**Existing systems**

**Traditional methods:** Traditional methods of weed control consists of manual labour, cultural practices and herbicide application. Manual labour is the process of detecting and removing unwanted plants by hand in a crop field and preventing damage to cultivating crops. This process is extremely time consuming and taxing but also is an essential part in agriculture. Despite it being time consuming it also is really effective and provides precision in removal of weeds and protecting crops. Traditional practices of weed removal include tilling, hoeing, hand-weeding, digging, burning, sickling and mowing etc. which help in disruption of growth of weeds and also prevent seed germination. Manual method is also cost effective compared to the newer methods which consists of using machines and other latest technology for weed detection. Although initially it is cost effective it can become expensive over time due to repeated wages, when compared to a one-time investment in automated tools. Moreover, there can be seasonal labour shortages, where fewer workers are available during certain seasons to take on strenuous roles during peak times due to which challenges can arise in cultivation of crops. [1]

**Machine Vision Based System:** Uses image processing, machine learning and pattern recognition techniques to identify and detect any weeds in an agricultural field. These systems usually involve placing a high resolution camera on tractors, drones or any handheld devices to distinguish between weeds and crops. The distinguishing is done based on various characteristics of a plant such as, the colour, shape and its texture and also on its growth patterns. The cameras or thermal sensors capture high resolution images which is then analysed and distinguished based on the above mentioned factors, helping differentiate between crops and weeds with precision. This also helps with reducing herbicide usage as these systems detect and spray on individual weeds instead of blanket application all over the field which in turn helps reduce costs and increases efficiency. One example for this is the WeedSeeker 2 automatic spot system [2]. When a weed passes the sensor, it signals the linked spray nozzle to spray herbicide on it. Other than the high initial costs for these systems, these provide high precision and accuracy, increased efficiency, reduced wastage and scalability. [3]

**Deep Learning Models**: In recent times, the ability of deep learning models to recognize patterns and gain valuable information from huge datasets, and using this ability to detect weed and other crop abnormalities, have become hugely popular. These powerful models train on vast image datasets, and then are used to differentiate crops from weed, resulting in highly accurate solutions. Not just that but these models have accuracy that increases over time giving them vast use cases. Some of the most recent examples being "See and Spray" from blue river technology [4] which target weeds in real time by using its deep learning model. These models make sure that crops are not harmed by herbicide and remain healthy and safe. [5]

**Thermal imaging:**  Thermal imaging, also known as thermography is a widely used technique in weed removal by farmers. It is an advanced technique which is non-destructive and uses no contact and helps in effectively removing weeds by using heat emitted from objects to monitor crops. There are temperature differences between various types of plants due to various factors such as water content, leaf shape, and metabolic rates allowing weeds to be distinguishable from crops and thermal imaging leverages that to distinguish between weeds and crops in a farm. This method is especially useful in early detection of weeds, which helps farmers to target and work on areas with more weed density. By pinpointing areas with higher weed density farmers can now reduce herbicide usage and labour costs by enabling, more precise and targeted interventions. Some of the tools used in thermal imaging are drones for Arial Thermal Imaging, thermal scanners for Ground Based Thermal Imaging and also mapping and analysis. Although thermal imaging helps in low visibility conditions, its effectiveness can be influenced by certain environmental factors which could limit its accuracy. [6]

**Robotics and Autonomous Weeders**: Autonomous robots that sort out weeds from crops which can be done with mechanical or chemical ways is another popularly used system in modern agriculture. These robots make use of computer vision and AI to segregate useful crop from weed. This type of sorting helps the robot avoiding to spray entire fields of crops with herbicide and only target specific weeds. The advantages of having these robots is that they reduce manual and repeated labour, and also promote less chemical usage in crops. An example of such a robot is FarmWise Titan robot, which uses the above said methods to segregate crops from weeds. [7]

**Limitations of existing systems:**

**Manual Labour**: Manual labour as much as it is prevalent, also comes with its downsides. Manual labour is often time consuming, expensive, and requires a lot of unnecessary hard work which could otherwise have been automated. The workers doing this job also need to have skills and experience which makes it even more demanding. The precision involved in manual labour is also diminished to an extent since human make mistakes often.

**Machine Vision-Based Systems**: These systems might be really useful at identifying weeds from crops based on their physical features like size and colour, but problems start coming up in situations where the weeds look very much alike the crops. Situations like low light conditions or uneven field can also set back this type of systems. These systems also need technical support from time to time which might not be feasible for budget constrained farms.

**Thermal imaging:** Thermal imaging makes use of the difference in temperature between the weeds and crops but this turns out to be a problem in climatic conditions where the temperature changes quickly, as this could affect the reading and in turns affect the results. Climatic regions where the weather is usually hot and humid might prove difficult for the system to work in.

**Robotics and autonomous weeders**: These robots are known for bringing in high precision and accuracy, but unfortunately come at a high cost. Farmers who want to implement this system in their farms would need to have a huge capital investment in the first place. Mostly these machines are used in well-structured farms, so any amount of terrain or crop diversity may affect the system negatively. Additionally to this, these systems need a lot of supporting architecture, which may cost even more to maintain.

[1] “STUDY OF TRADITIONAL METHOD OF WEEDING AND FERTILIZING AND THEIR DRAWBACKS” Mr. Mahesh K.Borbale, Mr. Ajinkya U.Pohekar, Mr. Jayesh R.Nistane, Mr.Nikhil S.Nichit, Mr.Triratna I.Yesankar, Mr.Aditya G.Kaware

[2] https://www.vantage-nz.com/portfolio/weedseeker-2-spot-spraying-system/

[3] “Weed Detection and Classification with Computer Vision Using a Limited Image Dataset” by László Moldvai , Péter Ákos Mesterházi, Gergely Teschner and Anikó Nyéki

[4] https://www.bluerivertechnology.com/our-products/

[5] “Early weed identification based on deep learning: A review” Yangkai Zhang, Mengke Wang, Danlei Zhao, Chunye Liu, Zhengguang Liu

[6] “Verification of a machine learning model for weed detection in maize (Zea mays) using infrared imaging” by Adam Hruška, Pavel Hamouz

[7] https://www.tangramvision.com/blog/sensing-breakdown-farmwise-ft35