PA-RDFKNet: Unifying Plant Age Estimation through RGB-Depth Fusion and Knowledge Distillation

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Multimodality in Growth Monitoring

- **Knowledge Distillation for Plant Age Estimation** – We leverage a multi-modal teacher model (RGB + depth) to train a single-modal student model (RGB only) for radish plant age prediction.
- **Overcoming Depth Data Unavailability** – Our approach ensures robust age estimation even when depth modality is unavailable at deployment.

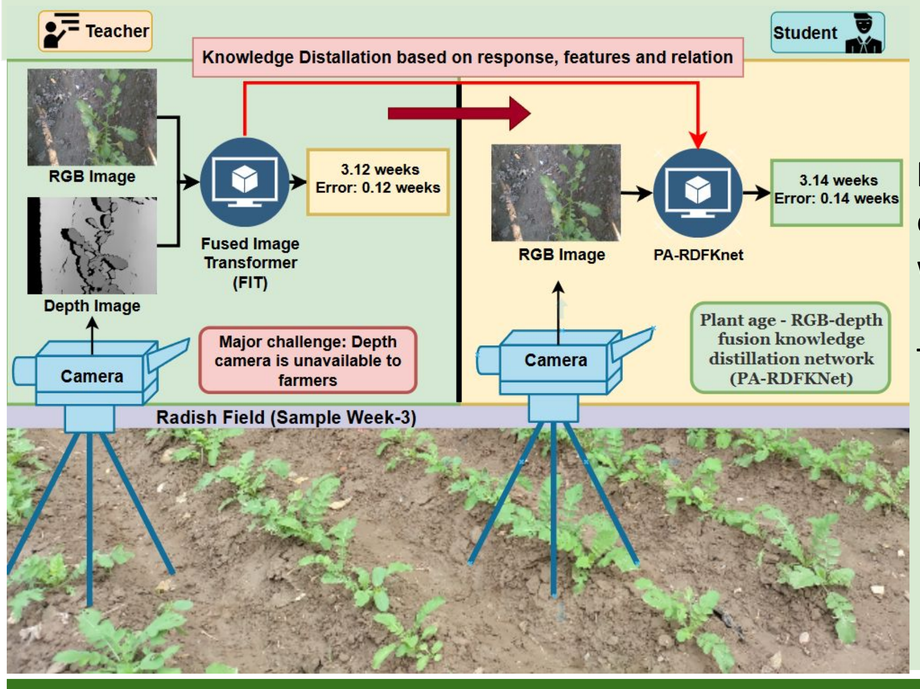

Figure 1. Overall objective of the work. (left)

Teacher model: FIT [1]

Student model: PA-RDFKNet

PA-RDFKNet

- **Enhanced Learning from Multi-Modal Features** – The student model learns rich representations from the teacher, improving performance using only RGB images.

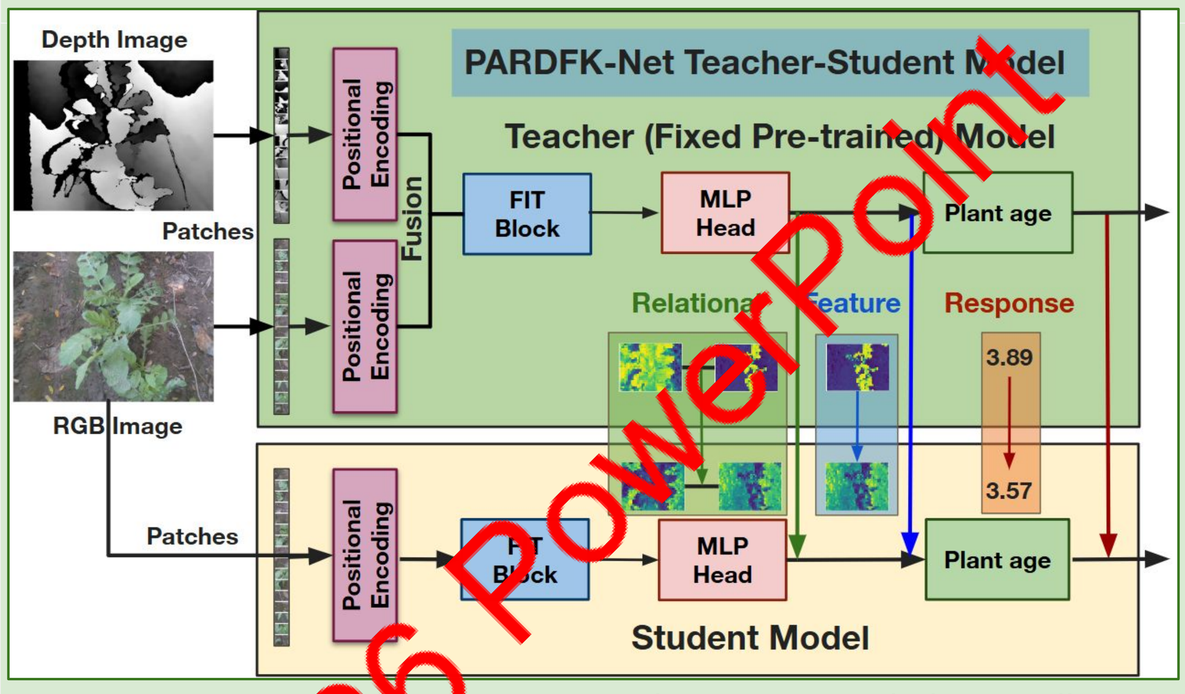

Figure 2. Proposed Plant Age RGB-Depth Fusion Knowledge Distillation Network (PA-RDFKNet) Architecture.

