PicknPack

D5.3 – Report on robot performance and lab test results

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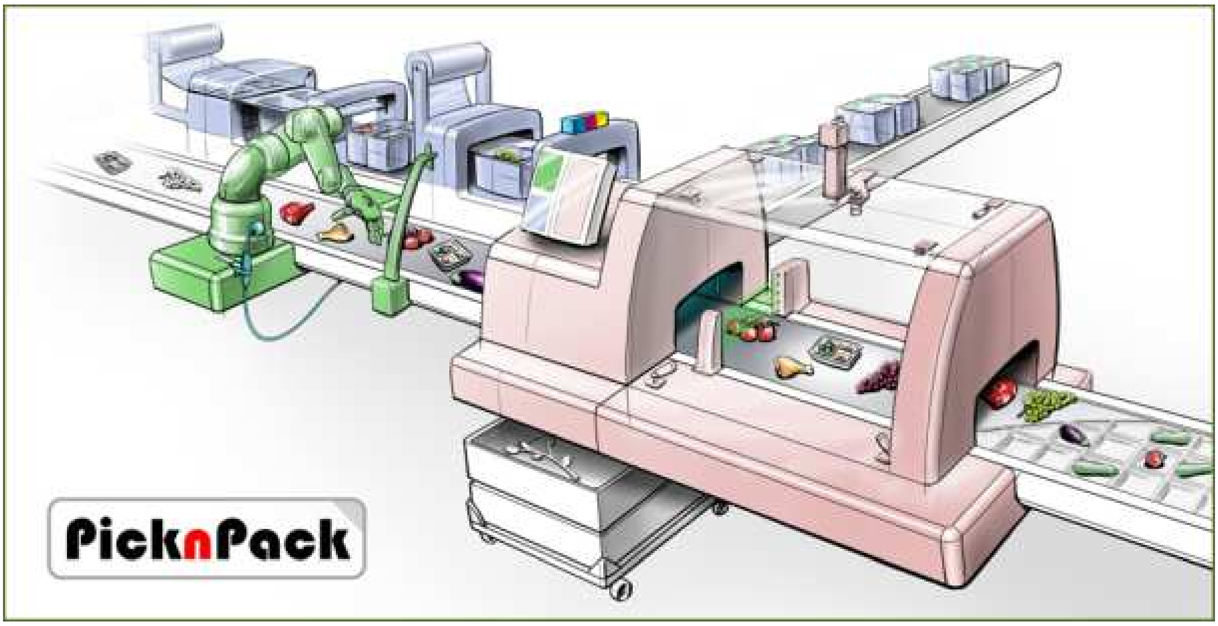

Flexible robotic systems for automated adaptive packaging of fresh and processed food products

The research leading to these results has received funding from the European Union Seventh Framework Programme under grant agreement n° 311987.

Dissemination level		
PU	Public	X
PR	Restricted to other programme participants (including the EC Services)	
RE	Restricted to a group specified by the consortium (including the EC Services)	
CO	Confidential, only for members of the consortium (including the EC Services)	

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1 Introduction

This document is a deliverable for the Pick and Pack project, in addition is the third one for the Workpackage 5. As it includes the improved design and testing results on novel developments, it is considered to be confidential and only members of the Pick and Pack consortium are allowed for its distribution.

Current document is divided in several parts regarding the submodules which complete the complete WP5 robotic module.

Regarding the cable robot, the results of the test are showed, two main goals must be accomplished. The former is the test of the individual parts (winches pulleys, platform and so on) which complete the manipulator. The latter is the evaluations of its dynamic behaviour. A similar view is presented regarding the IPL robot. Also results on the performance on the machine vision system are included and the integration of this system with the robot. Different kinds of grippers have been considered in the scope of the Pick and Pack project. One gripper for tomatoes, another one for grapes and finally another one for closed packages. The performance of all these grippers is also considered in this text. During this period of time clean-ability tests have also been carried out in The United Kingdom and their results have also been presented.

2 Modules performance

2.1 Cable robot submodule

2.1.1 Implemented design

General view of cable robot

The global design of the cable robot was finished and sent to Fraunhofer on 15th March 2014.

In this design the seals were still not integrated: Screws will have a seal and will be hexa head and nuts will be sealed and closed off.

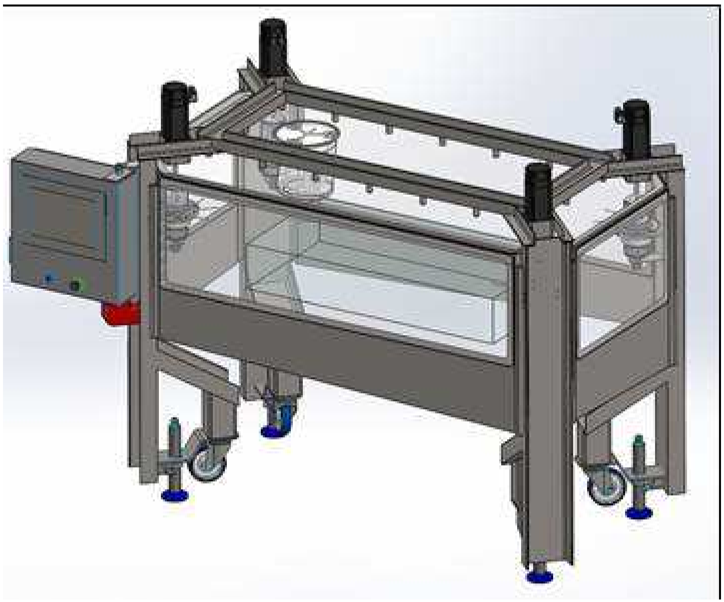


Figure 1: General view of cable robot

Frame and support plane

The frame and support plane is composed by:

- Plexiglas support plate maintained by U shaped frame held by screws
- Lateral windows of Plexiglas fixed tightly to an U shaped frame weld to the main frame.
- Pillars which support the top frame
- Median frame weld to the pillars to provide tightness of the Plexiglas

Figure 2: Detailed view of frame and support plane

Winch

In this design the motor is fixed and the drum are on a linear rail and moving along with the winding of the cable thanks to lead screw, by this way the cable takeoff point is always at the same position. The drum shape is made in SLS plastic and outside is covered of epoxy varnish to make it tight.

The mechanism with the rollers does not move so it keeps the cable onto the drum, although cable can completely uncoil from the drum for a suitable cleaning through a seal that keeps the inside of the drum tight.

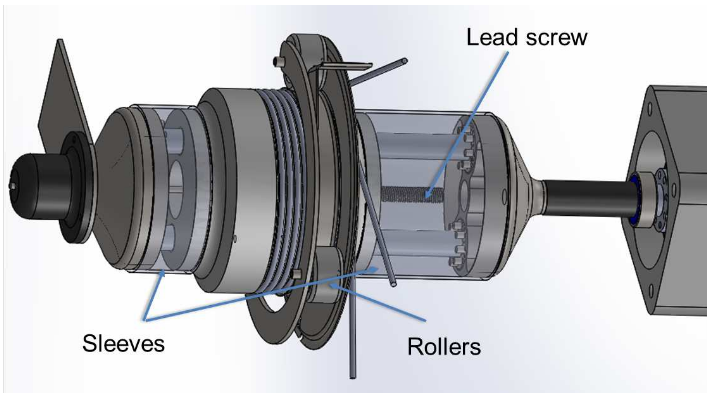


Figure 3: Detailed view of winch

Plattform with Omniballs and vacuum chamber

The support plate is machined and made by POM, has got hexapod structure and is sealed by a seamless sleeve forced on the extrusion. The plate is used to cover a set of channels machined in the plastic to direct the flow of cleaning agent towards the balls to clean them.

The mechanism for the Z translation and rotation is inside the sealed volume, sealed downwards by wiping seal and V-ring.

In the following image is missing the tool changer detailed design and the orifice for venturi cartridge.

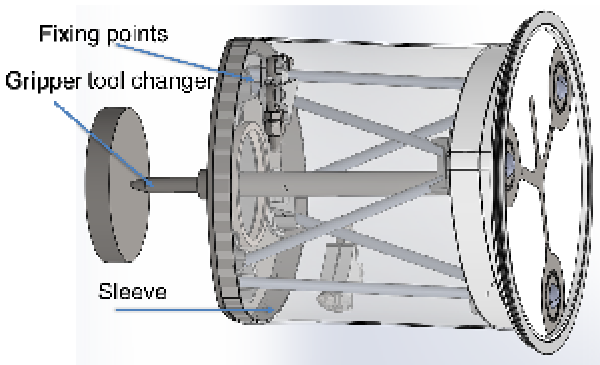


Figure 4: Detailed view of the platform

Safety considerations

The cable robot is composed by a vacuum chamber that could fall down over the food and breaks in case of air failure. For this reason, it is included a pressure switch to detect loss of pressure in the general air, and one accumulator to feed the vacuum chamber for at least 5 second in case of air failure, enough time to allow the mobile platform to achieve their security position.

