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Development of a Microcontroller-based Solar-powered Reversed Vending Machine for the Potential Application on Barangays in the Philippines

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***Abstract*—The prototype for this Reverse Vending Machine (RVM) will have a brand name of "WISE Recycle Bin". RVM is a device that accepts used (empty) beverage containers and usually returns money to the user (the reverse of typical vending cycle). Our solar-powered prototype enables the user to recycle plastic bottle beverage containers and gives a mobile charging time in return. The prototype of this study will be developed using the integration of the commercially available Proximity Sensor Circuits, PIC16F48A Microcontroller, Solar-Power System Package, and as add-ons, a Display Screen and Street Lamp. Microcontroller PIC16F84A receives input from sensor circuits, and gives a necessary output. The microcontroller is programmed to be activated by the 2 sensors simultaneously, like an AND function, to give a response. The energy supply of the RVM will be coming from the Solar Power System. It includes the Photovoltaic Cells, the charge controller, and the batteries. The prototype shall then be brought on communities/barangays in the Philippines as a way of compliance to the Republic Act (RA) 9003 or the Ecological Solid Waste Management Act of 2000, a landmark environmental legislation in the Philippines.**

***Index Terms*—Reverse Vending Machine, WISE Recycle Bin, Solar-powered, Microcontrollers, Waste Management**

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I. Introduction

According to the second law of thermodynamics, the entropy, often symbolized as S, of an isolated system never decreases, because isolated systems spontaneously evolve towards thermodynamic equilibrium pertaining to balance as described in a measure of disorder. In a layman's term, the stated law implies that all things are bound to disorder, hence, into useless one and an object or a material that is useless and not consumable as commodity is considered as waste. Every day, millions of wasted and useless materials are being compacted as garbage having no proper waste disposal. Even in most developed and industrial countries, only small percentage is being subjected to the 3R mantra: reuse, reduce and recycle. In an article updated May 16, 2010 in Livestrong, United States (US) alone produces 230 million tons of trash each year and only 25 percent is recycled and the rest goes in landfills, incinerated, or in ditches and roadsides (learner.org). 2.5 million Plastic bottles from these 230 million tons of trash are being thrown every hour and only 1/5 of these are being recycled (geowords.org.) Such improper waste disposal is detrimental to the sake of nature and to the world we living into. On this note, the development of a Microcontroller-based Solar-powered Reversed Vending Machine (RVM) will be beneficial in collecting and recycling wasted beverage materials especially plastic bottles, as the subject of this research, as utilized by an advanced technology.

This RVM project aims to provide a unique solution to the perennial and detrimental commotion of proper waste disposal. The said machine shall be utilized to encourage members of the community to properly dispose of their waste, particularly plastic containers which are non-biodegradable, and be provided with a service in return. Instead of giving back money, the RVM is designed to provide certain minutes of charging time for the user's mobile phone. WISE Recycle Bin will have one (1) charging bay with multiple connectors for different mobile phones. For every bottle, charging time of five (5) minutes will be rewarded. It shall only process one bottle at a time, meaning, one must complete the 5-minute charge before transacting another bottle. The machine is designed for plastic bottles ranging 5 – 7.5 cm (in diameter) and 17 – 45 cm (in length), a typical plastic bottle. Furthermore, The RVM should be advised to only accept plastic bottles. Unlike commercially available RVMs, the machine will not have the ability to crush bottles. Therefore, a regular maintenance of the machine should be implemented.

