BOOK
OF
PROCEEDINGS

WASTES

solutions treatments opportunities

1st

september
guimarães
12 > 14

2011

International Conference

RECYCLING PRINTERS FOR EDUCATIONAL PURPOSES

S. Shahidian[1], R.P.Serralheiro[2], J.M.Serrano[3] and R.M.Machado[4]
1 ICAAM, Universidade de Évora, Apt.94, Núcleo de Mitra, shakib@uevora.pt
2 ICAAM, Universidade de Évora, Apt.94, Núcleo de Mitra, ricardo@uevora.pt
3 ICAAM, Universidade de Évora, Apt.94, Núcleo de Mitra, jmrs@uevora.pt
4 ICAAM, Universidade de Évora, Apt.94, Núcleo de Mitra, rmam@uevora.pt

ABSTRACT
Large amounts of printers are thrown out annually, since it is usually more attractive to buy a new printer than to replace ink cartridges, especially if the apparent cost is very similar. Most of the discarded printers either end up in land fills, or are melted for recovery of the metal components. At the University of Évora, a new approach has been developed since 2007: old printers are dismantled and the parts are used in electronics and automation classes, saving the environment and helping to reduce the annual cost of running the laboratory classes. One of the most widely available and useful printers is the HP 600 series that were manufactured between 1994 and 2000. These printers, once dismantled can provide various precious components for electronic classes. These components include: 2 step motors, one 12V motor complete with gear-head and trolley, a LM35DZ precision thermometer, one contact relay, one infra-red switch, two LDRs and one high quality cable and a LPT connector that can be used in automation developments using the PC´s LPT port. The four years of experience have shown that the students are more than willing to take the time to dismantle the equipment and carefully extract the components. With the proper tools, two students can dismantle a printer and remove the parts in less than 15 minutes. This paper presents the individual components that can be removed and presents sample circuits and uses for the parts in electronic and automation laboratory classes.

Keywords: Printer recycling, printer dismantling, teaching electronics

INTRODUCTION
The volume of end-of-life electronic waste is increasing rapidly. In 2010, more than 125 million printers were shipped globally, of which over 52 million were hp branded (Bienvenu, 2011). This is a 12% increase over 2009 volumes, and this number is expected to grow. Assuming an average weight of 5kg per unit, this represents a total of 750 000 ton. of electronic waste that needs to be recycles annually. In the US alone, annual plastic flows through the business and consumer electronics manufacturing supply chain in 2003 included nearly 15 million ton. of high value engineering plastics (Rios et al. 2003).

The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is the European Community directive 2002/96/EC on waste electrical and electronic equipment (WEEE) which, became European Law in February 2003, setting collection, recycling and recovery targets for all types of electrical goods. The directive imposes the responsibility for the disposal of waste electrical and electronic equipment on the manufacturers of such equipment. Those companies should establish an infrastructure for collecting WEEE, in such a way that "Users of electrical and electronic equipment from private households should have the possibility of returning WEEE at least free of charge". Also, the companies are compelled to use the collected waste in an ecologically-friendly manner, either by ecological disposal or by reuse/refurbishment of the collected WEEE.

Conventional recycling

The conventional recycling process in use today consists of shredding the equipment to small parts, and then using physical and chemical properties of the individual components to separate the various materials. The recycling starts at an initial staging space where products are sorted and queued in batches for shredding. Once shredded, the material is sorted using magnetic separation, grinding, density separation and manual sorting. The output of this bulk recycling process of electronics is ferrous metals, mixed metals, glass, mixed plastics and mixed material. Each batch is then sold for further processing.

Metals comprise 57 percent of the total amount of electronics scrap (Klatt 2003), and thus many recycling processes focus primarily on precious metals recovery. Metals used are primarily iron, cast iron, stainless steel and other steel alloys, aluminum and aluminum alloys, copper alloys, lead, and zinc. They also contain many toxic substances, such as dioxins, polychlorinated biphenyls (PCBs), cadmium, chromium, radioactive isotopes, and mercury. Reuse of these material can reduce the costs of constructing new systems. Some components such as gold and copper are valuable enough to reclaim in their own right.

