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AUTO-ID CENTRE

# WHITE PAPER

## Auto-ID Based Control Demonstration
## Phase 1: Pick and Place Packing with Conventional Control

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## ABSTRACT

A demonstration environment is being developed at the Auto-ID Centre Laboratory in Cambridge in order to show the benefits of applying Auto-ID information in the context of automated control systems. This document provides a technical overview of the developments required to produce the first of 3 demonstration phases planned for this environment. In this first phase, Auto-ID based information is integrated with a conventional control system to regulate a simple retail product pick and place packing environment. The demonstration in this first phase will show the ability of Auto-ID based systems to provide for orderly, accurately controlled operations in a changing and potentially disorderly environment.

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## Auto-ID Based Control Demonstration

Phase 1: Pick and Place Packing with Conventional Control

## Biography

**Steve Hodges**
Senior Research Associate

Steve Hodges is a researcher at the Auto-ID Centre Lab at Cambridge University. Steve received his first degree in Computer Science with Electronic Engineering, from University College London, and received his Ph.D. from Cambridge University Engineering Department in the area of Robotics and Computer Vision. His interests include embedded sensor systems, intelligent devices, computer augmented environments, mobile robotics, image processing, low-power radio communication, mass customization of consumer products and RF tagging technologies.

**Alan Thorne**
Laboratory Manager

Alan Thorne is the Program Manager for the Auto-ID Centre Lab at Cambridge University. Mr. Thorne graduated from Anglia Polytechnic University in Electronics and Control Systems and has a varied background in the field of Automation and Control. He has been involved in British Aerospace/IBM research projects as a systems engineer investigating flexible manufacturing systems on civil and military aircraft production. He has most recently been involved in projects relating to the development of novel AI-based control strategies.

**Andy Garcia**
Senior Research Associate

Andy H. Garcia received his Ph.D. from the Polytechnic Univ. of Madrid as well as an MSc in Electronics and Automation Engineering. He also has an MSc in Mechanical Engineering from Cordoba Univ. (Spain). He has been an Assistant Professor at the Polytechnic Univ. of Madrid, where he also worked in close collaboration with companies such as: Dragados y Construcciones (one year based at one of their sites), Iberdrola, Menasa and more. He continued these collaborations while an Assistant Professor at Carlos III Univ., also in Madrid. After that he became a Projects Engineer at Thyssen Automation, setting up automated warehouses in Spain, South America and the UK, until he joined Castilla La Mancha Univ. (Spain) as Lecturer-Senior Lecturer in Industrial Engineering.

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## Biography

**Jin-Lung Chirn**
Ph.D. Candidate

Jin-Lung Chirn received his BS and MS degree from the Department of Mechanical Engineering in National Taiwan University and National Tsing Hua University respectively. From 1990 until 1997, he was a researcher in the Mechanical Industrial Research Laboratory/Industrial Technology Research Institute (MIRL/ITRI), which is the leading industrial R&D centre in Taiwan. During this period, he worked on projects related to the design of automatic machine controllers. Later, he worked on projects related to the integration of manufacturing control systems applied to material handling systems, product packaging lines, and flexible manufacturing cells/systems. Currently, he is completing his PhD degree in the Manufacturing Automation and Control Systems Research Group at the University of Cambridge. His research is related to reconfigurability and modularity issues in the design of advanced manufacturing control systems.

**Mark Harrison**
Research Associate

Mark Harrison is currently collaborating with the Auto-ID Centre lab in Cambridge on the development of a PML server and web-based graphical control interfaces. In 1995, after completing his PhD research at the Cavendish Laboratory, University of Cambridge on the spectroscopy of semiconducting polymers, Mark continued to study these materials further while a Research Fellow at St. John's College, Cambridge and during 18 months at the Philipps University, Marburg, Germany. In April 1999, he returned to Cambridge, where he has worked for three years as a software engineer for Cambridge Advanced Electronics/Internet-Extra, developing internet applications for collaborative working, infrastructure for a data synchronisation service and various automated web navigation/capture tools. He has also developed intranet applications for his former research group in the Physics department and for an EU R&D network on flat panel displays.

**Duncan McFarlane**
Research Director Europe

Duncan McFarlane is a Senior Lecturer in Manufacturing Engineering in the Cambridge University Engineering Department. He has been involved in the design and operation of manufacturing and control systems for over fifteen years. He completed a Bachelor of Engineering degree at Melbourne University in 1984, a PhD in the control system design at Cambridge in 1988, and worked industrially with BHP Australia in engineering and research positions between 1980 and 1994. Dr McFarlane joined the Department of Engineering at Cambridge in 1995 where his work is focused in the areas of response and agility strategies for manufacturing businesses, distributed (holonic) factory automation and control, and integration of manufacturing information systems. He is particularly interested in the interface between production automation systems and manufacturing business processes.

