sowing of ginger in the same direction. To achieve this, an enhanced YOLOv4 and YOLOv3 with different backbone networks were explored, respectively. The results show that ML can enable the planting of ginger shoots in the same direction. Kolesnikova et al. [9] explored the use of a transfer learning approach in detecting bacterial wilt disease in ginger leaf. The finding shows that the use of the fine-tuning of the MobileNet V2 reduced the training time and achieved an improved accuracy of 97% compared with the CNN-based DL technique of 95% used in [79].

Advanced techniques, such as edge detection, threshold, and morphological operations, enhance the quality of input data for AI models, leading to improved disease detection performance. While the use of ML and DL has enabled the detection of plant diseases and classification, it involves several steps, such as noise reduction from the background, labeling, data augmentation, data splitting, feature extraction, and training. This may take considerable resources. To overcome the cost of using ML and DL, the use of transfer learning is now being employed. This involves the use of pretrained models on a large dataset for new datasets. Some of the pretrained models include AlexNet, VGG, and GoogleNet. The pretrained model comprises a large number of parameters that require fine-tuning. Table II provides a summary of various ML techniques.

C. Summary

Molecular methods for detecting ginger diseases, such as PCR and sequencing, offer high sensitivity and specificity but are costly, require expensive equipment and specialized training, and can be time-consuming. They are less accessible to small-scale farmers and regions with limited resources, and their accuracy depends on high-quality samples and stringent protocols. Moreover, they employ destructive sampling and cannot distinguish between viable and dead DNA, which will likely result in some false positives. In contrast, image processing is more cost-effective, noninvasive, nondestructive, and suitable for real-time field monitoring, making it accessible and practical for small-scale farmers. However, it may not match the accuracy and specificity of molecular methods, especially for early stage or visually indistinct diseases, and can be influenced by environmental factors. Combining both methods can provide a comprehensive solution for effective disease management in ginger.

VI. AIoT Technique

The AIoT, which involves the combination of ML, a subset of AI and IoT, provides the intelligence need for the sustain ability of ginger farming. The IoT has been largely explored in the area of agriculture for precision farming, smart irrigation, livestock monitoring, crop monitoring and management, environmental monitoring, automated machinery, and robotics. The use of IoT for disease prediction and forecasting is being advocated for disease prevention in agriculture [82], [83], [84]. This involves the use of IoT devices with incorporated sensors for data acquisition [85]. The acquired data are sent via a gateway to a cloud platform using preferred communication technologies. The use