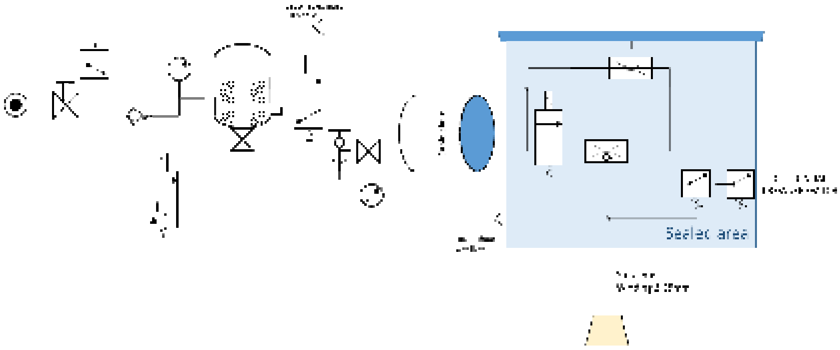


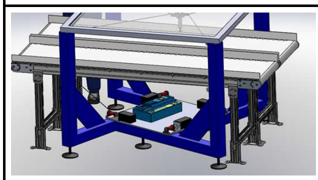
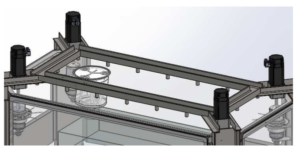
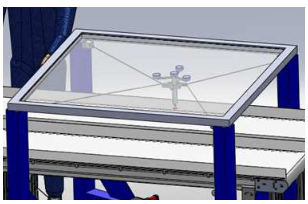
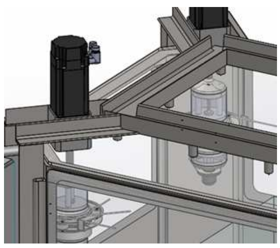
Figure 5: Pneumatic draft

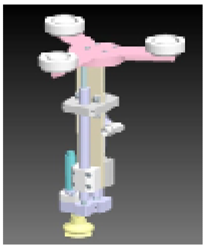
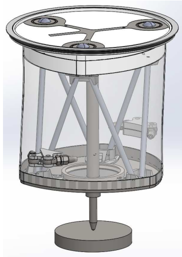
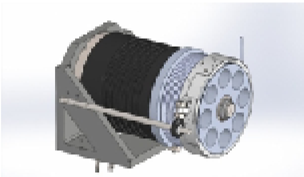
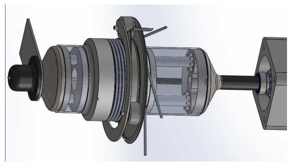
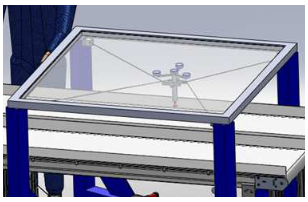
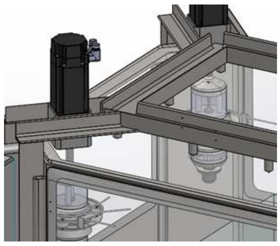
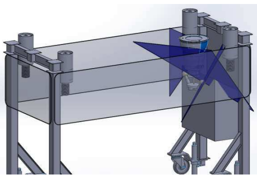
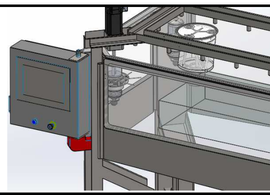
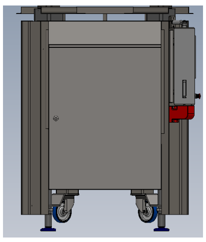
Budget considerations

There has been a deviation between the scheduled and the spent consumable costs. Dis is due to the complexity of the complete new development of an innovative product like Pickable. Apart from the machining parts, there has been an over budget due to the general electronic peripherals, the conveyor, the pneumatic storage components , the two industrial PCs, the specific training and the machine vision systems. Some of these modules (gripper, conveyor machine vision) were not considered in the proposal of the project to be bought by Tecnalia.

2.1.2 Improvement on hygienic issues

During the project, Fraunhofer has given some suggestions and different corrections of the initial design regarding hygienic issues. In the following table are summarized the main problems he presented and how they have been solved.

Old design	Hygienic suggestion	State	Updated design
	Put motors on the top of the frame	The implemented robot has motors on the top of the platform	
	The top of the frame must not have flat surface to be drainable	The implemented robot has slightly inclination on the top of the frame	

	Air bearings are not hygienic due to pores size.	A new system with a vacuum chamber and ball-bearings has been implemented	
	Cables must be completely cleaning so they should be unrolled from the winch from up to down.	Cables can completely uncoil for a suitable cleaning in the implemented robot	
	It is preferable to use stainless steel for the top plate. Omniballs might wear off the Plexiglas and small particles can fall on the product.	The implemented robot has got Plexiglas top plate, but it will be stainless steel in the food grade design	
	The control cabinet must not be inside of the module to avoid spray shadows	The control cabinet is outside the frame in the implemented robot	
	Industrial cable chains are not good regarding cleanability. The use of a hose drum or Rolatube could be a good alternative.	For the demonstrator a typical industrial chain will be use, but the hygienic design includes Rolatube solution	
	Pneumatic connectors must be made of stainless steel. Brass is not resistant against acids and alkaline solutions.	Stainless steel (not necessary FDA) connectors will be used in the pneumatic-electrical connections.	
	Since the pneumatic cabinet is not inside the module it should be suitable for the demonstrator if it is IP65.	A pneumatic wardrobe with IP66 (more than necessary) will be used for the demonstrator.	

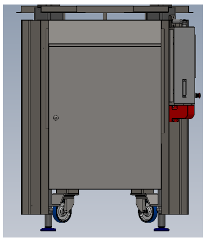
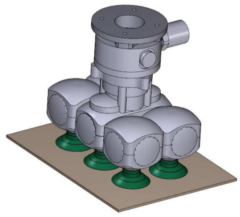
	The electrical cabinet should be IP69 for a washable cable robot.	No commercial cabinets of the required size with the required IP, so an electrical cabinet of IP55 will be used for the demonstrator	
	Suggest the use of POM or PTFE as FDA materials to reduce the weight of the gripper	Bridle made of Anodyzed Aluminum, body of the gripper made of PSU and PPSU (suitable for foodstruffs) and suckers made of Silicon SI (FDA)	

Table 1: Summary of recommendations regarding hygienic issues

In any case, cleanibility tests are recommended for the relevant design features in order to prove the hygienic design or to define measures for further improvement or to give more application recommendations.

2.1.3 Lab test results

Verifying air bearing behavior on different surfaces

The objective of this test was to verify the behaviour of the air bearings on different surfaces with different qualities (marble, steel, Plexiglass) measuring the detaching force.

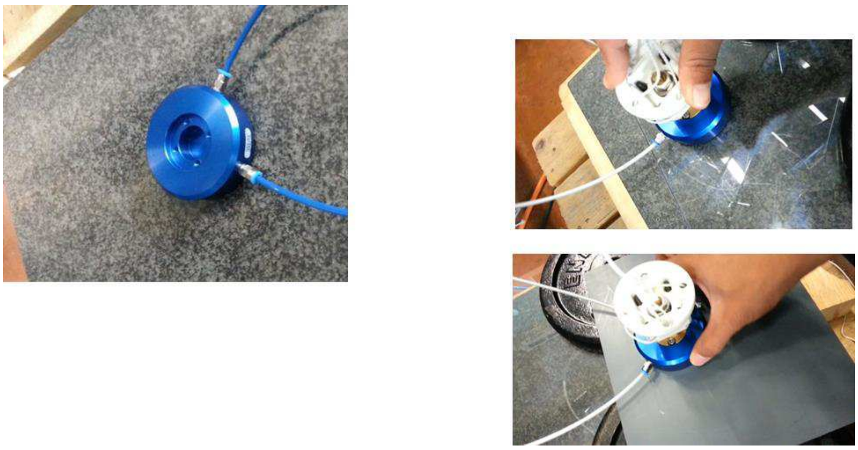


Figure 6 Air-bearing tests (static, difference surfaces)

Following image shows different behaviors on surfaces with different qualities.

Figure 7 Preparation of different surfaces (thin plates)

Following image shows polishing operations carried out in Tecnalia in order to check the behaviour in different prepared surfaces.

Figure 8 Preparation of different surfaces

Detached forces were worked out as shown in following image.

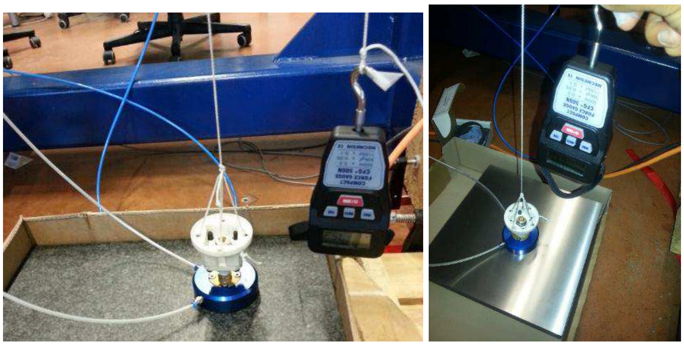


Figure 9: Test of air bearings behaviour

The following table shows the results obtained in function of the material, air pressure and vacuum supply. We concluded that the detaching force greatly varies with the air pressure and the vacuum supply. The material surface has got less dependency within an expectable range. By this reason, the material will be considered in the application recommendations of the robot depending on the customer requirements.

Suppy pression		Marble		Steel		Plexi Glass		
Pressure (Bar)	Vacuum	Detaching force (N)						
5	7	104	103.6	107.3	103.2	101.5	100.7	101.1
5	6	98.2	99.9	94.4	94	92.4	97.4	95.7
5	5	90.7	91.1	81.1	82.4	82.4	82.8	81.1
5	4	78.6	75.3	72.4	71.6	69.1	66.2	67
6	7	96.5	96.9	92.8	94	96	104.4	105.7
6	6	91.1	90.4	86.6	87.8	95.3	94	99
6	5	78.2	76.6	74.1	72.4	81.5	80.7	77.8
6	4	64.6	64.5	59.5	59.1	66.6	64.5	64.5

Table 2: Results of static air-bearing test

Verify dynamic air bearing behavior

The objective of this test was to verify the proper behavior of the air-bearings in required motion condition and under different loads. To achieve this goal were used a Quattro Robot and a preload spring system between the robot end-effector and the air bearing to limit the load on the air bearing to an acceptable level.