Plastic materials represent 19 percent of total electronics scrap (Klatt, 2003) . One of the problems with plastics recycling and recovery is the difficulty in sorting the parts by types. While thermoplastic materials are recyclable, compound plastics are unacceptable. Because of the incompatibility of various plastics, the parts disassembled from old products must be identified and sorted into separate different types of plastic. Co-mingled plastics are more difficult to find markets for, than single resin materials and have a lower market value. Plastic reprocessors will pay appropriately for consistent and clean quality recycled material which has been granulated to a designated specification.

The sustainable recovery of potentially high-value engineering plastic streams requires that recyclers separate small plastic pieces created in volume reduction steps such as shredding. This is a difficult and expensive process that poses limitation to a viable plastics to plastics supply cycles. Since the limited electronics recycling infrastructure existing today focuses primarily on precious metals recovery, less than 1% of the plastics from end of life electronics are actually processed for plastics to plastics recycling (Dilon and Aqua, 2000).

Printer recycling

Hp, world´s largest electronics company started in 1998 a global Hardware Return and Recycling Program, as part of their Planet Partners Program, which was hailed as the most comprehensive hardware return program of its competitors worldwide (Degher, 2002). In this program the equipment is ground into small pieces and subsequently separated into its component parts (steel, aluminum, copper, plastic, etc). Once separated, these material are sent to specialty recyclers or used for energy recovery. Brigden et al. (2005) visited many recycling facilities in China and India where local and imported end of life electronic equipment are recycled. They observed the release of substantial quantities of toxic heavy metals and organic compounds to the workplace environment and to the surrounding soils and water courses, indicating the risks associated with conventional recycling.

Dismanteling vs. conventional shredding

Ideally, the goal of recycling is to economically generate material that is no different from virgin material. But in the manufacturing and assembly process the virgin material is inevitably combined with a variety of different materials, and in a sense, becomes impure. A product composed of a single material provides the highest recycling yield, since the impurity levels are very low.

A level of high impurity in recycled materials is one of the most common obstacles to more widespread recycling. The level of purity determines the quality of the recycled material and its market price (Das and Matthew 1999). Dismantling is the ideal process for maintaining the purity of the raw material. This process is perceived as uneconomical and labor intensive, but with a high unemployment rate, and the environmental impact and hazards of the alternatives, it might turn out to be feasible and a means of providing some employment in depressed regions of the western countries.

Rios et al.(2003) used discrete event simulations with spectrochemical plastic resin identification and subsequent sorting, and concluded that limited disassembly with whole-part identification can produce substantial yields in separated streams of recovered engineering plastics. Additionally they found that disassembly with identification did not constitute a bottleneck in the process.

A research conducted at the University of Massachusetts evaluated the cost of dismantling the electronic wastes stream of the institute. They found that dismantling one ton of electronics represented 19.1 hours of labor, plus an additional 2.4 hours for loading and unloading the material. The study indicated that the University could earn an estimated $175 per ton of material processed, assuming a labor cost of $6.25 per hour.

OBJECTIVES

With a renewed focus on automation and electronics in agricultural sciences, the curriculum of the Bachelors and Masters Programs at the University of Évora now include subjects on automation, electronics and data acquisition. In order to provide the students with the equipment and material needed for their learning process a new approach has been successfully used: Old printers are dismantled by the students and the parts used in class to develop their own projects. This has helped reduce the environmental footprint of the classes, and helped to reduce the total cost of running the laboratory classes.

There are an estimated 2000 printers on duty at the University of Évora, with a life expectancy of five years. This translates into an annual stream of 400 decommissioned printers that are available free of charge. One of the most widely available and useful printers is the HP 600 series that were manufactures between 1994 and 2000.

This study presents the results of the four years experiment with dismantling and recycling of the printers, describes the recovered parts and some uses for them in teaching electronics. Additionally it describes how this dismantling programme has helped the general recycling process of the printers.