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## Auto-ID Based Control Demonstration

Phase 1: Pick and Place Packing with Conventional Control

Contents

# 1. AN OVERVIEW OF THE DEMONSTRATION ENVIRONMENT

A demonstration environment is being developed in order to show the benefits of applying Auto-ID systems to automated control systems. Three phases of demonstrations are being developed as part of the Control Systems Research activity within the Auto-ID Centre. As well as providing tangible evidence of the way in which Auto-ID information can influence industrial operations, such a demonstration environment plays two other important roles:

– It provides a live testbed for developing, testing and revising elements of the Auto-ID systems under development
– It enables industrial guidelines for the development of Auto-ID systems to be established and tested in a controlled environment

This document provides a technical overview of the developments required to produce the first of three demonstration phases planned for this environment.

## 1.1. The Cambridge Demonstration Environment

The demonstration environment is intended to explore with increasing levels of complexity the potential benefits of Auto-ID based data for closed loop control. Although the demonstration environment will focus on manufacturing supply chain applications, it is emphasised that the demonstrator results are intended to map directly into other domains. Apart from the ready availability of facilities, manufacturing has been selected for these demonstrations because of the well understood need for rapid and cost effective customisation of products to customer demand. In particular, Phases 2 and 3 will explore this issue.

**The 3 phases, their aims and timings are:**

| PHASE | DEMONSTRATION ENVIRONMENT | DELIVERY DATE |
|---|---|---|
| 1 | Pick and Place – Conventional Control | June 2002 |
| 2 | Pick and Place – Intelligent Control | November 2002 |
| 3 | Mini Supply Chain/Flexible Production | June 2003 |

**Phase 1**
Phase 1 will show the ability of Auto-ID based systems to provide for orderly operations in a changing and potentially disorderly environment. Disrupted product sequences and changed production schedules will still lead to accurate and orderly packing for multiple customers.

**Phase 2**
Phase 2 will then introduce an intelligent distributed control system into the same pick and place environment and will demonstrate the ability for a customer to (remotely) track and influence the progress of an order by exploiting the timely, item level data afforded by Auto-ID information. Intelligent quality control will ensure 100% reliability of packaging.

**Phase 3**
Phase 3 will then integrate several different manufacturing operations with storage facilities and demonstrate the ability for a high level of coordination to be afforded between operations when parts and products with designated ID are able to influence their own production and either individually or as part of a single customer order. The difference between Phases 2 and 3 is predominantly one of scale although additional requirements are likely to be added following the conclusion of Phase 2.

## 1.2. Phase 1: Demonstration Environment

The Phase 1 (and Phase 2) Auto-ID based control demonstration developed at Cambridge will involve a simple pick and place assembly operation associated with forming men's personal care gift boxes which are loosely based on those produced by Gillette during festive periods. A schematic and a visualisation of the demonstrator setup are shown in Figure 1 and Figure 2.