RVM is an innovative concept which has been introduced to western countries to help collect recycling materials and hence, to boost recycling activities and therefore improve waste management. The photo below shows the popularity of RVMs now on rise for its significant help in the society:

Fig. 1. RVM is introduced to the locality of Australia. Retrieved from http://www.cityofsydney.nsw.gov.au/ (2015 July 1)

Meanwhile in the Philippines, an article published by Philippine Star, last 2013 October 11, stated that: "In a speech at the Manila Hotel to mark his first 100 days as Manila mayor, Estrada said Manila generates around 8,700 tons of garbage every day and only 70 percent is collected efficiently while 30 percent goes to canals, creeks and rivers. The 2,610 tons of garbage "clog the drainage pipes and *esteros*, which used to be effective drainage systems. The disappearance of these creeks has contributed to the metropolitan flood problem," he said:

Fig. 2. The scenario on Manila during stormy seasons. Retrieved from http://newsinfo.inquirer.net/wp-content/blogs.dir/10/files/2012/08/roxas-blvd-flood.jpg (2015 July 1)

On a global scale, aside from an education as the empowered key, the installation and application of science in the manner of technology will eradicate the hazards of improper waste disposal and will utilize an advanced, appropriate and a two-way processed disposal method. The RVM as well, in the case of the Philippines, will help reduce the misleading disposal of plastics and will help to the recycling process as also advocated by some institutions and local groups especially Philippine Plastic Industry Association (PPIA). In addition, RVM is in beneficial to the provisions of Republic Act (RA) 9003, or the Ecological Solid Waste Management Act of 2000 intensifying recycling.

II. CONCEPTUAL FRAMEWORK

On the basis of the foregoing concepts, theories and findings of related literature, studies and insights taken from them, a conceptual model was developed shown below.

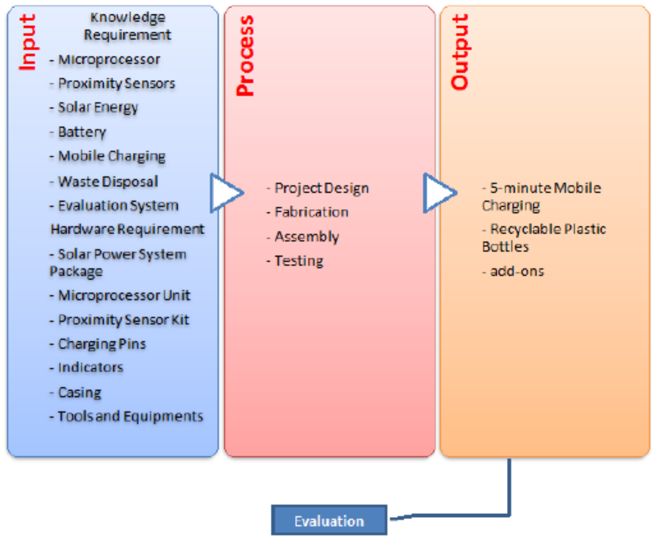

Fig. 3. Conceptual Model of WISE Recycle Bin.

The input stage consists of the knowledge requirements gathered needed to come up with the design. The process block is composed of project design, fabrication, and assembly and testing. Having had an acceptable output, it was subjected to a set of evaluation based on a set forth criteria.

III. PROJECT STRUCTURE

The project is divided into 4 major parts: Solar Power System, Input, Process and Output Stages. The Solar Power System supplies the whole system, the Input Stage involves the Proximity Sensors, the Process Stage consists of the Microcontroller Unit and the Output Stage gives the incentive to the user, which is the 5-minute charging time of mobile phones.

For evaluation, establish three moments or "checkpoints" along the development of the project to ensure that a simultaneous development and teamwork can be achieved:

(i) At the beginning of the project, make thorough research on each part in the project and discuss ways to approach the ideas.

(ii) In the middle of the process, when problems in the initial approach can be detected, discuss necessary corrections and future works.

(iii) A final assessment checkpoint should be done when the work is completed and individual parts are integrated into a complete project.

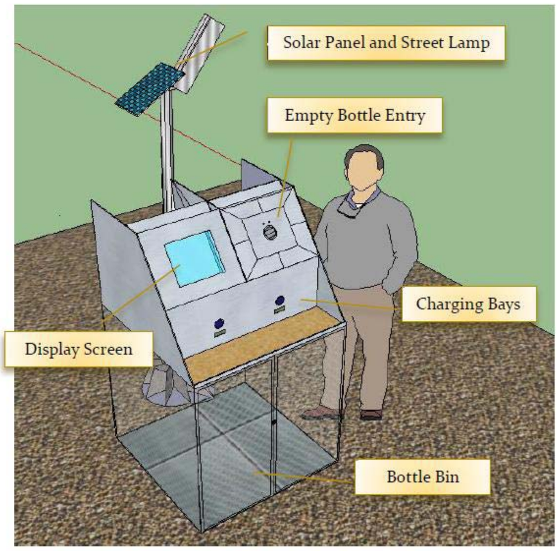

Fig. 4. Proposed design of WISE Recycle Bin.

