EE4-60: HCR Design Report - MailBot

Callum Alder
ca1815@ic.ac.uk

Ryan Armiger
rsa115@ic.ac.uk

Ifeanyi Chinweze
aic15@ic.ac.uk

Adel Haddad
afh115@ic.ac.uk

Koral Hassan
kbh15@ic.ac.uk

Javi Geis
jg3215@ic.ac.uk

Jack Pearson
jcp115@ic.ac.uk

Abstract

This paper presents the research and design of MailBot an interactive robot that will serve as an internal mail delivery option for Imperial College London. This would serve as a proposed solution to the challenges presented within the 'Final Mile', the last stage of the delivery process of goods from a transportation hub to a final destination in the home. This design report describes and justifies the high-level decisions made when building MailBot, with a focus on how human-robot interactions can affect the user's experience.

1. Introduction

The coming milestones for postage and logistics will be realised through improvements to the cost and efficiency of the 'Final Mile', it is industrially recognised as the terminating problem step from depot to door which incurs the biggest reduction to profit and customer satisfaction [1]. Attempts to solve this include drone delivery - which is opposed by increasingly stringent air regulation and weight and weather limitations - and ground robots which currently struggle to accommodate multiple packages or endure today's large volumes of mail in their infancy [2, 3, 4].

Additionally, local post offices are decreasing in number, in contrast to the rapidly increasing volume of packages and urgency in which they are expected, creating large strains on existing logistics systems. Further agitated by the growth of e-commerce and its sporadic demands including 'Black Friday' and seasonal events, the infrastructure for a smart, reconfigurable 'Final Mile' service is becoming increasingly urgent.

The 'Final Mile' problem critically relies on human interaction for both accepting and sending mail, coupled with understanding and answering user queries. Secondary interactions in collision avoidance or GPS tracking are also fundamental to the technologies' success. Here, we document MailBot: our group's proposed solution to the outlined problem. MailBot will first serve as Imperial's own internal delivery system taking packages across the campus, and then advance as a potential solution to the Final Mile problem.

2. Hypothesis

This project acts as a study to investigate whether MailBot can distribute mail more efficiently than existing services through automation and better accommodation of mail volume and chosen morphology. The success of this study relies upon the quality of human interaction with MailBot. Hence, in creating MailBot, our group primarily seeks to optimise the parameters of perceived usefulness and perceived ease of use, outlined by the Technology Acceptance Model (TAM) [5], Figure 2a.

Our approach to designing MailBot considers the TAM and the Theory of Planned Behaviour (TPB) [6], Figure 2b, to produce a solution with the following aims.

Aims:

1. Foster trust between the user by integrating into an existing social structure (humanoid interface).
2. Realise high utilisation in urgent, short distance orders in early models and, in later models, progress to high utilisation in urgent, short to long distance orders.
3. Provide a practical, efficient and user-friendly solution to the Final Mile problem.

Our hypothesis is that if MailBot can first achieve these aims at campus-wide scale, it can be progressed to a larger scale to resolve the 'Final Mile' problem. The proposed **Aims** will be the standards against which MailBot is tested for performance, and its success will determine if it validates the hypothesis.

3. Literature Survey

In the last decade, next-day delivery has become a common and often-expected delivery option. Amazon is the largest advertiser of this service, offering *Prime* Delivery and even *Prime Now*, a 2-hour delivery service. An important part of this business model is the use of robots to automate the logistics of the picking and packing process in their fulfilment warehouses [7]. The obvious next step in the world of online shopping is to increase the efficiency of the delivery process. Amazon's drone delivery service [2] is not the only proposed solution. Large companies and organisations across the world are getting involved and providing ground-based services.

The Norwegian postal service has developed a locker on wheels. It moves at a walking pace of ≈4mph, which has been proposed as "a low-risk and environment friendly speed" [8]. As well as prioritising safety for the people around the robot and the packages inside of it, this slow speed adheres to human social expectations. Meeting these expectations of navigation will portray the technology as competent and facilitate enjoyable interaction [9]. Within navigation some social conventions are clear, such as avoiding blocking other people's paths, while others are less tangible, such as moving in a predictable fashion and the effect that may have on the comfort of other users of that shared space.

