Smart Refrigerator

Design Review

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Statement of Needs

- The New York Times reports that an average American family of four will account for over 120 pounds of food waste per month and that 27% percent of all food available will be lost to waste [1]. In addition, other resources are lost due to inefficient shopping practices; forgetting common items or special trips made for recipe ingredients waste time and fuel. A system is required for shoppers both to ensure their purchases are used before expiration and to assist in planning of grocery shopping trips.

Objective Statement

- The objective of this project is to design a prototype that will allow a user to track food items in order to reduce waste and improve shopping efficiency. The system will remind the user about items nearing their expiration date and track the frequency of purchased items. From this frequency calculation the system will suggest typical shopping lists. A mobile phone application will provide an interface to the unit to view or create shopping lists and to query inventory.

Customer Needs

- The system should provide an intuitive, easy to use graphical interface.
- The system should require minimal user input.
- The system should be able to scan product codes and identify corresponding items quickly.
- The system should provide secure remote access.
- The system should report items nearing expiration.
- The system should provide access to the current inventory.
- The system should provide a method to create and edit shopping lists.
- The system should recommend shopping lists which accurately reflect buying habits.
- The system should function as an add-on to an existing refrigerator or pantry.
- The system should indicate if food products are stored safely.

Engineering Specifications

Customer Need	Engineering Requirement	Justification
2,3	A. An off-the-shelf UPC scanner should be used to input items.	A UPC scanner can read product codes with a single click.
3	B. An internal UPC code database should be used to associate codes with items.	An internal database will remove delays associated with an internet look-up.
1,4,6	C. The system should be internet enabled and provide a web interface.	By providing a web interface any other internet-connected device can access the system.
4	D. Remote access should be authenticated with user name and password.	User names and passwords are standard for access control.
⋮	⋮	⋮

Engineering Specifications

Customer Need	Engineering Requirement	Justification
2,5	E. An internal database will store default recommended expiration estimates for common categories of items.	Inferring expiration dates based on item category helps minimizes user input. It is well known how long some products take to expire.
1,5	F. The user interface will provide a method for updating default expiration estimates.	Default estimates will not account for condition of product on arrival and may need to be updated.
1,5	G. Interface will provide a visual indication to the user when items are within a user-defined margin of expiration.	The goal of the system is to reduce waste due to expiration.
⋮	⋮	⋮