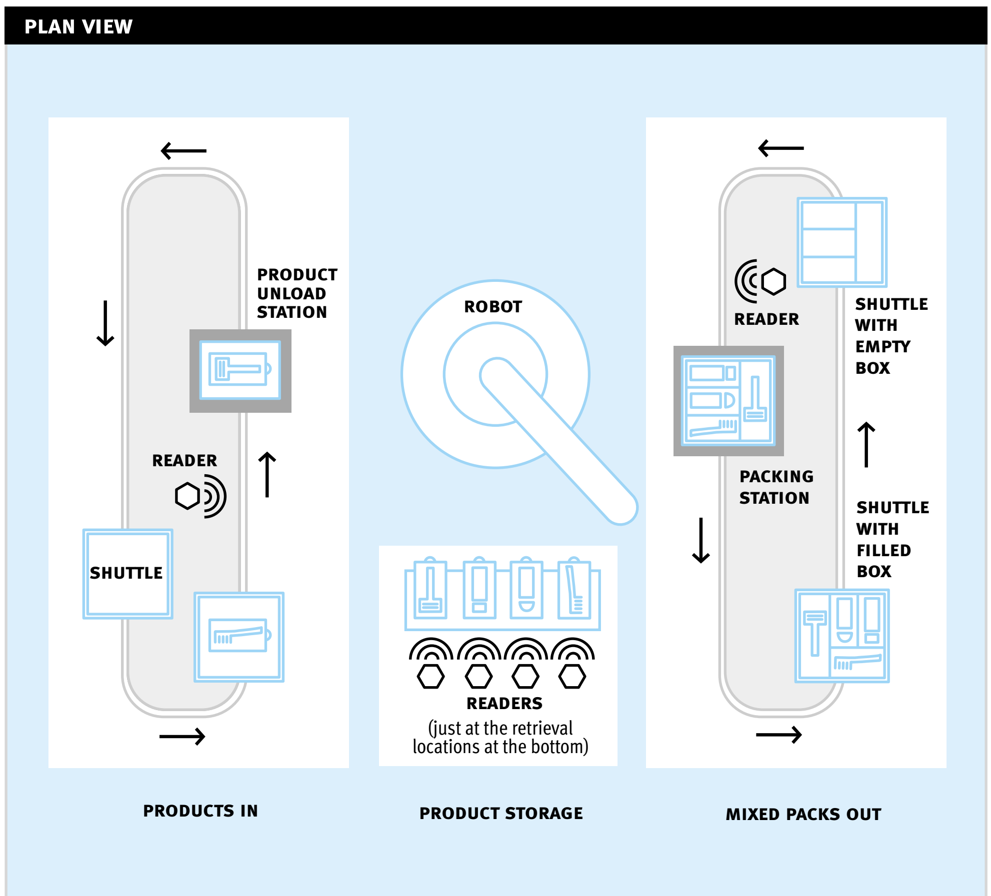



**Figure 1:** Schematic of packing and storage system

Referring to Figure 1, Individual gift box items – razors, blades, shaving gel, deodorant – are sourced either from a simple storage unit or from an incoming conveyor system. For simplicity in developing the automation, each item is self contained within standard carrier and each item is tagged with an appropriate EPC. Empty gift boxes – also tagged with EPCs – are sourced from another conveyor, and are moved to a packing station and then filled according to a packing instruction.

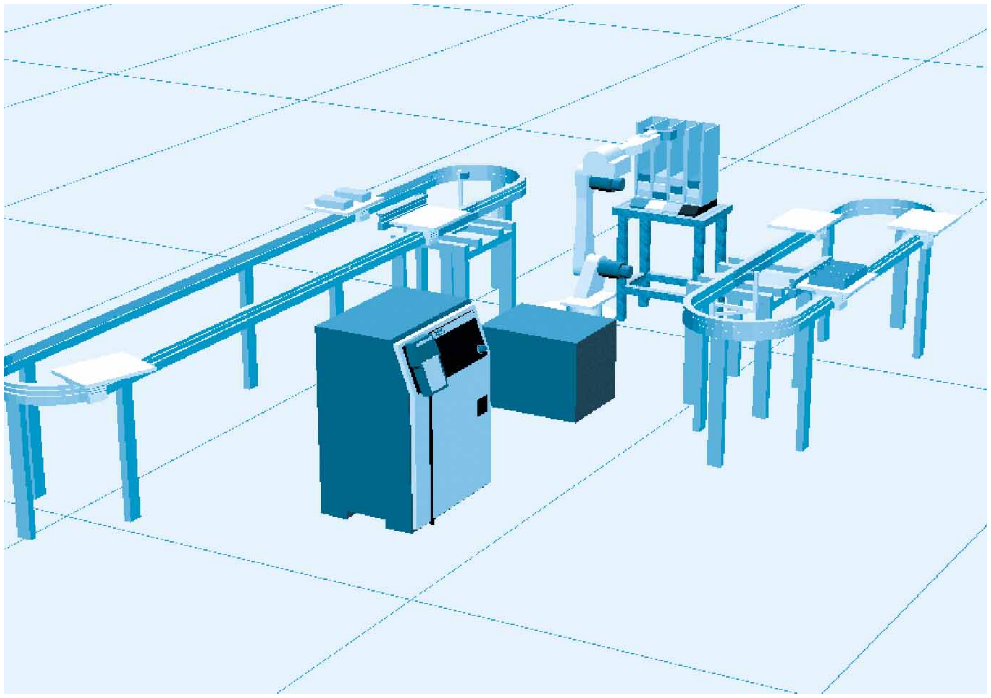


**Figure 2:** Visualisation of packing and storage system – operational view

## 1.3. Aims of Phase 1 Demonstration

**The aims of this first demonstration phase are to show that:**

1. Auto-ID infrastructure (EPC, RFID systems, Savant interfacing system, PML) can be integrated into a closed loop control system;

2. Effective packing can still be achieved when raw materials supply is random and varying.

These modest aims do not accurately reflect the numerous developments required to put the Auto-ID infrastructure into place in a relatively short timeframe. As well as demonstrating the benefits of the Auto-ID based control environment, the demonstrator environment is perhaps more importantly a live test bed for driving development of the Auto-ID infrastructure.