The ability to interact with the user in a intuitive way is something that we believe requires more attention and thus, we have adopted successful properties from other products in the market while maintaining an anthropomorphic look. Japanese company ZMP announced their take on the delivery bot in 2017, *CarriRo Deli* [10]. It features little eyes on the front LCD screen, displaying emotion to the user and providing a more comforting experience when interacting with the robot. Emotion provides a level of trust with the user and does not detach from the face-to-face interaction in the same way that a phone app or text-based terminal would. Marek N. Posard and R. Gordon Rinderknech showed that people "felt a greater sense of partnership with computer partners, regardless of appearance, than human partners following an exchange requiring trust" [11]. This base level of computer trust is something that emotional interaction can strengthen. The *CarriRo Deli* also features interchangeable locker sizes. Within the roughly half meter cube shaped chassis you can insert either one large locker, four medium or eight small compartments, highlighting the need for different parcel sizes as a must for general purpose delivery.

Autonomous parcel and grocery delivery service Starship technologies [4] have rolled out their six wheeled robot. They too have focused on the 'Final Mile' of delivery, their use of a centralised docking point is of particular interest.

Furthermore, room service robots adopted by many hotel chains is a further example of a simplistic interface with automated delivery. *Savioke* [12], is a notable example that uses ROS [13]. Room service items are loaded from the front desk/kitchen of the hotel and the robot navigates to the desired room to be unlocked as the customer opens their door. The robots are easily accessible and require very minimal interaction. This is a design that could be integrated to MailBot and leverage off of internal ID systems of Educational institutions or companies. The initial design plan is laid out with further justification in the following section.

4. Design Outline

Inspired by *StarShip* [4], MailBot will wait in a designated drop off zone, ideally next to a mail point within a campus or office building. The senders will then be able to load the lockers with letters and parcels entirely with the aid of the touch screen interface. MailBot applies a security level to each locker with a mail item and broadcasts delivery updates to the sender and recipient. MailBot will navigate to each recipient and play a 'knock-knock' sound to alert them to its presence. It will request the code to open the locker and, if successful, the mail can be retrieved. MailBot notes the outcome of the delivery and proceeds to the next one. When deliveries are completed, MailBot will return to a designated space or depot. In this way, it will always be available at the earliest convenience, allowing it to be refilled faster and operate more efficiently. This also prevents it from violating social expectations on loitering.

The overall interaction style will have a simplistic Tool-Like personality. This is easier to implement and may have positive impacts on its acceptance. Robots which perform service tasks on command "exhibit traits usually associated with tools (dependability, reliability, etc)" [14]. These are good traits for a mail delivery robots to have and through symbolic association [15], these may also be attributed to the company which deploys them.

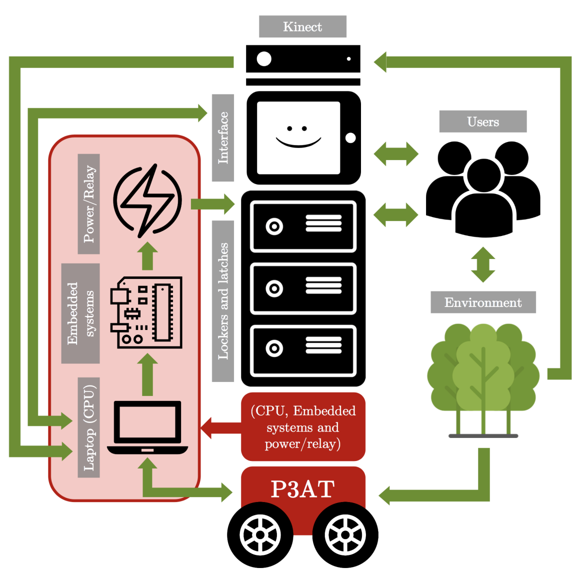

Figure 1. System diagram of the different components of MailBot. The green arrows symbolise data transfer between components.