RESULTS

Each group of two students is offered a set of equipment including a microcontroller, voltimeter, 12V battery, solar panel and miscellaneous tools and parts. Additionally, they receive an end-of-life printer to dismantle for additional parts. The students are able to dismantle completely the printer and separate the components based on their material in less than 15 min. The 72 individual parts (except for screws) of a dismanteled printer are presented in Fig. 1. In Table 1 are presented the weight and material type of these components. It should be noted that once the reusable components are removed, practically all the remaining components can be separated into single composition material, ready for recycling and mixture with virgin material. Each printer represents a total weight of 5000 g, of which only some 500g need further separation before recycling.

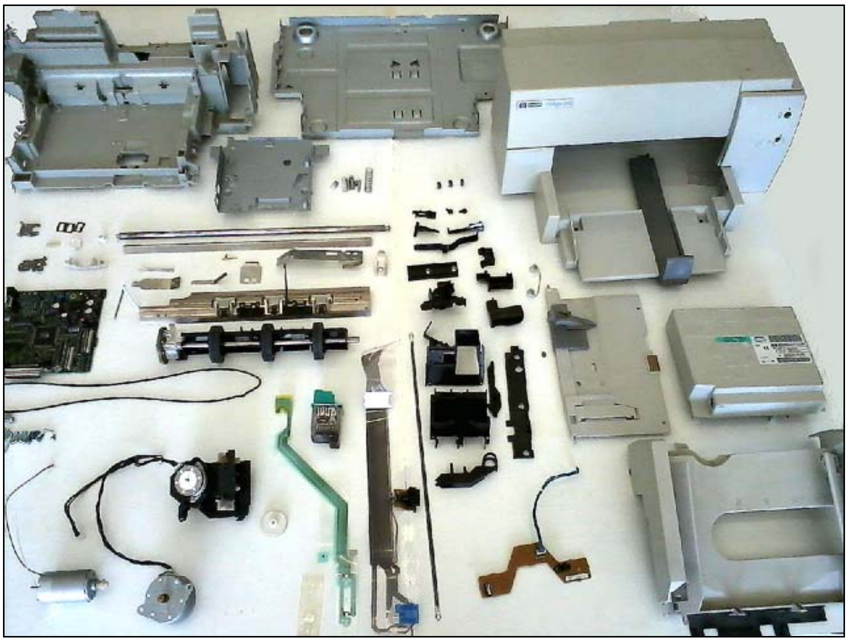

Figure 1. Overview of the component parts of an HP 540 printer

The objective of the dismantling is to obtain electronic and electric components for use by the students in their laboratory experiments. The main reusable components are 2 step motors, one 12V motor complete with gear-head and trolley, a LM35DZ precision thermometer, one contact relay, one photodiode/photosensor switch, two LDRs, and one high quality LPT cable. A market survey of the main component suppliers reveals that the total cost of purchasing these recovered components is around 70 € (Table 2).

Table 1. Components of an HP 600 series by weight and material type.

	Weight, g	***Material***	***Destination***
Reusable components			
PM55L Motor	219.2	Ferreous metals	Reuse
PM35L motor assembly	180.7	Ferreous metals	Reuse
C2162-6006 Motor	221.1	Ferreous metals	Reuse
Sensor Assembly	11.4	Misc. electronic	Reuse
Stripe + sensor	10.9	Misc. electronic	Reuse
LPT cable		Copper and PE	Reuse
Ferreous components			
Bottom plate	1136.2	Alloy	Recycle
Stainless Steel parts	415.2	Stainless steel	Recycle
Back plate	174.6	Alloy	Recycle
Plastic components			
Misc. Black Plastic	134.7	PC 30GF	Recycle
Inner beige plastic frame	411.4	PC 20GF	Recycle
Beige plastic outer shell	1559.6	Policarbonate - PC	Recycle
Roller Assembly	266.9	PC, rubber	Shred and recycle
Electronics			
PCB	146	Misc. electronic	Shred and recycle
Other			
Misc. Plastic and metal parts	46.5	Misc. plastic and metal	Shred and recycle
Total	4934.9		

Four years of experience have shown that the students are more than willing to take the time and dismantle the equipment in order to recover the components for their projects. Additionally they make the extra effort to dismantle and separate the remaining components based on the material and the markings on the plastics, thus obtaining batches of pure recyclable material.

