System for Separation of Recyclables

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1. Abstract

The United States has become a country of mass consumption and this consumption is pouring millions of tons of waste into landfills every year. This may be more economical in the short term, but these policies hinge on the extensive depletion of vital natural resources and will prove devastating to the environment in the future. Landfills are not a sustainable solution if we continue at our current consumption rates. For every person in the United States, one ton of trash goes in to a landfill every year. The most feasible solution to this problem is to recover recyclable material. The widespread implementation of recycling programs could reduce the disposal of 14.4 million tons per year of plastics alone [2]; however, there are several factors that prevent an effective recycling program: participation is usually low, municipal support is can be lacking and it can be cost prohibitive to process the materials.

State governments have recognized the growing concern over landfills and have applied pressure to municipal governments in support these programs. For example, California Assembly Bill 939 required every city and county in California to reduce its landfill waste stream 25% by 1995 and 50% by the year 2000. Similar mandates are now in place for many other states [4]. Using material sorting lines in conjunction with commingled recycling programs can greatly assist municipalities in achieving these goals.

However, improved participation and efficiency are also necessary if the programs are to be effective. For this reason, we undertook the development of the System for Separation of Recyclables (SSR). With this project, we strive to improve the speed and accuracy of a commingled separation system. Our system also simplifies recycling at the consumer level and can therefore make it more accepted and widespread.

In support of the project, we have conducted extensive research concerning the current methods of waste management and we have designed our system to be scalable so that it will suit the needs of facilities serving small communities or large municipalities. Through this research we determined that material recovery facilities can have a dramatic effect on the reliance on landfills. Our system will improve these facilities and aid in reducing landfill usage and conserving resources.

2. System Overview

This section presents a general overview of the system. First, it details the design methodology we used. Then it gives a system overview, giving operational and architectural considerations. Finally, it discusses the innovations this project introduces.

2.1. Design Methodology

When considering the development process for this project, one major constraint for us has been time. Our team members have very diverse schedules and additional projects to complete throughout the semester, which limits the total and collective time we can spend working on the project. Therefore, we needed a development process that would allow us to work independently and concurrently. We chose a component-based approach for this project with three phases, as illustrated in Figure 1, to address this issue.



Figure 1: Design Methodology

2.2. Operational Overview

The design of the system is built around a conveyor belt, where a combination of recyclables and non-recyclables are delivered into the system. Using mechanical processes, which were not implemented by us, the items arrive separated from one another and move through the system independently at a nominal interval from each other. When the items enter the system, they are identified by an RFID reader and the system begins tracking them as they continue moving through the remaining stages.

When an item arrives at an extraction stage, a rotary extractor will sweep it from the conveyor belt into a storage container if it is the type of recyclable removed at this stage. Otherwise, the extractor will remain stationary, allowing the item to simply pass between its blades. The last stage in the system is designated to collect any recyclables that may have been missed at previous stages due to error. Any items collected at this stage are sent back through the system for reprocessing. Finally, items that are not extracted by the end of the conveyer belt are collected and disposed of as regular waste. A structural view of the system can be seen in Figure 2. A more detailed description of

the design and implementation of each component can be found in Section **Error! Reference source not found.**



Figure 2: System Diagram

With the last stage and the high accuracy of the RFID reader and optical sensors, this system will be highly effective. The performance of our system will be more accurate than the current systems and will have all the benefits of a fully-automated system.

2.3. Innovation

In the past, recyclables separation and sorting has been done manually. In recent years, the use of manual labor has declined for several reasons. Labor costs, decreasing profits, and safety concerns have all led to the adoption of completely automated systems that distribute recyclables into segregated containers without the assistance of human workers. These automated sorting systems may consist of many mechanical stages or a complicated system of sensors and often are expensive and inefficient [1]. Currently, semi-automated systems are the most common. They consist of a primitive automated sorting method as the initial stage, combined with manual sorting at the end.

