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SMART WEEDER NOVEL APPROACH IN 3D OBJECT RECOGNITION LOCALIZATION AND TREATEMENT OF BROAD DOCK IN ITS NATURAL ENVIROMENT

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Abstract: This document presents the current progress in development of weed recognition in the scope of the project “SmartWeeder”. It describes novel approaches in sensor selection for outdoor usage as well as recognition of natural objects in their domestic environment using 3D object detection.

Keywords: Machine Vision, Vision Systems, Precision Farming, Control, Navigation

1 INTRODUCTION

One of the most invasive and persistent kind of weed in agriculture, according to the Federal Office for Agriculture in Switzerland, is Rumex Obtusifolius also called (“Broad-leaved Dock”). Origin of the plant is Europe and northern Asia, but it has also been reported to occur in wide parts of Northern America. The plant itself is very robust and resists most of the common physical and chemical weed-treatment methods. If the plant is mechanically destroyed, its roots and plant parts must be milled to “juice” to prevent the further spreading by distribution of possible new germ cells. There are several known ways to control the plant:

- Manually detection and destruction of the plant.
- Using herbicides with dedicated application on a single plant. Human operator detects the plant and applies herbicide on its leaves.
- “Burned earth” method by applying chemical or biochemical substances on the whole area (including all other useful plants).

These methods are used at present time and certainly will be continued to use in the near future. However, the work is physically exhausting and requires large human and / or machine resources. Considering current trends towards sustainable, organic agriculture, where general application of poison is strictly forbidden, the Federal Office for Agriculture started a study on possibilities of automatic recognition, localisation and destruction of weed without using of any kind of herbicides or reducing their application to a minimum. Automatic recognition, localisation and destruction of weed is known under the general term “Precision Farming”. This project is founded by “Gerbert Rüf Stiftung” and its goal is to build a vehicle prototype to find, localize and mark the broad-leaved dock within its natural environment

Figure 1: Broad-leaved Dock, Rumcex Obtusifolius (www nearctica)

This paper presents the current status of our development. Special attention is given to the description of a novel approach to process collected high resolution 3D-Ground data. It is shown that it is possible to acquire data in high quality with a sensor that is not constructed for an out-door usage. Further we show that adequate calibration of the system can improve the accuracy of the observations. Accurate data is essential for fast and reliable segmentation and recognition algorithms.

Plant detection based on classification of leaves is one of the topmost research strands in agriculture since many years. Scientific work focuses on the classical two dimensional analysis with feature recognition in binary images. Novel methods like species identification using elliptic Fourier shape analysis (Neto et al 2005) work well with clearly projected complete leaves. There are also commercial products on the market that use frame-by-frame video analysis to extract potential candidates (QualiVision AG, 2004). Major disadvantage of all two dimensional solutions is, that they work on the projection of the natural scenery and interpret the three dimensional world by applying models on the data. On the other hand, in geodetic and photogrammetric "world" data processing follows a different approach: Collected data is three dimensional and products and interpretations are two dimensional, for example topographic maps. In the last decade "new" branches of surveying equipment was put on the market: High Definition Surveying Devices (HDS-D). Also real time photogrammetry made a substantial progress in acquiring, processing and interpreting three dimensional data (Förstner 2005).

2 REQIREMENTS

SmartWeeder is a vehicle prototype that is constructed to carry a 3D sensor and two computers. It must be robust mechanically, suppress shocks (≥4 g) to protect computer equipment and minimize sunlight influence within the vehicle. Requirements on the measurement "engine" are:

- Vehicle speed 1 m/s
- Resolution in object space 2 mm maximum in all three dimensions
- Field of view:
    - Width: 1.0 m
    - Height: 0.3 m
    - Length: infinite

SmartWeeder is intended to be a real time data acquisition; processing and control system that recognizes plants immediately and marks them during continuous movement of the carrier system. Considering the speed of the vehicle and system design we estimated the processing time for the recognition and localisation to about 0.6 seconds. In this tight time frame it is essential to mention that data pre-processing like segmentation, pre-selection, etc. take as less as possible time without consuming too much processing power!

3 DATA ACQUISITION

Today, acquiring three dimensional data is mostly bound to the application type and the budget available for the equipment. Numerous sensors are available and their quality range from non-utilizable to unaffordable.

First sensor evaluated was *Sick LMS 400 (Time of Light laser scanner)*. Data sheet promises that needed resolution is achievable if the sensor height over the ground is approx. 0.71 m. Then maximal laser spot size is 1.5 mm that actually satisfies our requirements (T. Frei, M. Porath 2005). Although the calculated resolution seem to be adequate, the accuracy of the data was disappointing. Tests showed that natural objects like plants due their reflection characteristics cause minimum data quality. In the data sheet the standard deviation is stated as ±0.01m.