The constituent parts of the MailBot system are illustrated in Figure 1. The user interacts with the interface and relevant data is sent to and from the computer. The computer is the main processor and it coordinates the navigation of the robot and controls the opening and closing of the lockers based on inputs from the Kinect camera and the interface.

4.1. Hardware

The hardware component of MailBot takes its inspiration from an Amazon locker. It utilises a locking solenoid latch system that works in conjunction with spring loaded doors to easily display to the user which locker they have been allocated. The simplicity of this design ensures minimal maintenance. All solenoid latches are connected to a central embedded system to control the opening of the locker doors. We chose to use an Arduino [16] for this task as we only require seven digital outputs and the device simply acts as a slave to the ROS node running for the locker operation. Sending commands to the Arduino will be done over serial communication. The ROS node will run either it's own serial integration or a Matlab script that controls RealTerm [17].

On a small scale, campus-based robot such as ours, there will not be an available fleet to house different locker configurations and as a result we will be carrying four small, two medium and one large locker. Providing sufficient storage for most if not all internal deliveries. Small letters (240 mm x 165 mm x 5mm), large letters (353 mm x 250mm x 25mm), and parcel (450mm x 350mm x 160mm) [18].

The parcel locker has been positioned lower in the bot for stability while moving and to minimise back strain of the user when loading the locker. The layout of the lockers is space efficient to reduce the total height, all lockers are between ≈300-1000mm off the ground and the centre of the tablet interface is positioned at ≈800mm. This is in-line with standards for wheelchair access requesting items such as door handles and plug sockets to be positioned between 450-1200mm above floor level [19]. Providing an accessible, easy to use and efficient product is in line with the TAM [5] model for product feasibility and gives us confidence our hardware design will be up to a market acceptable standard.

Ground-based robots also offer a benefit to human interaction by appearing in a more familiar morphology, similar to other products that share the public space, e.g. cars, bikes. This morphology also offers the opportunity to more appropriately build human-like features into the design and explore its anthropomorphic effect on interactions.

4.2. Navigation

The design choices made to solve robot navigation are chosen to optimise practical solutions while carefully considering the solution's effect on robot-human interaction. These choices are based on initial expectations and will be evaluated in detail later.

The MailBot's movement speed will be reasonably slow, both to ensure the safety of other users of that space and to conform to expectations about speed. Speed limitations aligning to teachings "not to run in hallways" may help imbue positive anthropomorphic characteristics to perception of the robot.

Path planning & collision avoidance are important parts of the navigation design. This entails avoidance of humans within the space to ensure their safety, and avoidance of obstacles to reach the delivery location. The ground-based MailBot makes this simpler as movement is confined to 2 dimensions. If carefully designed, this system may be interpreted by onlookers as significantly intelligent, this may positively affect trust in the service or comfort in interactions. Additionally, smooth movement trajectories will improve a human's ability to predict the robot's path, which may have a positive effect on user comfort.

4.3. Interface

The user interface will run on a touchscreen tablet position at roughly ≈800mm off the floor, hip height for a standing adult. Using a tablet is the most cost-effective and user-friendly option, compared to error-prone alternatives such as purely verbal interaction with the robot. Serial communication will be the communication pathway between the tablet and the main laptop. This pathway enables status updates for each locker to be shared, detailing whether they are in use or empty - allowing the interface to inform the user of whether there are spaces for mail items - and sender/recipient details (i.e. name, address, e-mail) to plan out the delivery route and broadcast delivery updates.

Interface design choices aim to improve the user experience, such as a mailbox-inspired colour scheme so that it can be easily identified as a delivery service. MailBot also has an anthropomorphic design with a cheery face to invite users in, and it will include a 'Help' button that will provide information on how to use each part of the interface.