We have come up with an idea that will make a completely automated system not only feasible, but also the most economical method for sorting. Our project assumes that RFID tags have been placed on consumer products at some point in the supply chain, a likely reality in the near future due to the cost-effectiveness and increasing popularity of the RFID technology among retailers and manufacturers to enhance product sale and tracking. These same tags can then be used to improve sorting efficiency by providing an automated system with a fast and effective method of item identification. Currently,

materials are sorted by characteristics such as size or composition which is not very precise and causes lower quality post-recycled products to be manufactured.

3. System Design and Implementation

In this section, the development process of our system is described. First, an overall system design is presented that describes how the individual components interact with one another. Second, each component is described in detail in its own section. Finally, testing results of the current implementation are presented.

As described in section 2.1, our team chose a component based approach to developing our system. After the system operational characteristics were established, the system was divided into several components to facilitate a fast prototyping cycle. There have been only minor restructuring in the overall design. The most notable is the recent combination of the motor controllers and optical sensors into generic stage controllers.

The major components of our system are:

Hardware

- Conveyor Belt
- Rotary Extractor
- Stage Controller
- RFID Reader
- Host Controller

Software

- Software
- Stage Controller Firmware

3.1.1. The Rotary Extractor

The rotary extractor is the mechanical component of every extraction stage. This type of actuator was selected over other designs our group considered because of its fast resettime, simplicity, efficiency, and ease of implementation. All of these features are a product of its one-way motion. Unlike other designs, when the rotary extractor removes an item from the conveyor belt, it is immediately in a position to remove another item. There is not return-time like there would be with a push-pull actuator. This saves both time and energy that would otherwise be wasted in having the actuator reset. Additionally, the cost of the system is reduced because unidirectional motors can be used to spin the rotor. These motors are in general more efficient that bidirectional motors.

3.1.1.1. Design

The rotary extractor consists of an axle, and several extraction blades, sweepers and an electric motor. The blades and sweepers together form the rotor which is them spun by the electric motor. The rotor's construction is difficult to describe in words, therefore a rendering of what one looks like is shown as Figure 3.

The diameter of the rotor, the number of blades, and the coverage angles of the blades and the open areas depend on many factors. These include the velocity of the extractor, the velocity of the conveyor belt the frequency at which items arrive at the extraction stage and maximum item dimensions. This allows extractors of different sizes to be constructed based on the requirements of the target recycling facility.



Figure 3: Rotary Extractor - Rotor

3.1.1.2. Implementation

In our prototype implementation, we have chosen to build the extractor out of wood. In an industrial setting, aluminum or steel would be more appropriate, but our team does not have access to the necessary tools that would allow us to work with these materials. The remaining parameters were chosen based on calculations we performed in an Excel spreadsheet. This spreadsheet converted the dimensions of the extractor, its average velocity, the average velocity of the conveyor belt and maximum size of the largest possible object into parameters we can compare. What we were looking for were timing problems. For example, items arriving too fast and jamming the extractor in the current inputted configuration. After inputting many different scenarios into the spreadsheet, we selected the following specifications for the extractors:

Number of blades	3
Diameter	2 ft.
Blade angle	54°
Open space angle	66°
Rotation rate	1 ft. per min.

These specifications were created assuming the conveyor belt moves at 1 foot per minute and the largest item we will process is a standard, two gallon, milk container.

At this stage in the project's development, the majority of materials necessary for the construction of the rotary extractor have been purchased. Currently, time at a workshop needs to be scheduled so construction can begin on the rotor. The motor has also been purchased and once the rotor has been completed, an appropriate mount will be constructed and the extractor will be attached to the conveyor belt. After this is complete, the rotor will have to be calibrated to work together with the remaining parts of the system.

