Prototyping The User Experience of an Urban Express Robotic Delivery Network

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ABSTRACT

Automated public urban freight transportation networks have the potential to greatly increase the energy efficiency of material transport by more closely matching the mass of the goods being transported with the mass of the transportation apparatus and reduce the cost to society by removing the requirement for human supervision for each package. In this paper, we present an overview of the considerations for the design of the user interface for such a system (the Urban Express Robotic Network), a description of the implemented prototype and its user interface, lessons learned from focus group testing, and plans for future work on this project.

INTRODUCTION

Current implementations of intra-city transportation networks suffer from a number of severe core inefficiencies. One major example is disproportionate energy expenditure compared with the mass of people and products being transported, particularly in the case of personal passenger vehicles, which may outweigh their contents on any given trip by an order of magnitude. Another is lost time and productivity caused by both the intrinsic need for human drivers to accompany physical objects during transport, and the extrinsic additional personnel time and fuel lost to traffic congestion. Statistics are available to quantify the scale of the problem: in the United States transportation activities are the second largest net consumer of energy and largest contributor to carbon emissions (EIA 2005) and approximately 4.5 working days are lost per person on average due to road congestion-related delays alone (Schrank & Lomax 2009). However, potential solutions exist to mitigate these inefficiencies. We have previously proposed the development of parallel, packet-switched robotic networks for intra-city transportation and delivery of physical objects (Thompson & Brooks 2010a). Such networks are inherently more efficient in terms of the expenditure of energy by more closely matching the mass of the goods being transported with the mass of the transportation apparatus, and in terms of time by removing the requirement for human supervision of each packet. Furthermore, by reducing the need for private personal vehicles to transport physical objects (such as purchased goods) through the existing general-purpose transportation network, congestion can be minimized as well.

The use of automation to improve the movement of physical items is not a new concept. Functional Automatic Guided Vehicles (AGVs) for material transport in industrial settings were introduced in 1955, only two years after the first concepts for Automated People Movers (APMs) and Personal Rapid Transit (PRT) systems (Muller 1983). Since then, they have been used in a variety of industries including manufacturing, warehousing, and distribution (Le-Ahn & Koster 2006). However, these systems can be seen as object-delivery analogs of public transportation systems, as they tend to have limited scope compared to the ultimate destination of the objects, and focus on transport between a small number of high-traffic delivery terminals. We envisage...
more of an ideal PRT model for physical objects: a network of small, high-efficiency automated transports that deliver packages between their source and ultimate destination. In fact, some PRT systems, such as the one under construction in Masdar City, envisage a freight capability (2getthere 2010). However, this requires freight vehicles to share the passenger PRT network, limiting its ability to truly tackle the congestion problem. Similarly, freight-focused parallel logistical networks such as OLS-ASH (Pielage 2001) and CargoCap (Stein & Shoesser 2003) aim to remove bulk freight transport from the congested shared transportation networks, but do little to alleviate the congestion that comes from the transportation of non-bulk freight in individual passenger vehicles.

Our proposal therefore outlined a radically different model for the urban movement of consumer goods, in which items are packetized to a standard volumetric configuration and efficiently routed point-to-point through dedicated transportation channels connecting private and public access transmission and delivery terminals. Rather than catering primarily to organizations performing bulk transshipment, the model is intended for use by private citizens to move personal items. We now refer to this network as the UrBan Express Robotic NETwork (UBER-NET).

This paper summarizes our initial prototype of the UBER-NET system with a focus on the user interface and user experience. In our previous work, we identified what we consider to be the most important design considerations in the development of automated civil transportation systems (Thompson & Brooks 2010b). Several of these axioms concerned the need for realism in the scale, context and “feel” of demonstration systems in order to properly evaluate their effectiveness. We also stated that the user experience must be realistic to obtain meaningful social proof of concept. We have used these considerations to guide our prototyping efforts and have therefore concentrated on prototyping a realistic user interface to a demonstration pair of public access terminals connected by a single transport robot. In this paper, we present an overview of the considerations for the design of the user interface for the UBER-NET, a description of the implemented prototype and its user interface, lessons learned from focus group testing, and plans for future work on this project.