By way of contrast with the Phase 2 demonstration we note that although the physical system used for the Phase 1 demonstration is very flexible in its nature, the control strategy in this demonstration will be conventional and predetermined in nature and will therefore not make full use of the flexibility of the physical hardware. However, Phase 2 of the demonstration will deploy intelligent control software to build on Phase 1 in order to demonstrate interactive order adjustment, dynamic packing adjustment in the face of errors and quality control procedures.

## 1.4. Overview of The White Paper

The remainder of this paper provides a detailed technical description of the Phase 1 demonstration environment. Sections 2, 3 and 4 provide an overview of the product packaging, tag and reader systems and packing system control respectively[1]. Section 5 then describes the integration of these elements into a single system.

[1] Note that at the time of writing the PML file system was not completed and hence this will be reported within the Phase 2 demonstration documentation.

## 2. ITEM AND GIFT BOX DESCRIPTION

A variety of Gillette products will be used in the demonstration, namely razors, deodorant, shower gel and shaving cream. For simplicity, the different items to be included in the gift boxes will be pre-mounted into individual, standard sized, plastic item carriers (Figure 3) which will enable simple robotic handling, stacking and assembly.

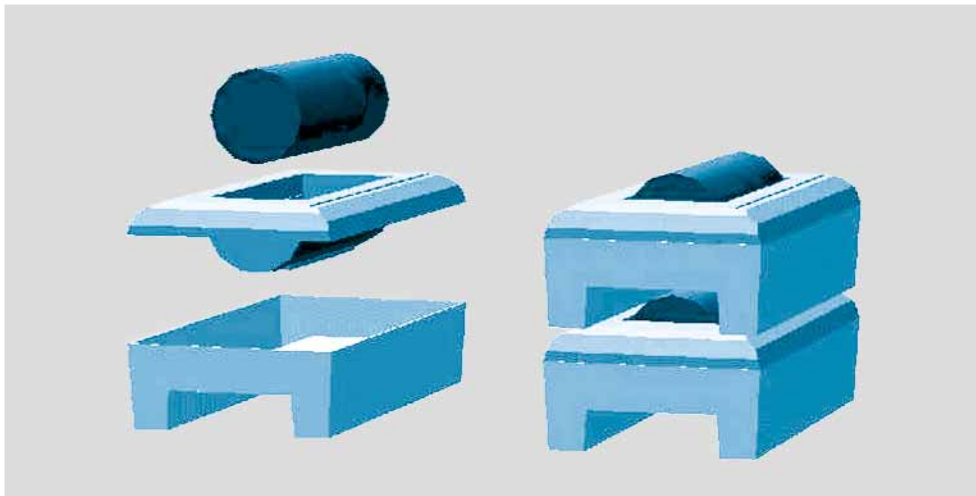


**Figure 3:** Item Carriers (left: the construction of the item carrier along with an item; right: two item carriers stacked on top of each other)

It is intended that – at least in the first instance – item carriers be tagged rather than the individual items, and that the two will not be separated throughout the demonstration. We emphasise here that there is no intention in this demonstration to replicate Gillette gift packaging operations – the use of Gillette products here is purely for illustrative purposes.

Two physically different styles of gift box are to be used in the demonstration to reflect different retailers' needs (the styles are shown in Figure 4). Each box can hold three different items with their respective plastic item carriers, which gives rise to a large number of different gift box configurations (64 for each box style). The gift boxes themselves will also be tagged (and assembly instructions for them can therefore maintained in an associated PML file).