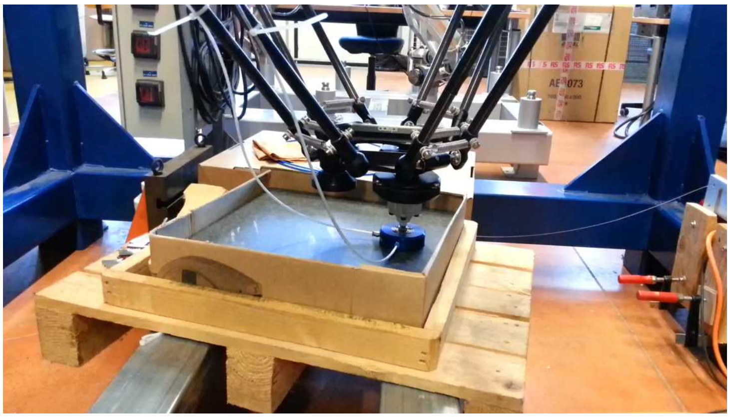


Figure 10: Test of dynamic behaviour for air bearings

Although the results of the test were successful, the air-bearing are not hygienic, so a new vacuum cup (to guarantee planar constraints) plus three Omni-balls (to warrantee the displacement) was designed to replace the air bearings.

Verifying mobile platform

By means of the vacuum cup and the omni ball system, the kinematic behavior of the mobile platform was tested. The results of this test showed a good relationship between vacuum and sliding, allowing a fluent movement of the mobile platform with high detaching forces.

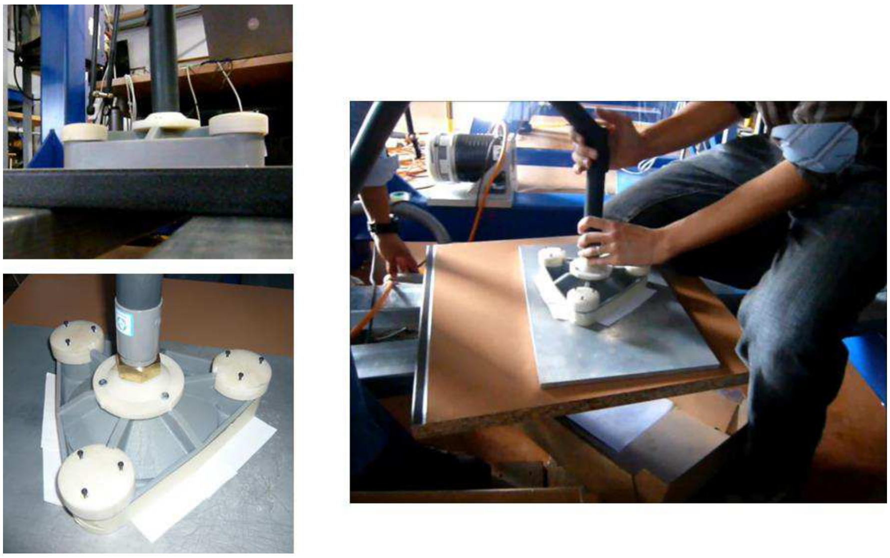


Figure 11 Testing the mobile platform

Verifying the cable guiding system

For this robot is critical the behavior of the cable guiding elements such us motors, drums and winches. The feasibility trials concluded that is possible to control the length of the cables (by rolling and unrolling them) and therefore the mobile platform position with a accuracy of 1mm, which fulfils the requirements presented on D5.1"Report on system requirements" document.

Figure 12 Testing individual parts

Verifying the dynamic behavior of the complete robot configuration

The objective of this test was to verify the new developed concept of vaccum cup+omni-balls regarding attaching force and movement issues, verify the cable's proper behavior under high dynamic winding and unwinding conditions, as well as to verify the design of drums and setup of pulley in required motion condition and characterize the functioning limits of a winch (minimum required cable tension for ensuring good winding and maximum speed).

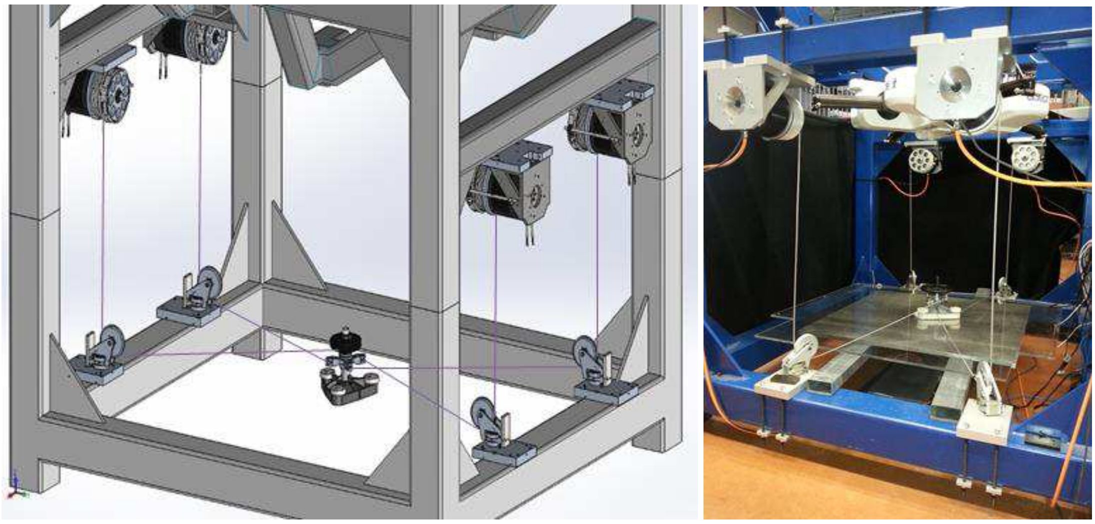


Figure 13: Test bench for the test of cables, drums and winch behaviour

The dynamic tests showed following main results: The maximum speed was 4,5 m/s. with a maximum reached acceleration about 4,5 g. With this behavior it is relatively easy to achieve the PicknPack promise of 30 picks per minute or even more. Taking into account the working area of the cable robot and the results of the dynamic behavior, a cycle time of about 1.5 seconds is expected.

2.1.4 Control and communications

For the management of the robot, the vision system PC will behave as master in the cable robot module. It will communicate with the general line and will configure the robot behavior depending on the received information of the line by Ethernet communication.

The robot controller will manage the kinematics of the cable robot in order to reach the pick and place positions, will continuously inform to the vision system PC about their own state and their peripherals and will manage the conveyor and the change of boxes signals based on the information received by the vision system.

In order to plan and control the movement of the cable robot is necessary to compute the forces and torques of the engines that manage the length of the cables to provide the desired position of the end effector with the required speed and acceleration. The control of the motors will be driven by an ETEL position controller.

The following image shows all the required signals to communicate the cable robot module with the complete line as well as with peripherals (camera, gripper, conveyor…). For more information please consults WP2.

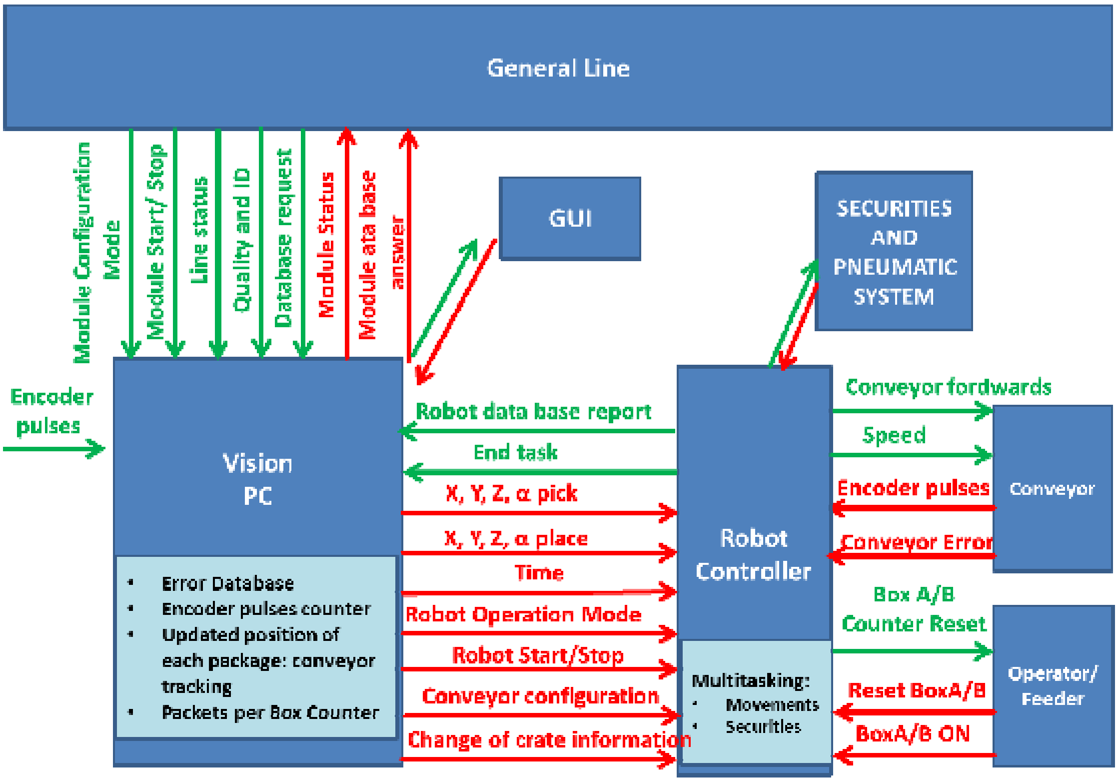


Figure 14: Internal and external communications of the cable robot module

2.1.4.1 Operation modes of the robot controller

Different operation modes have been defined for the configuration and control of the cable robot. Depending on the information received by the vision system PC, the robot will automatically self-configure to operate based of the following operation modes (additional tasks could be added if required):

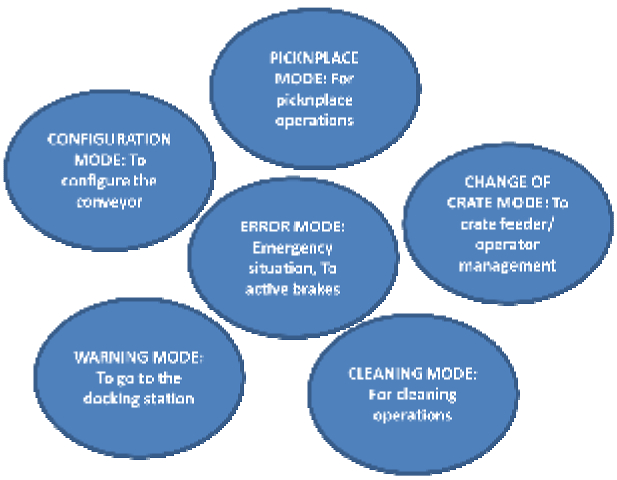


Figure 15: Operation modes of the cable robot

Configuration mode: The vision system will send to the robot a message for the configuration of the module. This message usually will be sent at the start, right after communication between vision and PC is established, but it could be also possible to use this configuration after a warning or error mode. From now, this message will only contain information about the conveyor configuration. There is not necessary information for the gripper because from now there is only one. The robot will block all the doors and will go to home position.

