16TH ITU ACADEMIC CONFERENCE

ITU KALEIDOSCOPE
GENEVA 2026

AI and frontier technologies for good

7-9 July 2026
Geneva, Switzerland

Hosted by AI for Good Global Summit

Deep Learning - Based Monitoring and Control of Hydroponic Leafy Vegetables for Urban Farming

9 July 2026

Dhananjay Kumar
Department of Information Technology, Anna University, Chennai, India

Gowtham Rajasekaran
Department of Information Technology, Anna University, Chennai, India

Session #S7.4

ITU KALEIDOSCOPE GENEVA 2026

Outline

- Need for a rooftop hydroponic system
- System architecture
- Algorithm development
- Deep learning Model
- System DL model performance on leafy vegetables
- Conclusion and standardization aspects

Why a Rooftop Hydroponic System?

- **Space & Weight Efficiency**

  Hydroponics eliminates the need for heavy, structural-stressing soil. Vertical and stacked setups can thrive, making efficient use of rooftop space

- **Water Conservation**

  Closed-loop hydroponic systems recycle water, consuming drastically less water than conventional agriculture

- **Faster Growth & Higher Yields**

  Plants typically grow 30% to 50% faster and yield 3 to 10 times more food per ft. compared to conventional agriculture

- **Building Energy Savings**

  The water mass and vegetation act as a thermal buffer, reducing a building's cooling energy consumption

- **Local Food Security**

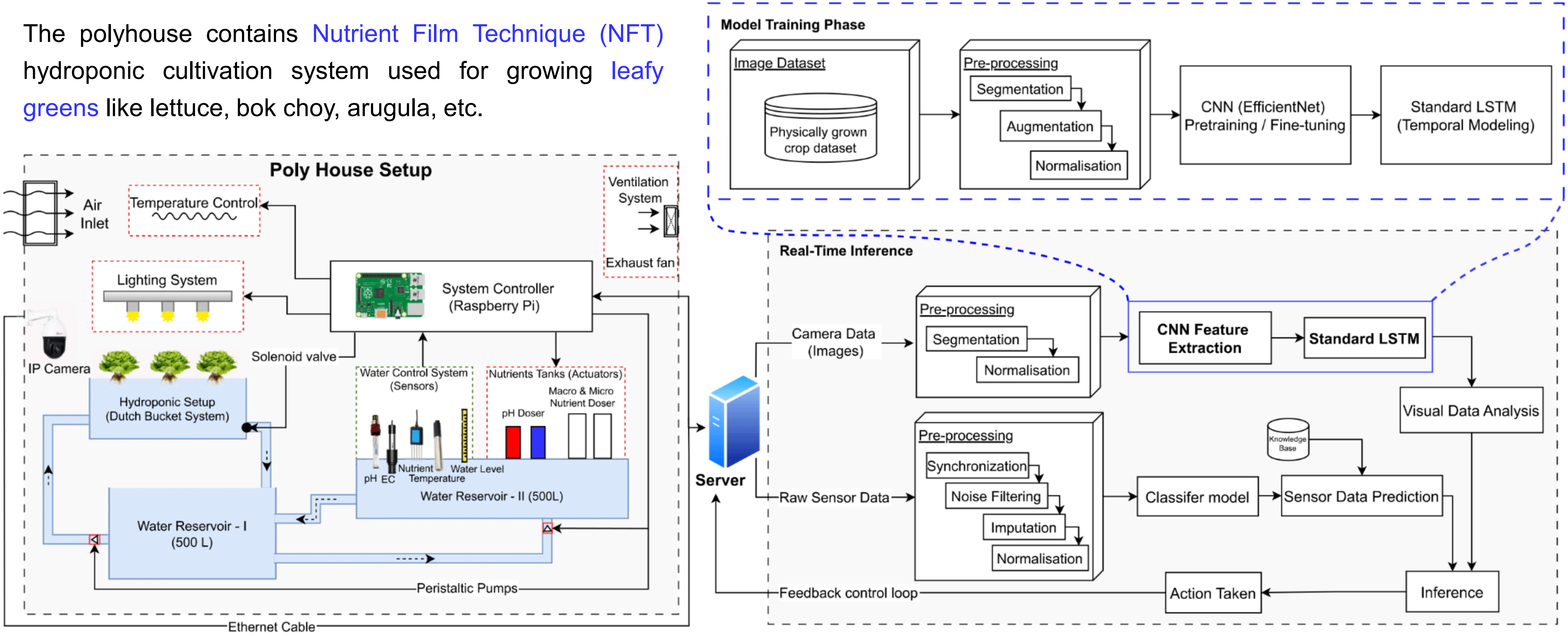
  Growing fresh produce right where it is consumed cuts down on carbon emissions associated with long-distance food transport