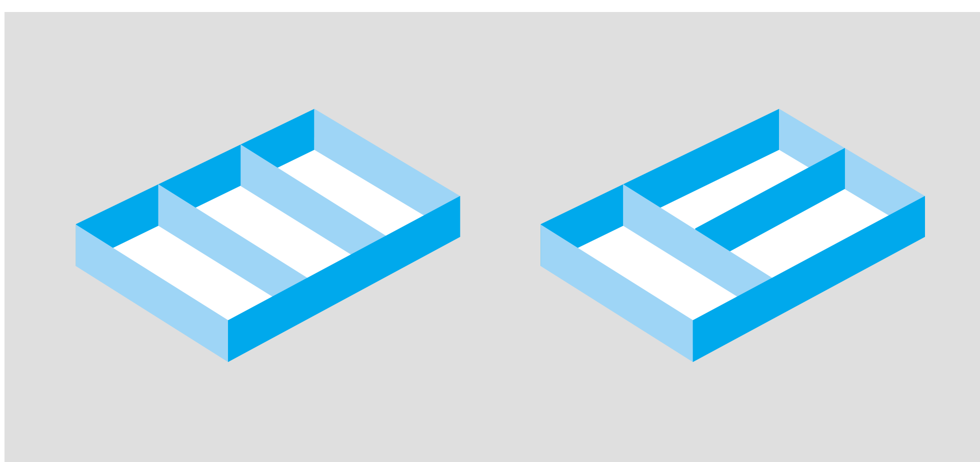


**Figure 4:** The two different styles of gift boxes

# 3. TAG AND READER REQUIREMENTS

The Phase 1 demonstrations will be using 13.56 MHz RFID equipment that is compliant with EU power emission guidelines. For this initial phase, 'Performa' series tags and readers from Checkpoint Systems Inc. will be used, although it is emphasised that this selection is not intended to indicate that these products are more or less suited for industrial applications. Later phases are likely to deploy tags and readers from different sources.

## 3.1. Tagging

Initial experiments with the Checkpoint RFID systems in our environment indicate that the 0.78" x 5.67" tags give the best performance. For the initial demonstrations, there will be 20 of each type of item carrier, giving a total of 80 item carriers. Each carrier will have two identical tags attached internally (not visible from the outside), one at each end of the carrier.

There will also be approximately 10 of each type of cardboard gift box, and again each box will be tagged with two tags.

## 3.2. Readers

**Referring to Figure 1 and Figure 2, the main reader locations in the Phase 1 demonstrator will be:**

- Incoming item conveyor (1 x)
- Storage unit (4 x)
- Incoming gift box conveyor (1 x)
- Order placement (1 x) [not shown in figures]

We expect that a single reader will be sufficient to reliably detect the tagged item carriers and gift boxes as they pass by on the two conveyors; because the tagged objects will be moving through the reader field, any dead-spots should not be significant. By tagging each of the objects twice, we can guarantee that one of the tags will pass close to the face of the reader. (We emphasise again that assessing tag/reader performance is not a goal of this demonstration.)

Four readers are required for the storage unit in order to be able to read tags attached to item carriers that are located towards the bottom of the four delivery chutes. Checkpoint's hand-held readers, deployed in a fixed, hard-wired fashion, will be used for this, since they have a more limited range of operation which prevents readers from detecting tags in adjacent delivery chutes.

# 4. EQUIPMENT CONTROL

The conventional control system deployed in this demonstration has been developed very much as an interchangeable unit with the intention that it be replaced by a more intelligent, distributed controller in Phase 2. The control system consists of five key operations:

**Local control of Robots and Conveyors**

– Control of individual motion sequences for the conveyor and robot systems is developed on a dedicated controller in the case of the Fanuc robot and in a supervisory PLC (Programmable Logic Controller) in the case of the conveyor system).

**Blackboard system**

– A middleware on PC called the blackboard system (BBS) is developed to bridge local controllers and PC based cell controller. This provides a standard interface for a cell controller to access real-time status from individual local controllers, which are PLC and robot controller in this case.

**Pick-and-place dispatching algorithm**

– A dispatching algorithm is developed to generate a sequence of pick-and-place robot commands to drive the packaging operations of the cell. The algorithm has been developed to coordinate the collection of required item carriers and their correct placement in gift boxes according to the rules of priority. The control system for the laboratory equipment runs on a Microsoft Windows PC.

**"Virtual Warehouse"**

– simple PC based software which maintains a record of current locations of the different product types for access on demand when a packing request is made.

**Network capability**

– PC cell controller with the capability of Internet access is able to receive and update the orders or recipes of products from higher level systems.

# 5. SYSTEM INTEGRATION

In this section we overview the way in which the different components of this development are combined. Figure 5 shows the architecture of the physical system that will make up phase 1. The automation hardware components (robots, conveyors, sensors etc.) are either connected directly to the laboratory ethernet, or are networked via a specialist industrial control network, the Sysmac Link. Checkpoint RFID readers are similarly either connected directly to the ethernet, or are connected via RS232 serial links. There will of course be more readers than are depicted in the figure (see Section 6).

