February 6th, 2012

Dr. Andrew Rawicz
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Functional Specifications for Smart TransLink System

Dear Dr. Rawicz,

The document attached outlines the functional specification for the Smart TransLink System. Our group is designing a fare-card system that will help prevent fraud on TransLink's SkyTrains and provide useful statistics to better allocate resources such as security officers and train carts. Strategically placed RFID readers and cameras (using computer vision techniques) throughout SkyTrain carts will be used to help distinguish between paid vs. non-paid customers. Moreover, the semi-passive RFID cards are reusable which results in less waste and a more sustainable system. This system aims to be a cost-effective and reliable alternative to other fare card systems like the Opus Card which cost over 217 Million dollars to implement [1] and require passengers to enter through faregates.

This functional specification provides a detailed outline of our system along with its requirements. This document will analyze the functionality of our system throughout the project life cycle and Engineers at TransNet will use these specifications to effectively design our modules.

TransNet consists of five highly talented engineers with tremendous amount of experience in the industry: Bilal Nurhusien, Alex Moore, Maxim Soleimani-Nouri, Mohammad Osama, and Daniel Frigo. If you have any questions or concerns, please don't hesitate to contact us by email at akmoore@sfu.ca or by phone at Alex's number here.

Sincerely,

Alex Moore

Alex Moore
CEO
TransNet Inc.

Enclosure: ***Functional Specifications for Smart TransLink System***

TRANSNET RFID SYSTEM

FUNCTIONAL SPECIFICATION

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Executive Summary

Due to its inability to prevent fare-card evasion, TransLink loses considerable amounts of money every year. According to The Vancouver Sun, TransLink loses 15 Million per year alone on its U-Pass programs through third-party websites such as Craigslist [2]. In one instance, TransLink lost $153,000 due to fare savers that were stolen by a contractor they hired specifically to shred passes [3]. In order to ensure passengers have paid their fare, TransLink typically places police officers at different SkyTrain platforms to ensure consumers pay to use their service. Since fare-evasion is still rampant, TransLink is preparing to implement a fare-card system to address the aforementioned security concerns. However, this proposed solution will cost over 100 Million dollars [4] and require passengers to enter SkyTrain platforms through faregates which will cause congestion during peak hours and may frustrate consumers.

TransNet has put forward an innovative system that helps prevent fare-evasion and provides transit authorities statistical data on the state of the transit system in a cost-effective and non-invasive way for passengers. Furthermore, this system helps eliminate the need for physical barriers (found in many fare-card systems) which irritates most consumers entering the train platforms or subway stations.

TransNet's system will be developed in three different phases outlined below.

- RFID Reader/BAP RFID Tags – Used to count the number of passengers who have purchased their fare legitimately. The reader/tag system will be implemented using UHF Readers and Battery Assisted RFID Tags which provide long distance reading capabilities
- Camera/ Image Processing – This provides a total count for people entering/exiting sky trains by using computer vision and image processing techniques
- Database – Each Train will send data collected from the RFID reader and image processing software to a server that will analyze and store the data. This information will then be displayed to system administrators in a user-friendly way

Individual testing of each phase is necessary to ensure correct functionality of each module. Once all phases have been developed, they will require numerous amounts of testing before entering the integration stage. When the correct functionality of each module is ensured, TransNet will enter the integration stage beginning on March 11th and combine all modules together. TransNet aims to have a working prototype by the April 6th. Additional subsystems modules might be added along the project's life cycle as necessary.

List of Figures

Glossary

FPS - frames per second

GUI – Graphical User Interface

IP – Internet Protocol

RFID – Radio Frequency Identification

SSL - Secure Sockets Layer

The System -The TransNet RFID System currently under development

TCP – Transmission Control Protocol

TLS – Transmission Layer Security Protocol

UHF – Ultra High Frequency

FOV – Field of View

Table of Contents

1.0 – Introduction

The TransNet RFID System is intended for use by TransLink in detecting fare evaders and improving security aboard SkyTrains in a cost-effective way. It is also a system intended to make fare payments more convenient for passengers by eliminating the need for physical barriers (found in many fare-card systems). This system will count the number of paying and non-paying passengers boarding a public transit vehicle. TransLink can then use this information to find locations where fare evaders are present. By seeing how many people are boarding in certain locations and seeing how many resources, such as buses, are allocated to that location, TransLink can further utilize this data to send more buses as they are needed.