PicknPlace mode: Normal pick and place operation of the robot. If all is OK, the robot will go to a “ready position” (fixed position). The vision system will send a message that contains coordinates and time, the robot will reach the pick position with the pick orientation in the ms provided by the time, will switch on the gripper, will go to the place position and will switch off the gripper.

Change of crate mode: The vision system will keep track of the packets in each box. When one box is full, the vision will send a message to the robot with the type of box to be changed. The robot will go to a “not disturb” position out of the crate zone, will unblock the crate door so the operator has got access to the crate zone (security reasons), and will inform to the operator with a light to change the crate. When the vision system PC checks that the Box is in the correct position and the operator has finished the task it will send a new message to the robot and it will block the crate door and will go to the ready position.

Cleaning mode: The robot will implement fixed movements in order to the water reaches up all the points of the robot, and finally it will go to the home position and will inform to the vision system.

Warning mode: When there is a warning situation, the robot will go to the docking station. This mode will be generated by the robot, not by the vision system (for example when the robot checks that the pressure in the docking station is not in the desired range, it must change the configuration mode to warning mode).

Error mode: When there is an error in the cable robot module that inhibit the normal operation of the robot, it will switch on the brakes of the motors (stop the movement of the robot), stop the conveyor and unblock the frame door (securities reason) for the manual movement of the robot if necessary. This mode will be generated by the robot, not by the vision system (for example when the temperature of the motors is above the limit and a movement can cause breakage, it must change the configuration mode to error mode). This mode must interrupt the operation of the other operation modes.

2.2 IPL robot submodule

2.2.1 General description

This module has completed the full electrical and mechanical design, manufacture and assembly including the addition of the weigh cell. Electrical communications hardware is designed into the unit for interfacing with the other planned modules. HMI unit is powered up and running with basic software. Product program memory is built in for fast change-overs between products. Operator manual and CE Certificate is generated and is kept with the machine.

Figure 16 IPL robot

The complete unit has been tested for CIP cleaning at the Holbeach UKCFM facility.

Figure 17 IPL robot

Design and manufacture of the machine vision system has been finished. Cables for the Camera's are already installed ready for the Camera's to be mounted. Ethernet port is assigned in the robot control system for the Vision system communications.

Figure 18 IPL robot

Quick release coupling is installed ready to receive the Lacquey gripper. A selection of Electrical signals, Pneumatic valves and disconnect plug are installed in the Gripper connection box near the top of the unit. This will hopefully drive the needs for both the Electrical and Pneumatic powered grippers from Lacquey.

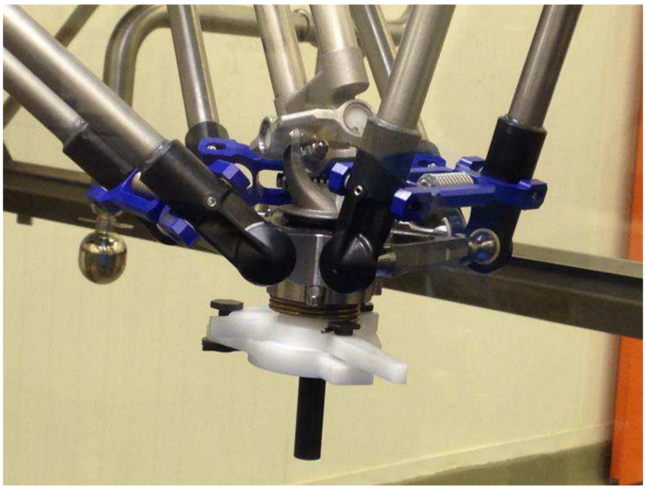


Figure 19 Fast gripper changer

Ethernet port is defined for communications to the master line controller. RFID reader head is installed in the infeed tunnel of the module, ready to read the RFID tags on the incoming crates. 3 blue and 3 green crates are purchased to allow basic testing of the complete unit with Food product. The Marel M1100 weighcell control module is mounted and has the Ethernet connection port wired into the main control cabinet ready for communication directly with the master controller. The CIP system is installed and recently tested.

2.2.2 IPL software

The software for the robot is on two platforms one controls the machine and the second runs the graphical user interface (GUI) software and in the future the vision software.

- The robot controller is based on a PLC (Lenze) running a structured text program according to IEC 61131-3 which is the international standard for programmable controllers. All the transformations from angular movement to Cartesian Co-ordinates as well as the motion programs are handled on this platform. These movements are sent from this platform to servo controllers of the same manufacture.
- The GUI uses a program called Visiwin supplied by Inosoft based on the Microsoft Visual Basic platform and performs all the recipe selection, parameter changes and storage as well as being able to store production data. The hardware is an Windows 7 embedded computer specially manufactured for the harsh environment of the food industry. The computer has no fans or cable harnesses and utilises a solid state hard-drive. Being an "embedded" system it does not require uninterruptable power supplies for safe shutdown, and will always reboot with a viable system.

2.3 Grippers submodule

2.3.1 Grippers design for IPL robot

Two grippers, one electric for fresh food and one pneumatic for chicken breast were developed and tested.

The electric gripper contained a hook to initially pick the tomatoes by the stem using the following strategy (more details on deliverable "D5.2 Design report on robotic module"):

- Gripper is located above the product
- Gripper is moved downwards (to position the hook)
- Gripper is moved sideways (the pick the tomato by the stem with the hook)
- A row of fingers is rotated downwards (the product is grasped also with the fingers).

This gripper with the described strategy was tested in combination with a vision system, but the results were not as expected because the tomatoes were in too many cases not free enough to grasp. For this reason the design of the gripper has been modified, the hook has been removed, a servo motor has been included in the gripper instead of a DC motor (which allows more control on the aperture of the fingers) and a new grasping strategy has been defined.

Now is possible to grasp vine tomatoes from the top by adapting the gripper opening to the tomato, displacing the tomatoes inside the bin to a free location and finally grasp the tomatoes. It is possible to do this in all directions, and the stem is not necessary anymore. With this strategy is possible to pick tomatoes from a crate, but the required cycle time is increased.

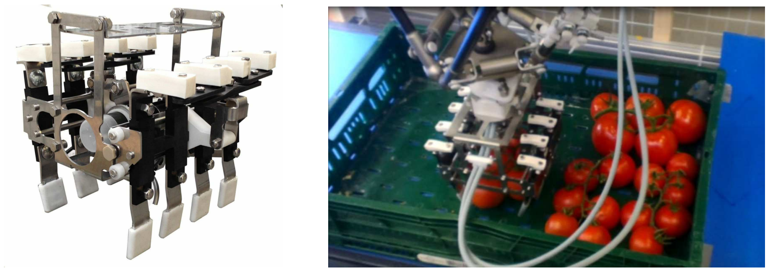


Figure 20 Electrical gripper

Regarding the chicken breast, the gripper operation and grasp strategy were validated, obtaining reliable picking results even with touching and stacked chicken breasts.

Figure 21 Pneumatic gripper

After the validation of the operation of the pneumatic gripper, a design optimization regarding hygienic issues was made, and it passed from functional prototype to hygienic tool as can be seen on following images.

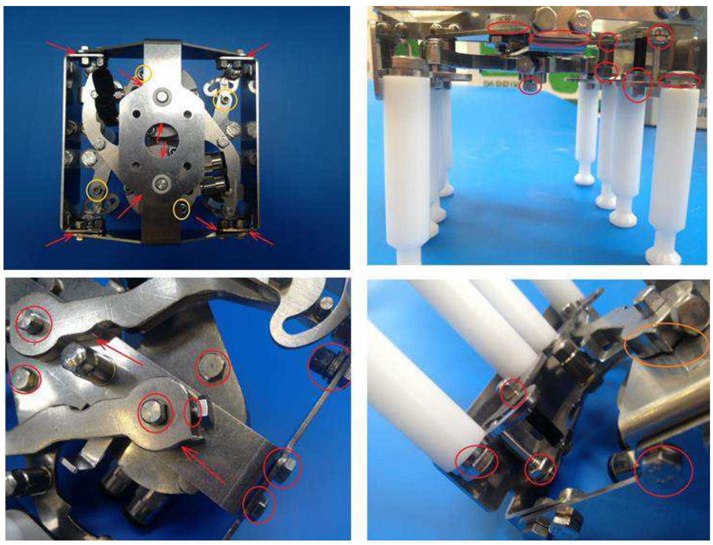


Figure 22 Design optimization for the chicken gripper

2.3.2 Gripper design for cable robot

The size of the packaged to be manipulated is between 240x160mm and 160x120mm and has got a maximum weight of 550gr. Taking into account that in this stage of the project the behavior of the upper film when the packages are full is still unknown, it is assumed a medium scenario for slightly flexible packages (not planar surface) to select the most suitable commercial gripper for picking of packages.

It has been selected a modular and configurable gripper by SCHMALZ specifically designed for high speed manipulation of packages in the food industry (highly dynamic processes) with a payload up to 2.5Kg. It reduces the configuration and assembly times in a 80% and the manufacturing cost up to 75%. It is composed by the following elements: A bridle for the connection with the robot made of Anodyzed Aluminum, the body of the gripper made of PSU and PPSU (suitable for foodstruffs) and suckers made of Silicon SI (FDA) . The Aluminium should be cleaned only with dedicated cleaning agents, so it is could be possible to implement the bridle in stainless steel (which will increase the weight of the gripper) or even plastic material in order to avoid a mix up of cleaning procedures. It includes a P3010 vacuum pump of Piab with an integrated CU (control unit) with electric valves for vacuum ON/OFF and blow-off (including mechanical valve for blow-off flow adjustment).