Basically, the project is divided into a few stages to ensure smooth progress and success. The first stage focuses on literature review to get more information and idea about this project. Microprocessor technology is studied to understand the features, applications and how to program them. Also, studies on sensor, solar power system and existing Reverse Vending Machines are done. The second stage is to choose the suitable microcontroller and sensor. In choosing a suitable microcontroller type, it should be ensured that the PIC must have a minimum of two (2) inputs, for the sensors, and one (1) output, for the charging outlet. Therefore, PIC16F84A could be used as the microcontroller. For the sensor, a commercially available Proximity Sensor kit by E-Gizmo is integrated. It can detect objects as far as 25cm from the sensor face and relatively insensitive to ambient light and color (of target object). The third stage involves the programming of the PIC. Microcontroller PIC16F84A is programmed using the PIC Kit v2.61 software. HEX File is generated through MPASMWIN. Fourth stage involves integration of the individual projects namely the electrical and mechanical, solar energy system and miscellaneous part. The operation of these parts as a whole is tested. Finally, analysis of WISE Recycle Bin is done in terms of its user-friendliness and accuracy. Limitation of the project and future enhancement is also analyzed.

IV. EXPERIMENT AND TESTING RESULTS

A. Operation and Testing Procedure

This section is to discuss the software, hardware and circuit diagrams used to give better view on the overall operation and testing of the project. The architecture and characteristics of the components and devices is included in this section.

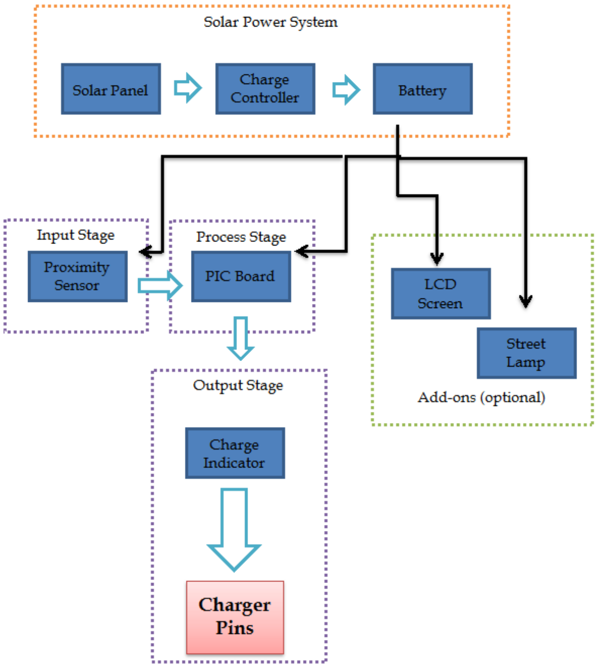

Fig. 5. Block Diagram of WISE Recycle Bin.

After determining the microcontroller to be used, the next step is to choose the software to program them. In creating the source code, MPASMWIN software is used to generate a HEX file. In exporting the .hex file to the PIC, PIC Kit v2.61 software is used. PICkit is a family of programmers for PIC microcontrollers made by Microchip Technology. They are used to program and debug microcontrollers, as well as program EEPROM. For the Hardware Implementation, "WISE Recycle Bin system" consists of a PIC16F84A microcontroller, 2 Proximity Sensors, and the Solar Power System. Microcontroller PIC16F84Areceives input from sensor circuits, and gives 5V as output voltage. The microcontroller is programmed to be activated by the 2 sensors simultaneously, like an AND function, to give a response. The energy supply of the RVM is coming from the Solar Power System. It includes the Photovoltaic Cells, the charge controller, and the batteries.