This system is divided into three subsystems. One system consists of integrating battery-assisted RFID tags into fare passes. An RFID reader onboard the vehicle will read these tag's unique codes and securely transmit them to a main server with a database at TransLink's headquarters. The second system will use video cameras and computer vision techniques to count the total number of people boarding each vehicle. The third system is the database server where each passenger's account associated with his/her RFID tag will be stored.

This functional specification outlines the requirements for each of these three subsystems. Once the requirements for each individual subsystem are met, integration of the three subsystems into the overall system will begin. This document also outlines the requirements for the overall system.

TransNet's engineers will use this document throughout the project's lifecycle to come up with design solutions. It will also be used as a measure of progress and functionality of the final product. After completion of the subsystems as well as integration into the overall system, this document will be referenced to ensure the system has met the needed requirements. A test plan is also outlined to test the system meets certain requirements. Any requirements that prove to be difficult to meet will be fully justified in writing and possible solutions will be outlined.

2.0 – System Overview

The TransNet RFID System can be modeled at a high-level as shown in Figure 1.

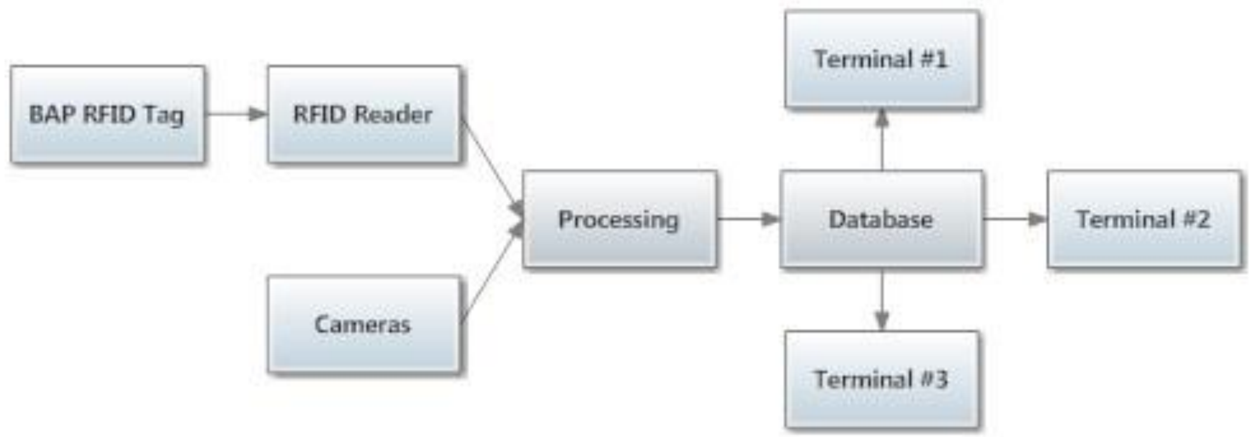

Figure 1: High-level block diagram of TransNet RFID system

All riders will have their own personal transit card with an embedded BAP RFID tag. The unique ID of each rider's RFID tag is directly associated with that rider's transit account, which keeps track of what transit services the rider has paid for and automatically bills the rider for any unpaid services used. For example, a frequent SkyTrain user may wish to purchase a monthly pass in advance, in which case they are not billed for any SkyTrain services used that month. However, a less frequent user may just ride the SkyTrain as needed and will be automatically billed on a zone by zone basis.

The embedded RFID tags are scanned by an RFID reader with one to four antennas located in the SkyTrain. The exact number of antennas required to fully cover an entire SkyTrain is not known at this time, but will be tested on an individual basis for any mass transit systems wishing to purchase and implement the TransNet RFID System. Due to budget constraints, only one antenna will be used for the prototype system currently under development. RFID scanning will occur at three equally spaced times once the SkyTrain has left the station. This is done to ensure that no tags of riders standing on the station platform are inadvertently scanned, and to triple check that no tags were missed by accident.

Video cameras are mounted above each SkyTrain door; these cameras point towards the floor and observe all riders entering and exiting the SkyTrain at each station. No rider identification is performed by these cameras to address any privacy concerns. People tracking will be implemented using computer vision and image processing techniques discussed later in the document.