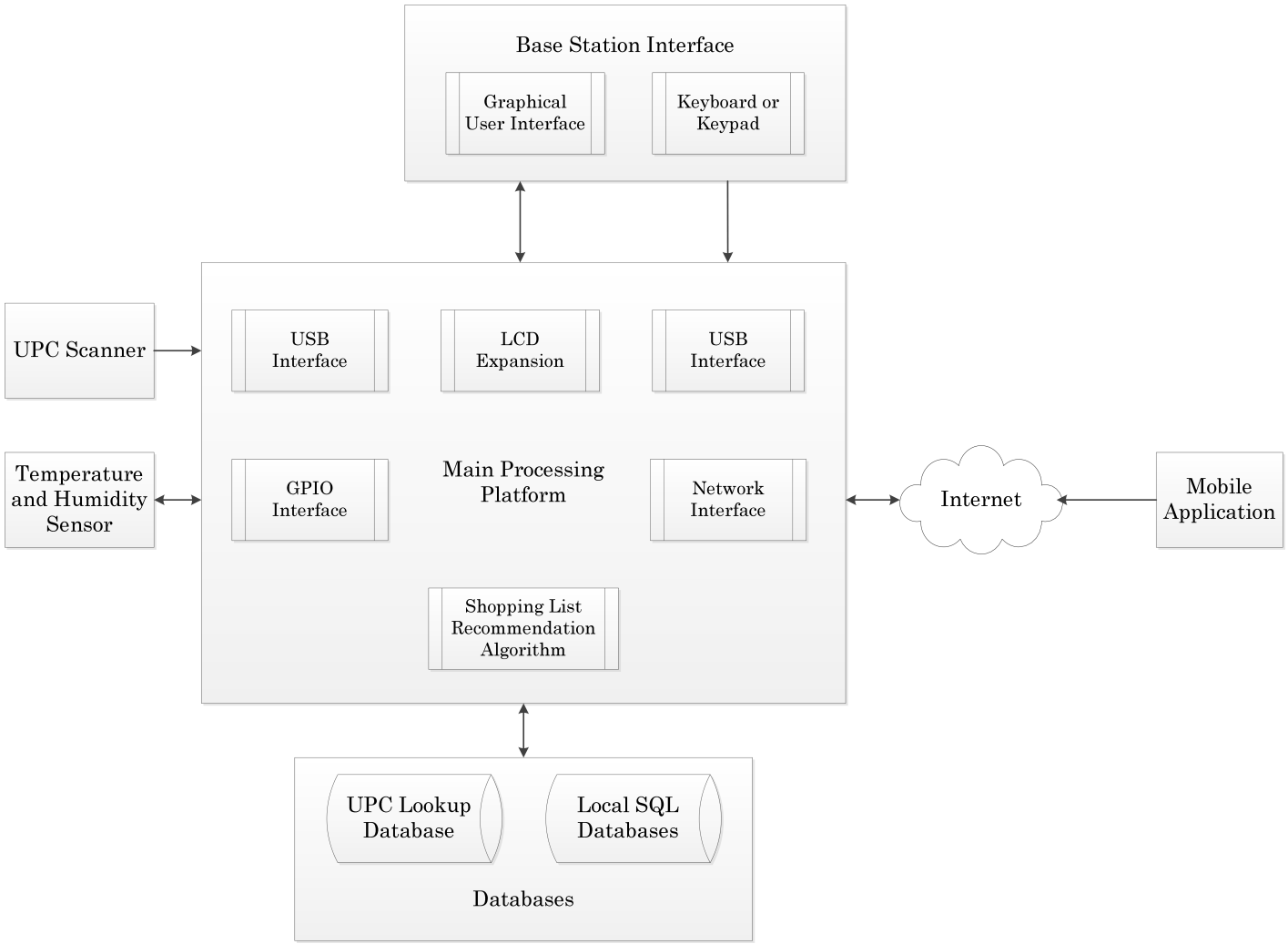
Engineering Specifications

Customer Need	Engineering Requirement	Justification
1,6	H. From both the base station and mobile application the user will be able to view an inventory list.	The user needs access to the current inventory in order to use items and shop effectively.
7,8	I. A database will be devoted to storing recommend shopping lists produced by the system.	User may wish to retain generic shopping lists for future use.
8	J. Recommended shopping lists will reflect purchasing history and expiration dates of current inventory.	Recommendation policy must suggest items relevant to the user in order to be useful.
⋮	⋮	⋮

Engineering Specifications

Customer Need	Engineering Requirement	Justification
7	K. Custom shopping lists, created either from the base station or the mobile interface, can be added to shopping list database.	Inefficient shopping practices can be prevented by storing shopping lists and the system can not anticipate all required items.
9	L. The system will be self-contained and no modifications will be required to existing appliances.	Similar systems are commercially available but require costly replacement of existing appliances.
10	M. The system should measure temperature and humidity within the refrigerator.	Temperature and humidity measurements will allow the user to determine if food storage conditions are safe.

Top Level System Diagram



Concept Selection – Processing Platform

- Difficult to find Micro-controller with adequate peripherals / performance
- Personal computer implementation is too general, does not fit form factor well
- BeagleBoard offers flexibility of full Linux environment

	Method			
	Personal Computer	Tablet (Combined UI and Processing)	Micro-controller	BeagleBoard-xM
Processing Resources	+ + + +	+ +	+	+ + +
Cost	- - -	+	+ + +	+ + +
Size	- - -	+ +	+ + +	+ + +
Total	2-	5+	7+	9+

Concept Selection – Display

- Related to choice of processing platform
- Ideally, ULCD7 Lite, Supported by BeagleBoard / Angstrom OS

	Method		
	LCD PC Monitor	Tablet	LCD with BeagleBoard-xM
Integration with Unit	- - -	-	+ + +
Ease of Use	+ + +	+ + +	+ +
Size of Display	+ + +	+ + +	+ +
GUI Quality	+ + +	+ + +	+ + +
Size of Unit	- - -	+ + +	+ + +
Total	3+	12+	13+

Concept Selection – Expiration Date Prediction System

- itemMaster UPC database provides GS1 catagory
- FDA and community resources like `www.stilltasty.com` provide "rule of thumb" estimates

	Method			
	User Input of expiration dates	Image to Text Recognition	Predictive Strategy without itemMaster	Predictive Strategy with itemMaster
Ease of Use	- - -	+	+ + +	+ + +
Feasibility	+ + +	- - -	- - -	+ + +
Accuracy	+ +	+ +	+	+
Total	2+	0	4+	7+