Table 2. Market value of the recovered components

Component	Bulk price, € (100 units)	Supplier
NMB PM55L bipolar stepper motor	27.40	Digi-Key
NMB PM35L bipolar stepper motor	22.80	Digi-Key
LM35DZ thermometer	0.76	Farnell
C2162-6006 Motor	12.50	Digi-Key
Omron D2F-01FL snap switch	1.82	Mouser
photodiode/ photosensor pairs	1.75	inmotion
LPT cable	2.00	Local computer shop
Total	69.03	

Reusing valuable parts and subsystems
The sensor board provides three very useful sensors for teaching electronics: a high precision LM35 thermometer, a contact relay and a photodiode/photosensor pair. The electric circuit of the board is presented in Fig.2. The board can be either used directly or then the sensors can be removed and used separately.

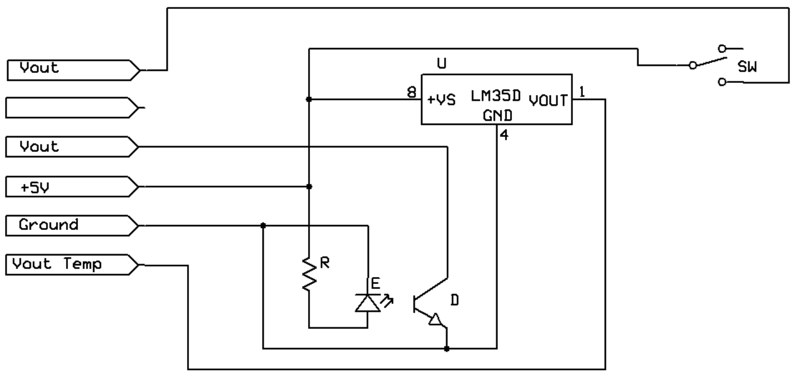

Figure 2. Electric circuit of the C2162 sensor board used in the HP 500 and 600 series.

LM35DZ

The LM35 series are integrated circuit high precision thermometers, with a precision of 0.4ºC. The DZ provides linear voltage to temperature output, which makes it ideal for quick implementation in the classroom. It provides a gain of 0.01 V per ºC, which facilitates temperature reading with the ADC incorporated in the AVR microprocessors.

One of the first class works is to make a digital thermometer using the LM35 thermometer. A LCD and the microcontroller are the only two other components necessary for this project. Figure 3 shows a digital thermometer built using the printer sensor board. It is possible to add many functions using the two switches, such as a function that shows the average temperature when the switch lever is pressed.