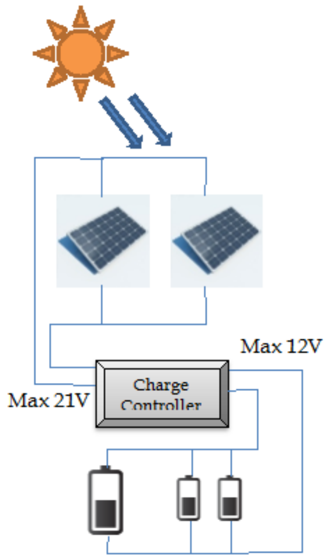

Fig. 6. Solar Power System Stage of RVM.

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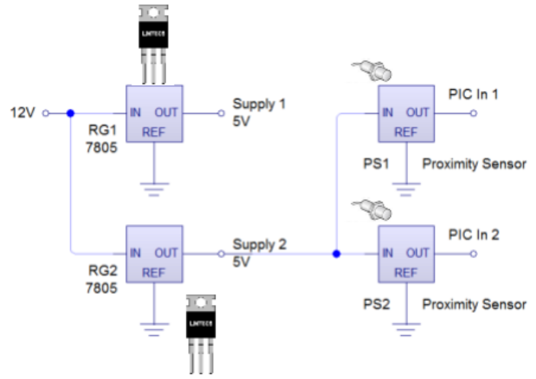

Fig. 7. Input Stage of RVM.

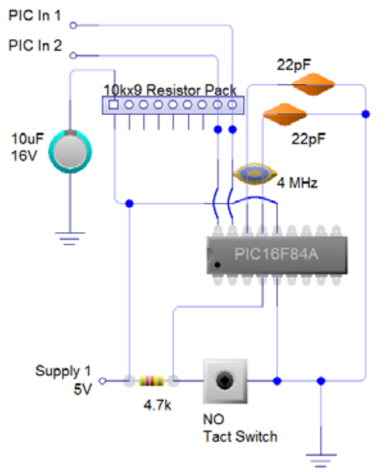

Fig. 8. Process Stage of RVM.

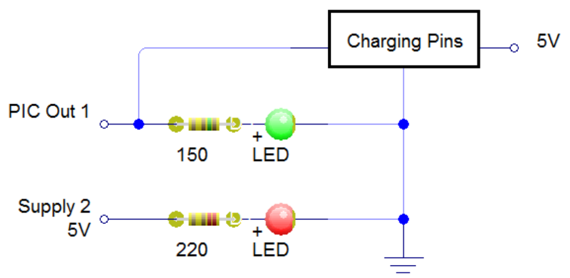

Fig. 9. Output Stage of RVM.

B. Testing Results

The RVM's Solar Power System consists of two (2) 10Wp photovoltaic cells, a charge controller and 3 rechargeable batteries. A maximum of 21V DC can be obtained from the PV cells, which are connected in parallel. This is then connected to the charge controller, where it converts the supply from the PV cells down to 12V DC. The Charge controller then gives charge to the 3 batteries which are connected in parallel. The Input, Process and Output Stages, even the miscellaneous parts, shall be getting power from these batteries. That makes the RVM a stand-alone machine.

Two (2) 7805 IC Voltage Regulator are used as 5V DC sources. Supply 1 delivers 5V to the PIC16F84A Microcontroller, while Supply 2 is connected to the Sensor Circuits and Red LED indicator. The proximity sensor circuits are responsible for detecting the bottle that will be entered by the user. The sensors are pre-set not to detect the 'pipe' itself, where the bottle would travel through, but only the bottle that would be inserted in it. The green LED on the circuit board signifies its 'on' state. When there shall be a bottle to enter through, the red LED will light. The distance between the two (2) sensors is the minimum length of an acceptable bottle. In our RVM, we set is as 17cm. The good thing for the machine's proximity sensor is its insensitivity to ambient light.

