An Information Based Systematic Design Method for Robotics in Greenhouses

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Abstract

The paper presents an information based systematic design method for robotics in greenhouses. The method was used to develop a de-leafing robot in a period of one year with a limited budget. This robot is used in this paper as a design example. This approach proved to be a success. The design methodology enabled the efficient design of a complex machine. Bottlenecks were identified at an early stage. The methodology produced insight into design alternatives, thus limiting trial and error. Within one year the de-leafing robot was tested in a greenhouse, with success.

INTRODUCTION

Labour is with 30% of the total production cost the largest cost factor today of a modern greenhouse holding. This percentage is increasing. De-leafing of cucumbers grown in a high wire cultivation system is a tedious and time consuming job that does not produce any direct income for a grower. Automation of this job would reduce the production costs. For more details refer to the companion paper of van Henten and van Tuijl (2004). The aim of this paper is to present the design methodology used to build a de-leafing robot.

Our aim was to design, build and test in one year, with a restricted budget, a functional model of a de-leafing robot for cucumbers. Within these limits, there is little room for trial and error. With this in mind a systematic approach had to be used to increase the chance of a successful design. This paper describes how system design and sensor information flow is combined to a useful design method for the design of an agrobotic system.

MATERIALS AND METHODS

Using a Design Method

Why use a design methodology in the first place? In the industrial age designers have many tools (2D-3D CAD software) to aid them to efficiently make technical designs in a short period of time. But technical changes are going fast and technology is becoming more and more complex. Also sustainability and environmental issues have become important design issues nowadays. A product design diagram or PSD shows the basic factors that are linked within a technical design nowadays, Fig. 1 (Pugh, 1999). There are some subtle differences between industrial design and design for research applications that are shown in Fig. 1. Research produces usually what is called a functional model and during the design process aspects like aesthetics are often left out. Using a design method ensures that a broad range of aspects of designing technical systems are dealt with during the design process. (Kroonenberg, 1999). The structured design approach:

- Prevents jumping too quickly to a solution while not having looked into the overall problem seriously,
- Produces a good overview of the design requirements,
- Reduces the chance of overlooking some essential requirements,
- Identifies bottle-necks at an early stage,
- Offers insight into design alternatives,

- Offers a basis for sound decisions during the design procedure,
- Increases the chance of an effective design result.

Experience has learned that costly trial and error processes often occur when not using a design method.

Existing design methods are mainly used and constructed with an industrial environment in mind. Many machines operate in these environments with less sensors in comparison with agricultural automated machines. Mainly because of the predictability and the possibility to mould and use the work environment to benefit the machine. This is very different in a greenhouse where the robot is confronted with different scenes over and over again and not one plant is the same. Because of the highly unstructured crop, a lot of sensor information is needed to successfully guide a robot in this complex environment and to have a sound performance, (van Henten et al., 2002, 2003). This gathering and use of sensor data becomes important part of a robot. How data is gathered and used within robot systems is frequently left out of many design methods. With the design method used this gathering and use of data becomes an important aspect within each and every step during the design process. Our approach will be illustrated in the next paragraph.

A structured design method does not turn a bad designer into a skilled designer. A structured design method forces the designer to think before acting.

Developing the Design Method

At the beginning of 2002, the research team stated a goal to build a working prototype that would prove that automatic de-leafing of cucumber plant is feasible in a high wire cultivation system. During the design process the following subjects from a methodological design method were used:

- List the specification of the desired product (weight, speed, shape etc.).
- Make a system analysis (function, work space).
- Draft development (identify multiple mode of operations by functions).
- Identify critical technical bottlenecks.
- Feasibility test of critical technology.
- Quantitative evaluation of concepts.
- Build a functional model to test the feasibility of the whole system.

