Signalling information from embedded sensors to promote lifetime extension in electrical & electronic equipment

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Abstract. The work presented in this paper proposes how life cycle data attained from embedded sensors in electronic systems can be used to potentially enhance their environmental efficiency. Signalling is a means whereby sensor information can be utilised to enhance consumer perception of the value of used equipment and therefore promote lifetime extension for these systems. This can help mitigate a large portion of the environmental impact associated with electronic system manufacture. A case study of a Personal Computer (PC) is presented together with potential signals that can ultimately serve to stimulate secondary market activity for this system.

1. Introduction
The use of embedded sensors to monitor the health of complex mechanical systems has long been recognised in established engineering disciplines. Safety-critical mechanical systems and structures such as buildings, bridges, roads, propulsion engines, military equipment, space structures, air traffic control systems, and aircraft entities have enormously benefited from embedded sensor systems developed specifically for condition monitoring and health and usage monitoring. [1-4] There have also been developments in employing embedded sensors in electronic systems for condition monitoring purposes typically to predict failure and provide warning of catastrophic failure. [5-6]

This conventional use of embedded sensor information as an indication for system maintenance plays an important role in increasing the operational availability of these systems and has undoubtedly aided in preventing costly consequences for a wide range of applications. However, for certain systems, it is a truism that life cycle data is very much underutilised. The capture and dissemination of such usage data can potentially play a significant role in increasing their environmental efficiency.

In this paper we discuss how life cycle data monitored by embedded sensors maybe used to signal quality in secondary durable markets, by enhancing consumer perception in the value of used equipment. The adoption of signalling strategies in future business models can serve to promote value recovery, reduce whole life cycle impact and ultimately realise a more sustainable life cycle for future systems.

2. Signalling in Secondary Markets
Secondary markets have long been criticised by economists with one of the main barriers being lack of credible information exchange between the buyer and the seller. Theories on these concepts
were the subject of the Nobel Prize in Economics in 2001. [7] This phenomenon, known as adverse selection, reduces the profitability of these markets with the higher quality second hand products usually being driven out of the market by substandard “lemon” equivalents, as whoever has the least information can never be confident about what is being traded. The inclusion of a signaling mechanism is one means of qualifying products merchantability and a potential solution to alleviate circumstances where sellers offer a product whose quality a buyer cannot easily evaluate. [8]

Signaling can be observed in most high end value secondary durable markets where its inclusion is an obvious means of qualifying products merchantability. The used car market has incorporated several signals, the most distinguished of these being the provision of accumulated mileage together with the full vehicle service history in second hand transactions. Standardised pricing schemes such as the widely renowned “Kelley-blue book” service helps stimulate growth in this market.” Another recognised signal is the “One Lady Owner” tag. Even the presence of a towbar can influence a potential buyer’s decision.

Signaling is not so common in lower end value durable markets and in particular used electronics markets. When dealing with secondary electronics products, many consumers perceive the quality value of a new system as far superior to that of a used equivalent. The absence of signals is clearly stifling the development of second hand markets and driving a demand for more and more new electronics systems.

When establishing signals for this market one must evaluate what consumers perceive as value. With used electronic products, reliability continues to be a key source of concern for consumer’s being the most popular pre-requisite of their satisfaction. However, accessing reliability of second hand products is becoming more and more difficult due to increased levels of integration and due to the micron and sub micron nature of their constituent assemblies [9].

This is where life cycle information accessible from embedded sensors may serve useful. It is well known that all electronic products are designed for a specific use and environment. This is mainly for warranty purposes. When products are operated outside their intended specifications unknown or unforeseen events can occur. Their usage is likely to have the largest impact on their reliability. [10] The provision of this life cycle usage information from embedded sensors to consumers can serve to increase their perception in the value of used equipment thus significantly increase secondary market activity. The following case study of a PC illustrates this concept using temperature data attained from Self Monitoring and Reporting Technology (SMART) Sensors embedded in the system processor.

3. Case Study: Personal Computer (PC)

PC manufacture has been identified as a major environmental burden when compared to other manufactured products, due to the low entropy nature of its sub assemblies [11-12]. While there have been efficiency improvements in computer manufacturing processes over the last decade, [13] the energy requirement for PC manufacture still remains large for an electronic product that typically has a 4-6 year service life. With numerous government and educational initiatives in place to bridge the digital divide, the increasing demand for new PC systems in developed as well as developing countries is inevitable. This will have considerable environmental implications. The development of business to consumer (B2C) and consumer to consumer (C2C) secondary PC markets is one means of nullifying a large portion of the manufacturing burden posed by this demand.

There have already been many recommendations in literature suggesting ways to enhance activity in secondary PC markets. [14] However, the use of signals, based on system usage to enhance activity has not yet been considered. Signalling value in this market is made even more difficult as a consequence of the recent dramatic fall in the price of new PC systems.

However the information accessible from embedded SMART sensors together with other readily available usage information can potentially change consumer attitudes towards the purchase of second hand PCs. In recent years critical computer components have been designed with built-in temperature sensors that monitor PC components as to how they are being used. The rate of hard faults occurring
in the useful life of components is tightly coupled with the increasing temperature. [15] Temperature sensors are currently embedded in all modern processors and certain high performance graphics cards. These sensors are all software visible and are accessible while the system is in operating mode. [10] The sensors themselves have been incorporated primarily as health monitors to provide feedback to users on the current operating health of their systems. The information provided by these sensors is particularly of interest to power users were “over clocking” is common practice causing their system components to run at higher temperatures than intended by the manufacturer.