5. User Testing

5.1. User Reviews

Once the sender or the recipient has finished using the system, they will have the option to complete a survey. The survey will ask the users to quantify the human traits of the MailBot, such as its trustworthiness, reliability and intelligence, and their reaction to them. Additionally, the survey will query what people think about companies that deploy these robots.

5.2. User Interaction

Whilst the user (sender or recipient) is using MailBot, it is important that they are sufficiently engaged with the robot. Studies have found that gaze is a powerful reinforcement tool in strengthening social influence [20, 21]. This influence would be important in establishing engagement and trust between the MailBot and its users. The MailBot will be monitoring the amount of eye contact that the user holds with the Kinect camera and tablet. This can be measured by using a facial recognition algorithm on the image data coming from the Kinect while the user is engaged with the interface, to detect when a user is looking at, or away from the camera and tablet. Typically, an engaged party who is receiving information will look at the listener's face 75% of the time [20, 21] and ideally our results would show approximately the same level, if not higher.

5.3. Quantifying Utilisation

There are two main values that will allow us to quantify the utilisation of the MailBot. The first will be the number of lockers that are full on each of the delivery runs that the MailBot completes. This data can be logged at the start of each delivery run. The second will be the number of successful deliveries completed by the robot each day. This data can be updated by the MailBot as it completes each successful delivery. Additionally, logging the number of unique users, user growth and repeat users can give further insights into predicted utilisation.

6. Evaluation

The results from user testing outlined in Section 5 will allow our group to evaluate whether the MailBot validates the hypothesis and **Aims** laid out in Section 2.

User reviews will allow us to quantify user perception of the robot's purpose, assess its general performance and answer whether the anthropomorphic design choices have a prevailing positive effect on user interaction. This is a test of **Aims** 1. and 3. and also provides guidance for iterative improvements to all other aspects of the system.

The data from the user interaction will primarily contribute to the assessment of the level of engagement and trust that the user shares with the MailBot, its success in this regard is encapsulated in **Aim** 1.

Analysis of the utilisation data will allow us to assess the performance of the MailBot in **Aim** 2. The results will allow us to ascertain when and where mail traffic is busiest and make adjustments to operation of the MailBot. Moreover, it will be an indicator of whether people are receptive to using the MailBot and if it is perceived as an efficient delivery option.

If the MailBot performs successfully in its tests, it will have accomplished the aims set out in the project. In achieving these aims, the MailBot would demonstrate it is capable of solving the 'Final Mile' problem on the proposed campus-wide scale and that, with some development, it can be applied to a larger consumer base. That is to say, we can accept our hypothesis.

7. Preliminary Work

A preliminary overall system flow has been designed, Figure 1. Additionally, individual subsystem progress is detailed below.

7.1. Hardware

An enclosure has been fabricated to fit onto the base P3-AT. This sets the base dimensions for subsequent parcel or letter lockers. The steel base is shown in Figure 4a. This is bolted to the P3-AT and is extremely robust. On top of this is a wooden base plate which has a cut out for wire access. The steel frame is constructed of 6mm strut and M6 studding seen in Figure 4b. The strut was drilled through its core to be bolted onto the steel base. The M6 studding supports the wooden panels, Figure 4c, which the locker doors will be cut out of and squeezes the panels tight to the frame.

7.2. Navigation

The navigation system will be designed following the redundancy design principle. At this stage we propose a ultrasonic based and Kinect based sensors. Depth information will form a primary collision avoidance system, while visual information can be used to predict the path of objects (i.e. people) for more refined avoidance. See Figure 3.

The visual information provided by the Kinect may also be used to pre-map the delivery spaces, using the GMapping ROS package. Simultaneous Localisation and Mapping (SLAM) could also be used [22], utilising ROS package including the: Navigation Stack, GMapping, OpenNI-Kinect and p2os. The proposed system can be tested in multiple environments using different mapped Gazebo worlds [23].

7.3. Interface

A framework for the interface has been designed and programmed for the collection and delivery operations of MailBot. Figure 5 describes the collection mode, and Figure 6 describes the delivery mode. The interface is being developed as an Android application designed for a Lenovo Tab 2 A10-70 tablet, as can be seen in Figure 7. All the activities depicted in Figure 5 and Figure 6 have been written and the Java files defining their basic functionality have been written.