3.1.2. Stage controller

The stage controller is the electrical component of an extraction stage. Its main purpose it to control the motion of the rotary extractor and report back when faults occur. Very recently, the optical sensors in the original system design were redistributed from having an independent controller to being a part of the motor control circuitry, forming the combined stage controller. This was possible because of the available computational power within the PIC18F4550. In addition, the overall design time for the project was reduced because of the decreased number of different components that had to be designed. The goals in designing the stage controller were simplicity, low cost, and ease of configuration.

3.1.2.1. Design

In general, every stage controller has three main parts, a host transceiver, a processing device, sensor array, and a power section. The host transceiver provides the interface between the host controller and the processing device. It allows the processing device to receive instructions and provide status information back to the host controller. For

easier installation and configuration of the system, it is recommended that the communication protocol running through the host transceiver supports device discovery features. The processing device also controls the power section and receives information from the sensors.

The power section of the controller controls the motor of the rotary extractor. It simply provides an amplification of the PWM signal that is generated by the processing device. Finally, the sensor array returns various data about the operation of the stage to the processing device and from there possibly to the host controller.

3.1.2.2. Implementation

For our prototype implementation, we decided to use a USB interface for the host transceiver. Automatic discovery and configuration features are already implemented into the communication protocol, which will reduce the total design time of the device. In addition, USB also allows multiple devices to connect to our host controller, the eBox-II.

The power section will be implementing as an optoisolated full-bridge motor driver. The driver will consist of two components, NEC/CEL's PS2501-4 photocoupler and either ST's L6203 DMOS full-bridge driver or the L298 dual full-bridge driver in parallel operation to drive more current to the rotary extractor's motor. The pulse-width modulated signal for the driver will be provided by the processing device, in our case the PIC18F4550.

The sensor array will consist of one or more photodetectors that will indicate when an item is entering the extraction stage. When a photodiode or phototransistor is illuminated, it conductive properties change, and this change is detectable by an analog to digital converter like the one in our PIC18F4550. This part of the project is still under development. The main issues we are concerned with are whether the detector's acceptance spectrum is too wide and interference from light sources other than our light source, a laser diode, might cause a higher failure rate than desired.

The processing device of the controller is the PIC18F4550. This device was selected because of its integrated USB transceiver and A/D converter, its low cost, good documentation and recommendation from other students that have used it in the past. Figure 4 shows how this device integrates with the remaining parts of the controller. As stated above, the sensor array circuitry is still under development and is not shown. When it is complete, it will be connected to the A/D ports on the PIC, labeled AN0 through AN7 and colored in red, as seen in Figure 4.

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Figure 4: Stage Controller circuit diagram

3.1.3. Stage controller firmware

The stage controller firmware, while an integral part of the controller, is considered a separate component in our design process and is therefore given a separate section.

Because this component is specific to our implementation of the system, the design and implementation subsections have been combined into one.

3.1.3.1. Design and Implementation

At this time in the project's development, the design stage for this component is not yet complete. However, the major features that need to be implemented have been identified and research has been conducted into how these features can be programmed onto the processing device, the PIC18F4550. The expectation is that this process will not consume a significant amount of time because of the extensive help Microchip provides with its products and the availability of many user supported resources.

The features that need to be implemented into the controller firmware are the following:

- Boot loader for on-site programmability
- USB interface routines for using the onboard USB transceiver
- Motor control routines for delivering the correct amount of power to the rotary extractor's motor
- A/D conversion routines for reading sensor data
- Central management routine contains the main program loop

3.1.4. Conveyor belt

The conveyor belt is the central component of the system. It is responsible for transporting the recyclable items thought the system and it is the base to which all of the remaining components are attached. For this particular component, there are no concrete specifications due to the fact that a version of our system may be installed on a preexisting conveyor belt.

3.1.4.1. Design and Implementation

Originally, our team intended to purchase a conveyor belt to save time during the component phase, but both of our attempts were unsuccessful. The price of a commercial conveyor belt restricted our budget and a decision was made to abandon purchasing the conveyor and attempt to construct one.