4. Experiments
This section describes a continuation of previous work on data acquisition for the purpose of Usage Monitoring [10]. A Linux Operating System was used to access the software visible sensor readings from the Pentium 4 chip used in this study. Temperature readings were accessible via an IT8712F IC. This is an interface-based super I/O device with environment controller integration. A sample of experiments representing examples of common everyday user applications with their resulting temperature effects on a system have been presented in previous work. These following experiments attempt to translate temperature degradation effects into meaningful signals that consumers can understand and derive their own interpretation of quality from. 3 benchmarks were created to simulate various user profiles and are detailed in table 1. Each benchmark constitutes a mix of typical office and power user applications depending on the profile. The test time for each benchmark was 8 hours.

Table 1: Benchmarks for User Profile Classification

| User Profile     | Applications                                      | Test Duration |
|------------------|---------------------------------------------------|---------------|
| **Light User**   | Office (Open Office Writer)                       | 3 Hrs         |
|                  | Internet/Email (Firefox/Evolution)                | 3 Hrs         |
|                  | Internet/Email/MP3(Firefox/Evolution/Rhythmbox)  | 1Hr           |
|                  | Playing DVDs ( MPlayer)                           | 40mins        |
|                  | Ripping DVD (dvdrip)                              | 20mins        |
| **Intermediate User** | Office (Open Office Writer)                       | 2 Hrs         |
|                  | Internet/Email/MP3(Firefox/Evolution/Rhythmbox)  | 3 Hrs         |
|                  | Playing DVDs ( MPlayer)                           | 2Hrs 20mins   |
|                  | Ripping DVDs (dvdrip)                             | 40mins        |
| **Power User**   | Ripping DVDs (dvdrip)                             | 2 Hrs         |
|                  | Game (Astromenace)                                | 4 Hrs         |
|                  | Internet/Email/MP3(Firefox/Evolution/Rhythmbox)  | 2 Hrs         |

The use of the above benchmarks is simply to illustrate that user profiles can be placed within separate classifications. There also exists a wide range of profiles within each classification. LabView was used to collate the time series temperature data from event logs into the signals for each user profile. The sampling rate for acquisition of the temperature data was chosen at 1 minute interval for all these tests.

5. Results
Figures 1-3 represent potential signals for the 3 types of user specified. Figure 4 shows a sample of output attainable from SMART capable hard disks which also maybe utilised in signalling. This is further discussed at the end of this section.
The signals themselves are extremely intuitive. When simulating a light user session, the Pentium processor temperature resides between 40 and 45 degrees for 75% of the testing period. Operating temperature values never exceed 55 degrees when simulating this type of user. This contrasts with the gamer profile where the Pentium chip exhibits temperature values between 55 and 60 degrees for almost half of the test period. When using a simple Arhenius based rule of thumb, this margin of approximately 10 degrees between the 2 user profiles has been said to double system reliability. [16] In our example, the system used by the “Light User”, having been utilised for non taxing office applications will obviously be the most enticing to potential buyers.

Other potential signals that could be extrapolated from the temperature sensors include temperature cycle counts and ramp rates. These temperature phenomena have also been proven to significantly impact the life of electronic equipment and could potentially influence a secondary buyer’s decision. [17] The addition of an operating time variable can further distinguish between various types of user. Non-operating hardware failure rate is considered to be less probable than that of operating failure.

All current PC hard drives also incorporate SMART technology that permit the end user to determine the health of their various mechanical and electrical attributes. Predictable failures are characterized by degradation of a certain attribute over time before the disk drive fails. Mechanical failures and other certain electronic failures are considered predictable because they show a degree of degradation before failing. [18] A recent survey carried out on a large population of disk drives has confirmed that certain SMART parameters (scan errors, reallocation counts, offline reallocation counts, and probabilational counts) have a large impact on disk drive reliability. [19] SmartmonTools [20] was used to access these readings and a sample is shown in figure 4. A more user friendly representation of this data will be implemented in future work and this information can also contribute as an important signal to used PC markets. It is also important to note that a non functioning system

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**Figure 1:** Light User Profile  
**Figure 2:** Intermediate User Profile  
**Figure 3:** Power User/Gamer Profile  
**Figure 4:** SMART Output for HDD
does not mean it isn’t of value. When certain buyers with appropriate levels of expertise observe that all a PC requires is, for example—the installation of a new hard drive with the result being a perfectly functioning PC, a “value creating trade” [21] maybe accomplished. Signaling software quality to potential second hand buyers will also be an important aspect of this work. It is anticipated that logging of events such as number of crashes and maintenance procedures will be integral to addressing this issue.

6. Conclusion

A new application for life cycle data attainable from embedded sensors has been proposed. The proposed approach adopts the concept of signalling from economic market theory. The provision of life cycle data qualifying the usage of a system in its original life cycle environment can serve to raise customer confidence in the value of the used equipment and can ultimately serve to create a secondary market a for this system.

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