Taking into account the specifications described above, a configuration with 6 suckers of 30mm and 4.5 folds, external dimensions of 118x92x123mm and total weight of 525gr has been selected. It fulfill the requirements of weight under 1Kg, Is suitable for picking both flat and flexible packages and supports packages between 120 and 240mm. It includes a manual quick-change adapter with bayonet coupling, additional vacuum suction pads and other body parts to implement a new gripper configuration (for example with 8 suckers or with more separate suckers for bigger packages) in less than 20min.

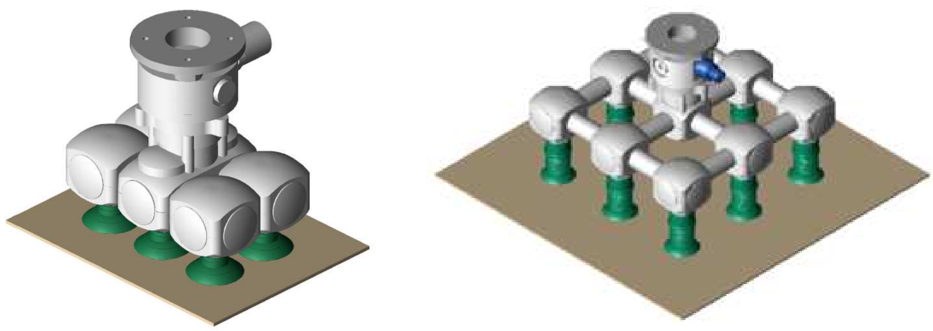


Figure 23: Gripper design for packaging and other possible alternatives

This gripper has been tested with an anthropomorphic robot (enough to check its behavior)on 160x120mm of packages 100gr weight with a top film made of OPALEN 45 AF PP joined to the package using silicone. Also a separate part with 1Kg weight has also be tested. Although it was not possible to achieve the desired cycle time because of a low speed of the robot (anthropomorphic are usually slower than parallel kinematic robots), the behavior of the gripper has been greatly satisfactory.

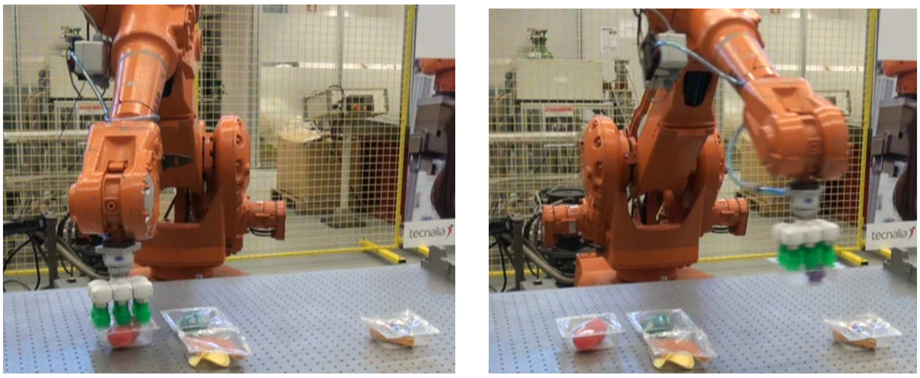


Figure 24: Gripper for packaging lab test results

The gripper is able to fully adapt to the height irregularities and wrinkles of the packages and because of the blow-off function, is possible to pick and place the packages without delay (minimum wait time up to 100ms) in the movements of the robot even manipulating parts up to 1Kg. Taking into account the presented results, as well as the speed achieved for the cable robot during the dynamic behavior testing, it is expected to fulfil the objective of 30 packages per minute.

2.4 Machine vision submodule

2.4.1 Aims

The main aim of the machine-vision subsystem is to provide information to the robot and gripper subsytems about where and how to grasp the products. This contains information about the 3D position and orientation (pose) of the object and the object's dimensions (width, length, height). The grasping strategy for some of the products requires …

2.4.2 Vision guidance for picking products from a crate

2.4.2.1 Setup

The sensor system gives colour and 3D depth information using an Ensenso N20 for the 3D depth data and an iDS camera for colour information. Both sensors are calibrated with respect to each other, so that colour and depth information can be overlaid and both types of information are available for the objects in the scene.

Figure 25 – The sensor system

The robot will have to perform multiple pick-and-place operations on a single crate of products. Each pick requires up-to-date sensor information. Sensor system and robot therefore have to share the same workspace. In cooperation, Marel and WUR-DLO redesigned Marel's robot unit, in order to optimally mount the sensor, so that the crate is fully visible, the view is not permanently occluded by parts of the robot, and the sensor is as straight as possible above the crate. Figure 26 shows the resulted mounting position of the sensor. The sensor is placed slightly off the centre of the crate and with a slight tilt of approximately 5° with respect to horizontal. The scene is illuminated using two LED bars placed at either side of the sensor.

Figure 26 – The robot setup, including camera mounting and LED bars for illumination.

2.4.2.2 Using expert knowledge

In order to detect the pose of the objects and to determine how the robot should grasp the objects, we exploit expert knowledge on the product and the gripper, to constrain the search space. This top-down knowledge is described in more detail below.

Product knowledge

For the vine tomatoes and grapes, we use knowledge that a tomato attaches to a calyx, which attaches to the stalk via a peduncle. A stalk can hold multiple tomatoes. The tomatoes and the stalk make up the vine. We furthermore use the fact that tomatoes are roughly circularly/elliptically shaped. In a training phase, we let experts label images of vine tomatoes in order to learn several parameters, such as the colours that tomatoes and stalk usually hold, stored in a colour histogram. We furthermore learn the typical diameters of tomatoes and the width and size of the stalk.

For the chicken breasts, we also use their typical colours, dimensions and size. For the detection, we furthermore use the fact that the 3D shape of a chicken breast placed in the correct orientation can be considered a unimodal hill, that is containing one peak. We currently don't use more sophisticated knowledge about the shape of chicken breast, but this might further improve detection performance.

Gripper knowledge

The shape and functionalities of the gripper constrain if and how items can be grasped. The gripper's geometry is represented with a low-level of detail. This representation is projected on the input images to optimize the pose of the gripper and analyse potential collisions with other objects in the scene. The open and close configurations of the gripper are both represented. The first is used to analyse if there is sufficient free space to grasp the object. The latter is used to analyse the grip on the object. We furthermore use the fact that objects are grasped most stably close to their centre of mass.

2.4.2.3 Vine tomatoes

Assumptions

We deal with blue harvest crates of 600 x 400 mm with a single layer of non-overlapping vine tomatoes. To grasp the vines, the robot needs to be able to move the vines in the crate so that there is sufficient space to wrap the fingers around the product.

Sensor

The detection of vine tomatoes is mainly based on the colour images of the iDS colour camera. The 3D information from the Ensenso N20 is used to determine the grasping position and orientation in 3D.

Detection of the vines

The vines are detected using the knowledge of vine tomatoes that we represented. Specifically, the tomatoes are detected based on their colour (green to red) and on their shape (circular with a range for the radius) and the stalk is detected on colour, total surface and a minimum and maximum thickness. Tomatoes and stalks are then associated with each other based on distance. Figure 27 gives an example of the results of the detection algorithm. On the left, the different vines are labelled by colour. The drawn ellipses are fitted on the contour of the detected tomatoes. The image on the right shows the detection of the main stalk (excluding the calyces and peduncles). In tests, the method was shown to be robust and able to handle a range of colours and shapes of the tomatoes on the vine.

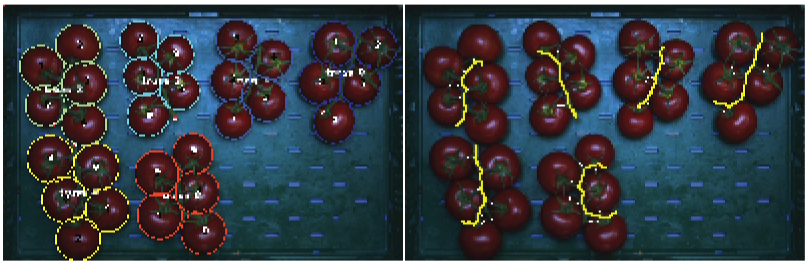


Figure 27 – Detection of the vines in the crate.

Proposing a grasping action

A grasping action has three phases. In phase one, a pinch grasp is performed on the stalk, while one row of fingers is open (see Figure 28). In the second phase, using the pinch grasp, the vine is moved to a free location so that the open fingers can close. A full grasp is performed in the third phase. Once grasped, the vine tomato can be moved from the crate to the package.

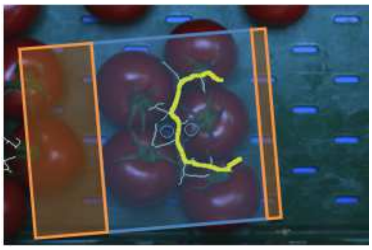


Figure 28 – An illustration of the gripper placed on the vine. The blue circles form the pinch gripper. The small orange rectangle is the row of closed fingers and the larger orange rectangle is the row of open fingers. When opened, the fingers do not collide with other vine tomatoes.

For the pinch grasp, a position and orientation need to be proposed. In the ideal case, the orientation is set to the orientation of the stalk and the position is on the stalk as close as possible to the centre of mass of the vine. However, a restriction is that the fingers should not collide with the vine tomatoes, nor the borders of the crate. Collisions are analysed by projecting the gripper model on the image with the desired position and orientation and detecting overlap with the objects in the scene (tomatoes, stalk, and crate). When a collision is detected, other grasp positions and orientations are analysed, until a collision-free grasp is detected which is as close as possible to the centre of mass.