The heart of the RVM is the microcontroller. It gives output when the two sensors detect a bottle simultaneously. To test it first, a tact switch was put in replacement for the Sensor Output. By pressing either of the switches, nothing happens. But when both pressed at the same time, the green LED will light up. It will be easy for testing and troubleshooting if we are to put a reset switch to the microcontroller. The inputs used in the RVM's microcontroller are A0 (Pin 17) and A1 (Pin 18), while output will be generated from A2 (Pin 1). The microcontroller is programmed to give an output for 5 minutes. After such, the code will loop again, where it will give output just the same way again.

The output stage contains the charging bays and the indicators. When the red LED is the only one lit up, it signifies a non-charging mode. It also indicates that the Sensor Circuits are turned 'on'. During successful entry of a plastic bottle, the green Blinking LED lights up together with the Red LED. It shall only turn 'high' for 5 minutes as programmed in the microcontroller. The output pin of the microcontroller, A2 (Pin 1), gives a 5V DC to be utilized for charging mobile phones.

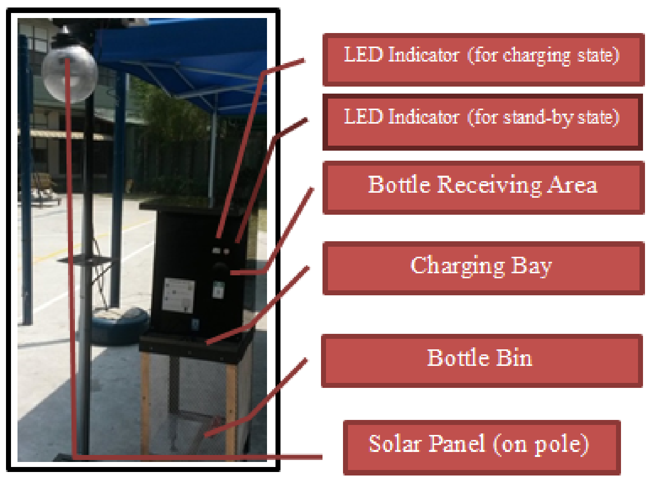

Fig. 10. Sample Prototype of WISE Recycle Bin.

C. Evaluation System

After the initial testing and test-run of the machine, we have noted all successful steps in the checklist as part of the evaluation of the project.

1) Solar Power System

a) *Photovoltaic Cells should be placed on a fixed pole overhead to efficiently collect sunlight.*

b) *PV Cells should be connected to a charge controller that gives 12V DC as output.*

c) *Batteries should be connected to the charge controller's output for continuous charging.*

d) *There should be available outlets for add-ons (e.g. the streetlamp, display screen).*

2) Input

a) *Sensor circuits must be fixed along the end of bottle entry for detecting purposes. It should also have an indicator if it's turned on or not.*

b) *Sample bottles should be tested with the sensors to know its functionality.*

3) Process

a) *Program the code into the Microprocessor.*

b) *The Microcontroller board must be placed on a secured casing.*

c) *Terminal blocks and connector pins/headers are encouraged to be used for accessibility.*

d) *Before connecting the sensors and charging pins, replace it first by tact switches and LED light, respectively. In this way, we could easily test the functionality of the Microcontroller unit.*

4) Output

a) *Multiple charging pins must be connected to the Microcontroller's output.*

b) *An indicator must be integrated to display charging state.*

c) *Measure the voltage output from the Microcontroller to confirm its sufficient supply for the mobile phone's charging purpose.*

5) Casing and Miscellaneous

a) *Casing must be secured enough and rainproof. Accessibility in maintenance should also be observed.*

b) *Bottle bin must be 'see trough' for user's recognition of the proper input required of the machine.*

With all these being favorable, we can say that the objectives and imposed operation of the machine is successful. Below are the results gathered after testing.

