** | **References** |
| 1 | photochemical reflectance index, PRI | $$PRI\_{570}=(R\_{570}-R\_{531})/(R\_{570}+R\_{531})$$ | (Gamon et al., 1992) |
| 2 | $$PRI\_{512}=(R\_{512}-R\_{531})/(R\_{512}+R\_{531})$$ | (Hernández-Clemente et al., 2011) |
| 3 | simple ratio pigment index, SRPI | $$SRPI=R\_{430}/R\_{680}$$ | (Peñuelas et al., 1995) |
| 4 | normalized difference vegetation index, NDVI | $$NDVI=(R\_{800}-R\_{670})/(R\_{800}+R\_{670})$$ | (Rouse et al., 1974) |
| 5 | green normalized different vegetation index, GNDVI | $$GNDVI=(R\_{800}-R\_{550})/(R\_{800}+R\_{550})$$ | (Gitelson et al., 1996) |
| 6 | ND705 | $$ND\_{705}=(R\_{750}-R\_{705})/(R\_{750}+R\_{705})$$ | (Sims & Gamon, 2002) |
| 7 | modified red-edge normalized difference vegetation index，mND705 | $$mND\_{705}=(R\_{750}-R\_{705})/(R\_{750}+R\_{705}-2R\_{445})$$ | (Sims & Gamon, 2002) |
| 8 | atmospheric resistant vegetation index, ARVI | $$ARVI=(R\_{800}-(2R\_{680}-R\_{450}))/(R\_{800}+(2R\_{680}-R\_{450}))$$ | (Kaufman & Tanré, 1996) |
| 9 | red edge vegetation stress index, RVSI | $$RVSI=(R\_{714}-R\_{752})/2-R\_{733}$$ | (Merton, 1998) |
| 10 | renormalized difference vegetation index, RDVI | $$RDVI=(R\_{800}-R\_{670})/\sqrt{(R\_{800}+R\_{670})}$$ | (Roujean & Breon, 1995) |
| 11 | difference vegetation index, DVI | $$DVI=R\_{800}-R\_{680}$$ | (Jordan, 1969) |
| 12 | enhanced vegetation index, EVI | $$EVI=2.5×\frac{(R\_{800}-R\_{670})}{(1+R\_{800}+6R\_{670}-7R\_{479})}$$ | (Huete et al., 2002) |
| 13 | enhanced vegetation index, EVI2 | $$EVI2=2.5×\frac{(R\_{800}-R\_{660})}{(1+R\_{800}+2.4R\_{660})}$$ | (Jiang et al., 2008) |
| 14 | chlorophyll absorption ratio index, CARI | $$CARI=\left(R\_{700}-R\_{670}\right)-0.2×(R\_{700}-R\_{550})$$ | (Kim et al., 1994) |
| 15 | pigment-specific normalized difference, PSND | $$PSND\_{a}=(R\_{800}-R\_{680})/(R\_{800}+R\_{680})$$ | (Blackburn, 1998) |
| 16 | $$PSND\_{b}=(R\_{800}-R\_{635})/(R\_{800}+R\_{635})$$ |
| 17 | $$PSND\_{c}=(R\_{800}-R\_{470})/(R\_{800}+R\_{470})$$ |

