Publishable summary

1. Executive summary

The selective harvesting of white asparagus is exclusively done manually worldwide. Some supporting harvesting aids exist; however, being totally dependent on seasonal workers implies the following problems to frames as:

- Seasonal workers are hired for a fix date, however, the real harvesting season depends strongly on the weather; this causes that…
- … with a late harvesting start (cold conditions) the workers cause costs but cannot work, or with an early start asparagus cannot be harvested due to the lack of workers;
- Minimum wages (e.g. in Germany) make manual harvesting very cost intensive
- The organisation of seasonal workers (transporting, accommodation) is time consuming;
- Residents of villages in asparagus farming areas in general dislike the large number of seasonal workers,
- Harvesting is only possible in day light;

The introduction of automated harvesting could solve all above named problems. That in focus the AutoSpar consortium started back in 2008 with the development of an automatic & selective harvesting machine **AutoSpar** for white and violet asparagus. The project ended in a pre-competitive prototype, which became the starting point of the DASH project. However, only by the implementation of technical improvements of the prototype in terms of increased robustness, higher efficiency, and improved reliability as well as for safety aspects the AutoSpar prototype would become a commercial product.

Figure 1 AutoSpar demonstrated at expoSE 2013

In order to reach a fully functional and reliable harvesting machine the 'new' AutoSpar prototype has been intensively tested. The testing of the machine, partly together with end-users (potential clients), was done through field demonstrations (during the harvesting seasons 2014 and 2015) and through off-season demonstrations by means of exhibitions and other indoor events.

2. Description of the DASH project context and objectives

The overall objective of the DASH project was to improve and demonstrate the AutoSpar harvesting machine. In terms of a harvesting machine it means that a minimum of 95% of existing/available asparagus stalks must be harvested sucessfully. The way towards this ambitious target was divided into three technical work packages and two WPs aiming for commercial success after the end of the project. The context and objectives of each WP are summarised below:

WP1 – Implementation of new technological solutions and technical improvements

Based on the experiences from the AutoSpar project and the technical recommendation plan developed at the end of the AutoSpar project technical improvements were specified at the beginning of DASH. Soon it became clear that modifications to the old prototype would not lead to success, therefore it was decided to building a new prototype into which all new technological solutions were implemented. However, testing these new technologies and advice from farmers after demonstrations made it necessary to continue modifications and optimisations until the very end of the project.

WP2 – Field demonstration and performance verification

The new AutoSpar prototype reached 80% functionality only towards the end of the harvesting season in 2015. The delay in technical completion (the machine is still not ready for commercialisation) had negative impact on the demonstration activities. The experience of the industrial partners is that a not fully functional machine should not be demonstrated or customers lose faith into your technical competence. This in mind the machine was exclusively demonstrated to local to STRAUSS farmer, to which STRAUSS has a long lasting and trustful working relationship. The farmer (WERNER) attended most of all tests and helped with advice from the end-user point of view. Through the field demonstrations and the support of WERNER the consortium was enabled to improve the harvesting machine step by step, reaching (as worked out through performance verification sessions) an 80% functional machine at the end of the project.

WP3 – Off season demonstrations

Off-season demonstrations were planned as two types of activities. For one part it was planned to invite potential clients for workshops at STRAUSS facilities and to show and explain them the concept of the machine while running some harvesting sequences. For another part the prototype was planned to be taken to exhibitions for demonstration purposes.

While the workshops did not take place the demonstration at exhibitions was of great success. In total the AutoSpar prototype was demonstrated at three exhibitions; (i) the ‘expoSE’ in Karlsruhe, the ‘Interaspa’ in Hannover and the ‘food logistica’ in Berlin. The figure on the right shows the DASH exhibition booth at the ‘expoSE’. The machine was demonstrated by means of harvesting sequences during which the searching, scanning and harvesting procedures could be witnessed. After a demonstration the spectators were invited to discuss the functions of the machine and to complete a questionnaire. In total more than 80 questionnaires have been completed by asparagus producers.

One additional outcome from WP3 was the development of a video clip to be used as ‘entry information’ for potential clients. The DASH video clip had been uploaded to the AutoSpar website.