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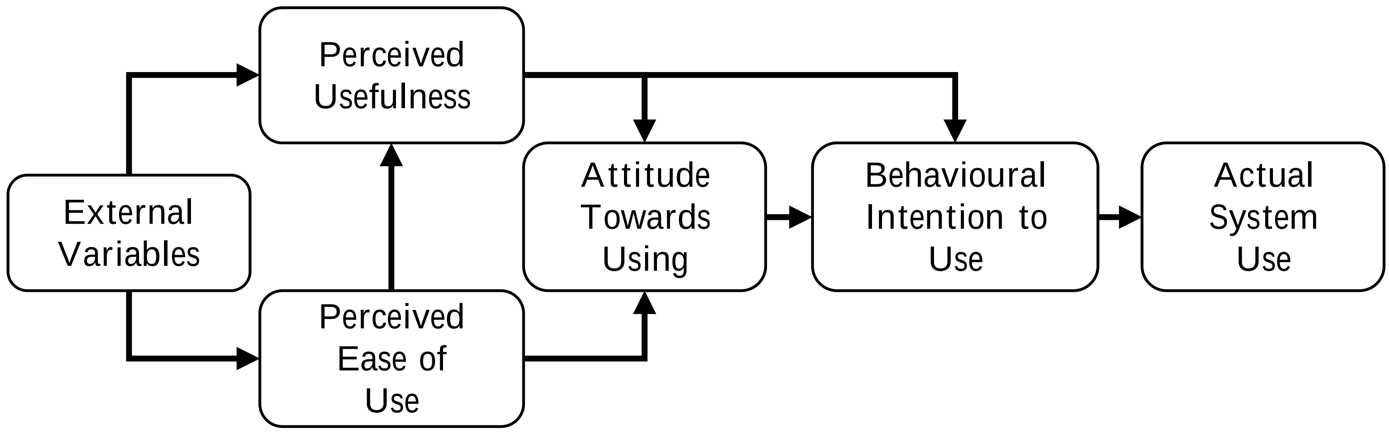
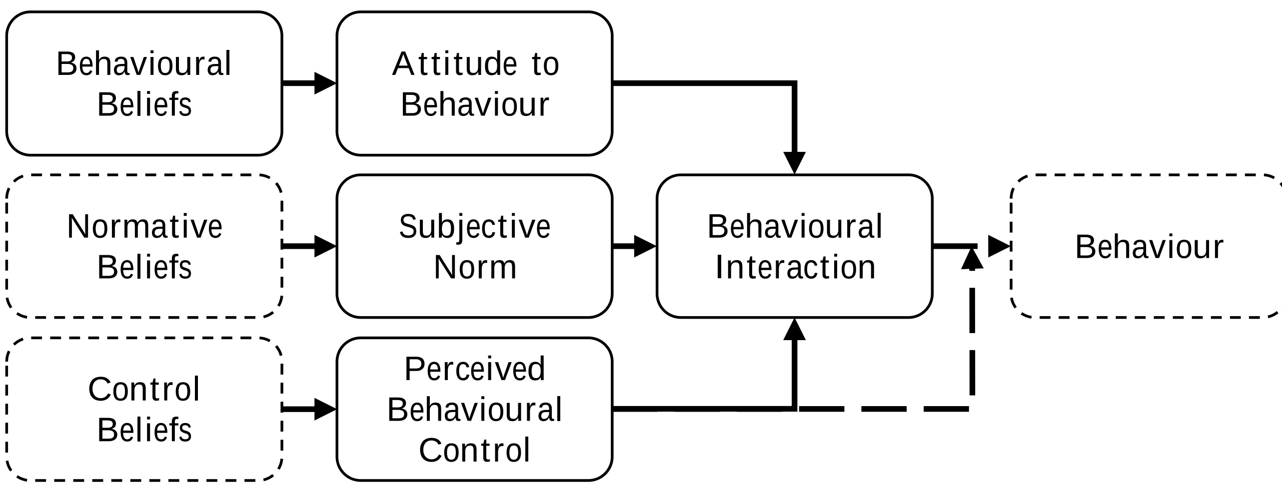
List of Figures

A. Supplementary Figures



(a) TAM



(b) TPB

Figure 2. TAM and TPB. Models for technology acceptance.