Designing the System by Using the Design Method

Designing a system begins with a clear system definition and step by step a more detailed definition is generated until at the end the system is described at component level. Or to put it differently, at each step the resolution of the system description is increased. The first, low resolution, definition of the de-leafing robot is a virtual system in which information, energy and material is used as an input to the system. The output, over a period of time, is a removed leaf from the plant. The design activities create a system that makes this conversion possible. The next step will be the definition of the required functions to perform the desired task: a so-called function analysis. This is illustrated in Fig. 2 for the de-leafing robot. To remove a leaf with an autonomous electro-mechanical system, a few questions have to be answered and those are found as follows. By picturing a virtual system in mind you can do a mind exercise by asking which steps have to be done to pick a leaf. Step by step the following line of reasoning was constructed to fill in the non existent empty system:

Since there is no information in the system first some detection is needed of a characteristic out of the environment to successfully make a next step, in this case the used question is: "*what do or can I detect*". When using this information to reach out into the environment the next question could be: "*where do or can I go to*". When arrived at that point: "*what do or can I grasp*". If a useful part of the plant can be grasped: "*what can I separate*". If this leads to a separated leaf the last questions are: "*how do I transport and buffer the leaf*" need to be answered. During this mind exercise a map was used/generated as shown in Fig. 3. Note that not necessarily every step needs to get an answer. Also “nothing” can be a valid answer. The method can lead to two sequential steps if a line of reasoning comes to an end in the middle of the map, as illustrated in Fig. 3. Line I stops after the answer: “*what will I hold*?”; *the plant stem*. At this point in the map the leaf stem has not been reached and the sequence starts anew with the first question: “*from where do I start detecting*”. Note that answering all questions stated above will yield a conceptual system description of a de-leafing robot.

Alternative answers to the questions posed in the previous steps may result in different systems. Combining various answers results in different conceptual system descriptions. In case of the de-leafing robot, 9 different systems were found. One of them was selected on the basis of a collection of objective criteria not further described in this paper. The system that was actually build, is drawn into the map of Fig. 3 with dotted lines and can be described as follows:

- Step I: From where do I start detecting? : detect from the system.
    - What do I detect? : detect the plant stem.
    - Where do I go to? : go directly to that plant stem.
    - What will I hold? : grasp the plant stem, end of line I.
- Step II: From where do I start detecting? : detecting from the tool.
    - What do I detect? : a leaf stem while moving upwards along the main stem.
    - Where do I go to? : go to and grasp the leaf stem.
    - What will I hold? : grasp the leaf stem.
    - What will I separate? : cut the leaf stem.
    - How do I transport it? : use gravity to convey the leaf.
    - Where do I store it? : on the greenhouse floor, end of line II.

Adding the Information Layer to the System

During the design of the system the designer was asked to specify the usage of information by each step in the design of the system. Finding a leaf stem is much more difficult because of the orientation in three dimensions and the variation in shape. As an example, compare finding the main stem of the plant with finding the leaf stem. By using the plant stem to find the leaf stem many difficulties at detection level have been overcome. The build system requires to find a plant stem, a description of that information is a vector with a known start point X, Y, Z. This helps to choose the right sensors when the more technical side of the system has to be designed and to identify sensor bottlenecks.

From the design procedure surprisingly followed that, to deal with the considerable biological variability in the working environment of the robot, an automated de-leafing procedure for cucumber grown in a high wire cultivation system, should first find the main stem of the plant and then move upwards to find the leaves. This contradicts human operation. Humans tend to grab the leaf and move their hand along the leaf stem before breaking the leaf from the plant.

Filling in the Technical Side of a System

When at system level a few promising systems have been composed a morphological map is generated using brainstorm sessions, literature and internet surveys and personal technical insight. The morphological map contains technical alternatives for every function. For every step at system level the techniques found are filled into a matrix, see Fig. 4. This map is used to weigh techniques in comparison to each other and for future reference might a technique fail to work. Some of the identified bottleneck or unknown techniques were tested in straightforward set ups.

Linking the System Map with the Technique Map

At this point two maps have been made that combined give a complete plan to build a de-leafing robot. The maps are combined into a string of symbols that once linked together display the complete system. The iconic display of the system is given in Fig. 5. Table 1 lists the successive actions of the system given in this figure. This iconic reproduction is useful as a presentation tool and to check the logical course of the system.

RESULTS AND DISCUSSION

Fig. 6. shows at the left the developed tool for the de-leafing robot and the total system at the right. The icons show how the separate design features are materialised. This system has actually been build and tested in a greenhouse at Agrotechnology and Food Innovations ltd. (formerly know as IMAG ltd.). Furthermore, it was concluded that the de-leafing robot, to a large extent, could be based on the mobile platform and constituents of the cucumber-harvesting robot. Refer to van Henten et al. (2002a,b) for a detailed description. The most important adaptations are the end-effector and the imaging software to find the stems of the cucumber plant.