WP4 – Business and marketing strategies

The commercial success of any machine depends on its functionality, its reliability and the price. Hence all material costs have been listed for the calculation of the AutoSpar machine costs. Items and materials from that list were than analysed with respect to potential cost reduction in the case of multiple machine manufacturing. The list of material costs and estimations for the reductions of these costs have been implemented to the business plan. The very ambitious aim of being able to build one machine for a maximum of 50.000 €, however, was not achieved, mainly for the reason that quite a large number of added technologies was necessary to reach functionality. At the moment the selling price for one machine would be 70.000 €. However, compared to other approaches for automated harvesting of asparagus, the AutoSpar machine is still relatively low priced.
As the main outcome from WP4 a comprehensive business plan for the commercialisation of the AutoSpar harvesting machine has been developed during the second period of the project. The business plan comprises (i) a general description of company STRAUSS, their business philosophy and an analysis of their industry; (ii) a product and service description offered by AutoSpar; (iii) a marketing plan, including economics, potential barriers to the market, competitions, promotion and budget issues.
The operational plan, however, has not been completed due to the fact that the AutoSpar machine still has not reached its final technical status, thus production, manufacturing and supplier aspects could not finally be determined.

WP5 – Dissemination and IPR management

The project website (http://www.autospar.net) has been continuously updated. Towards the end of the project the content as well as the appearance of the website was entirely changed from being a 'typical' project's' website into a commercial website. The new style of the AutoSpar website is mainly addressing potential clients by providing attractive edited information in words, pictures and movies. It also offers potential clients the possibility to online register for a demonstration of the harvesting machine. The main contact of any requests from the website is company STRAUSS.

Also several dissemination attempts were made by the partners in order to raise awareness about the AutoSpar machine and its functionality. TTC presented DASH project at the Innovation Forum event in 2012 and 2013 in Bucharest to an international audience, ensuring thus awareness raise in Eastern Europe. In 2013, 2014 and 2015 the team of TTC also discussed the opportunity of Asparagus cultivation in Romania with various farmers present at the Agraria fair in Cluj-Napoca, Romania. Furthermore, partners were contacted by the press which published several articles and interviews in the local media such as (i) an article in a Dutch magazine called 'Mechatronica & Machinebouw' in February 2014, (2) an article in a German magazine called 'Die Zeit' in April 2015 and (3) an interview with BZN in a German radio channel called 'Radio Karlsruhe' also in April 2015.

The interim PUDK which had been developed in the first period was updated by all partners during the second period, maintaining the same structure. One of the main activities and results in WP5 during the second project period, however, was the development of an extended IPR agreement. Without changing the original AutoSpar IPR agreement, additional foreground intellectual property has been shared among partners according to their

activities and responsibilities within the project. All additions to the original IPR are visibly marked in order to quickly perceive add-ons.

3. S&T results

The initial approach of DASH was to optimise the AutoSpar prototype by the implementation of technological solutions. However, after re-assessing the AutoSpar recommendation plan and discussing necessary technical improvements the DASH consortium decided to build a 'new' AutoSpar prototype from zero. The main technological changes and/or improvements made during the DASH project are described below:

The top picture of figure 2 show the AutoSpar prototype during a field test in comparison to the new DASH prototype (bottom picture) as it has been field demonstrated during the harvesting seasons in 2014 and 2015 to end-users.
All technological solutions which meant a significant change to the machine and thus having a major influence on the functionality of the harvesting are listed below:

Figure 2 Comparission between 'old' and 'new' AutoSpar prototyp during field tests

Orientation of driving

The AutoSpar prototype had the driving wheels in the front and the steering wheels at the rear end of the machine. The advantage was that the machine could be turned with a small radius between two dams, with the draw back that it wouldn't follow easily the dam.
The DASH prototype has been changed into a back driven and front steered vehicle, which also made the rather heavy machine easily following the dams.
With the introduction of a second driving motor (see next point) the turning between dams remained unproblematic.