All of the scanned RFID data and the camera video footage are then sent through a wired connection to a computer on board each SkyTrain. This computer compiles a list of all the scanned RFID tags, along with the time of reading and what location the train is currently at; the total number of tags is also computed. The footage from each camera is processed by image processing software running on the computer which keeps a numerical count of the number of riders entering and leaving the train at each station. A comparison between the number of tags scanned and number of actual riders on the train is then performed. This data can then be used by the transit company to target their fare evasion policing efforts as they see fit. All of this information is then updated from the SkyTrain computer to a central database over private Wi-Fi connection at each station.

The central database serves several important functions. Firstly, it allows any transit system personnel at an authorized terminal to monitor the live transit data in real time. Secondly, it routinely stores (configurable by the transit company) a snapshot of the current transit data and stores it to disk. This allows the transit company to collect, analyze, and manipulate their full transit data history for any desired research purpose, such as determining low or peak usage times and adjusting the number of trains in service accordingly.

3.0 – Hardware Requirements

3.1 – RFID Reader

General Requirements

- The cost of implementing the TransNet RFID System for the TransLink SkyTrain transit system must be below CDN$100,000,000 [4]
- No privacy or ethical concerns should be raised through implementation of the TransNet RFID System

Physical Requirements

- All components of The System intended to be installed in a SkyTrain should not protrude or interfere with the general riding space or operation of the SkyTrain
- The cameras and RFID reader should communicate with the on-board computer with a protocol capable of transmitting the data the required distance

Electrical Requirements

- Power over Ethernet (PoE) IEEE 802.3af
- +24 VDC @ 800 mA via external universal power supply with locking connector

Environmental Factors

- The RFID unit must operate in temperature conditions ranging from -20 to 35°C [5] [6]
- The unit must be dry at all times
- It must operate in typical humidity levels found in Vancouver, BC (43%-99%) [7]

Standards

- Air Interface Protocol: EPCglobal UHF Class 1 Gen 2 / ISO 18000-6C [8]

Reliability and Durability Requirements

- The RFID reader must be reliable and durable enough to work throughout the year in a variety of weather conditions
- When the reader malfunctions, it must be easily repairable and its parts replaceable by technicians
- It must be able to withstand fast acceleration and deceleration typically found on a train
- The reader must be secure enough so that the data sent back and forth is encrypted and cannot be intercepted by others

Safety Requirements

- The electrical connections must be hidden from users and protected from exposure to water
- The reader must not overheat or catch on fire
- If the reader malfunctions, it cannot harm others
- RF signal produced by the reader must not be harmful to biological life

Performance Requirements

- The RFID reader must be able to read 300 tags/sec [9]
- The RFID reader must be able to detect the tag even if it's near a person's body, bag, or wallet
- The RFID reader shall never miss a tag located in the SkyTrain after three scans.
- The RFID reader shall be able to read hundreds of tags in a sufficiently short time interval
- The RFID reader must have a reading distance of at least 10 meters

3.2 – RFID Tags

General Requirements

- The tags must be Battery Assisted Passive (BAP)

- The data on the tags should be persistent and have unique identification numbers
- Even if the battery should fail on a BAP RFID tag, the tag shall remain functional at close range
- The BAP RFID tags shall be readable by the RFID reader even if placed in pockets, wallets, or bags, or in close proximity to metal such as keys

Physical Requirements

- The tags must be the dimensions of a credit card (slightly thicker)
- The tags must weigh less than 55 g

Environmental Requirements

- The RFID unit must operate in a variety of temperature conditions ranging from -20 to 35^{o}C.
- It must operate in typical humidity levels found in Vancouver, BC (43%-99%)

Standards

- Air Interface Protocol: EPCglobal UHF Class 1 Gen 2 / ISO 18000-6C

Reliability and Durability Requirements

- The System shall remain fully functional under all environmental conditions of typical SkyTrain operation, including but not limited to: periods of bumpiness/acceleration, shock, temperature, humidity
- The System shall be easily accessible for servicing as needed
- Should not be easily tampered with

Safety Requirements

- The System shall not cause cancer or other medical defects in any users
- The System’s electrical components shall not cause interference with any other devices or components
- The System will not become self-aware and initiate a nuclear holocaust of mankind

Performance Requirements

- The BAP RFID tags shall last two years before needing replacement
- Even if the battery should fail on the BAP RFID tag, the tag shall remain functional at close range
- The on-board computer shall be able to fully process each station’s worth of video

data in a sufficiently short period of time.