|  |  |  |
| --- | --- | --- |
| **Vegetation indices** | **Formula** | **References** |
| 18 | Datt vegetation index | $$Datt=(R\_{850}-R\_{710})/(R\_{850}-R\_{680})$$ | (Datt, 1999) |
| 19 | triangular vegetation index, TVI | $$TVI=0.5×\left[120×\left(R\_{750}-R\_{550}\right)-200×(R\_{670}-R\_{550})\right]$$ | (Broge & Leblanc, 2001) |
| 20 | modified triangular index, MTVI1 | $$MTVI1=1.2×\left[1.2×\left(R\_{800}-R\_{550}\right)-2.5×(R\_{670}-R\_{550})\right]$$ | (Haboudane et al., 2004) |
| 21 | Maccioni vegetation index | $$Maccioni=(R\_{780}-R\_{710})/(R\_{780}-R\_{680})$$ | (Maccioni et al., 2001) |
| 22 | normalized pigment chlorophyll index, NPCI | $$NPCI=(R\_{680}-R\_{430})/(R\_{680}+R\_{430})$$ | (Peñuelas et al., 1994) |
| 23 | structual independent pigment index, SIPI | $$SIPI=(R\_{800}-R\_{445})/(R\_{800}+R\_{680})$$ | (Peñuelas et al., 1995) |
| 24 | optimized soil-adjusted vegetation index, OSAVI | $$OSAVI=\frac{(1+0.16)×(R\_{800}-R\_{670})}{(R\_{800}-R\_{670}+0.16)}$$ | (Rondeaux et al., 1996) |
| 25 | $$OSAVI2=\frac{(1+0.16)×(R\_{750}-R\_{705})}{(R\_{750}-R\_{705}+0.16)}$$ | (Wu et al., 2008) |
| 26 | modified soil-adjusted vegetation index, MSAVI | $MSAVI=0.5×\left(2R\_{800}+1-\sqrt{\left(2R\_{800}+1\right)^{2}-8×\left(R\_{800}-R\_{670}\right)}\right)$  | (Qi et al., 1994) |
| 27 | simple ration, SR | $$SR=R\_{800}/R\_{670}$$ | (Jordan, 1969; Pearson & Miller, 1972) |
| 28 | modified simple ratio, MSR | $$MSR=\frac{{R\_{800}}/{R\_{670}}-1}{\left(\sqrt{{R\_{800}}/{R\_{670}}}-1\right)}$$ | (Chen, 1996) |
| 29 | pigment-specific simple ratio, PSSR | $$PSSR\_{a}=R\_{800}/R\_{680}$$ | (Blackburn, 1998) |
| 30 | $$PSSR\_{b}=R\_{800}/R\_{635}$$ |
| 31 | $$PSSR\_{c}=R\_{800}/R\_{470}$$ |
| 32 | modified simple ratio index | $$mSR\_{705}=(R\_{750}-R\_{445})/(R\_{705}-R\_{445})$$ | (Sims & Gamon, 2002) |
| 33 | modified chlorophyll absorption in reflectance index, MCARI | $$MCARI=\left[\left(R\_{700}-R\_{670}\right)-0.2×(R\_{700}-R\_{550})\right]×(R\_{700}/R\_{670})$$ | (Daughtry et al., 2000) |
| 34 | transformed chlorophyll absorption in reflectance index, TCARI | $$TCARI=3×\left[\left(R\_{700}-R\_{670}\right)-0.2(R\_{700}-R\_{550})×(R\_{700}/R\_{670})\right]$$ | (Haboudane et al., 2002) |
| 35 | MERIS terrestrial chlorophyll index, MTCI | $$MTCI=(R\_{754}-R\_{709})/(R\_{709}-R\_{681})$$ | (Dash & Curran, 2004) |
| 36 | nitrogen reflectance index, NRI | $$NRI=(R\_{570}-R\_{670})/(R\_{570}+R\_{670})$$ | (Diker & Bausch, 2003) |

|  |  |  |
| --- | --- | --- |
| **Vegetation indices** | **Formula** | **References** |
| 37 | MCARI/OSAVI | MCARI/OSAVI | (Daughtry et al., 2000) |
| 38 | TCARI/OSAVI | TCARI/OSAVI | (Haboudane et al., 2002) |
| 39 | plant senescence reflectance index, PSRI | $$PSRI=(R\_{680}-R\_{500})/R\_{750}$$ | (Sims & Gamon, 2002) |
| 40 | anthocyanin reflectance index, ARI | $ARI1=$1/$R\_{550}-1/R\_{700}$ | (Gitelson et al., 2002b) |
| 41 | $ARI2=R\_{800}×($1/$R\_{550}-1/R\_{700})$ |
| 42 | carotenoid reflectance index, CRI | $CRI1=$1/$R\_{510}-1/R\_{550}$ |
| 43 | $CRI2=$1/$R\_{510}-1/R\_{700}$ |
| 44 | Vogelmann indices, VOG | $$VOG1=R\_{740}/R\_{720}$$ | (Vogelmann et al., 1993) |
| 45 | $$VOG2=(R\_{734}-R\_{747})/(R\_{715}-R\_{726})$$ | (Zarco-Tejada et al., 2001) |
| 46 | Zarco and Miller, ZM | $$ZM=R\_{750}/R\_{710}$$ | (Zarco-Tejada et al., 2001) |
| 47 | water index, WI | $$WI=R\_{900}/R\_{970}$$ | (Peñuelas et al., 1995) |
| 48 | healthy index, HI | $$HI=\frac{R\_{534}-R\_{698}}{R\_{534}+R\_{698}}-0.5R\_{704}$$ | (Mahlein et al., 2013) |
| 49 | greenness index | $$R\_{550}/R\_{670}$$ | (Carter, 1994) |
| 50 | blue/green pigment indices, BGI | $$BGI1=R\_{400}/R\_{550}$$ | (Zarco-Tejada et al., 2005) |
| 51 | $$BGI2=R\_{450}/R\_{550}$$ |
| 52 | blue/red pigment indices, BRI | $$BRI1=R\_{400}/R\_{690}$$ |
| 53 | $$BRI2=R\_{450}/R\_{690}$$ |
| 54 | Lichtenthaler index  | $$LIC3=R\_{440}/R\_{740}$$ | (Lichtenthaler et al., 1996) |
| 55 | carotenoid concentration | $$R\_{520}/R\_{500}$$ | (Zarco-Tejada et al., 2012) |
| 56 | $$R\_{515}/R\_{570}$$ |
| 57 | $$R\_{515}/R\_{670}$$ |
| 58 | normalized difference red edge index, NDRE | $$NDRE=(R\_{790}-R\_{720})/(R\_{790}+R\_{720})$$ | (Fitzgerald et al., 2010) |
| 59 | canopy chlorophyll content index, CCCI | $$CCCI=\frac{\left(NDRE-NDRE\_{MIN}\right)}{(NDRE\_{MAX}+NDRE\_{MIN})}$$ | (Fitzgerald et al., 2010) |
| 60 | red-edge model, R-M | R-M$=R\_{750}/R\_{720}-1$ | (Gitelson et al., 2005) |
| 61 | green model, G-M | G-M$=R\_{750}/R\_{550}-1$ | (Gitelson et al., 2005) |
| 62 | red edge position, REP | $$REP=700+40×\frac{\left[(R\_{670}+R\_{780})/2-R\_{700}\right]}{(R\_{740}+R\_{700})}$$ | (Guyot et al., 1988) |
| 63 | ratio spectral index, RSI | $$RSI\_{(R\_{λ1}, R\_{λ2})}=R\_{λ1}/R\_{λ2}$$ | (Zarco-Tejada et al., 2009; Inoue et al., 2012) |