The design technique has helped us to design this particular de-leafing robot in a short period of time within a limited budget. Bottlenecks were identified at an early stage and the methodology produced insight into design alternatives, thus limiting trial and error. It brought structure to the design process at system level. Another advantage of using a design method is to give managers insight into the design process and confidence in a successful outcome.

ACKNOWLEDGEMENTS

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Tables

Table 1. System defining actions 1A to 1H and 2A to 2J and their meaning. A bold " I" indicates where, when and how information is used within the system.

Number	Action.
1A	Start detection from the system.
1B	Detect the plant stem.
1C-**I**	Information needed: start and end coordinates that make up a vector in 3D space.
1D	Use digital camera technique to get this information.
1E	Go to the start point of this vector.
1F	Go directly.
1G	Use a robot to reach this point.
1H	Grasp or hold at this vector point the cucumber stem.
2A	Start detection from the system.
2B	Detect the leaf stem.
2C-**I**	Information needed: detect a leaf stem at one point around and away from the main plant stem.
2D	Use a disturbance of an electromagnetic field to detect this point.
2E	Move to this point.
2F	Hold or grasp this point with a comb-like structure.
2G	Separate the leaf stem and attached leaf.
2H	Use heat to separate the leaf stem and attached leaf from the plant.
2I	Use gravity to transport the leaf stem and leaf.
2J	Store the leaf on the greenhouse floor.

Figures

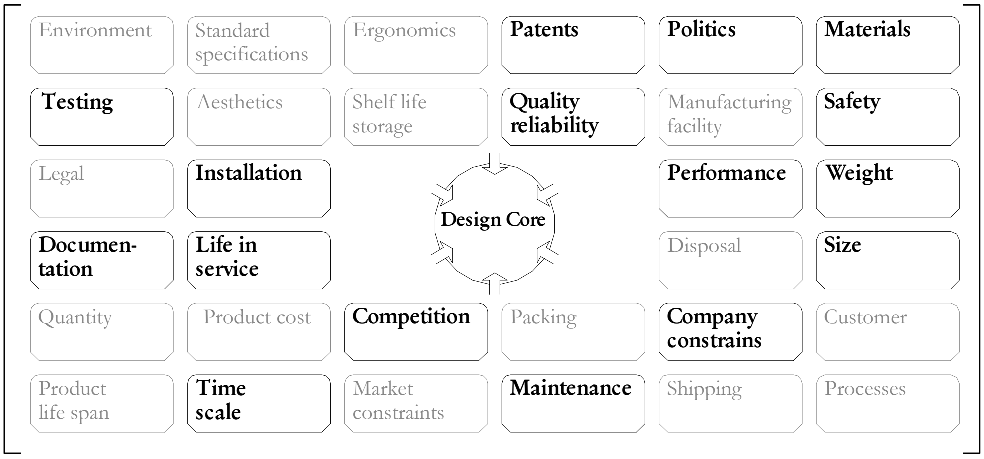


Fig. 1. The elements of a product design specification or PSD, designing a research application does not necessarily take every element into account. Those in black are in a research application the most important elements (S. Pugh 1996).

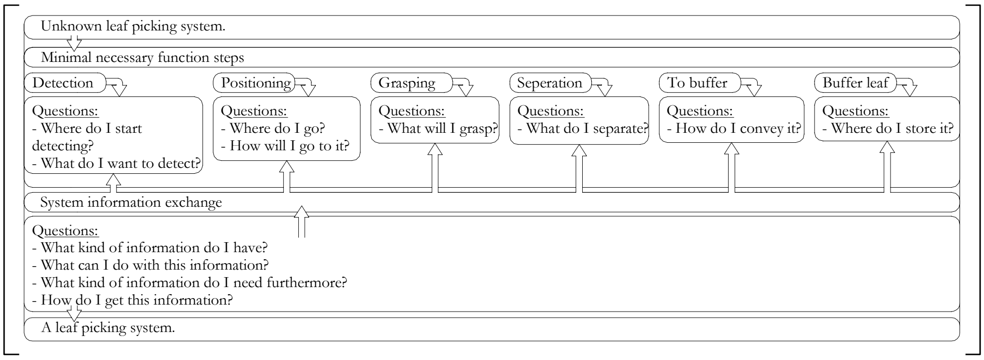


Fig. 2. A system design map for the de-leafing robot to analyse the minimal functions of the system.