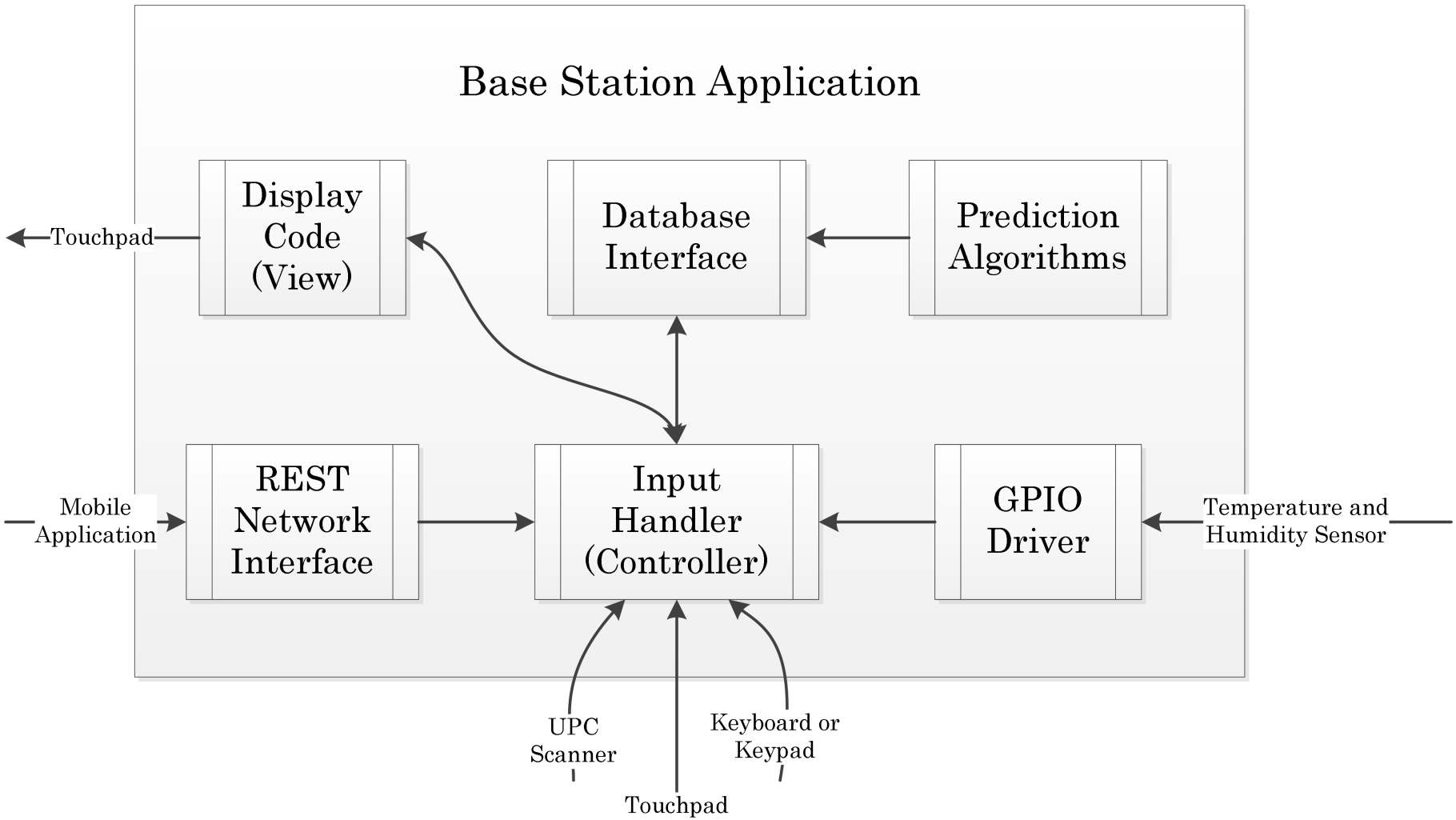
Concept Selection – Shopping List Prediction System

		Method		
	Trial	Normal Approximation	Non-Parametric Distribution	Clustering to produce sum of Gaussians
$\sum$ Log Probability Observed Habits (Goal to Maximize)	1	-38.3394	-35.9682	-34.7721
	2	-20.5647	-17.0897	-15.6641
	3	-47.8101	-44.9658	-43.9845
	4	-29.1931	-19.6762	-24.4915
Evaluation		- - -	-	+ + +
$\sum$ Log Probability Habits Not Observed (Goal to Minimize)	1	-36.7898	-38.4187	-50.6578
	2	-188.514	-225.002	-318.926
	3	-62.2909	-63.8609	-69.9759
	4	-29.6667	$-\infty$	-86.0767
Evaluation		- - -	+	+ +
Ease of Computation		+ + +	- - -	-
Total		3-	3-	4+

Design Overview

- Project divides evenly into three task groups: the mobile application and network interface, the base station user interface and prediction system, integration of Beagleboard with peripherals and databases.
- Base Station User Interface and Prediction System
  - Develop Application (Python 2.7 + Tkinter)
  - Expiration Data Prediction Algorithm
  - Shopping List Suggestion Algorithm
- Mobile Application and Network Interface
  - Develop Android Application (Java)
  - Network Interface must be robust to interrupts, and minimize data usage
- Integration of Beagleboard with Peripherals and Databases
  - Configure Angstrom OS Image
  - Interface with Temperature Sensor with GPIO pins (Level Shifter)
  - Scanner, keypad, display hopefully "plug and play"