Dataset and Results

Dataset (RGB images)

Data Collection and Modalities:

We collected data from three sources:

- **Intel® RealSense™ Depth Sensor(D_{IRD})** – RGB + Depth
- **Fluke Infrared Camera (D_{FTIC})** – RGB
- **Google Pixel 5 (D_{GP5})** – RGB

Comparative Analysis

Model	With distillation	Testing Error
RGB-D	X	0.12 weeks
Only RGB	X	2.05 weeks
Proposed	✓	0.14 weeks

Table 1. MSE Loss with or without distillation on RGB data.

Dataset	Without distillation		With distillation	
	R2 Score	MSE	R2 Score	MSE
D_{IRD}	-0.002	2.05 weeks	0.91	0.14 weeks
D_{FTIC}	-0.080	1.90 weeks	0.84	0.26 weeks
D_{GP5}	-0.050	1.98 weeks	0.63	0.69 weeks
Average	-0.044	1.97 weeks	0.79	0.36 weeks

Table 2. Performance of PA-RDFKNET on three datasets: D_{IRD}, D_{FTIC}, and D_{GP5} datasets.

Results

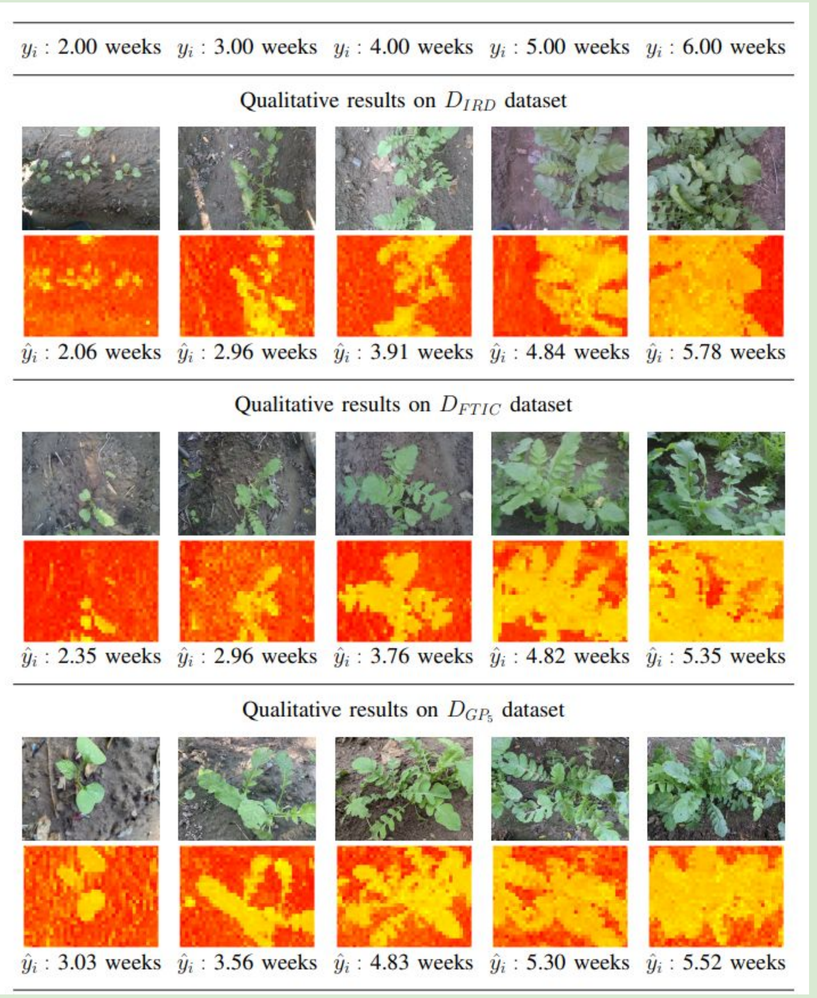

Figure 3. Week-wise sample images of radish plants from the D_{IRD}, D_{FTIC} and D_{GP5} datasets, captured using different sensors, along with their corresponding attention maps and predicted ages are provided.

Conclusion

- We introduced **PA-RDFKNet** to extrapolate depth knowledge onto RGB data for precise plant age estimation.
- Our earlier model, FIT, demonstrated the significance of depth information in radish plant age estimation.
- We train a teacher–student model that significantly improves age prediction from RGB images from **2 to 0.14 weeks**.
- We validated our proposed model with **three different RGB datasets**, depicting the applicability of the model in real-time.

References

[1] Shreya Bansal, M Singh, S Barda, V Kumar, N Goel, M Saini, Radish Plant Growth Monitoring using Multimodal Fusion, IEEE International Conference on Agrifood Electronics (CAFÉ) 2023.

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