Independently driven back wheels

After experiences of tests in rainy and muddy conditions and comments of end-users during the exPOSE 2013 it was decided to implement a second driving motor. The positive impacts were:

a) Double power to be able to drive the machine even through conditions of heavy soil
b) Better steering since wheels can be independent of each other on different speeds and hence
c) Small radius for turning the machine between two dams

Horizontal & height adjustment

The AutoSpar prototype was equipped with a sensor to measure the horizontal orientation. Two motors connected above the steering wheels were than moving the cross-transfer-table into a horizontal position. There was no opportunity for automatic height adjustment.
The sensing of horizontal orientation remained the same in DASH, however, the principle for moving the harvesting tools (see. 2.4) has completely been changed into a double frame assembly of which the outer frame is connected to four motors which are used to keep this outer frame horizontal while harvesting. An ultrasonic sensor for height measurement has additionally been installed, allowing to also adjusting the out frame in a constant height above the dam, and thus always cutting the same length of asparagus stalks.

Figure 3 Ultrasonic sensor

Double frame assembly

AutoSpar was equipped with a cross-transfer-table for the movement of the harvesting tool. One of the major disadvantages was that the (heavy) motor responsible for the Y-direction has always been moved together with the X-direction, which was causing unwanted vibrations and was slowing the overall harvesting process down.

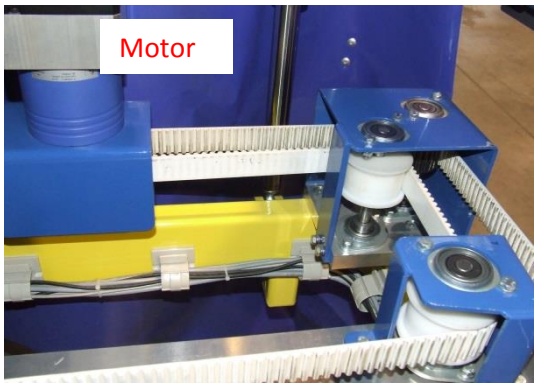


Figure 4 Belt driven crank-slide

Through the implementation of the double frame assembly the horizontal and height adjustment has been separated from the movement of the harvesting tool. One of the main innovations in DASH is a so called 'crank-slide' (inner frame), which consists of a long belt, which is connected to a platform (for harvesting tool) and which is driven by two motors. Using this technology means that the motor for the Y-movement will be stationary fixed to the frame, which reduces weight of moved parts. As a consequence of the weight reduction the speed of the harvesting tool was significantly increased.

Harvesting tool – cutting and gripping/lifting

<u>Cutting tool</u>

The cutting tool of the AutoSpar system was a two shaft, double blade system which had the following advantages and disadvantages:

- ✓ When cutting, both blades were pressing against each other and the cut-off asparagus stalk was 'sitting' on the blades. This way it was possible to move the stalk up by some cm in order to have a larger piece of the stalk above the soil for gripping.

- × Due to the two shafts (+blades) became more compacted than excepted by farmers and too much soil was taken out of the dam when the cutting tool was lifted up again.

- ✗ To minimise the before mentioned disadvantage the width of the blade was kept to a minimum with the impact, that too many stalks were missed and not cut.
- ✗ Cutting underground always implies the risk to catch and jam a stone. Two blades were doubling that risk.

Figure 5 Cutting tool

The cutting tool of the DASH machine only has one shaft and a knife, which rotates forwards and backwards by 90°. This system has the following advantages and disadvantages:

- ✓ Minimum impact on soil compacting
- ✓ Minimum damage to the dam by removed soil
- ✓ Minimum risk on jamming stones
- ✓ Long blade increases cutting success

- ✗ Asparagus stalk cannot get an initial lift. As a consequence of that the detection system needed to be changed, ensuring that only stalk that already look out of the dam 3 cm will be harvested.

<u>Gripping/lifting tool</u>

The gripping/lifting tool of AutoSpar was made of two fingers, which were spring loaded pressed against each other. This concept partly worked providing that an asparagus stalk was successfully pushed up by the bladed by about 2-3 cm. However, an increase of grip on the tips of an asparagus head was achieved by the development of a new gipping tool, which consists of inflatable rubber tube. This rubber tube was connected to a small mobile compressor and controlled through a pressure control device (see figure 6). The main disadvantage of this idea is that asparagus stalks must grow out from the dam (see also cutting tool) by a minimum of 3 cm to be able to grip on them.

Figure 6 Lifting tool

Light shield

Different to AutoSpar, where only a small area around the cameras has been shielded against the influence of ambient light, for DASH the entire harvesting part of the machine is encased by a plastic foil.