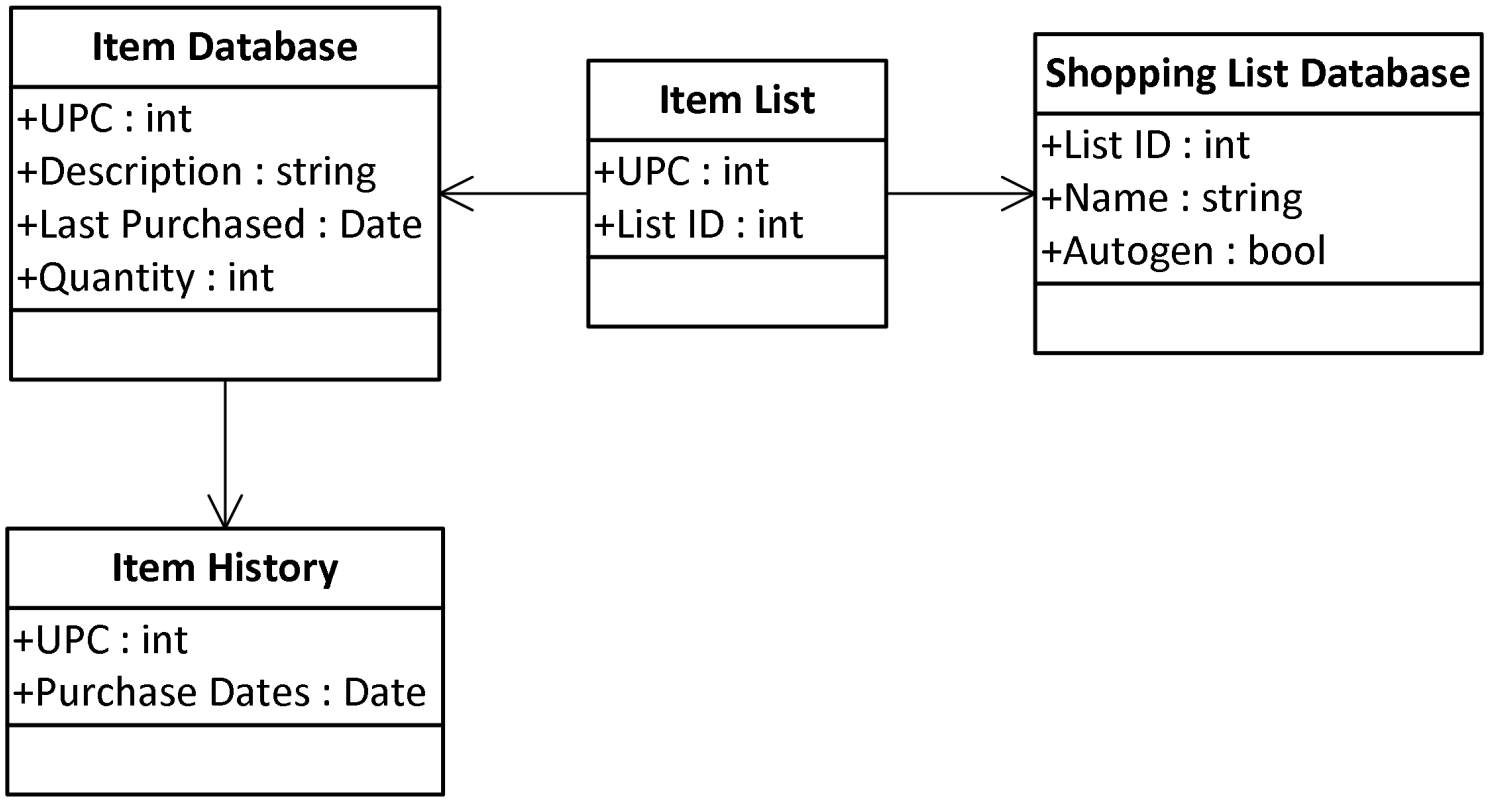
Beagle Board Subsystems



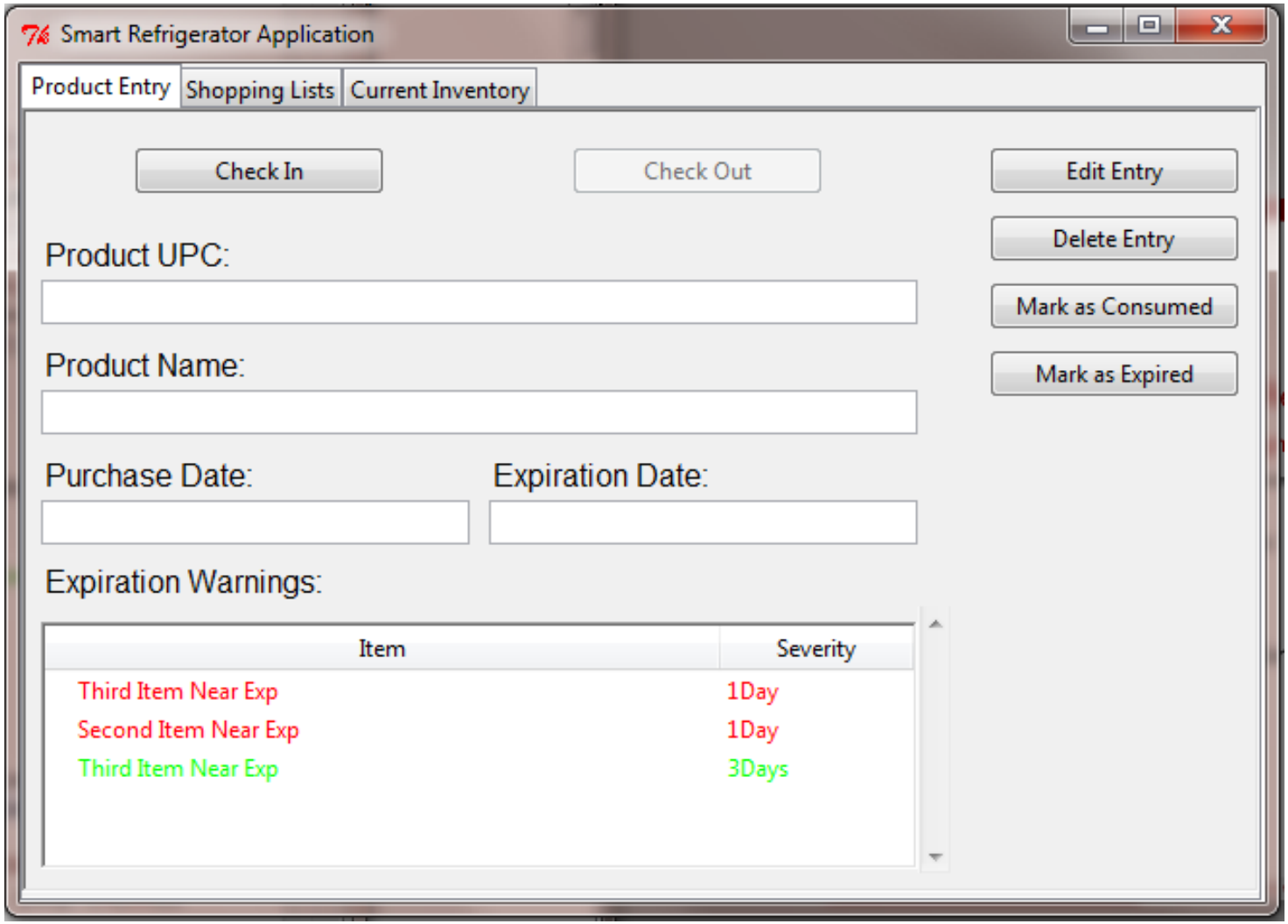
Base Station Application

- Base Station Application will be inspired by Model View Controller paradigm.
  - Input handler will be the "Controller"
  - Combination of prediction algorithms and databases will constitute the "Model"
  - Independent "View", created with TkInter GUI toolkit for Python
- Python chosen for development speed and also due to familiarity.
- SciPy scientific computing libraries will also increase speed of shopping list algorithm development.
- Will also interact with databases, some overlap of task groups will occur in this code project
- May also handle network interface, there is an unresolved design decision between using simple custom TCP interface and full web-server