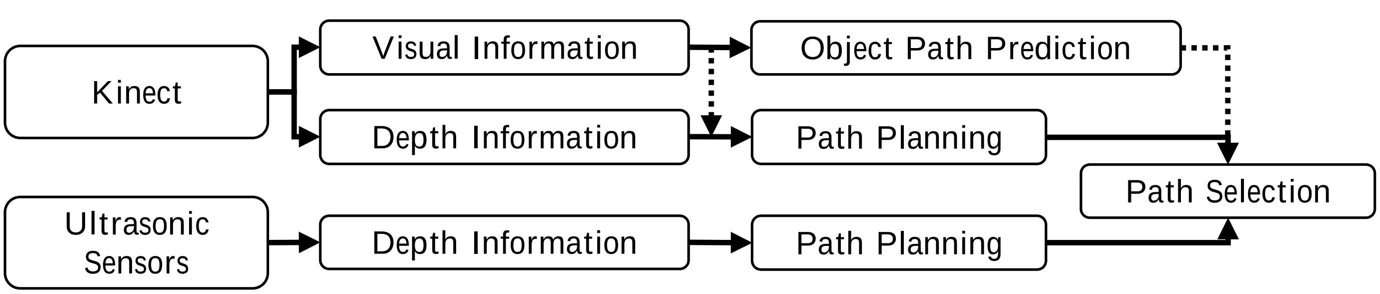


Figure 3. Navigation System Flow

(a) Welded steel plate.

(b) Steel strut frame.

(c) Wooden panels.
Figure 4. Preliminary hardware progress.