In the framework of a further research the *CSEM SwissRanger SR-2(Time of flight range camera)* was tested. The results showed that the resolution of the SR-2 did not fulfil the requirements. In the near future a resolution increase is expected for this product.

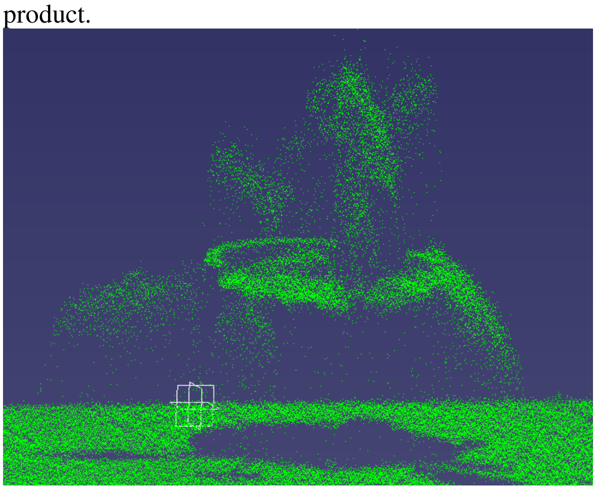

Figure 2: Plant data acquired with LMS 400

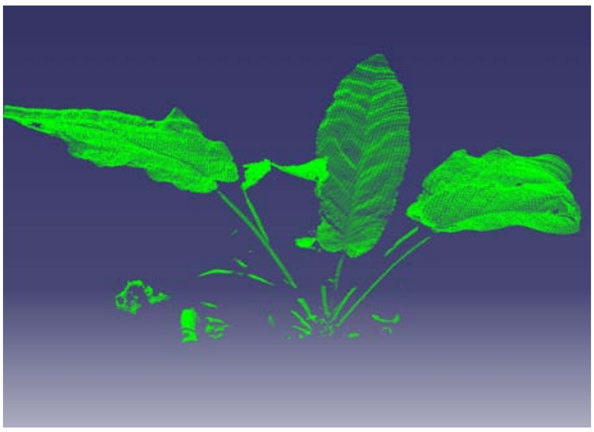

Figure 3: Plant data acquired with Ranger C55

Due the positive experience with *Sick RANGER C55* in another project, tests were run with C55 and a near infra red (NIR) laser (780nm). The fact that vegetation perfectly reflects NIR light is sufficiently known (B. Lorenzen, A. Jensen 1987). Also the

modular setup of such system as Ranger was an additional argument to use this kind of measurement device. Most important features that one measurement device must have were high resolution and high quality at high measurement speed. Ranger C55 is high resolution smart camera with 1536x512 pixels. It is high a speed sensor that can deliver up to 20000 lines per second. In Figure 2 and Figure 3 the difference is obvious between measurements of both sensors: LMS 400 and Ranger C55. The reader can see clear and homogeneous plant in Figure 3. The measurement principle of C55 is laser triangulation; on-camera FPGA processor allows high speed frame processing. It computes contours of the ground through processing of the laser beam projected line. Sensor delivers the contours in 1 kHz rate to the image processing computer.
The following sensors were not examined, but for the sake of completeness mentioned.

Passive sensors (mostly cameras) that use epipolar geometry to reconstruct scenery are gaining popularity with the increasing processing power of modern computers. Real time scene reconstruction and interpretation is quite limited if real-time performance is needed. High resolution cameras are not only expensive but also show a limited data transfer rate.

HDS Sensors are accurate and fast, but most of them are designed for stationary use. Even if the very high resolution and its range are embedded into the calculation, such device is far too expensive.

4 VEHICLE

The test vehicle consists of a base frame for our experiments. It is constructed to allow maximum flexibility for the experiments and maximum security for the operators: We use IR laser 70 mW strength (Laser class 3B). It can harm human eye if it is directly exposed to the laser beam.