USER INTERFACE DESIGN CONSIDERATIONS

The primary customer-facing component of the UBER-NET is intended to be a mechatronic terminal capable of being operated by the general public. The archetype of success in such terminals is the ubiquitous cash-dispensing automatic teller machine (ATM). We therefore envisage an ATM-style interface model for the UBER-NET that consists of a display screen soliciting user input via a series of visual prompts with associated feedback as the interaction progresses, and a mechanical “loading dock” area, modeled on an airlock, through which packages are introduced into the network and subsequently retrieved.

There are two essential user experiences with the UBER-NET: using a terminal to send an object to a remote destination, and receiving (or declining) an object at a terminal. In general terms, the first experience consists of doing any necessary preparation of the object for transmission, entering the destination address, negotiating payment, inserting the object, and confirming the transaction. The second consists of being notified that a shipment has been requested for transmission, being informed of any relevant details about the shipment such as its contents and the identity of the sender, having an opportunity to accept or reject the shipment, and finally receiving the shipment.

As with many user interface design problems, it is clear that within the conceptual simplicity of these interactions there are many potential options. These options include choices both directly observable by the user and others abstracted within the network. In the first category, an example is the order of operations. Should the package be loaded before or after payment? Should recipient acceptance be required before the package can be loaded, or should it be entered into the network and then returned if rejected? In the second category, an example is the scheduling of transportation robots. Should a robot be summoned to the terminal as soon as a sender begins the interaction, potentially wasting resources if the shipment is not accepted? Or should it only be summoned once the shipment is accepted, potentially forcing the sender to wait for it to arrive? Providing correct answers to these questions will be crucial in determining the success or failure of the system, because success depends more than anything else on the overall user experience with the system, compared to the typical user experience of manually delivering packages in a personal vehicle.

Numerous other considerations affect user interface (UI) design choices in this case. The privacy of users, including their addresses and the types of shipments they receive, must be balanced with the need to ensure the security of users, their terminals, and the network as a whole. The presence of terminals within private dwellings means that users should be able to protect themselves from potentially unwanted goods, ranging from advertising and unsolicited commercial deliveries to hazardous or harassing materials, while not being so shielded from the unknown as to be unable to receive a surprise birthday gift. Packetizing the object to be sent needs to result in a standard shipment that protects the integrity of the network from poorly packeted items or malicious impediments to the robots such as leaks and debris, but should not be an onerous task for the sender. And in the case of the visual prompts and feedback provided, ease of use must be paramount, while making every effort to optimize the usage of network resources that will only be apparent to the user through indirect feedback such as waiting times.
Just as the ATM attempts to some degree to replicate the experience of interacting with a human bank teller, our benchmark for the UBER-NET terminal sending interaction is the postal service counter. When mailing a package, it must be properly prepared and may have to have its contents described. Reasonable efforts are made to prevent the shipment of hazardous or destructive materials without making unduly intrusive demands of the sender. It is not possible to use the postal counter to find out other people’s addresses or mail-ordering habits. The interaction is fluid and takes place in a logical order: addressing, integrity checking, cost reporting, payment, acceptance. On the receiving side, there is acceptance or refusal as with a package requiring a signature. We therefore focused our UI design on merging the best aspects of the postal counter and the ATM.

**PROTOTYPE DESCRIPTION**

Since the only end-user-facing element of the UBER-NET is the terminal, it is possible to approximate the user experience at the terminal by constructing a single prototype terminal which could be used to simulate both sending and receiving shipments in separate test scenarios. However, because we wished to best approximate the full user experience, including dispatching robots and waiting for them to arrive, we constructed two fully operational terminals and a robot to convey goods through a tunnel representing the network. Since the structure and configuration of the network is hidden from the end user, it was not necessary to construct a complex network between the two terminals at this stage in order to prototype the user experience. However, the robot takes a measurable amount of time to traverse the network, so the user can appreciate the effect of robot scheduling decisions.