For phase two and three, the vine will be moved by the gripper over a straight line until it is at a location where the gripper can close around the vine without colliding with other objects in the scene. This movement of the gripper holding the vine is simulated. At every step, the simulated situation is analysed to determine if there is enough free space to close the gripper and if there are collisions with other objects in the scene. If not, other directions and distances of the movement are tried, until a successful movement is found, where the distance over which the vine is moved is minimized. In case no successful movement can be found at all, the algorithm reanalyses phase one, to try another position and orientation of the pinch grasp.

Results of the grasping method are show in Figure 29, showing a sequence of grasp detections. A video can be viewed on Youtube[1]

[1] https://www.youtube.com/watch?v=A4nk_1_oFWk

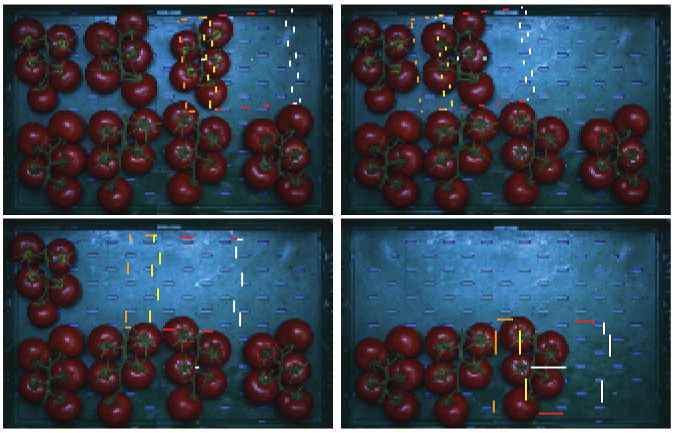


Figure 29 – Example of a sequence on grasps

This method was tested with Lacquey's vine-tomato gripper on a ABB Flex Picker. Integration and tests with Marel's IPL robot will take place starting from May 2015.

2.4.2.4 Chicken breast

Assumptions

For the PicknPack demo, we will work with a single layer of non-overlapping and horizontally placed chicken breast. The products will be placed in blue or green crates of 600 x 400 mm. The vision method can also deal with stacked chicken breast non-horizontally oriented. For grasping, sufficient free space needs to be available for the gripper to wrap around the product.

Sensor

The detection of chicken breast is based on 3D information originating from the Ensenso N20.

Detection of chicken breast

The first step in the detection method is the segmentation of the products from the crate, which is done based on height information. Since the chicken breast can be touching each other, we cannot simply use a connected-component method to segment each individual chicken breast, but we need to segment the touching chicken breasts from each other. We exploit the fact that a chicken breast causes a unimodal peak (hill) in the depth map. We compensate for noise in the depth measurements using anisotropic diffusion, a smoothing method that removes noise, but preserves significant changes in the data, such as the boundaries of the objects. After smoothing, we apply watershed segmentation to detect all hills in the depth map, resulting in masks for all individual chicken breasts. The mask of a chicken breast that is partially occluded will not be complete. However, as such a chicken breast cannot be grasped at that point anyway, there is no problem. When the occluding breasts are removed, the new sensory information will reveal the complete object.

Proposing a grasping action

For every detected chicken breast, an ellipse is fitted to its contours. The main axis of the ellipse determines the orientation of the chicken breast. Next, the minimum bounding box of the contour holding this orientation is determined. The width, length and centre of the box are determined and, using the 3D information, converted to real-world units. Additionally, the height of the breast is determined.

Similar to the grasp detection for the vine tomatoes, an iterative method is used to choose a target object and a grasping action. The chicken breasts are sorted based on height and analysed for their graspability, starting from the chicken breast that is placed highest. Preferably, the gripper is placed in the middle of the bounding box and with the orientation of the object. Similar to the vine tomatoes, the geometry of the gripper is projected in the image at the given position and orientation and the grasp is analysed for collisions and a stable grasp on the object. If a suitable grasp is found, it is proposed. If not, slightly different orientations and positions of the gripper are analysed. If no suitable grasp can be found for an object, the next object is considered.

Results of this method are shown in Figure 30. For iteration 2, 4, 5, 7, and 8, the preferred grasp – at the centre of the object and with the same orientation – turns out to be possible. For the other iterations (1, 3, and 6), an alternative position and orientation is proposed.

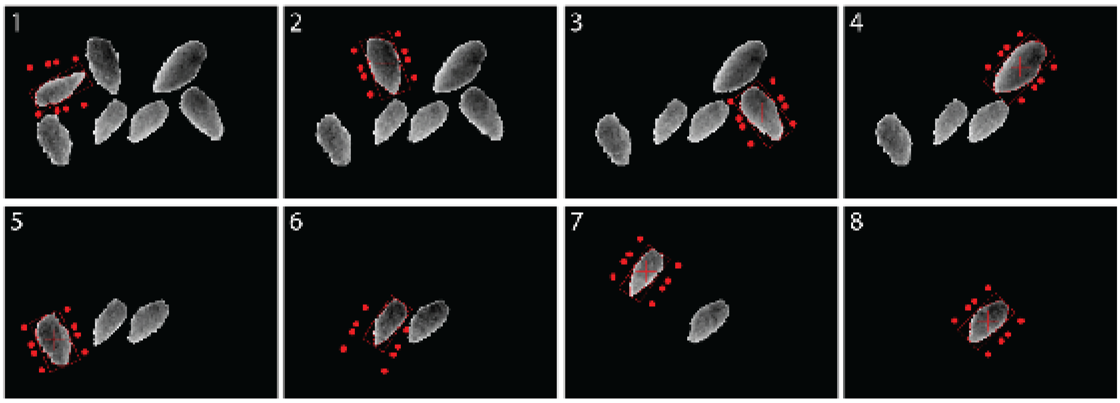


Figure 30 – A sequence of grasps from left to right, top to bottom. 1, 3, and 6 are examples where the optimal grasp was not possible due to collisions and another position and orientation was proposed.

The first tests of this method on the actual robot will take place starting from May 2015.

2.4.2.5 Grapes

Assumptions

Grape vines are very complex objects consisting of a complex stalk and many berries. Due to the complexity, there are many occlusions and the structure of the stalk and the connection of berries on the stalk are impossible to completely derive. To start with, we assume that the vines are separated in the crate without any overlap with other vines. This allows for the detection of the complete vine. Moreover, the current gripper requires space around the vine to perform the grasp. Otherwise, assumptions are the same as with the vine tomatoes

Sensor

As with the vine tomatoes, the detection of the grapes is also mainly based on the colour camera. To determine the relevant parameters for the grasp, 3D information of the Ensenso is used in addition.

Detection of grape vines

The grape vines are segmented from the background using knowledge about the colour of grapes and stalk, and of the harvest crate, learned in an off-line training phase. The stalk is detected by performing a morphological hat operator, which detects thin elongated parts in the grape bunch mask. Information about the thickness of the stalk is used to set the size of the structuring element. This step will detect the stalk at the outside of the bunch, not in the middle.

Proposing a grasp

The orientation of the vine is determined by fitting an ellipse to the contours of the grapes. The minimum bounding box around the object holding the same orientation is then found. Top and bottom of the vine are determined assuming that the top of the grape vine contains more grapes than the bottom. The preferred grasp is at the centre of the bounding box and with the same orientation. Figure 31 gives an example of the output.

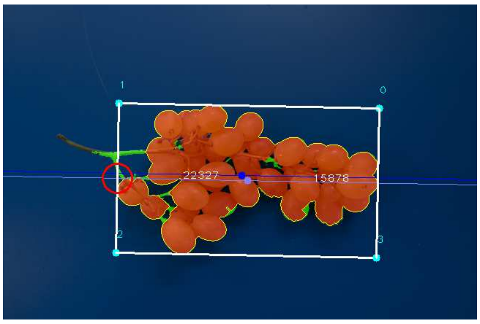


Figure 31 – An example of the detection of a grape vine. The preferred grasp is at the centre of the bounding box (light blue dot) and with the orientation of the bounding box (light blue line). The top of the bunch is marked with the red circle.

This detection algorithm yet has to be integrated with the work presented on the vine tomatoes and chicken breast, so that also for the grape vines, the grasp is analysed for collisions and stable grasp and alternatives are proposed if the preferred grasp is not possible.

2.4.2.6 Communication with the robot

Information about a grasp that is communicated to the robot contains the following information

- Position of the grip point
- Orientation of the gripper
- Vector over which the product needs to be displaced (if necessary)

- Width of the product (not used yet, but new version of the gripper has the capability to adapt the aperture of the gripper)

- Height of the product (not used yet, but will be used in the near future to displace the products)

The machine-vision software has currently been tested on a ABB Flex Picker. The above-mentioned information is send to the robot over TCP/IP using a simple comma separated string of integer values. We are currently working on a JSON formatted string to add more semantics to the numbers.

2.4.3 Vision guidance for packaging

Initially it was decided not to include a vision system for the picking operation because of the packages leaves the previous module (thermoformed) in matrix of different number of trays (3 to 6), in an ordered way and separated/leaded by guides which possibilities the picking operation in a fixed position using mechanical elements. However, flexibility requirements and changes at the end of the thermoformed (October 2014) have led the need to include a vision system for picking packages.

The objective is to develop a simple vision system able to calculate the picking position of each package, to update the coordinates with the movement of the conveyor (conveyor tracking), and to send them to the cable robot. To achieve it, the following specifications have been defined:

Trays will arrive to the conveyor without overlapping: It is not possible to detect in an easy way the overlapping between trays because they are transparent (even with human eyes).

- It is not necessary to identify the content of the packages.

- It is not necessary high accuracy on the picking position: 1mm is enough.

- A 3D camera is not required: The selected gripper is able to fully adapt to different irregularities in the height of the package through their suckers with folds. The theoretical height can be deduced depending on the size of each package.