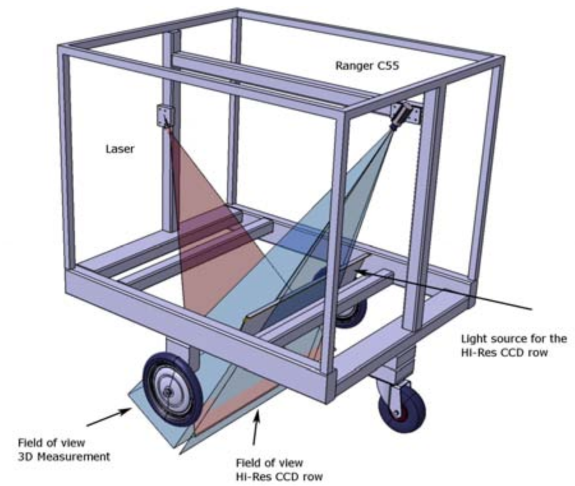

Figure 4: SmartWeeder vehicle draft

Figure 5: SmartWeeder test vehicle

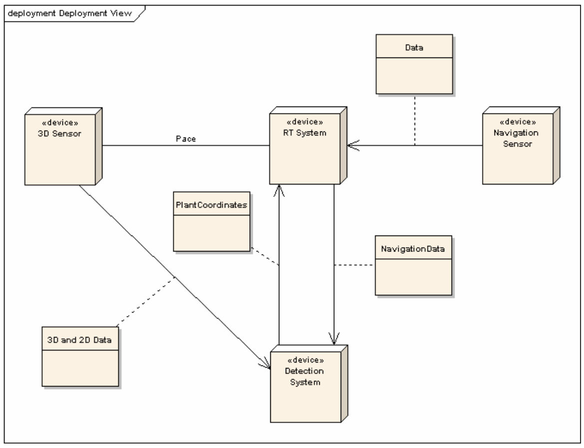

Figure 6: System design, main components and data flow

5 SYSTEM DESIGN

The System, beside the vehicle, is designed in two components, in Figure 6 “RT System” and “Detection System”. They represent two computers, one with real time operating system QNX and another image processing computer with Windows XP Professional. Both systems are connected over Ethernet peer to peer connection. The RT system delivers unique time for the whole system, calculates the navigation data and triggers the data acquisition on the ranger camera. The non real time system acquires and processes acquired 3D data. The 3D data processing contains the following steps:

- Data acquisition
- Data pre-processing (segmentation)
- Data processing (leaves detection)
- Data post-processing (location computation)

Every detected broad dock leaf has then coordinates of its middle point in the vehicle coordinate system and the bounding cube assigned to it. This information is passed to the RT system via network that further controls the herbicide nozzles to spray the localized leaf/ves.

6 SENSOR CALIBRATION

The Ranger C55's high resolution and its speed are the key features that made it our first choice. However, the accuracy of the system was unknown. Special attention must be given to issues regarding the outdoor application in contrast to its intended use such as in a production line. The camera is calibrated using the classical Tsai calibration procedure (R. Tsai 1987). Tsai's procedure was extended with an additional routine to determine the position and orientation of the laser plane relative to the principle point of the objective. System calibration is manually done. First calibration tests showed that an accuracy of 1 pixel could be achieved, considering the fact that the measurement data is approximately 2-4 mm per measurement point (pixel). An automatic calibration procedure will downsize this value to 1mm per measured point. Thorough calculations revealed that the calibrated system allows an observation of the ground with a maximum error of 2.4 mm per pixel.

7 FIRST RESULTS

First results have shown that the SmartWeeder concept is on the right way. Thus the intensive preparation and research we had to recognize that covering the sensor and the laser does not necessarily completely cut off the sunlight influence. With additional rubber barriers we achieved almost "hermetic" exclusion of the direct and indirect sunlight and increased data quality by the order of magnitude. Figures 7 and 8 show the difference.
With a small bit of imagination it is possible to recognize characteristic leaves of the broad-leaved dock in the point cloud shown in figure 8. Height is colour mapped in that way those higher parts have warmer colours. Black is height zero and red shows plant parts about 0.3 meters above ground.

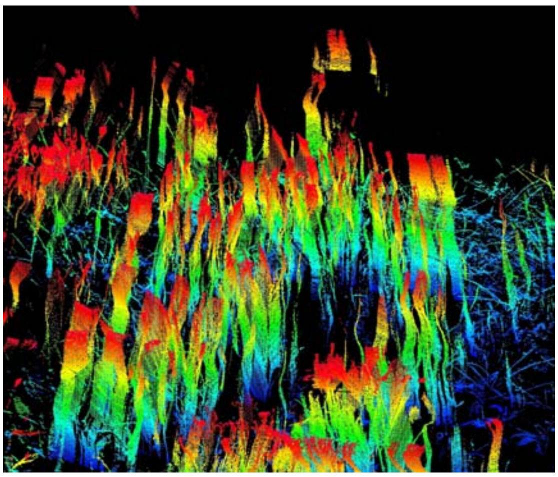

Figure 7: Influence of the reflected sunlight on measurements. "Flame" structures are invalid observations caused by sunlight.