Illumination

A new illumination plate was created having two aspects for improvements in mind:

a) To increase of luminance in order minimise any influence of interfering light which may enters the through the light shield where reaching soil level;
b) To increase the share of blue in the emitted light in order to get a better differentiation between asparagus and soil.

Plastic dam cover removal and repositioning

The plastic foils used for covering asparagus dams are can be lifted and replaced with roller system, which are standardly used for harvesting supporting systems. However, already the AutoSpar prototype was higher in construction than other harvesting aids, which caused an increased influence of wind to the machine. DASH being higher again compared to AutoSpar would have been even more effected height. Figure 7 shows the lowered removal roller on the left and the extended repositioning tool on the right.

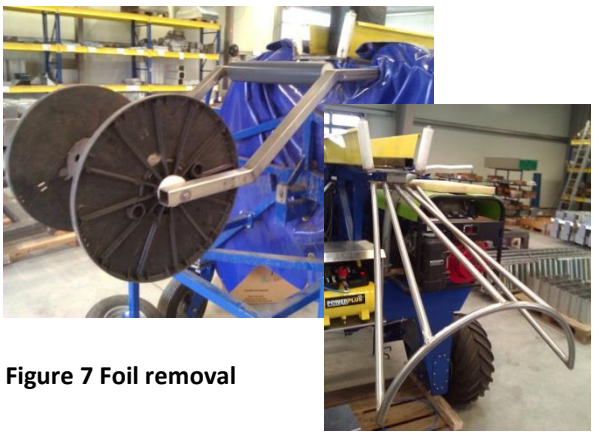


Figure 7 Foil removal

Power supply

The AutoSpar prototype was equipped with one set of batteries for the driving motor and an extra set of batteries as a power supply for the rest of the machine (motors, illumination, control etc.). For security reasons the batteries were designed that those for the driving motor would always deliver longer than those for the harvesting process. The major problem of this set-up was that once the batteries were empty, the machine needed to be taken into a place where the batteries could be recharged. In other words the machine could not be used longer than for an eight hours shift.

Figure 8 Generator for power supply

Making the system more flexible with respect to working times, allowing also for the possibility of even harvesting in night times; and with respect to the recharging/refilling it was decided to change the power supply from batteries to a petrol generator. The implemented generator as shown in figure 8 provides a maximum electric output of 6.4 kW. With a 5 litre tank capacity the DASH harvesting can run approximately 8 hours. The refilling of the tank can be done any time in any place with normal gasoline (no E10).

PLC control (hardware and software) / remote control

Considering the large number of changes from AutoSpar to DASH it was also decided to design a new control panel and a new PLC control program. The control unit connects all different systems of DASH; and the PLC inside the main cabinet converts asparagus positions of the IPP into motion schemes of the harvesting tool. The new designed remote control can be used be the operator of the machine to move AutoSpar while in manual-mode onto the field and between dams.