Subsequently, a general design was developed and the belt specifications were finalized. Like the rotary extractors, the conveyor will have a wooden frame. A spring loaded belt stretching mechanism will keep the belt tight and allow the motor drive it. It will be 8 feet in length with an 8 inch wide belt and have 6 inch high side panels. This length allows us to mount all of the rotary extractors and RFID readers. The side panels are high enough to prevent items from falling off the sides of the belt accidentally. Additionally, there will be openings along the side for the rotary extractors to move freely so items can be pushed into the collection bins.

3.1.5. Computational hardware (Host controller)

The computational hardware for this system is an eBox-II, a compact embedded system provided by the Microsoft Corporation. The operating system running on eBox will be Microsoft's Windows Mobile 5.0. This platform was selected because of its low cost and availability.

For the system in general, the processing power of this hardware is important. The more powerful the hardware, the more extraction stages can be simultaneously connected to and controlled by it. In out implementation the eBox processor is sufficient for our three extractors. In terms of connectivity, the necessary interfaces, USB and serial, for communicating with the stage controllers are also provided.

Currently, we have not begun integrating the eBox in to our implementation. There are issues with the RFID reading software components that need to be resolved before we can migrate the controlling software.

3.1.6. Software

Software is an important part of this system. Its interaction with the hardware is very important to proper system operation. This section describes the interaction with the hardware, the design of the software, and what is currently implemented.

3.1.6.1. Interaction with Hardware

The software is used as a tool to control the system as a whole, handle errors, and move the extractors. For control of the system, it receives information from multiple optical sensors and RFID readers. It also signals for – and controls – the movement of the rotary extractors. The software constantly polls the optical sensors and the final RFID reader to see if there is any change – that is, if there is an item breaking the optical sensor beam, or if the final RFID reader is picking up the signal of an item. The flow of control and hardware/software interaction can be seen in Figure 5.

As an item moves through the system on the conveyer belt, it encounters the first optical sensor and RFID reader. When the item breaks the beam of the optical sensor, the software detects the change in state after it polls the sensor the next time. At this time, the software signals the RFID reader so the tag on the item can be read. If no tag is read or the tag does not include information for a valid recyclable, the item is marked as trash. If a valid tag has been read, the software determines what type of recyclable the item is and at which stage it should be extracted.

Once the software has determined the type of recyclable, it decides what the next action is. For a Type A recyclable (extracted at the first stage), the software signals the first extractor to move after a short delay. This allows the item to enter the collection area of the first stage. If the extraction fails, the item is placed on the queue to be extracted at the last stage, which allows it to be recirculated through the system. If the recyclable is a Type B recyclable, it is added to the queue to be extracted at the second stage.

Items still on the conveyer belt after the first stage are either Type B, trash, or Type A that is still on the conveyer due to an error. When the software polls the sensors and the second optical sensor is triggered, the software checks to see if the item – which is at the front of the queue – is a Type B recyclable. If it is, the software creates a delay, and then signals for the second extractor to move. It then removes the item from the queue. If the item is anything except a Type B recyclable, it is removed from the queue – being either trash or a valid recyclable that will be caught at the last stage.

The final stage removes any type of valid recyclable. The second RFID reader is polled by the software, just as the optical sensors are. If either Type A or Type B recyclables are sensed, the extractor is moved after a delay to extract the item for recirculation through the system again. Otherwise, the items move to the end of the conveyer belt and fall off the end into a trash bin.



Figure 5: Hardware/Software Interaction

3.1.6.2. Design

Design of the software for controlling the system as a whole as well as the software that handles error control was done at the start of the project. UML diagrams such as class and sequence diagrams were used to aid the design process. This helped get the ideas solidified in a standardized way so that everyone could understand the design. The design for the system is such that the system could be easily expanded at a later time to hold more stages. Once the design was complete, the software was developed.

Just as the conveyer belt is central to the physical system, a queue is central to the software that controls our system. Item objects are placed on the queue, when necessary. The rest of the logic comes from the flow of the system, seen in Figure 5: Hardware/Software Interaction.