|  |  |  |
| --- | --- | --- |
| **Vegetation indices** | **Formula** | **References** |
| 64 | normalized difference spectral index, NDSI | $$NDSI\_{(R\_{λ1}, R\_{λ2})}=(R\_{λ1}-R\_{λ2})/(R\_{λ1}+R\_{λ2})$$$R\_{λ1}$*>*$R\_{λ2}$ | (Inoue et al., 2012) |
| 65 | difference spectral index, DSI | $$DSI\_{(R\_{λ1}, R\_{λ2})}=R\_{λ1}-R\_{λ2}$$ | (Jordan, 1969) |
| 66 | SAVI | $$SAVI\_{(R\_{λ1}, R\_{λ2})}=1.5×(R\_{λ1}-R\_{λ2})/(R\_{λ1}+R\_{λ2}+0.5)$$ | (Huete, 1988) |
| 67 | NDSI | $$NDSI\_{(D\_{λ1}, D\_{λ2})}=(D\_{λ1}-D\_{λ2})/(D\_{λ1}+D\_{λ2})$$ | (Inoue et al., 2012) |
| 68 | RSI | $$RSI\_{(D\_{λ1}, D\_{λ2})}=D\_{λ1}/D\_{λ2}$$ | (Zarco-Tejada et al., 2009; Inoue et al., 2012) |

**Table A4.** Texture characteristic parameter calculation methods.

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Texture characteristics | Formula | References |
| 1 | Average value |  | (Enu, 1985) |
| 2 | Variance |  | (Baraldi & Panniggiani, 1995) |
| 3 | Contrast ratio |  | (Hong, 2018) |
| 4 | Homogeneity |  | (Peña-Barragán et al., 2011) |
| 5 | Dissimilarity |  | (Kim & Yeom, 2014) |
| 6 | Entropy |  | (Yang et al., 2020) |
| 7 | Angular second-order moment |  | (Treitz et al., 1996) |
| 8 | Relevance |  | (Guijarro et al., 2011) |
| 9 | Autocorrelation |  | (Jung et al., 2006) |

**Table A5.** Application of deep learning in crop diseases monitoring.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Type | Crop | Diseases/ pests | Sensors | Deep learning method | Accuracy | References |
| Detection | Pine Trees | Pine wilt disease | - | Faster R-CNN | 82.42% | (Xu et al., 2022) |
| Pine Trees | Dead trees with pine wilt disease | RGB | Faster R-CNN-based ResNet | 89.10% | (Deng et al., 2020) |
| Soybean | soybean leaf diseases | RGB | Inception-v3 with FT 75% | 99.04% | (Tetila et al., 2019) |
| Wheat | Wheat yellow rust disease | - | PSNet | 94% | (Pan et al., 2021) |
| Rapeseed material | Freezing injury | RGB | ResNet50 | 93.33% | (Li et al., 2022) |
| Moso bamboo forest | Pantana phyllostachysae chao  | Multispectral | XGBoost | 86.47% | (Xu et al., 2022) |
| Maize | Maize drought | Hyperspectral | U-Net, SE-ResNeXt-50 | 91.66% | (Liu et al., 2020) |
| Yunnan Pine | Pine shoot beetle | Hyperspectral | - | 87.50% | (Liu et al., 2020) |
| Classification | Rice | rice pests | - | EfficientNet-B0 | 97.58% | (Yang et al., 2021) |
| Soybean | Soybean pests | RGB  | SLIC, ResNet-50 | 93.82% | (Tetila et al., 2020) |
| Abies mariesii | Individual sick fir tree | RGB  | ResNet | 98.09% | (Nguyen et al., 2021) |
| Plant leaf | Plant leaf disease | - | EfficientNet | 99.97% | (Atila et al., 2021) |

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