3.3 – Camera

One aspect of the project consists of counting the total number of people that are inside each SkyTrain wagon. This task is accomplished by mounting video cameras in each SkyTrain wagon door and using image processing algorithms to count the number of people entering and exiting through each door.

An important thing to take into consideration is the resolution of images the camera takes, the camera's maximum FPS rating and the time required for processing images. This is an important thing to consider as higher resolution images will take longer to process and can lead to a system that does not respond in an acceptable timely manner suitable for counting people in real time. It is therefore desirable to have a low resolution camera rather than a high resolution one for the purpose of this system.

The requirements for the camera are outlined below.

General Requirements

- The camera will only be active when the train comes to a full stop and the doors start opening
- The camera shall be quick in powering up so as to avoid delays
- The cost of the camera shall be less than $200

Physical Requirements

- The camera shall be mounted overhead in such a way as to completely avoid occlusion problems
- One camera per door will be installed
- The camera shall not obstruct passengers when entering or exiting
- The camera shall be easy to install on the ceiling of the Sky Train
- The camera shall blend with its surroundings such that it's not clearly visible to the passengers
- Each camera shall be connected to an onboard computer (via USB) for further processing or data transmission

Environmental Requirements

- The camera shall be able to operate within the temperature range of a normal day, between -20 °C. [10] to 35 °C [11]
- The camera shall be able to perform properly under varying lighting conditions, from bright sunny day, to dark rainy night

Standards

- Coding standard used for initial implementation would be Matlab. Depending on the level of progress, it may be converted to C/C++ for better performance
- Communication medium between camera and image processing software would be via Ethernet IEEE 802.3 standard

Reliability and Durability Requirements

- Expected to operate with changing theatre of operation (i.e. different station platforms)
- Must provide high degree of accuracy in passenger count
- Be able to deal with high traffic zones (i.e. peak rush hours)
- Functionality preserved under normal environmental changes

Performance Requirements

- The camera shall have a resolution between 75 Kpixels and 1 Mpixels
- The camera shall operate at a minimum of 5 FPS
- Detection of mobile passengers in Real-time
- Functionality would not aim to include detection of individual with disability
- Not expected to handle extreme weather changes

4.0 – Software Requirements

4.1 – Image Processing

Description

There are a number of scenarios to consider when developing the image processing algorithms for counting people and as such, these algorithms will have to meet certain requirements. In deciding these requirements, it was assumed that no more than 2 people can fit through a SkyTrain wagon door at the same time. These requirements are outlined below:

General Requirements

- The algorithm shall detect a single person entering through a wagon door
- The algorithm shall detect a single person exiting through a wagon door
- The algorithm shall detect 2 people entering through a wagon door while both are in the camera's FOV

- The algorithm shall detect 2 people exiting through a wagon door while both are in the camera's FOV
- The algorithm shall detect 1 person entering and 1 person exiting through a wagon door while both are in the camera's FOV
- The algorithm shall be able to handle people standing still at the door
- The processing time required by the algorithm shall not exceed 200 ms
- Every time a train is put into service, the people counter shall be initialized to 0
- Whenever 1 person enters, the counter shall be incremented by 1
- Whenever 1 person exits, the counter shall be decremented by 1
- Whenever 2 people enter at the same time, the counter shall be incremented by 2
- Whenever 2 people exit at the same time, the counter shall be decremented by 2
- Whenever one person enters at the same time someone else exits, the counter value shall not change
- The algorithm shall take a snapshot of the background when the train is stopped and before people start entering/exiting
- The algorithm shall take into account different lighting conditions
- The image processing software shall be able to count the physical number of riders with 99% accuracy

4.2 –Database Server

Description:

A database server will be created to communicate with computers aboard SkyTrains. This server application will be used to store information received from clients and also provide statistical information to transit officials such as determining low or peak usage times so that they may adjust the number of trains in service.

Within the database, an account will be created for each pre-paid fare-card that is purchased by passengers. The server will automatically deduct money from that account based on how many fare zones the passenger has travelled during the day and what type of fare-card it is (adult or concession). In order to avoid privacy concerns, only the identification number for each fare-card will be stored in the database and not personal information such as the name or age of a passenger.