For the optimal selection of the hardware and based on the previous specifications different cameras (lineal and matrix) and lights configuration (diffuse, direct, high power, fibber…) have been tested. Based on the results of these tests, the following equipment with the following configuration has been already selected:

- **Spyder 3 40MHz 1024x2 Lineal Camera Mono GigE:** the packages will arrive to the vision system in matrix which inhibit the use of a presence sensor for the trigger of a matrix camera and difficult their operation. Also, the area to be illuminated is bigger with matrix cameras, and it difficult to obtain a homogenous lighting in all the workspace. For this reason, a lineal camera for continuous acquisition (line by line) has been selected. It is not necessary to detect the content of the package, so a monochromatic camera is suitable for this application. The connection between camera and PC is through Ethernet, suitable for industrial environment and large distance. An independent camera and an open source software with a separate PC have been selected (instead of smart camera) because of cost reasons.

- **High power linear projector (Red light, continuous operation):** Different lights have been tested, but all of them (even diffuse light) produces non-homogeneous illumination into the workspace and brightness which difficult the location of the package due to the reflections of the plastic top film. For this reason it was decided to saturate the image and use a red light (wavelength of 630nm). By this way is possible to increase the contrast between the conveyor (blue color) and the package for an easily location of them (white package into black background). In order to achieve high intensity light during the acquisition to saturate the image, it will be suitable the use of strobe light. Assuming a maximum speed of the conveyor of 26m/min, it would be necessary to implement 500 blinks per second (very high) to obtain a resolution of 1mm. For this reason, a continuous operation of a more powerful lighting has been selected.

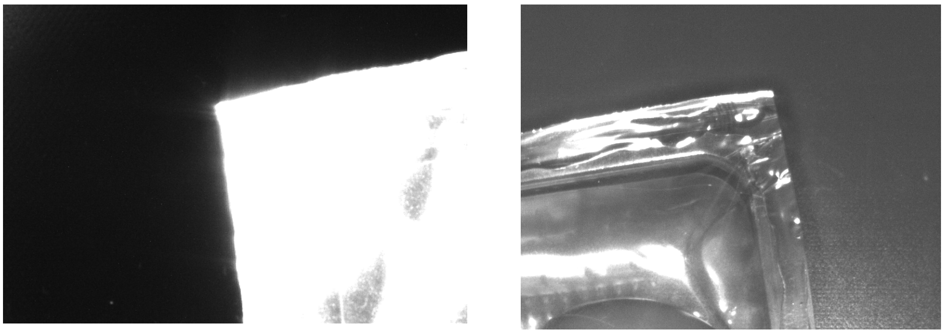


Figure 32: Red light vs white light (contrast increase)

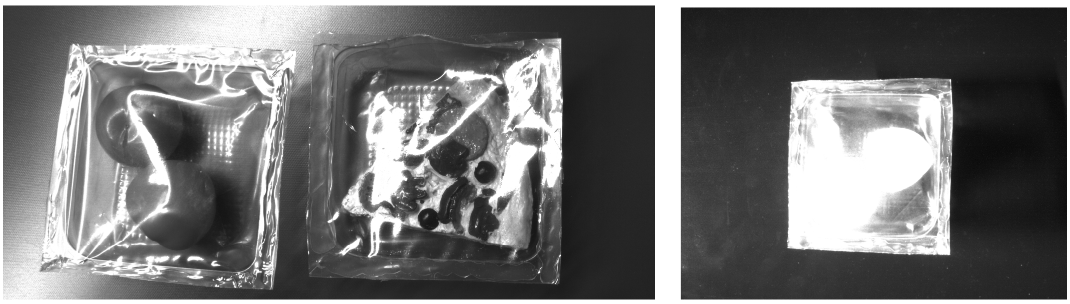


Figure 33: Diffuse light vs selected light (high intensity, red)

After the selection of the hardware, the required software has been developed. It is developed on C# language with the “Microsoft Visual C# 2010” development environment. It is based on thresholds, filters (remove edges, remove small objects, fill holes) and particle analysis.

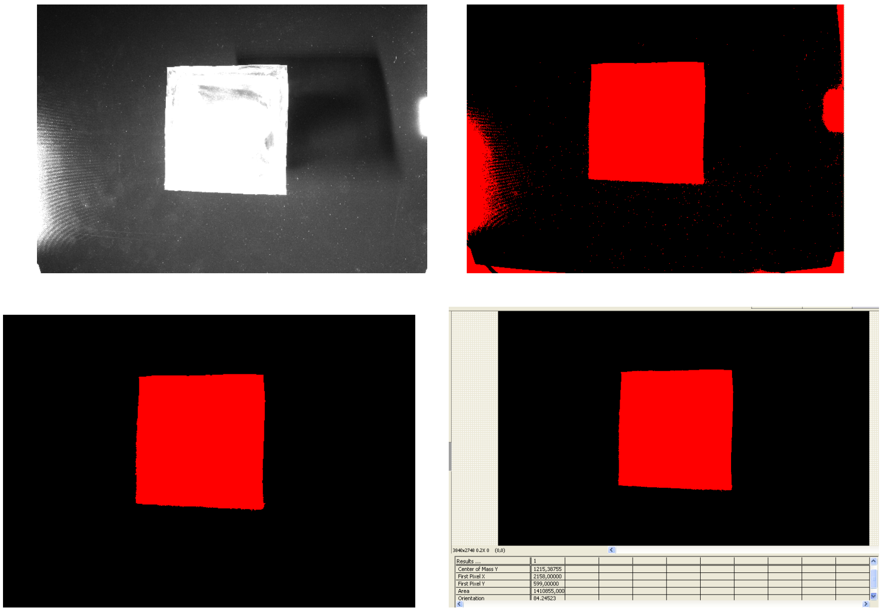


Figure 34: Algorithm result

The developed algorithm has been proved onto new images obtaining the required repeatability and accuracy:

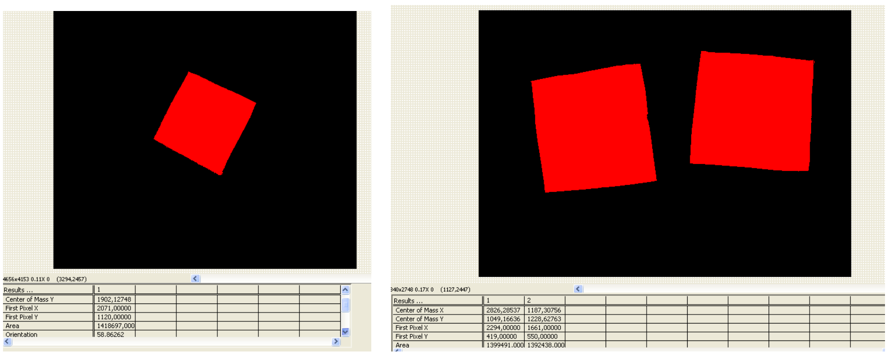


Figure 35: Algorithm result

Finally, the complete vision system has been integrated into the design of the cable robot, attached to the frame for an easily configuration and calibration of both systems. By this way, the distance between the coordinate systems (camera and robot) are fixed and known. The behavior of the cable robot with the integrated vision system and the gripper will be tested at the end of May.

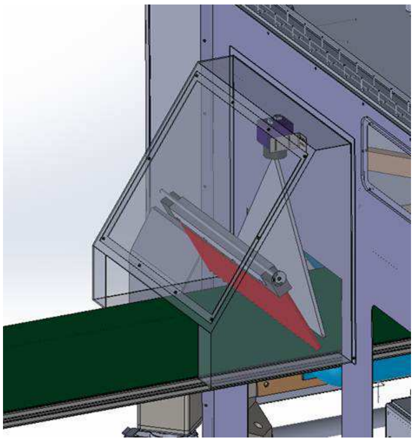


Figure 36: Integrated vision system into the frame of the robot

2.5 Cleaning system

To verify the cleanibility of the two developed grippers, two different tests have been done at Fraunhofer:

- A general cleanibility test with easily removable soil to detect parts that are completely not cleanable.
- A second test with persistent food soil (harder to remove) to examine which parts are harder to clean than others.

2.5.1 Tests with removable soil

The first tests were done with an easily removable soil called RET medium, which is often used to determine spray shadows in open cleaning applications. It is a fluid of a strong red colour, so that it can be easily detected. It can be easily applied to objects with a spray bottle and dries very fast because it contains ethanol. This test was applied to both grippers.

The soil crawls especially into critical areas like crevices. On big surfaces it tends to form droplets so they are only spottily soiled.

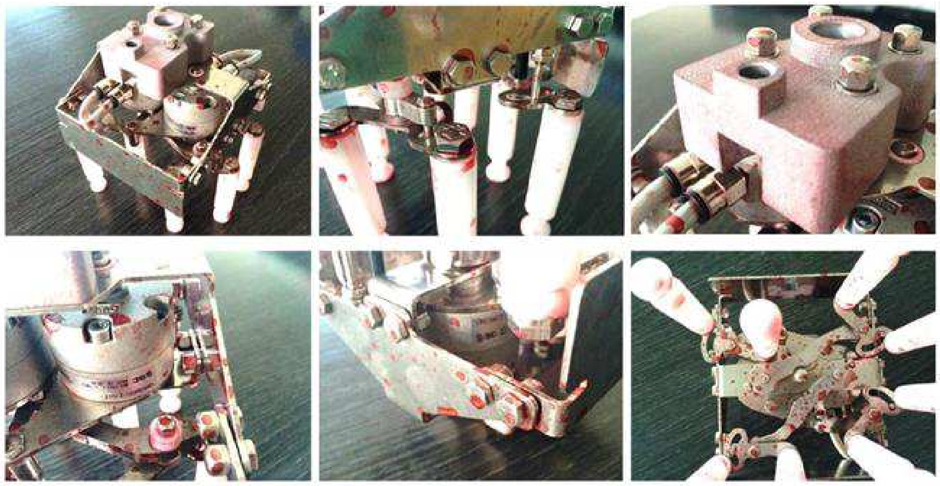


Figure 37: Chicken Gripper before Cleaning

Figure 38: Fresh food Gripper before Cleaning

The grippers were later cleaned in a conventional dishwasher with water at 40 °C in order to mimic industrial washing machines or spray cleaning chambers. The process was stopped after 2 minutes.

The cleaning tests showed that most of the open surfaces were wetted and cleaned. But a while after the cleaning was stopped the soil started “bleeding” from critical areas revealing them as not cleanable. In previous and the following figures these critical areas are marked for the Chicken Gripper.