The terminals, robot and network passage were designed to be approximate 1:5 scale representations of the UBER-NET assuming a target package size of 600 mm per side. Each loading dock prototype is 310 mm long, 280 mm tall, and 210 mm deep, while the tunnel is 300 mm long, 205mm tall, and 203 mm deep. All structural elements were modeled in SolidWorks and then constructed from laser-cut white acrylic sheet (Figure 1). This material allows the inner workings of the system to be opaque to the user under normal circumstances, but can be back-lit to render the robot visible for demonstration purposes. The user interface elements, consisting of a touch screen visual input device and a mechanical “airlock” door, were also scaled accordingly. The touch screen, a Casio COM26T2844VTX thin film transistor LCD touch screen, serves as the primary information input and feedback delivery mechanism. A separate keypad was deemed unnecessary due to the flexibility and text entry capabilities of an on-screen keyboard. The airlock door, which only opens when a robot is present, also serves as a physical feedback mechanism to prompt for insertion of the package to be sent and to notify the recipient of a successful package delivery. The computation for both terminals and the robot are performed on an Atmel ATMega 128 microcontroller within each independent unit. The terminals communicate with each other and a central control computer using a wireless Zigbee Digi XB24-ACI-001.

![Scale model of two connected UBER-NET terminals with a delivery vehicle: CAD model (left) and physical prototype (right).](image)

The information request pages on the touch screen were designed to offer simple choices uncluttered by extraneous information (Figures 2 and 3). Aesthetic and decorative flourishes were forgone at this stage in favor of straightforward functionality in order to evaluate the effects of fundamental interface choices such as order of operations. Example pages presented to the sender include an initial activation screen, an address entry screen, a delivery speed selection screen (e.g. “Express”, “Regular” and “Economy”), pure information screens (e.g. “Requesting delivery acceptance”), and interstitial confirmation screens offering the user a chance to cancel or correct a selection. Similarly, the recipient’s terminal offers screens notifying of delivery requests, soliciting acceptance or rejection of the delivery, and updating the recipient of the status and expected arrival time of the delivery.
This paged input model allows experimentation with different scenarios as detailed in the UI design discussion. For example, optimization of network resources can be achieved by waiting until a delivery has been fully addressed and accepted before dispatching the robot, at the cost of additional waiting time on the part of the sender. Conversely, Post Office-style minimal wait service can be achieved by allowing a sender to complete the sending transaction and dispatch the package before asking the recipient to accept or reject it. One possible scenario that we tested with focus-group users in our laboratory is illustrated in the flowchart in Figure 4. The sender first inputs recipient address information. The system then offers the sender example special service options (such as a refrigerated robot for transportation of frozen goods). Next, the user is presented with information about the availability of vehicles, and the cost and delivery time of various delivery options. The user is then prompted for a payment method. Once this process is complete, the recipient is notified and asked to accept or reject the package. If the shipment is accepted, then the sender’s payment is processed and the robot vehicle is dispatched to pick it up (optimizing for network resources). When the vehicle arrives, the terminal door opens and the sender is prompted to insert the package. The sender’s interaction ends after being prompted to dispatch the package, the door closes and the robot is dispatched to the destination terminal. After its arrival the recipient is notified and prompted to open the door and unload the package. When the recipient finishes unloading, the door closes and the robot is returned to the control of the network.