- **Pest & Weed Reduction**

  Without soil, many common soil-borne pests, diseases, and weeds are eliminated, significantly reducing the need for harsh pesticides

System Architecture

The polyhouse contains Nutrient Film Technique (NFT) hydroponic cultivation system used for growing leafy greens like lettuce, bok choy, arugula, etc.



A Raspberry Pi interfaces with all sensors and actuators, streams the real time sensor data to the central server, and executes actuation commands received from the server.

The analysis and then decisions sent by the server triggers the respective actuators on the Raspberry Pi; nutrient and pH dosing pumps, solenoid valves, ventilation fan, LED lighting units, and circulation pumps.

Algorithms

Algorithm 1: Preprocessing and Segmentation

1. Load the RGB color image I.
2. Convert the RGB image to HSV color space.
3. Compute mean intensity μ_v of the value-channel V.
4. If $\mu_v < V_{thresh}$, set the lower and upper HSV bounds to (L_{low}, U_{low}); else, set to (L_{norm}, U_{norm}).
5. Create binary vegetation mask M by thresholding HSV image within range $[L, U]$.
6. Find all external contours in mask M.
7. Compute A_{max} as the maximum contour area using $A_{max} \leftarrow \max\{\text{area}(c): c \in \text{contours}, 0\}$.
8. If $A_{max} < A_{small}$, the kernel size K is set to K_{large}; else if $A_{max} < A_{med}$, K is set to K_{med}; else, K is set to K_{small}.
9. Create square morphological kernel of size $K \times K$.
10. Compute M_{clean} by applying morphological opening followed by closing on M using the kernel.
11. Create filtered mask M_f with zeros.
12. For each contour c in contours, if $\text{area}(c) > A_{filter}$, draw filled contour c onto M_f.
13. Apply mask M_f to RGB image to obtain segmented plant region.
14. Resize segmented region to target size (W_{out}, H_{out}).
15. Normalize pixel values to obtain P.
16. **Return** preprocessed image P.

Algorithm-2: Plant Growth Stage Classification

Start
Input: Sequence of plant images $\{I_1, I_2, \ldots, I_T\}$

1. Load a pre-trained CNN. (e.g., trained on ImageNet dataset)
2. Apply Algorithm 1 to each image in $\{I_1, I_2, \ldots, I_T\}$ to obtain the preprocessed sequence $\{P_1, P_2, \ldots, P_T\}$.
3. Input each preprocessed image in the sequence $\{P_1, P_2, \ldots, P_T\}$ using a TimeDistributed layer of CNN, obtaining a feature vector per image.
4. Process the sequence of feature vectors through multi-layers of LSTM with dropout.
5. Pass the final LSTM output through a fully-connected network with softmax activation.
6. Obtain class probability scores.
7. Set g to the class with highest probability.
8. **Return** predicted growth-stage g.

Algorithm-1 enumerates the adaptive thresholding, contour-based filtering, and morphological refinement steps applied to each input image.