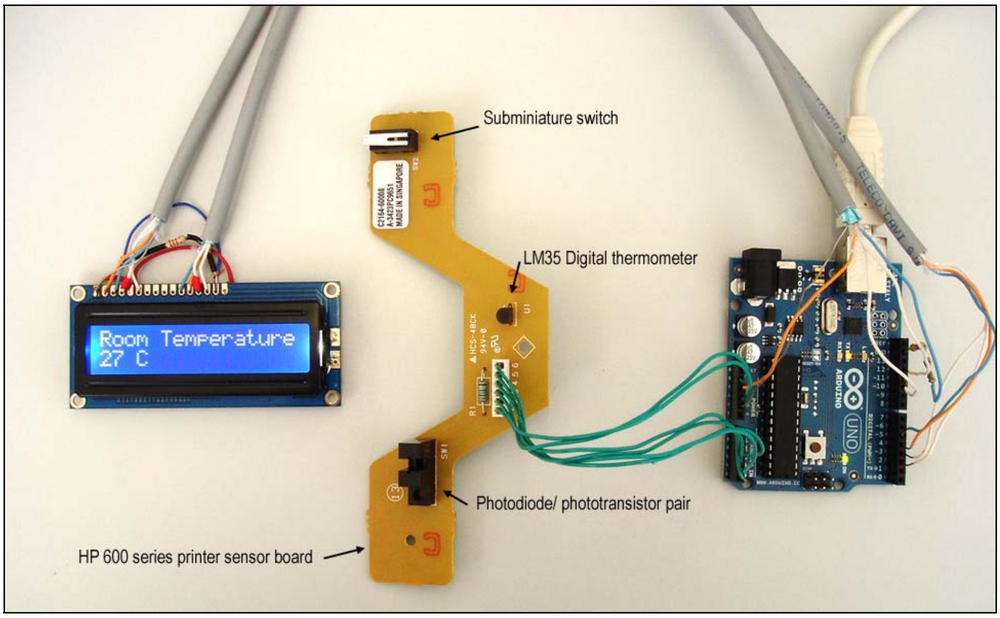

Figure 3. Digital Thermometer made with an HP 600 printer sensor board.

Infra-red Switch
Another very interesting component of the sensor board is an optical sensor with phototransistor output which is used by the printer to detect incoming paper. It is made of a LED emitter at near-infrared (850-940nm), and a sensor. An infra-red beam crosses the opening, and if it is interrupted by an object the output current is changed.

Omron subminiature basic switch
Hp has installed a microvoltage low-force switch to detect opening of the printer lid. It is assembled on the sensor board, but can be easily pulled off. In the class it is used as a general-purpose switch, as well as for control in automation.

Step motors
The most expensive parts provided by the printer are two unipolar step-motors: The PM55L and the PM35L permanent magnet motors made by NMB. These are precision step motors that can be used in robotics, since they can position the head with great precision. In the HP 600 series printers the PM35L is used for cleaning the printing head, and comes assembled with an elevator that provides and up and down movement. This is very useful in visualizing and implementing step-motor control under real-world conditions, enhancing the learning experience of the students.
A Darlington pair array such as the UNL2003A can be used to easily control the step-motors with a TTL signal from the microcontroller. The PM55L is the paper feed motor for the printer, and is a very powerful 1A step-motor.

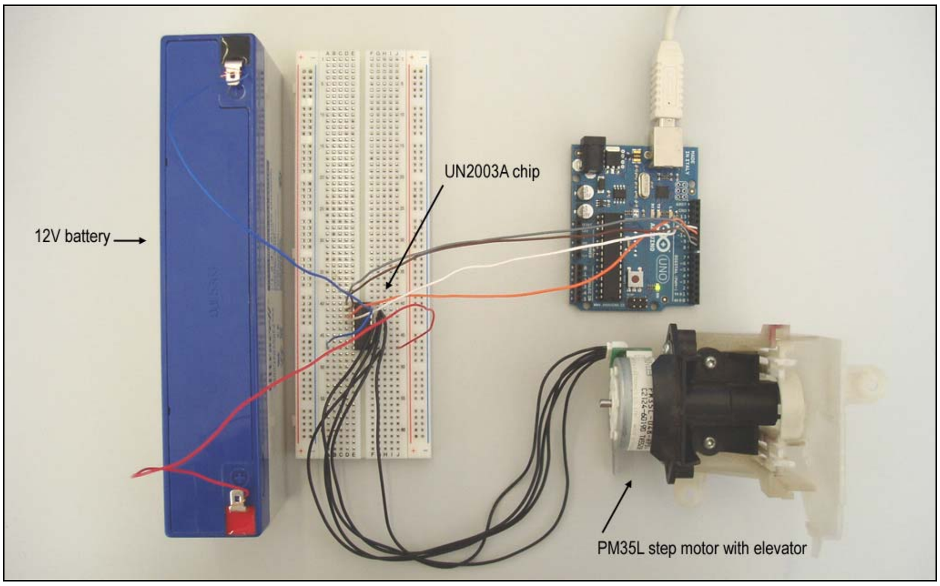

Fig.4 Use of the PM35L stepmotor and its elevator assembly. A UNL2003A chip is used to interface with the microcontroller.

DC Motor
HP uses a Mabuchi motor for the carriage drive. This is a 24V DC motor with a high initial torque (1.83 kg-cm) that rapidly moves the print cartridges during printing. In the classes, the whole cartridge assembly is used by the students to build automatic gates. This is an excellent exercise as it implies implementing timing and conditional routines in the programming.