Presently we represent terminal addresses as dot-separated numeric strings, modeled on IPv4 network addresses. We chose this not only for its similarity to packet-switched data networks, but because such addresses are difficult for people to remember, necessitating an address book feature. Even though the prototype network is small, a realistic user experience requires senders to be able to choose between a large variety of friends and businesses to whom they might wish to send a package, and any successful interface would assist users in selection of known or previously used addresses. We have implemented a rudimentary address book that maps names to terminal addresses. This cellphone-style address reference could ultimately be implemented on a phone, to facilitate package pre-addressing and advance recipient acceptance, or could be synchronized to the central computer so users have access to their personal address data from any terminal after an authentication step. Such “cloud” synchronization would also allow other customizations to be stored, with the result that to individual users every public terminal would appear like and behave the same way as their home terminal.
Informal focus group testing was performed with laboratory members and visitors in order to solicit opinions on fundamental UI questions such as order of operations, resulting in the example interaction presented in Figure 4. However, it is important to note that all such testing was performed with both sender and recipient in attendance at their respective terminals. The sender was therefore never forced to wait any significant time for acceptance or rejection of the delivery. We envisage terminals to be used to send packages at any time of the day or night, and users making use of public terminals to send goods to themselves (e.g. from a supermarket to home). Thus, it is clearly unacceptable from a user experience perspective to expect a recipient to be at the destination terminal to accept or reject a delivery as the request is made. There are two basic responses to this problem, each of which has ramifications beyond the scope of this paper. One is to continue to insist on real-time acceptance or rejection of a delivery, but to incorporate a mobile component to the recipient prompt, such as via cellular text messaging. This still has the potential to force the sender to wait indefinitely if the recipient is not able to receive the message. The other is to follow the postal service model and allow shipments into the network prior to acceptance, to be stored in buffer zones within the network. It must be understood that this allows potentially unapproved items entry to the network (subject to the packaging specifications) and requires a facility to deal with undeliverable or misaddressed packages. Allowing recipients to pre-authorize all shipments from certain individuals or businesses can help to alleviate some of these problems.

Test users did not report difficulties understanding the options presented by the touch screen system and assessing the state of the interaction. Where navigation difficulties were encountered, such as correcting an input versus resetting the interaction, these were corrected. Using a touch screen rather than a keypad may assist in alleviating the confusion that users sometimes report between the ‘Cancel’ and ‘Change’ keys present on some ATM keypads. Users also reported liking the opening of the terminal door acting as a signal to load or unload the package.

Although we have described the loading door as styled after an “airlock”, it is not exactly the same as a traditional airlock as it only has one door. Rather, the interior of the robot’s cargo bay serves as the secondary seal between the user and the network tunnel when the terminal door is open. This mechanism was selected in order to reduce the implementation cost of the terminal. (The alternative would be to have two doors, and an automatic loading mechanism to transfer the package from the loading area to the robot when the exterior door is closed.) As a result, users are currently not able to insert packets into the system when a robot is not present, and must wait for one to arrive. Similarly, packets cannot be automatically unloaded at the recipient terminal, so loaded robots must wait to be manually unloaded before they can be returned to the network to make other deliveries. Automatic loaders would improve the user experience and the overall network efficiency, as well as security and safety by providing one more layer of separation between the user and the robots at the expense of...
increased implementation costs.

Overall, the prototype terminal has assisted us in evaluating user interface design decisions and alternative interaction flow scenarios. These efforts have focused attention on the need to optimally balance responsiveness and resource utilization in order to maximize user satisfaction, and reinforced our conjecture that the primary driver of the success of a public, urban robotic delivery network will be a compelling and fluid user experience.

FUTURE WORK

Plans for the development of additional UBER-NET prototypes are concentrated in two ongoing areas of exploration. First, we will continue our work to develop an optimal user experience, which will concentrate on the investigation of automatic loading and unloading mechanisms and the construction of full-scale terminal prototypes. We intend to evaluate the effect of automated package handling at the terminal on expected resource utilization (given various estimates of network capacity, and average times per interaction) and terminal cost. We will also investigate hybrid approaches, such as automated loading at public terminals paired with manual loading and unloading at private home terminals. We also intend to evaluate mobile interfaces for shipment pre-addressing and pre-approval.

Our other main avenue of investigation is to move towards more detailed prototypes of the internal elements of the network, such as robot and intersection design, and the tracking of packages within the network. While these details will not be directly visible to the user, choices made in this area may have a significant impact on quantitative measurements that the user will be aware of, such as estimated and actual delivery times, and wait times at the terminals themselves, particularly in the case of high-traffic public terminals. Future prototypes will further assist us in answering these and other questions that are fundamental to ensuring a satisfactory user experience and the success of robotic delivery networks.

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