In Algorithm-2, a hybrid CNN–LSTM model is used for the growth stage classification

DL Model Overview

GROWTH STAGE DETECTION

Input

- ❑ Sequences of 4 images per day

Feature Extraction

- ❑ EfficientNet-B3 (frozen, pre-trained)

Temporal Modeling

- ❑ LSTM (64→32 units)

Output

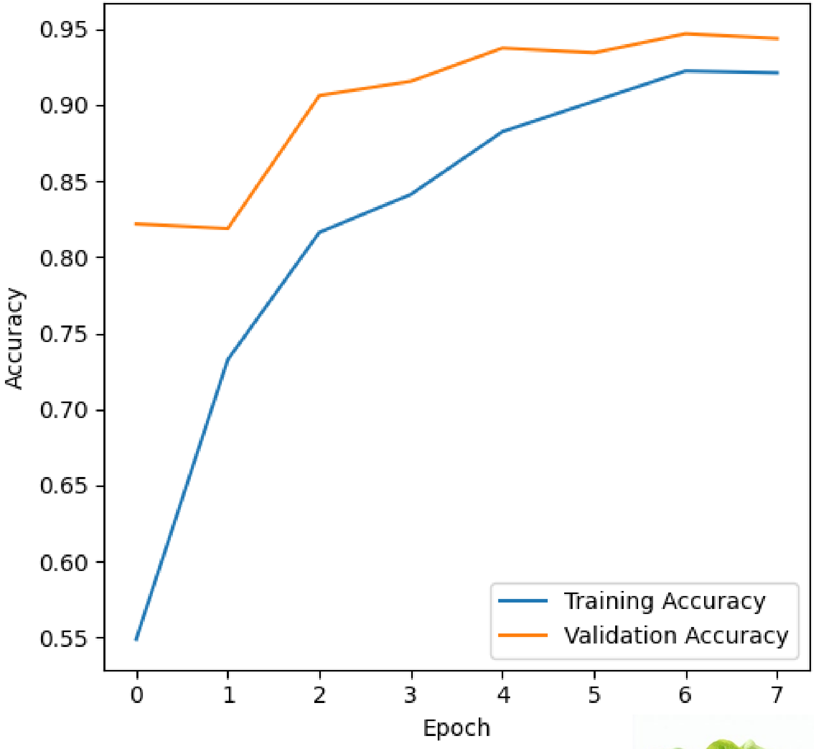
- ❑ 5 growth stages (0-4)

Layer (type)	Output Shape	Param #
time_distributed (TimeDistributed)	(None, 4, 1536)	10,783,535
lstm (LSTM)	(None, 4, 64)	409,856
dropout (Dropout)	(None, 4, 64)	0
lstm_1 (LSTM)	(None, 32)	12,416
dropout_1 (Dropout)	(None, 32)	0
dense (Dense)	(None, 64)	2,112
dropout_2 (Dropout)	(None, 64)	0
dense_1 (Dense)	(None, 5)	325