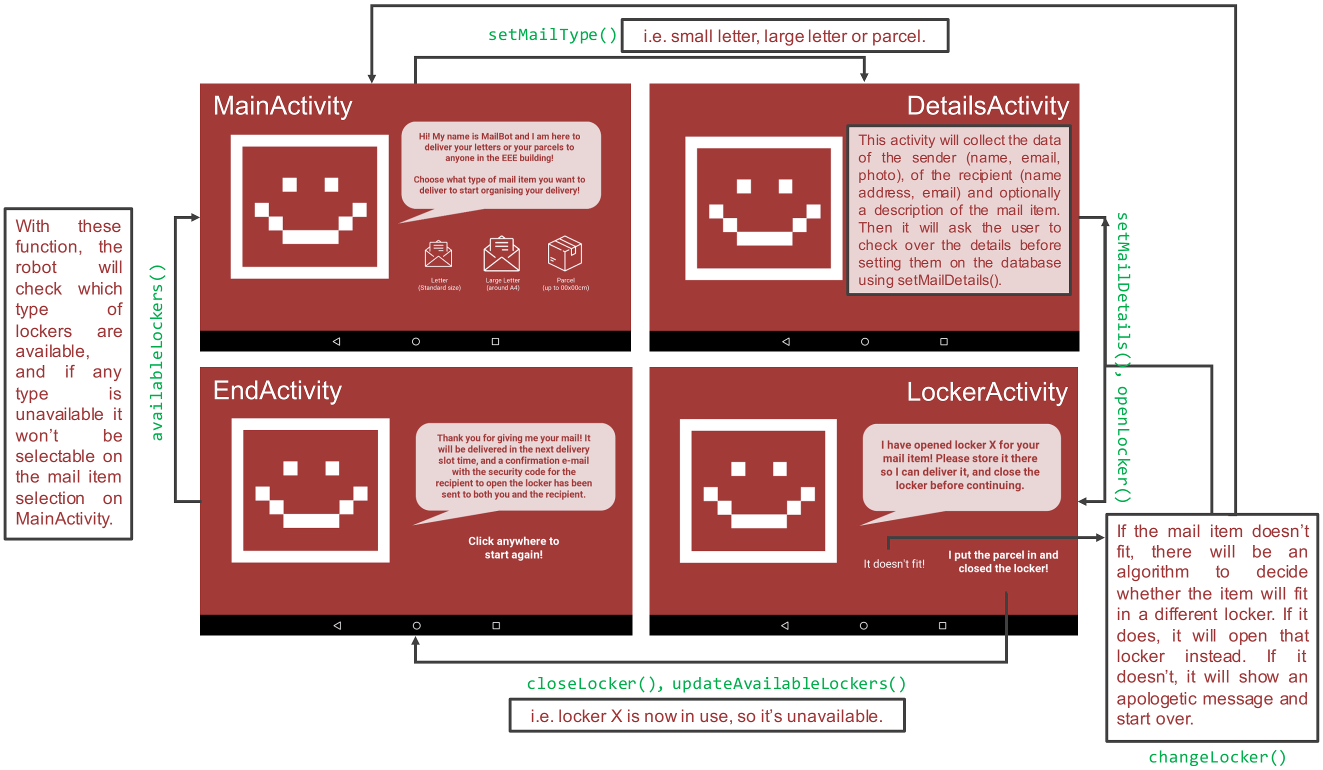


Figure 5. Preliminary interface progress of the collection mode, including the functions happening in the background.

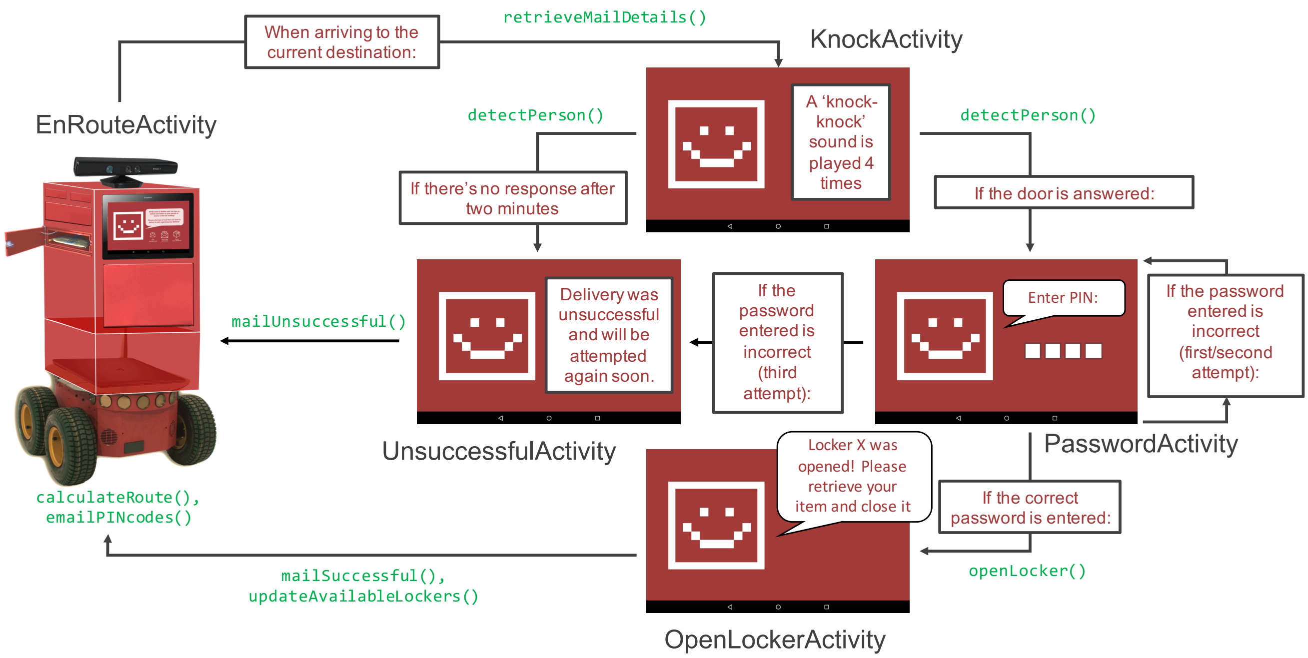


Figure 6. Preliminary interface progress of the delivery mode, including the functions happening in the background.