3.1.6.3. Implementation

At this point, the software that is used to control the system is mostly complete. Since the optical sensors are not finished, the software prompts the user to enter a Y or N for each optical sensor to indicate if it has been triggered. This sets off the same chain of events as if the optical sensor was integrated.

The error control software is partially implemented. For most cases, we will allow the problem item to pass through to the end. This error catch has been completed. We do not, however, have the software to back the extractor up if it is jammed. This will happen once everything else has been put together.

3.1.6.4. Tools

For testing the system software, we developed extra methods within the software to view the status of the system at various points. This is also useful for providing demonstrations of the system and simulation before all the hardware is complete.

We also created another test program to verify the queue class was working properly. This program followed the test suite we wrote, and made sure all the functionality was verified.

4. Testing

Testing has been conducted on several system components. The following sections describe in detail how the testing done on the system.

4.1.1. Hardware

A prototype of the stage controller with limited functionality has been tested. The prototype was capable of communicating with a host PC through its USB interface. From the PC, the velocity of the motor could be controlled by sending a 10 bit number

that determined the duty cycle of the pulse width modulator. The pulse width modulator then controlled a simple MOSFET amplifier that delivered power to the electric motor.

From experimenting with the prototype, we determined that a minimum starting power was required to get the motor to spin. In our case, a value of 350 had to be sent by the PC. As we increased the input value from the PC, the motor responded almost linearly. We had difficulty achieving maximum velocity, which was likely due to the design of the MOSFET amplifier.

4.1.2. Software

Software testing has been done in two segments. This follows design and development, which was done in two parts. To keep track of items, the software keeps a queue, which holds the necessary information about each item on the conveyer belt. Since this part is so important to the rest of the software, it was implemented – and therefore tested – first. The different functions of the queue were methodically tested.

The software as a whole was tested once the whole system was implemented. While the software was being written, the separate parts were tested ad hoc. A test suite was written for fuller coverage of testing once everything was written. This is important because it creates written documentation of what has and has not been tested. System testing is categorized three ways: adding items, removing items, and miscellaneous other tasks the software must perform. At this time, all tests have been run and have passed for the functionality that is implemented.

5. Summary

Currently, all component design phases have been completed except for the optical sensor circuitry. The software has been developed and currently runs on the Windows XP operating system. We expect to migrate to the eBox once the stage controllers have been constructed. All of the parts of the stage controllers are currently on order as of the writing of this report. The expectation is to have them constructed before the end of the week following the report submission. The optical sensors will have to be attached at a later time, once the circuit design has been finalized. The majority of the rotary extractor and conveyor belt parts have also been purchased. Scheduling workshop time has prevented us from building these components thus far.

The design of the system is well thought out and thoroughly developed. The goal of our prototype implementation was to demonstrate that such a system was feasible and would perform reasonably well for a first prototype. There are many ways that our general design can be expanded and a better system for larger-scale operations. The most obvious way is to add additional stages for finer-grain separation. Additional stages may necessitate a different communication interface between the computational hardware and the stage controllers. The rotary extractors can be scaled for faster system operation, and the number of conveyor belts controlled by a single computational hardware may be increased.

Additionally, the information gathered from our system need not be limited to simply the identification of type of recyclable for sorting. There is a significant amount of statistical information that can be obtained from a simple RFID tag affixed to the side of a consumer product. These tags are being used throughout the supply chain for shipment and inventory management, and we plan to extend their usefulness by using them to identify and extract recyclable materials from common household waste. The information that we could retrieve during the disposal phase would provide useful product information to marketers and allow them to track general consumption statistics. This allows for the creation of more effective marketing campaigns and gives consumers what they want. We anticipate that as RFID tags become more cost effective, they will be used more extensively in the supply chain and our system will utilize them to identify and sort many different materials at material recovery facilities.

6. References

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