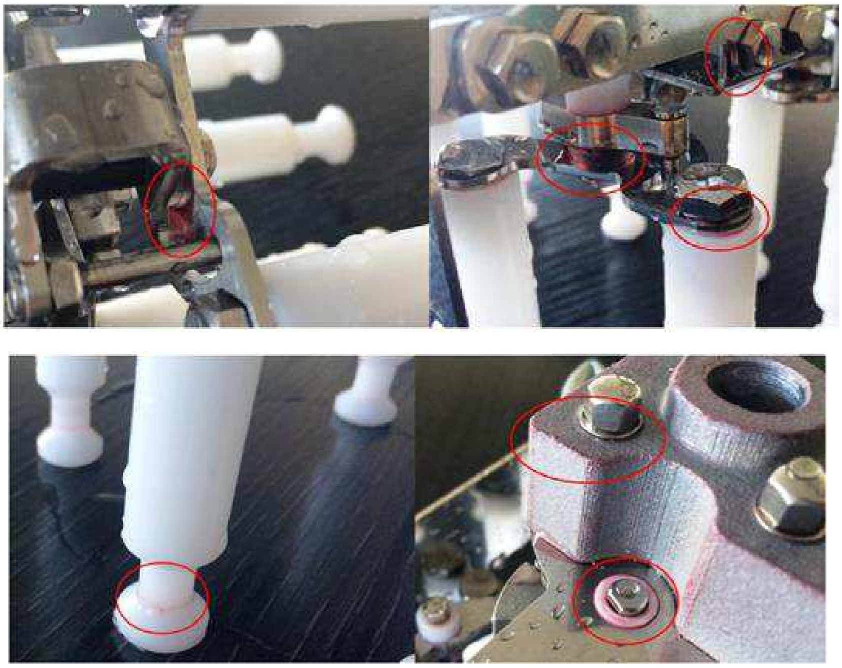


Figure 39: Chicken gripper after Cleaning

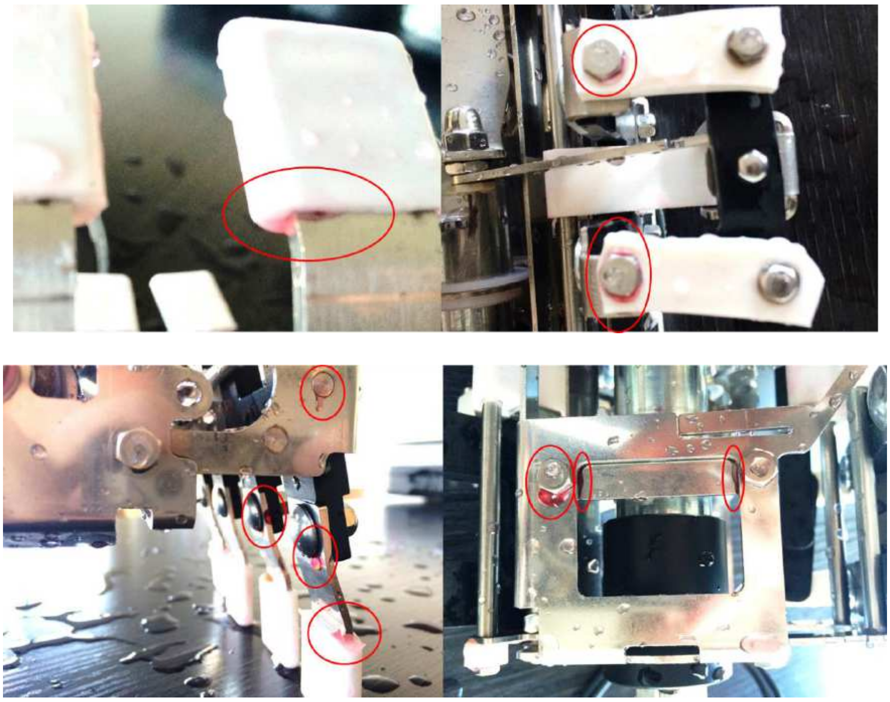


Figure 40: Tomato gripper after Cleaning

For both grippers could be shown that it is possible to reach all open surfaces within the cleaning procedure in a washing machine. All of those surfaces get at least wetted, so that the RET medium could be removed. But there were also a lot of critical spots on both grippers which were not cleanable at all. Those were especially:

- Crevices and small gaps,
- Sharp edges,
- Rough surfaces,
- And metal-to-metal-contacts.

These critical areas have to be redesigned because soil can easily accumulate there so that it can serve for germs as breeding ground. A dedicated discussion will be held in April to solve this issue.

2.5.2 Tests with persistent food soil

In order to detect which areas are harder to clean than other, a custard soil was used. It was poured over the grippers, which then dried for 24hours. The custard is fluorescent so it can be detected under UV light.

For both grippers it could be shown that their complex geometries lead to several areas which are very hard to clean. Due to the low flow rate in those areas the cleaning effect is pretty poor.

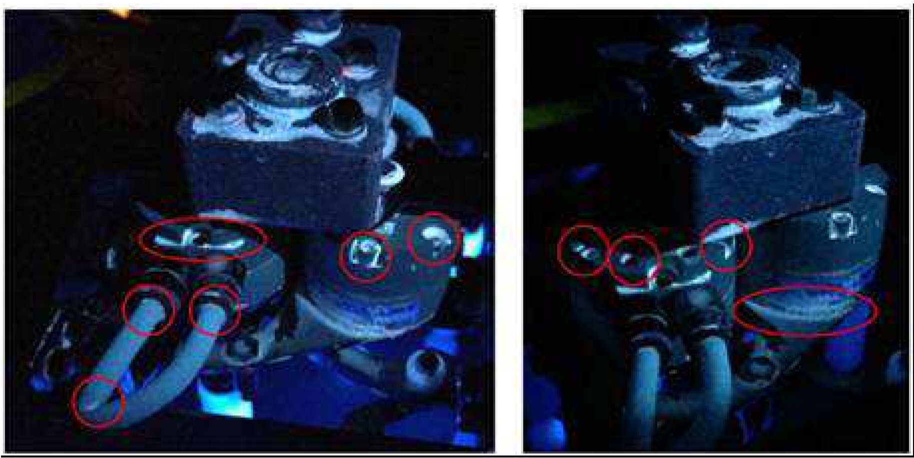


Figure 41: Chicken gripper after 3 minutes of cleaning

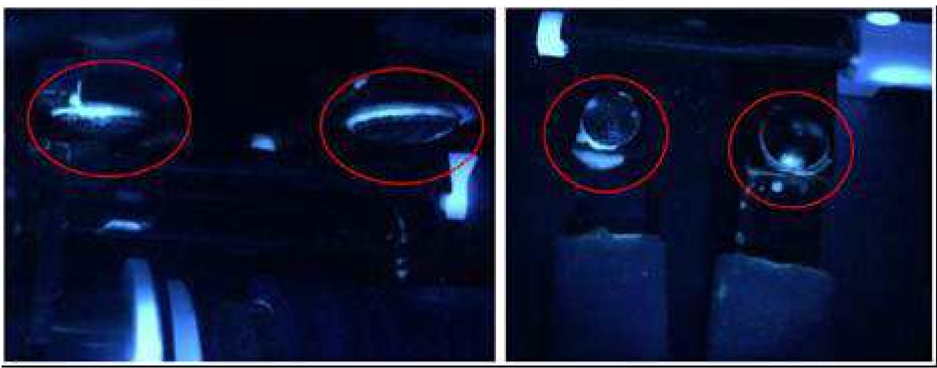


Figure 42: Tomato gripper after 3 minutes of cleaning

After a short cleaning procedure of 3 minutes widespread soil remains in areas which are hard to reach for the cleaning fluid.

Figure 43: Chicken gripper after 30 minutes of cleaning

Figure 44: Tomato gripper after 30 minutes of cleaning

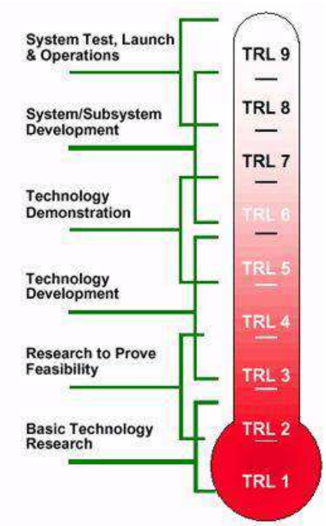
After a long cleaning procedure of 30 minutes soil still remains on critical, complex areas, which are similar to the ones which were detected within the tests with the RET medium. The marked areas should be redesigned according to the rules of hygienic design. Parts should be reduced on both grippers to make all areas better accessible for the cleaning fluid. Particularly critical are the high number of metal-to-metal contacts and the resulting crevices and small gaps which have to be sealed. In addition there are a lot of sharp edges which need to be removed.

In the current state it would be a high risk to use the grippers in direct contact with the product in a food production line, because there are too many spaces where soil can accumulate and germs can grow.

3 Conclusions

This document summarizes the work that has been carried out for the testing of all the submodules which are included in Workpackage five. Those main modules are the manipulators for pick and place operations, machine vision systems for robot guidance and grippers for foodstuff and package grasping. In addition there are some equipment and peripherals which are necessary and have been also taken into account.

A brief description of the different readiness levels of the main modules is now described since there are differences in them. Following table summarizes the scope of each readiness level for the further classification. It is suggested a suitable reference frame for a better understanding of current document



Readiness levels	
MODULE	LEVEL
IPL Robot	9
Cable Robot	6
Gripper (Chicken)	7
Gripper (fresh products)	7
Gripper (packages)	9

The results are positive and validate the innovative designs carried out during previous tasks. Taking this into account, we cannot think that these results are a complete guarantee for avoiding any risk during the final setup task. All the modules, submodules and individual components must be finally tuning and several troubles will occur. Not only this, but also the final integration of all the Pick and Pack modules must be achieved. This task is probably one of the more, maybe the main, difficult goal of the project.

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