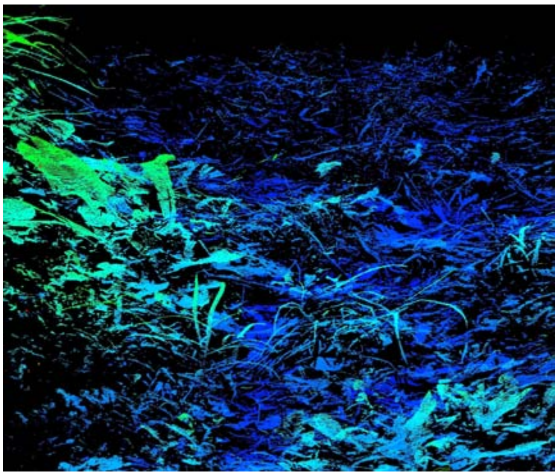

Figure 8: Observed field with IR filter and suppressed sunlight

Figure 9: Colour image of field scanned with SmartWeeder

Goal of the project, as already mentioned, is to create a machine that can recognize and localize broad-leaved dock in its natural environment. We have chosen the C55 sensor because of its speed, accuracy and flexibility. Still in development and testing phase are the segmentation, recognition and localization algorithms. Testing segmentation approaches showed that with minimal processing power is needed to achieve very precise and reliable segmentation results. In contrast to classical image processing where edges are modelled and detected in intensity or significant colour changes, in 3D data they are instantly there as geometrical features and relations between geometrical primitives such as triangles or quads. Single leaves are extracted using geometrical relations of neighbouring geometrical shapes and not "just" their gray values. Although one additional dimension increases the computation time in an exponential way, algorithms are straight forward and more robust. Separation of contiguous surface patches from each other is only one part of the problem. Analysis of them is another. We simplify the segmented data into surface patches and approximate them into surface primitives like paraboloid or similar. They are analysed using least squares surface fit on smoothness and to determine their trends and relationships between patches.

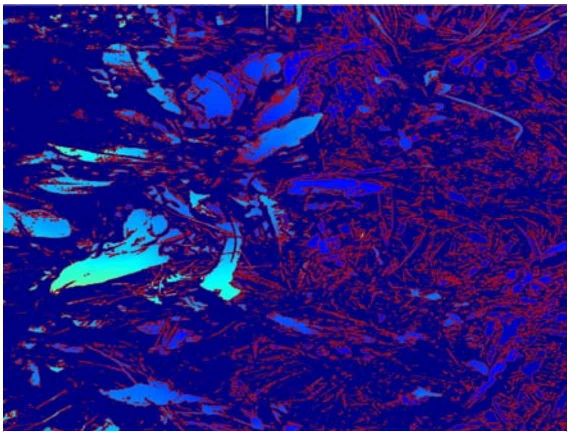

Figure 10: Segmented 3D data, red pixels are computed object (leaf) boundaries.

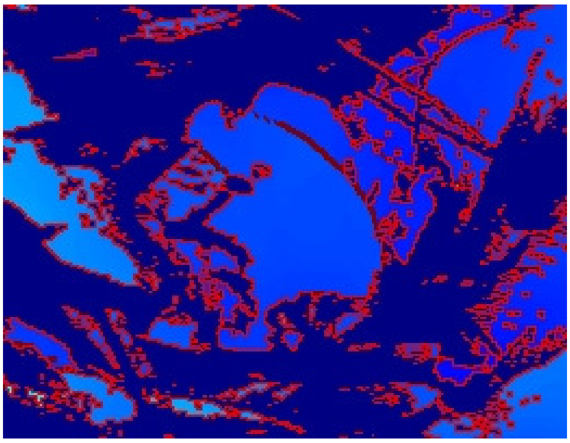

Figure 11: Segmented leaves (detail), pixels painted red are computed boundaries of the object. Brown pixels represent possible leaf edge within "merged" object.

Figures 10 and 11 and show how the segmentation algorithm recognizes the edges of the single leaves. Whenever one single object is recognized and it fulfils criteria according to plant database (surface metrics, shape, surface state, etc.) it will be set into the "recognition" queue to signal the system that deeper examination is needed for the particular object. If "deep" examination confirms: one object is recognized as leaf of broad leaved dock, its coordinates in the vehicle coordinate system will be computed and sent to the RT system via the network interface. Then the leaf will be sprayed with the herbicide.

8 SUMMARY

Finding specific plant in its natural environment is challenging task. It is also not new area of research; it is rather not "famous" one. Especially localisation of broad-leaved dock has some very successful solutions: S. Gebhardt, J. Schellberg, R. Lock, W. Kühbauch 2006. We believe that usage of 3D data will bring better results and higher performance in recognition and treatment systems, because the surface analysis in space can boost segmentation performance where other systems can not succeed without additional effort. These conditions can be low contrast or "green on green" images, noisy images or images taken from inappropriate position to the object(s). However 2D images containing texture information can be used for plant classification. The texture analysis is state of the art in image processing and widely successfully used for objects classification. It can be applied as supporting technique to finally distinguish plant species from each other, but after single leaves were already extracted and confirmed as possible candidates as leaves or leave parts. As the first results were promising, recognition system is still in development any quantification of the results would be slightly too early.

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