**Savant Data Processing System**

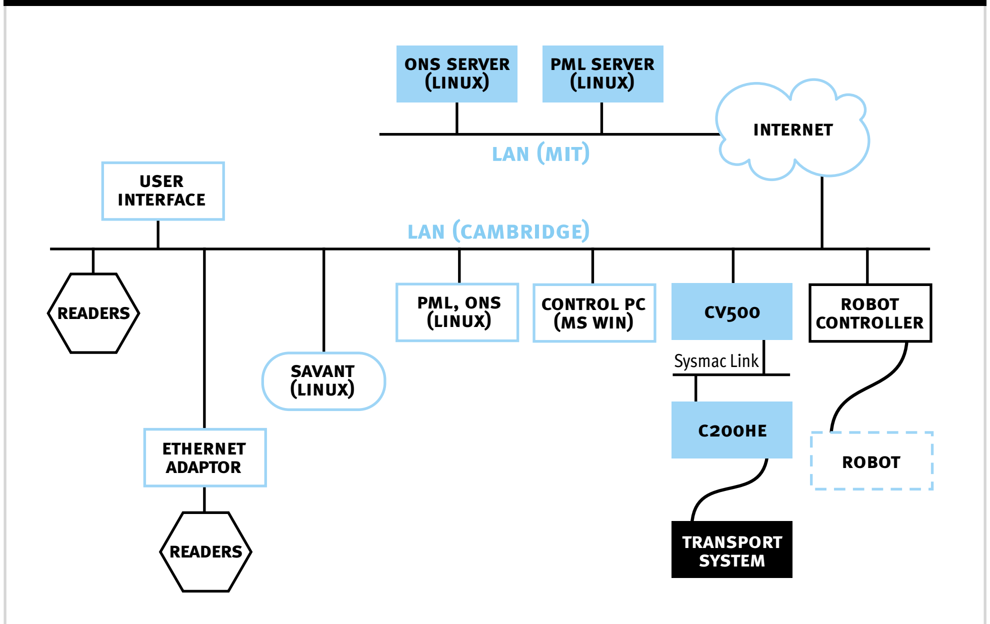
The Savant data collection and management software collects tag reads from all the readers on the network, labels them with a time stamp and reader identifier and filters this data in various ways before passing it to the control system. The Savant software runs on a single PC running Linux in this demonstrator.

**PML and ONS server**

The PML server deals with enquiries relating to information contained in PML files – in this case identifying items and retrieving simple assembly instructions. The ONS Server acts a reverse directory for associating EPC numbers with their PML file locations. In this development, a single Linux machine runs a PML server and the ONS. The Local Area Network (LAN) in the laboratory is, of course, connected to the outside world as well. This means that if, for example, an EPC resolves to an external PML server, the system can access that PML server.

Figure 5

**PHYSICAL SYSTEM ARCHITECTURE FOR PHASE 1**




### User interface

In addition to any user interfaces that may run on the computers listed so far, additional user interfaces may be run elsewhere (one is pictured) via a regular web browser.

Whilst Figure 5 shows the physical setup of the demonstrator, it is instructive to look at the logical arrangement of the system components. This is shown in Figure 6 below. All tag reads are mediated through the single savant, which filters these events in various ways and passes them on to (a) the control system and (b) any additional user interfaces, as appropriate. The savant itself does not, for the Phase 1 demonstration, need to communicate with the PML server. Instead, the control system and user interface components communicate directly with the PML server (possibly using the ONS). The control system also communicates with the automation hardware.

In order to further explain the operation of the demonstration system, it is perhaps instructive to consider different aspects of the system operation.

## 5.1. Arrival and Unloading of Item Carriers

As item carriers arrive on the incoming conveyor, the tag reader at that location detects them (shown as information flow 1 in Figure 7) and the savant passes the EPC information onto the control system (2). The control system will use the PML server to determine the nature of the items on the conveyor (3, 4). It can then stop the conveyor if necessary (5), so that the robot can unload the carriers (6). If one of the parts is needed for the gift box that is currently being assembled, that carrier can be transported directly to the box. Otherwise, the carrier will be placed in the storage system.