TABLE I
TEST RESULTS WITH RESPECT TO INPUT MATERIAL

Sample	Description	Ø (cm)	1 (cm)	Remarks
A	Empty Plastic Bottle	6	19.5	ACCEPTED
B	Empty Plastic Bottle	7	42	ACCEPTED
C	Empty Plastic Bottle	4	18	NOT ACCEPTED
D	Empty Plastic Bottle	6	15	NOT ACCEPTED
E	Empty Plastic Bottle	4.5	17	ACCEPTED
F	Random Material	> 1	20	NOT ACCEPTED
G	Random Material	6	20	ACCEPTED

Samples A, B, C, D displayed expected outcomes as guided by the limitations set beforehand, that is, the RVM will accept bottles of 5 – 7.5 cm (in diameter) and 17 – 45 cm (in length). Sample E showed favorable result despite lacking a 0.5cm deviation against the minimum diameter requirement. Therefore, it is an implication that the RVM has a greater tolerance on the material's diameter against the length of the material. Sample F, as a random material, also obtained an expected outcome for its lacking requirements set for the RVM. Sample G, as a random material, theoretically has been accepted by the RVM since the material itself meets the set requirement of the machine. This proves the limitation of the RVM on the material recognition. Therefore, it can only be addressed by proper instructions to the user.

TABLE II
CHARGING BAY RESPONSE

Sample	Initial Battery Level	Charging State	V_{out} (V)	Charging Time Duration	Final Battery Level
A	60%	ON	4.80	5 min	63%
B	0%	ON	4.60	5 min	2%
C	71%	OFF	0.10	0 min	71%
D	65%	OFF	0	0 min	65%
E	88%	ON	4.88	5 min	93%

*Results were reduced to the acceptable Samples A-E

Overall, the system can be implemented successfully. The system as a whole provides a cost effective and simple solution for the implementation of Reverse Vending Machine in the community.

V. CONCLUSION

The aim and objectives of this project has been achieved. The prototype of Reverse Vending Machine was successfully built and the whole system can function successfully. The prototype is then ready to be introduced in different communities/barangays in the Philippines.

Aside from the original target of this study, private sectors can also play a major role by sponsoring the machines. Take for instance, the University Administration could put this RVM on various places in school. In this way, the students would help in solving the perennial commotion on proper waste disposal and encourage them to recycle more. While for public parks and leisure places, it would really help in preserving the cleanliness of the place while giving extra benefits to their patrons. In addition to this, in the case of a shopping mall, it could also be an option to kill time for those shoppers who are waiting for their companions.

Reverse Vending Machines are available on other countries, yet, its popularity in the Philippines is still on a low side. Though simpler unlike the existing RVMs, this development of RVM in our country will introduce this technology that would really showcase the potential of renewable energy while promoting proper waste disposal. We hope that this small step that we took shall be appreciated by the government and eventually, could help us in developing the more advanced functions of the machine.

VI. RECOMMENDATIONS

The system achieved its main objectives; however, there are some limitations of the prototype. The system itself is still imperfect with certain shortcomings. Being a prototype for the Reverse Vending Machine, the system is still at its infancy stage and further development should be made to enhance its reliability, increase its accuracy and functions.

From an overview of our project, there are many obstacles hindering the optimization of the system. Budget allocated in resource limits the purchase of high end devices, and absence of a standardized bottle scanner, not to mention its wide database collection if the prototype was to implement material type processing approach.

The main recommendation is to add charging bays for simultaneous charging of the users' mobile phones. Minimal recommendation would be for the indicators of the RVM.

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We offer these all up to Him.

jae, dsf, jndt, jcdb, anbd, cllm, jpr, rrrs, sss
Manila, Philippines
September 2015

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MODIFICATIONS (Revised November 14, 2015)

1. Sponsor and financial support acknowledgment section (Page 1)
   - I have added additional department and organizations that have given their support in our trip.
   - Correction on D. S. Fainsan's email
   - Added a phone number to J. A. Exito

2. Acknowledgement section (Page 5-6)
   - Certain corrections

3. Abstract
   - Removed unnecessary words that could distract the readers with the essence of the paper.

4. Introduction
   - I have included discussion on related work, as appeared in the full paper of this study.

5. Experiment and Testing Result
   - I have provided additional test data and analysis of the results that could help the readers in understanding the quality of the prototype generated.