General Requirements

- Uses a reliable communication protocol such as TCP/IP when sending and receiving packets to and from the client. This protocol will also provide error detection, congestion control, and flow control

- Uses an encryption protocol in the application layer such as TLS/SSL protocols to authenticate the identity of each client and ensure secure transmission between computer aboard the train and the server
- Receives incoming data about the number of passengers and fare-cards detected on a train
- Processes incoming data in real-time and provides relevant statistical information such as peak hours and congestion in the transit system. It is able to display the information to transit authorities via a GUI
- This GUI will be provided at the server-end and offer the user an intuitive, user-friendly presentation of the data that has been collected
- Make sure the data is organized in such a way to minimize the time to execute queries
- In case the server goes down, the system state should be stored periodically to prevent information loss. Also, make sure the data is not vulnerable to attacks by hackers

5.0 - System Test Plan

Database Server

The main objective of this module is to develop a database server that will receive, store, and validate incoming information sent from computers stationed aboard SkyTrains.

- The software testing will begin by attempting to establish a reliable and secure connection between the client host and server using TCP/IP and TLS protocols.
- Once the connection has been made, the client will send data to the server where it will be stored in the database. The client will start off by sending a small file divided into packets. The server must check for any errors in the packets it receives.
- The team will search for any vulnerability in the software to ensure security of transmission and prevent hackers from intercepting data while it is transmitted from client to server. This will involve preventing common attacks such as denial of service attack and buffer over flow
- Then, a user friendly GUI will be developed at the server-end to display information about incoming data. This GUI must be able to provide data from the database in real-time and allow the user to look at statistical information such as peak hours (what time was busiest) and off-peak hours.
- Once the database server has passed a series of security and reliability test (outlined above) it will be integrated into the rest of the project.

RFID Reader / RFID Tags

The purpose of this module is to get a whole count of the number of customers who have paid for the service offered by Translink. Ideally, we would like to read as many tags as possible in any skytrain carts. Given the limits and distance constraints, we need to install multiple readers on each cart to cover the entire area. Once all passengers are on board and the doors are closed, each reader will poll in a timely interval to make sure all tags have been read independent of their location. We will conduct our tests in a room with one RFID reader and few passive RFID tags. For the following test cases, we assume each person present in the room has 1 RFID tag on them and the reader remains in one location at all times. In the beginning, we would like to test the reader with only one person present in the room to see if correct information is being read by the reader while the person remains motionless. The second test would be to perform the test above while the person is in motion resulting in variations in distance between the reader and the tag. Once these two test cases prove to be successful, more people with RFID tags will be added to the room to test the threshold of the reader.

Video processing to determine rider entry / exit

The main objective of this module is to count the total number of people entering or exiting through a SkyTrain wagon door. Once again, a standard size room with a door fitting no more than 2 people at a time will be used for testing purposes. A webcam will be installed directly above the doorway with its FOV pointing down towards the door area. Once the image processing algorithms are developed, a number of scenarios outlined below will be tested to ensure the algorithm performs to acceptable requirements.

- Single person will enter through the door
- Single person will exit through the door
- Two people will enter through the door side-by-side.
- Two people will exit through the door side-by-side.
- Two people will enter through the door, one slightly behind the other.
- Two people will exit through the door, one slightly behind the other.
- One person will enter through the door at the same time someone exits through the door.
- One person will stand still at the door for a while and either enters or exits later.
- One person will stand still at the door while another enters or exits.

In all these cases the algorithm should be able to properly detect the number of people that entered or exited. Whenever something happens that the algorithm cannot detect, a warning will be given.

Once all these tests have passed, given the time, improvements can be made to the algorithm and more complicated scenarios can be examined.

Finally, a number of trials will be performed with many people entering through the door at different times and representing different scenarios. The total number of people in the room the algorithm detected will be examined and compared to the actual number of people in the room. This will be used as a measure of the reliability of this system.

The speed of the algorithm will also be tested and ensured that it can keep up with the minimum required FPS of the camera.

6.0 – Conclusion

The functional specification defines the capabilities and requirements for our Smart TransLink System. The development of the system will take place in three phases. First, each of the modules will be independently designed and implemented: RFID reader/tag system, Database Server, and People Detection Software. Second, the modules will be initially integrated together before March 11th. Finally, the whole system will be tested and complete before April 6th, 2012.

7.0 – References

[1] http://www.cbc.ca/news/canada/montreal/story/2008/04/21/qc-smartcards0421.html

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[3]http://www.vancourier.com/TransLink+beefs+security+after+FareSavers+theft/5917942/story.html

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