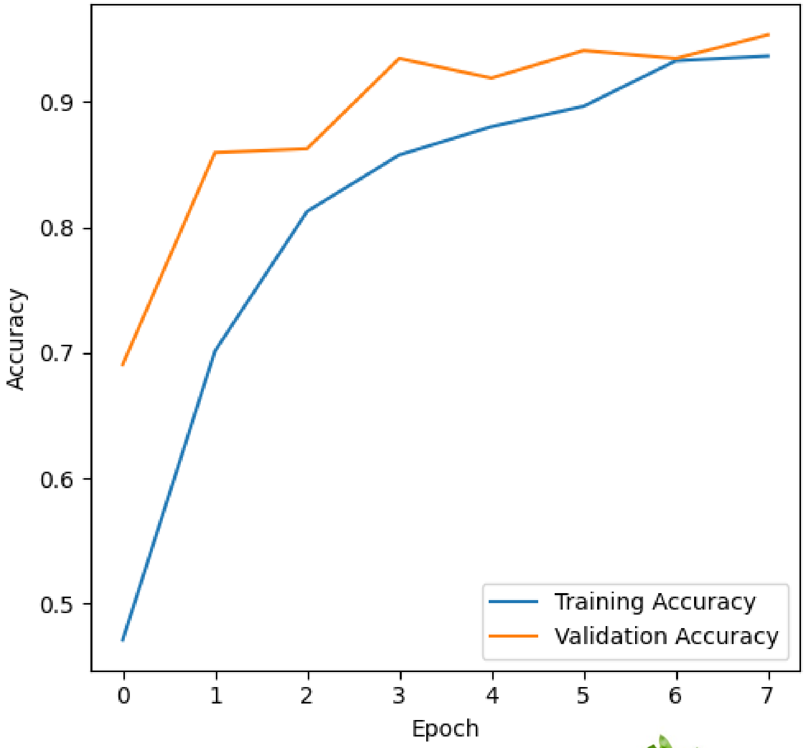
INPUT → TIMEDISTRIBUTED EFFICIENTNET → LSTM → DENSE → OUTPUT

Transfer learning was performed using ***EfficientNet-B3***, initialized with ***ImageNet*** weights.

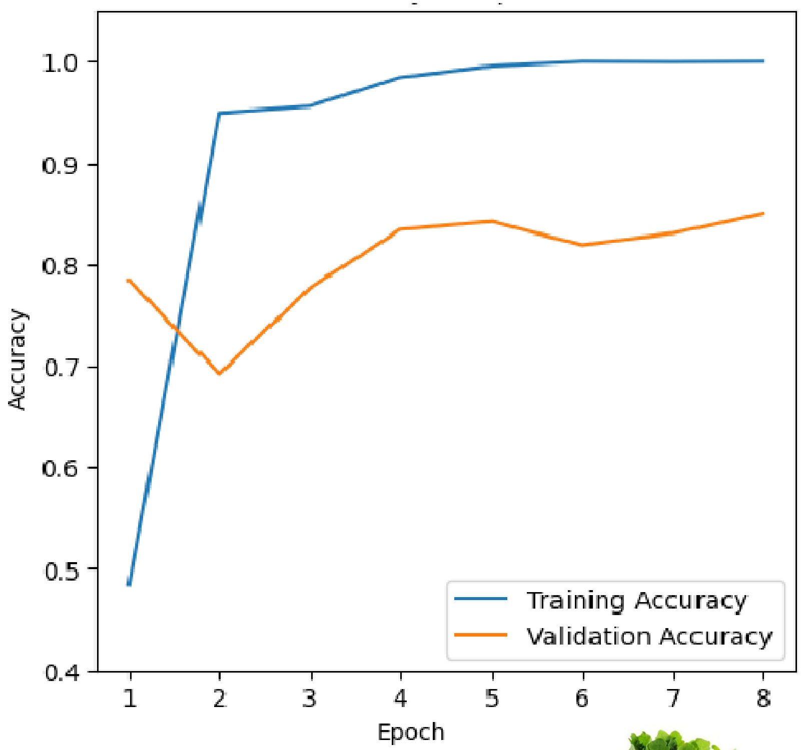
Model Performance



(a) Lettuce



(b) Bok Choy



(c) Arugula

Remarks:

- The proposed CNN-LSTM model successfully classified five growth stages of hydroponic leafy vegetables.
- Arugula showed the highest classification performance.
- Most errors occurred between adjacent intermediate growth stages because visual differences were subtle.

Locally Created Datasets

S. No.	Datasets	No. of Images
1	Lettuce	5,910
2	Arugula	5,184
3	Bok choy	8,046

Crop	Classification Accuracy
Lettuce	85.94%
Bok Choy	78.46%
Arugula	98.42%

Conclusion

- A hydroponic framework that combines image-based growth monitoring with sensor-driven environmental control in an IoT setup.
- A hybrid CNN–LSTM model is used to estimate plant growth stages from image sequences, combined with sensor feedback to adjust system parameters in a closed-loop manner.
- The system evaluation on three leafy vegetables under controlled conditions.

Standardization Aspects

- The overall design and operating concept are consistent with the smart hydroponics use cases described in ITU-T Y Suppl. 76 (09/2023), ITU-T Y.4000-series, which outlines IoT-based approaches for smart agriculture.

Acknowledgement

Anna University, Chennai

Government of Tamil Nadu, India

Authors sincerely thank Anna University, Chennai, and the Directorate of Technical Education, Government of Tamil Nadu, India, for their support under the Chief Minister's Research Grant (CMRG) scheme in carrying out this research work.

Thank you!