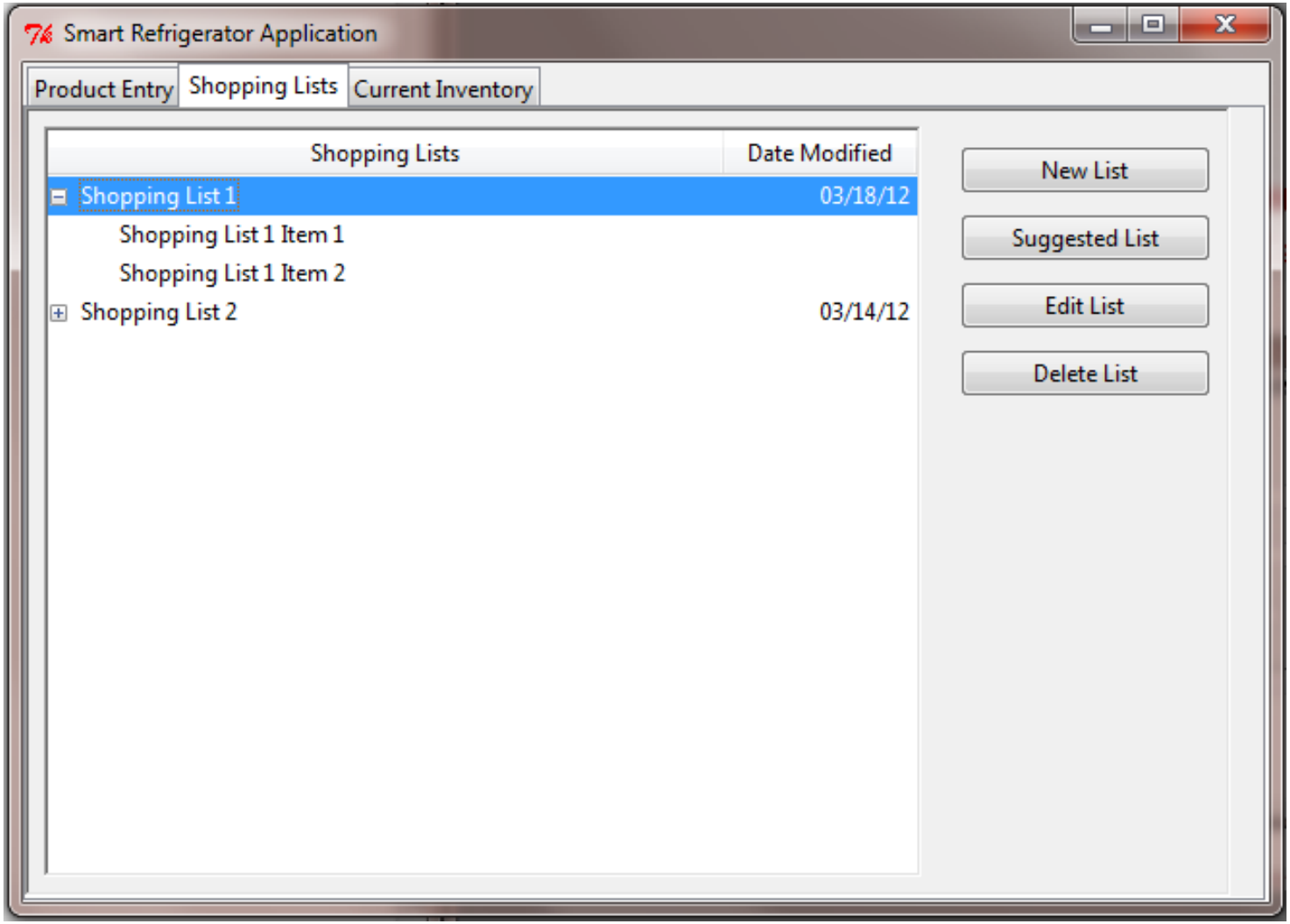
Database Organization



User Interface Screen Captures – Product Entry



User Interface Screen Captures – Shopping Lists



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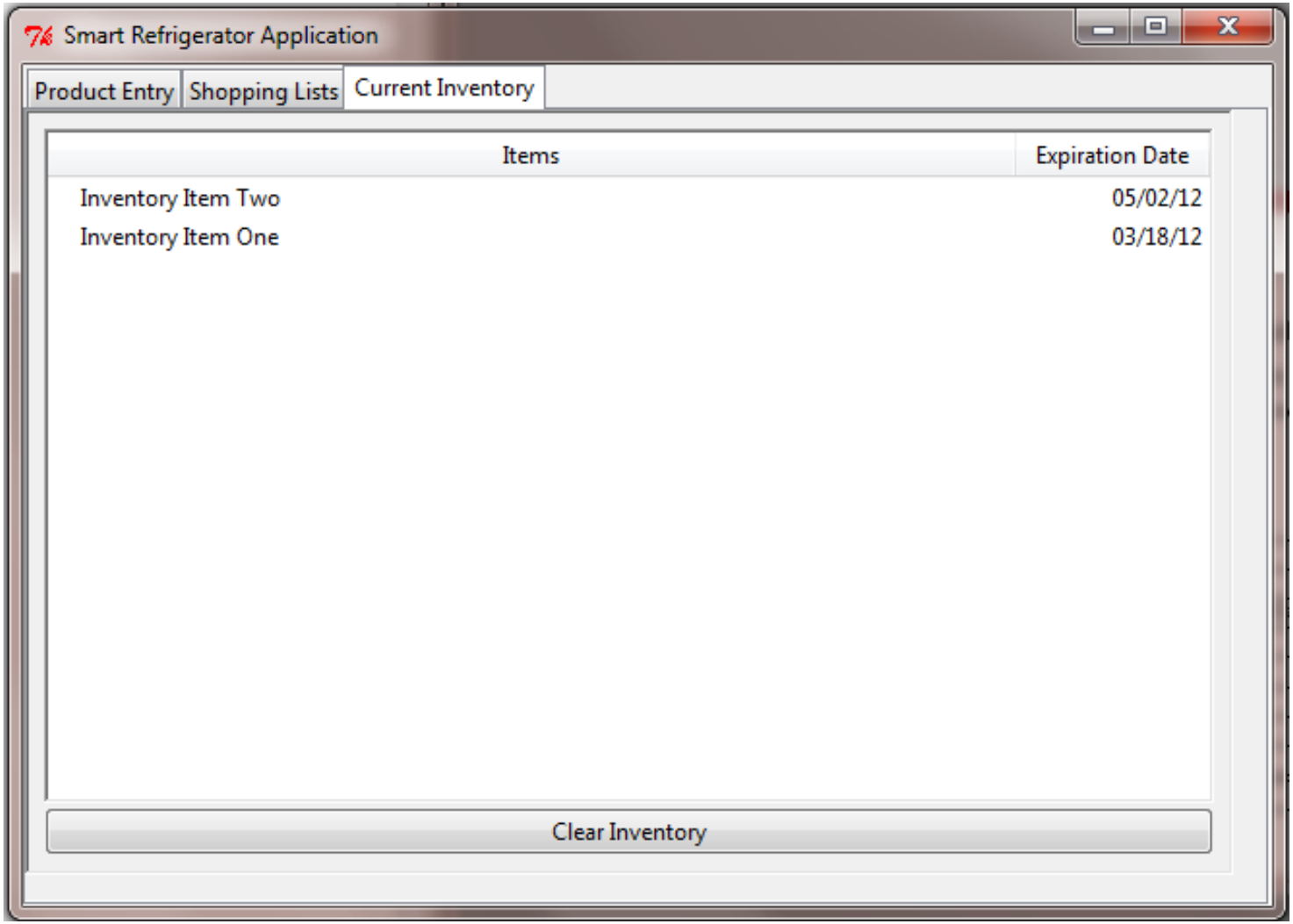
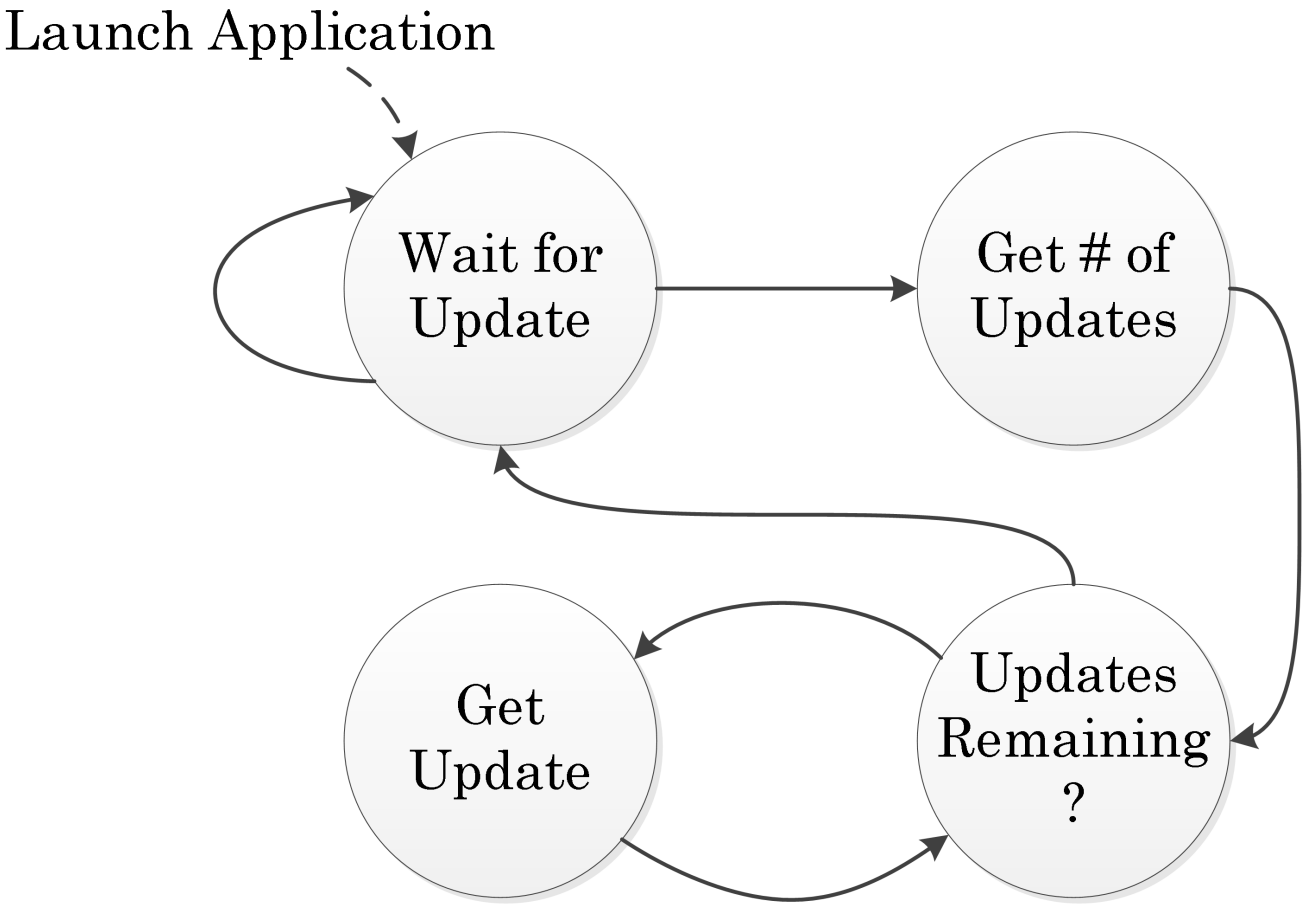


Mobile Interface

- Mobile interface layout will be as consistent as possible with base station interface, usability benefits from consistency.
- Mobile application should limit data usage, information exchanged only on “need to know” basis
- Updates will not occur until specific tabs / shoppings lists selected
- Mobile application should be tolerate of interrupted connections
- Impact of interruptions mitigated by changing many small messages instead of monolithic ones

Interface State Machine



Manufacturability, Reliability, and Background

Manufacturability - Smart Refrigerator system only a first step toward tackling food waste, could be extended to commercial systems. Prediction system could be improved by aggregating data from multiple users.