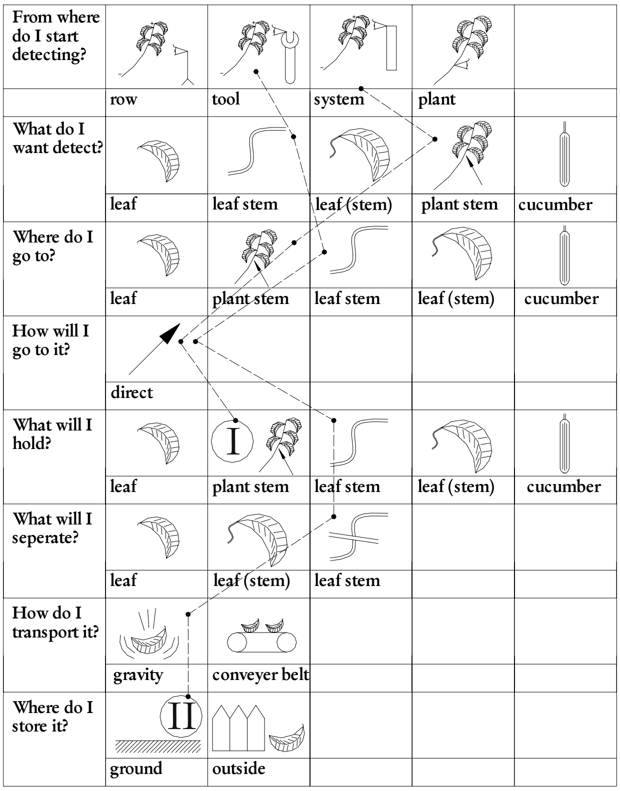
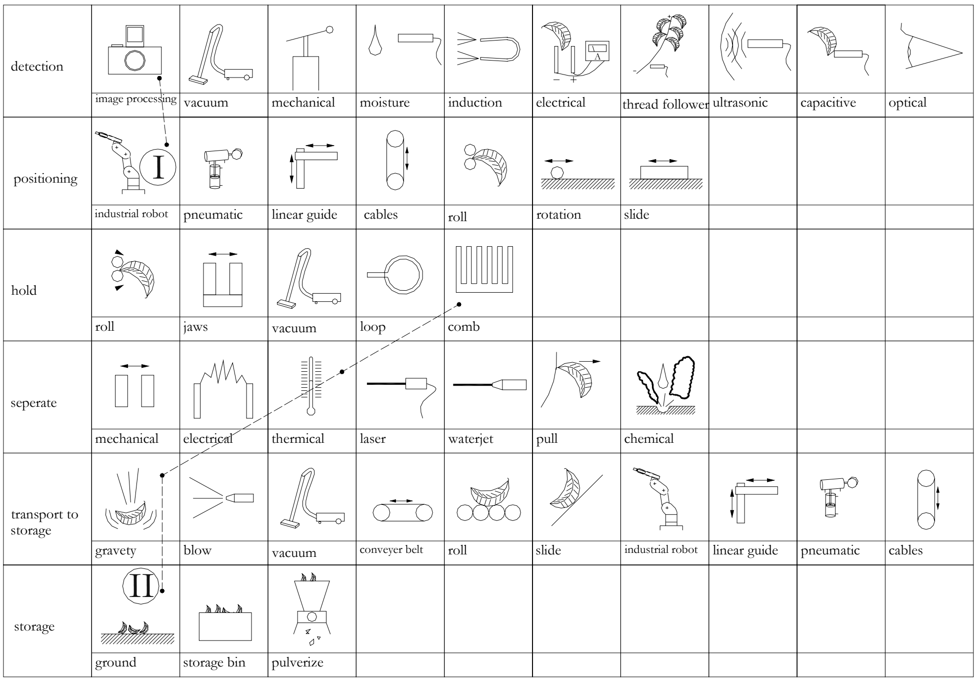


Fig. 3. A choice matrix, by linking the pictures a system is designed. By this many systems can be made up and evaluated on paper.