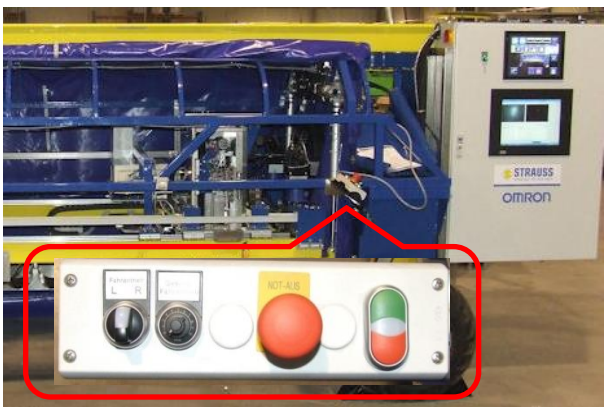


Figure 9 Control panel and remote control of DASH

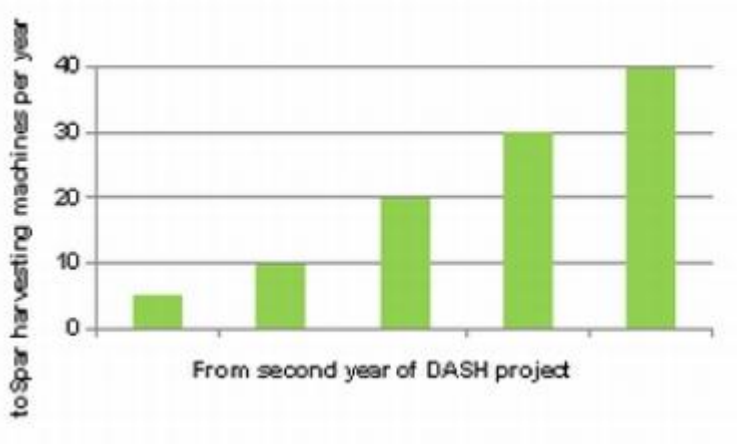
Throughout demonstration and testing activities the performance of implemented technologies was validated. The following table summarises the success of DASH S&T results:

Issue	Descriptions	Success
Stable behaviour of the carrier unit	The vehicle follows the dam and the foil is lifted and replaced even under windy conditions	
Asparagus detection and IPP	Success rate of asparagus detection has been 70% indoor even up to 100%	
Stable behaviour of the data communication	The PLC control program and the communication between the PLC and the IPP performs without malfunctions	
Height measurement	The height and horizontal adjustment function with 100% reliability	
Cutting tool	The asparagus stalks were cut with success rate of 60% to 90% depending on dam quality	
Gripper / Lifting tool	The gripper was successfully tested under real field condition with a success rate of 80%	
Overall machine	The harvesting success of the new AutoSpar prototype still depends on the quality of dams. Under best conditions it reached a harvesting success rate of about ...	**80%**

4. Potential impact, dissemination activities and exploitable results

Potential impact

The overall outcome of the DASH project is the new AutoSpar prototype which has reached a functionality of 80% (see table above). Bearing in mind the comment made by the industrial partners of DASH that a machine is always only advertised/commercialised when fully functional (95% harvesting success rate), it is clear that the current prototype still need improvements before it can generate commercial success. The main beneficiaries of latest developments are the SMEs STRAUSS and IMIX, who agreed already to meet again for planning possible next steps for the exploitation of results; however, the potential impact cannot be estimated more precisely at this stage compared to the beginning of the project. This is also reflected in the business plan in which the 'operational plan' could not have been worked out at the end of the DASH project.



However, there is still realistic hope that through further improvements and testes by STRAUSS and IMIX the machine reaches commercial status within the next two seasons (2016 and 2017), and that estimated sales of up to 100 machines within the following 5 years still can be reached.

Dissemination activities

During the entire duration of the project the consortium was active in trying to raise awareness of ongoing developments and demonstration, always pointing out that the machine was still under development and not at commercial status. TTC presented the DASH project at the Innovation Forum event in 2012 and 2013 in Bucharest to an international audience, ensuring thus awareness raise in Eastern Europe. In 2013, 2014 and 2015 the team of TTC also discussed the opportunity of Asparagus cultivation in Romania with various farmers present at the Agraria fair in Cluj-Napoca, Romania. Furthermore, partners were contacted by the press which published several articles and interviews in the local media such as (i) an article in a Dutch magazine called 'Mechatronica & Machinebouw' in February 2014, (2) an article in a German magazine called 'Die Zeit' in April 2015 and (3) an interview with BZN in a German radio channel called 'Radio Karlsruhe' also in April 2015.

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Exploitable results

From all implemented technologies as described above, the following superior technologies have been identified as exploitable results:

No.:	Exploitable Results + Knowledge	Type of IPR protection	Owner & Other Partner(s) involved
1	Inner frame – able to adjust horizontally and to the height of a dam	Knowledge	STRAUSS
2	System to use the camera connected to the harvesting tool while scanning and to disconnect the camera during harvesting	Knowledge	STRAUSS
3	Improved illumination system	Knowledge	IMIX
4	Stereo set-up and calibration procedure	Knowledge	IMIX
5	New control program (PLC based)	Knowledge	STRAUSS
6	Completed carrier unit	Knowledge	STRAUSS
7	Integrated 'scene shifter' for harvesting tool manipulation	Knowledge	STRAUSS /UNIHB
8	Gripping/lifting tool for asparagus stalks	Knowledge	STRAUSS