Figure 6

LOGICAL SYSTEM ARCHITECTURE FOR PHASE 1

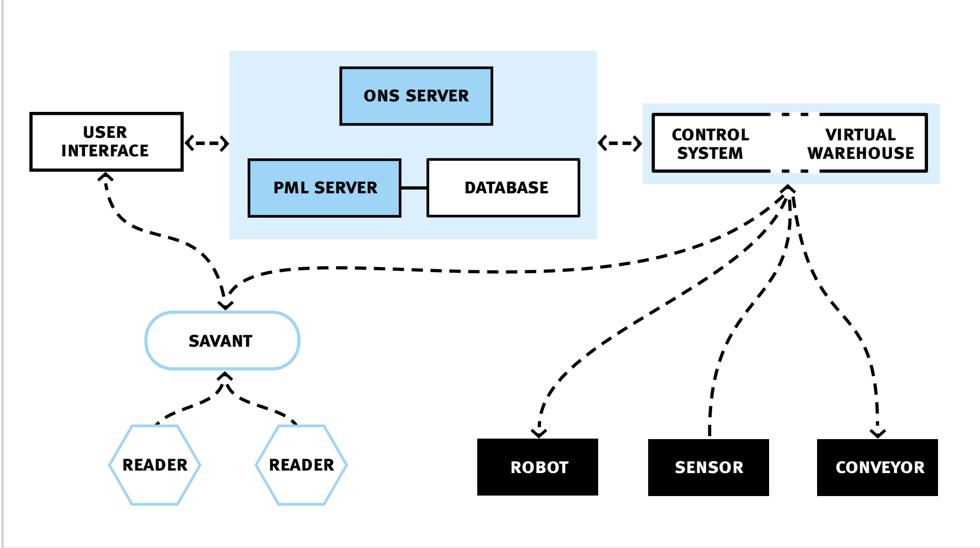
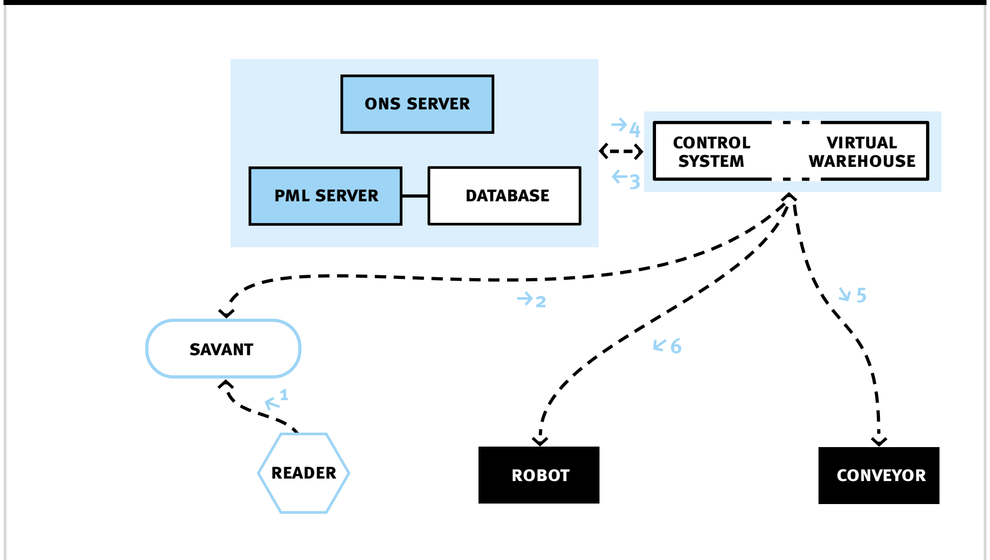