detection	image processing	vacuum	mechanical	moisture	induction	electrical	thread follower	ultrasonic	capacitive	optical
positioning	industrial robot	pneumatic	linear guide	cables	roll	rotation	slide			
hold	roll	jaws	vacuum	loop	comb					
seperate	mechanical	electrical	thermical	laser	waterjet	pull	chemical			
transport to storage	gravety	blow	vacuum	conveyer belt	roll	slide	industrial robot	linear guide	pneumatic	cables
storage	ground	storage bin	pulverize							

Fig. 4. A chart with practical solutions to technically fill in the system parts shown in the left column. The dotted lines I and II indicate the used techniques from the choice matrix in fig. 3.

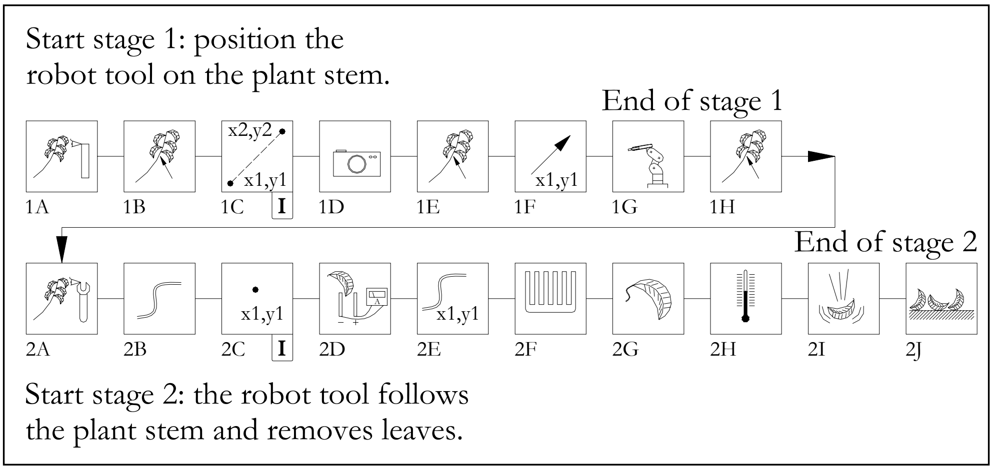


Fig. 5. The iconic flow diagram of a complete de-leafing system.

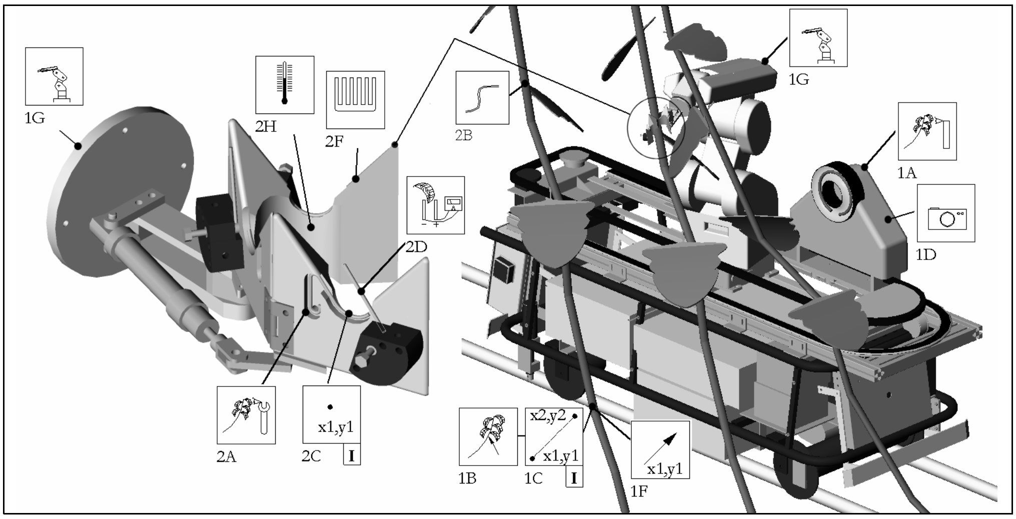


Fig. 6. Left: the developed tool for the de-leafing robot and the total system at the right. The icons show how the separate design features are materialised.