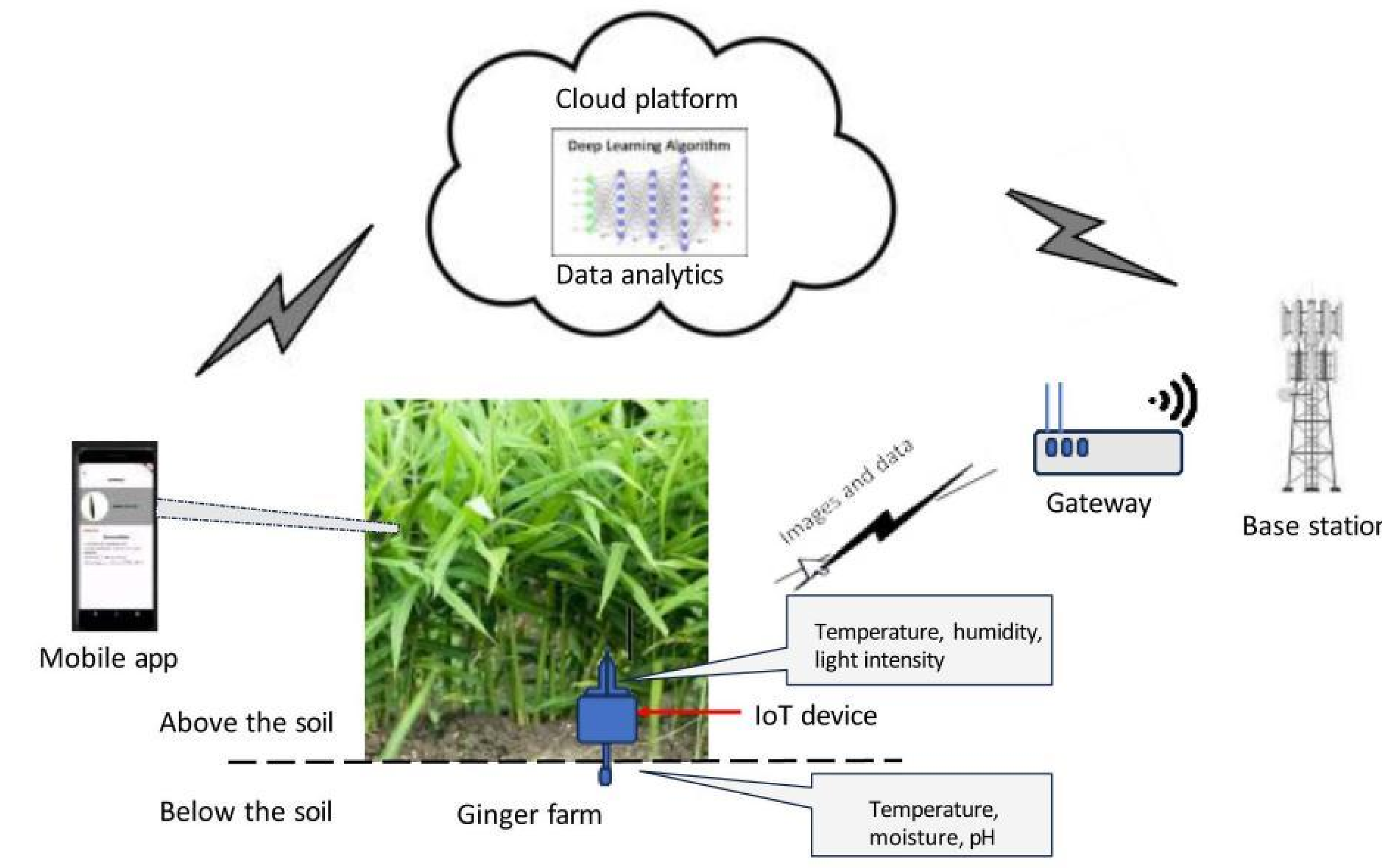

Fig. 4. AIoT for ginger disease detection.

of IoT can enable the monitoring of weather conditions that make ginger susceptible to any of the diseases. Fig. 4 illustrates the application of IoT for ginger plants.

While IoT allows for data acquisition, ML is been combined to generate insight from the volume of data accumulated. Hence, the combination of ML and IoT for agricultural purposes has been explored in [86], [87], and [88]. The AIoT techniques can offer tremendous benefits to ginger farmers. Unlike the use of only ML techniques that rely on the use of historical datasets for disease detection, the application of AIoT can enable proactive monitoring based on environmental conditions. Early warning systems can be implemented to generate alerts or notifications when conditions conducive to the development of ginger diseases are detected. This involves the development of predictive models that leverage historical data on ginger diseases, environmental conditions, and crop management practices to forecast disease outbreaks with real-time data. By deploying AIoT technologies for ginger disease detection, farmers can proactively monitor their crops, identify disease outbreaks early, and implement timely interventions to mitigate crop losses and improve yield and quality.

VII. Challenges

The integration of AI techniques for ginger disease detection has the potential to revolutionize agricultural practices by providing fast, accurate, and nondestructive diagnostic tools. Automated disease detection systems can enable early intervention and targeted management strategies, ultimately improving crop health and productivity. However, several challenges need to be addressed to realize the full potential of AI in ginger cultivation. These include the need for large, annotated datasets, robust model generalization across different environmental conditions and disease severity, and user-friendly deployment of AI solutions for farmers in resource-limited settings. The challenges of deployment of emerging techniques for the detection of diseases in ginger farming are discussed as follows.

A. Skills Set

There are diverse skills required for the successful deployment of AIoT in ginger production. It requires the services