Figure 7

INFORMATION FLOW FOLLOWING THE ARRIVAL OF AN ITEM CARRIER

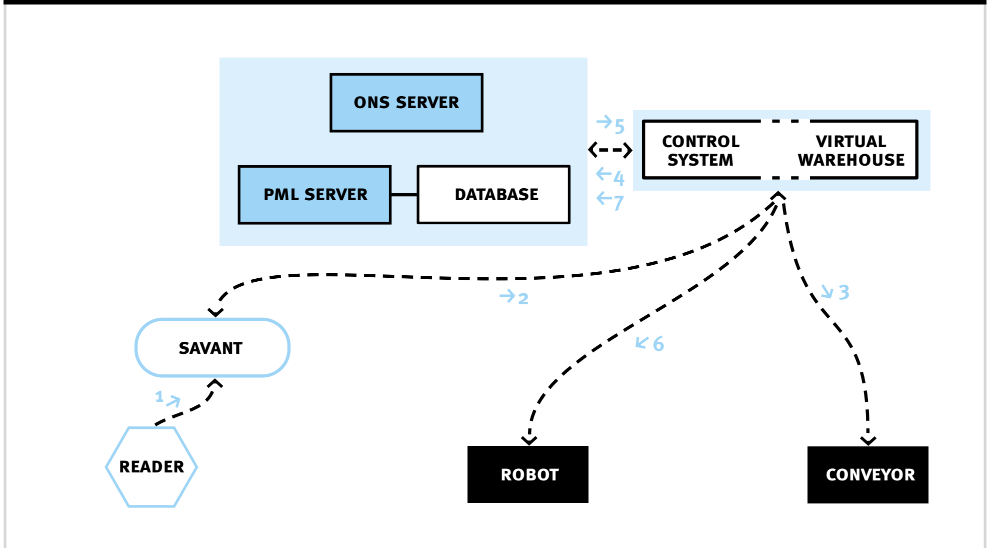



## 5.2. Arrival and Filling of Gift Boxes

Referring to Figure 8, the arrival of a gift box on the second conveyor will be detected by a suitably placed reader (1), in a similar setup to that for item carriers. Once again, the savant will pass the EPC of the gift box onto the control system (2). The control system will then stop the conveyor (3). The PML associated with each gift box describes an 'ingredients list' for that box, along with a description of anything that has already been packed into the box. The control system retrieves this information from the PML server (4, 5) to determine what (if anything) needs to be packed into the box to complete its assembly (6). The gift box PML file is then updated to include serial number data relating to the items packed in the gift box (7).

Figure 8

INFORMATION FLOW FOLLOWING THE ARRIVAL OF A GIFT BOX




## 5.3. Use of the Storage System

A (permanently mounted) handheld reader is located towards the bottom of each of the storage chutes in the storage system. These readers will detect the bottom few item carriers in each chute (if any are present), and pass this information onto the savant. The savant, in turn, informs the control system of any items that are available.

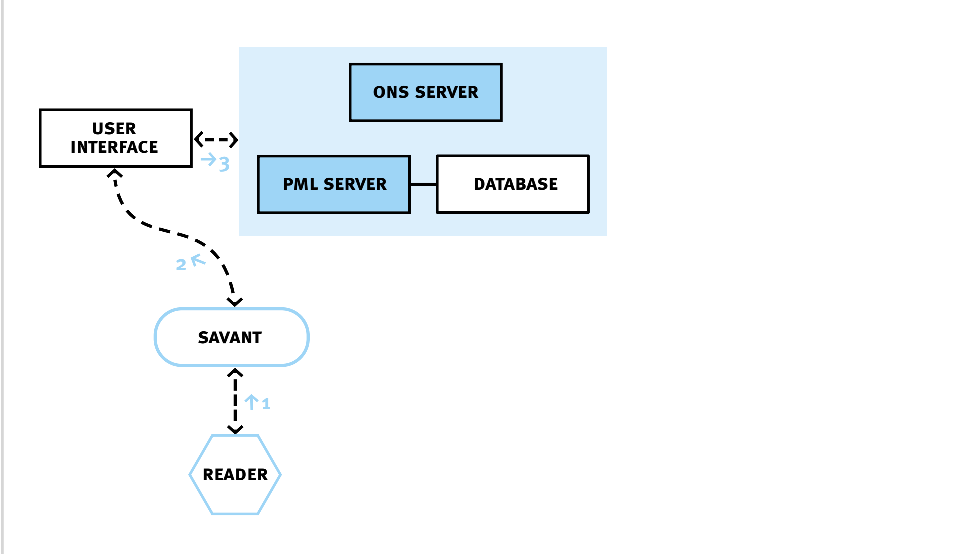
If the control system removes an item carrier from one of the chutes, the savant will detect the removal of the corresponding EPC from the reader field. This removal is used as a check by the control system to make sure that the robot has grasped the item that was intended. In case of an error at this stage, the control system will instruct the robot to place the item carrier back in the storage system (in the appropriate chute), and to then repeat the operation.

## 5.4. Customer Order Generation

A web browser based user interface is used to generate customer orders. An RFID reader located by the computer that runs this user interface is used to determine the EPC of a particular (empty) gift box (1 in Figure 9), and this information is passed through the savant to the user interface (2). An operator can then specify the contents required for that gift box, and this information is used to update the PML associated with that gift box (3). By doing this, the relevant packing requirements for that box are effectively stored with the other item details, and can therefore be subsequently accessed by the control system when the box is being filled.

Figure 9

**INFORMATION FLOW FOR CUSTOMER ORDER PLACEMENT USING THE USER INTERFACE**



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