Reliability - Some components tested externally (Angstrom OS, SQL Databases). Network interface and shopping list algorithms can not be verified for all scenarios. Errors most likely in integration.

Background -

- Experience with Linux based operating systems critical
- GUI development experience provided by Computer Science sequence
- Interface to Digital Electronics useful for integrating temperature sensor

Bill of Materials

- BeagleBoard-xM provided through ARM Developer Day.
- ULCD7 Lite LCD Display hopefully will also be provided by ARM Developer Day, though availability of this display is a significant unresolved risk.

Part	Retail Cost	Our Cost
BeagleBoard-xM	$149	$0
BeagleBoard-xM Power Adapter	$14.87	$14.87
Dorm Room Refrigerator	$100	$0
Android Smart Phone	$100	$0
LCD Display	$80	$0
UPC Barcode Scanner	$35	$35
USB Keyboard/Keypad	$10	$10
Total Cost	$488.87	$59.87

Unresolved Risks – Overview

- Identified Unresolved Risks, ordered by severity:
  - LCD Display Availability
  - Practicality of Prediction Algorithm
  - Mobile Application Data Exchange
  - Efficiency of Database Access

Unresolved Risk – LCD Display Availability

- The ULCD7 Lite is the preferred choice for the display to accompany the Beagleboard. The 7-inch resistive touchscreen is designed to work with the Beagleboard and has drivers built into the Angstrom Linux distribution.
- However, the touchscreen does not seem to be stocked by online suppliers and our request through the Arm Developer Day proposal process is still pending.
- The BeagleBoard provides a DVI-D and S-video output, this risk could be mitigated using a traditional computer monitor if the preferred touch screen is not available.

Unresolved Risk – Practicality of Prediction Algorithm

- The shopping list prediction algorithm outlined appears optimal for the test data considered. However, the analysis performed did not consider a large sample of shoppers and the conclusions drawn may not be appropriate for a larger population.
- Also, the prediction algorithm outlined will not perform well with only a few samples; it is unclear how unacceptable this warm-up period will appear to end users.
- The strategy presented is also quite heavy-handed and may be superfluous for this prototype system.
- The system will not serve as an effective shopping aid without an accurate prediction system, but a prototype may be acceptable with a much simpler system requiring significantly less effort.

Unresolved Risk – Mobile Application Data Exchange

- Exchanging inventory and shopping lists data with the mobile application presents two risk areas: the amount of data plan usage required and interrupted network connections.
- These risks are partially mitigated by the design, which exchanges data in small increments on a "need to know" basis only, however the degree to which these risks are truly problematic is not know.
- Interrupted connections are considered in the design, but the effectiveness of the design will be difficult to measure since it may be difficult to repeatedly interrupt the data connection.

Efficiency of Database Access

- Efficient practices for database access were not known or considered when partitioning information into separate tables.
- For example, using the same database to store all possible items and the current inventory may be an inefficient choice. This strategy requires looking over all elements and extracting only those with non-zero quantities.
- If the system was extended to large commercial applications, or if the Beagleboard was replaced with a more cost-efficient and less powerful alternative, this organization may become a significant risk.

Condensed Test Plan – Overview

- Test strategy organized by subsystem:
  - Base Station User Interface
  - Mobile User Interface and Network Interface
  - Shopping List and Expiration Prediction
  - Integration with BeagleBoard
- Integration and System Testing

Condensed Test Plan – Base Station User Interface

- The user interface is required to be easy to use and intuitive; in order to verify this someone not involved in the project should contribute to top-level testing of this sub-system.
- Current inventory will be stored using an SQL database, test effort at this step will be verifying integration, not the storage of items.
- The user interface must provide a notification of expiring items to the user, testing will not verify the estimate is correct, only that user interface will display notifications.

Condensed Test Plan – Mobile User Interface

- Shorten up tables

Condensed Test Plan – Shopping List and Expiration Prediction

- Systems date must be adjustable to facilitate quick testing.
- Enter a product code and verify that the expiration date system is initialized with recommended "rule of thumb" value.
- Provide feedback indicating that a product expired before estimate and validate that the estimate is decreased. Also validate the opposite case.
- Enter a product code and advance the system time until the product is nearly expired. Verify that the prediction subsystem has indicated to controller that the product is nearing expiration.
- Verify shoppings habits with outliers and multiple modes are modeled reasonably.

Condensed Test Plan – Integration with BeagleBoard

- Verify that the BeagleBoard, with power adapter, can power all peripheral devices reliably.
- Verify that MAC address of Ethernet interface can be statically assigned and the BeagleBoard can be pinged reliably.
- Verify that the BeagleBoard can reliably interface with the USB scanner and USB keypad.
- Verify that the BeagleBoard's consistently receives accurate temperature and humidity measurements from the sensor, via the general purpose input/output pins.
- Verify that the touchscreen display accurately records users clicks and controls the pointer.
- Verify that touchscreen accurately displays the graphical user interface without artifacts or distortion consistently, and ensure all controls on the display are accessible.

Conclusion

Questions or Feedback?

References

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