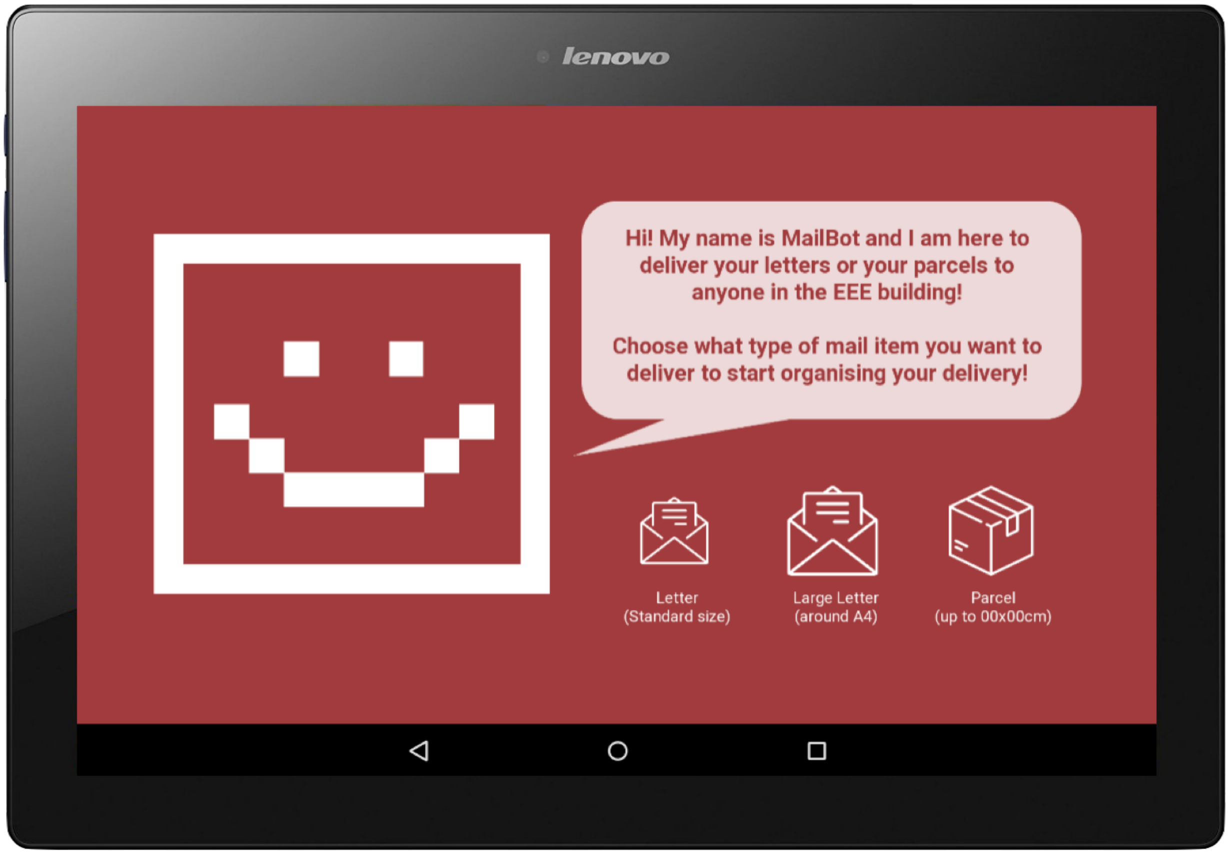


Figure 7. Recreation of how the interface will look.