LPT Cable
The LPT cable provides an easy method for using a computer to control electric equipment. The LPT1 port supplies a 5V current through each of the 8 wires, and this signal can be used to operate a 5V relay, such as the Finder 40.52. A simple program, such as QBasic, can turn the relay on or off through command “OUT &H378, 255”. Eight different electric devices can be controlled through this cable.

Recycling left over parts
Thanks to the dismantling, it is possible to fully separate the remaining plastic and metal parts into high purity raw material. The main categories consist of.

- Stainless steel

The most successfully recycled material is probably stainless steel, in which virgin and recycled material are almost identical. In fact in 1996, the 28 million ton. of stainless steel that were produced contained about 17 million tons of recycled material, which means that any stainless steel object has an average of 60% recycled material. Recycled stainless steel (18:8 stainless steel solids) can fetch 1.25 €/kg.

PC-GF30

- Many mechanical parts are made of fiberglass reinforce polymers, known as PC-GF30. These plastics have a Young´s moduel of 7000MPa, and a tensile strength of around 100 MPa. Regranulated reinforced polymers can easily be mixed with virgin material and are sold bulk at 2.30-3.00 USD/Kg.

CONCLUSIONS

Four years of experience have shown that the students are more than willing to take the time and dismantle electronic equipment for component recovery and as part of their learning process. From each printer the students are able to retrieve useful motors, sensors and cables worth an estimated 70€ at bulk prices. These components provided resources for creating various automation and robotics experiments at the classroom.

The students are also willing to make the extra effort to dismantle and separate the remaining components based on the material and the markings on the plastics. This has resulted in the separation of 4500 g of “pure” recycled material per printer, in addition to the useful recovered components

The experiment has also served to further awaken the environmental concern of the students, with many of them bringing their own end-of-life equipment for dismantling at the university. Others have asked advice on how to use end-of-life equipment to implement simple automation systems at their homes.

An analysis of the parts and the design of these printers reiterates the need for manufacturers to develop and design clean products with longer life-spans, that are safe and easy to repair, upgrade and recycle. In this particular case, the way the parts are intermixed, the screw types and the difficulty in accessing the inside of the printer clearly indicate a deliberate effort at discouraging repair and maintenance by the end user. This seems contradictory to the various environmentally concerned programs setup by HP to encourage end-of-life recycling. Additionally, the current policy of most printer makers to sell their printers at little more than the cost of the ink cartridges, also encourages frequent renewing of the equipment and the ensuing environmental impact.

REFERENCES

Brigden, K, Labunska, I, Santillo D, Allsopp M. 2005. Recycling of electronic wastes in China and India: workplace and environmental contamination. Greenpeace Research Laboratories. Technical Note: 09/2005

Degher A. 2002. HP´s worldwide take back and recycling programs: lessons on improving program implementation. International Symposium on Electronics and the Environment. p.224-227. 10.1109/ISEE.2002.1003270

Dillon, P. S.; Aqua, E. N. *Recycling Market Development forEngineering Thermoplastics from Used Electronic Equipment*;
Technical Report 20; Chelsea Center for Recycling and Economic Development, University of Massachusetts: Lowell, MA, 2000.

Bienvenu. J. 2011. U.S. and Worldwide production color printer 2011-2015 forcast and 2010 vender shares. IDC Doc#229205

Klatt S. 2003. Recycling personal computers, in. Computers and the environment: Understanding and Managing their Impacts. Edited by Kuehr and Williams, pp 211-229. Kluwer Academic Publishers.

Ross V., Choong H, 1996. HP Deskjet Printers with Recycled Plastics: A success story. Proceedings of the 1996 IEEE International Symposium on Electronics and the Environement. 10.1109/ISEE.1996.500396

Rios P, Stuart, JA, Grant ED. 2003. Plastics disassembly versus bulk recycling: Engineering design for end-of-life electronics resource recovery. Environ. Sci. Technol. 37. 5463-5470.
http://www.letsrecycle.com/prices