Draft of invited paper for Memory special issue on SenseCam

SenseCam: A wearable camera which stimulates and rehabilitates autobiographical memory

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Abstract. SenseCam is a wearable digital camera which captures an electronic record of the wearer's day. It does this by automatically recording a series of still images through its wide-angle lens, and simultaneously capturing a log of data from a number of built-in electronic sensors. Subsequently reviewing a sequence of images appears to provide a powerful autobiographical memory cue. A preliminary evaluation of SenseCam with a patient diagnosed with severe memory impairment was extremely positive; periodic review of images of events recorded by SenseCam resulted in significant recall of those events. Following this, a great deal of work has been undertaken to explore this phenomenon and there are early indications that SenseCam technology may be beneficial to a variety of patients with physical and mental health problems and is valuable as a tool for investigating normal memory through behavioural and neuroimaging means. Elsewhere, it is becoming clear that judicious use of SenseCam could significantly impact the study of human behaviour. Meanwhile, research and development of the technology itself continues with the aim of providing robust hardware and software tools to meet the needs of clinicians, patients, carers and researchers. In this paper we describe the history of SenseCam, the design and operation of the SenseCam device and the associated viewing software, and we overview some of the ongoing research questions being addressed with the help of SenseCam.

1 An Introduction to SenseCam

SenseCam is a small digital camera designed to take photographs automatically, without user intervention, whilst it is being worn [1, 2]. Unlike a regular digital camera or a cameraphone, it does not have a viewfinder or a display that can be used to frame photos. Instead, it is fitted with a wide-angle (fish-eye) lens that maximizes its field-of-view. This means that nearly everything in view of the wearer is captured by the camera. See Figures 1 and 2.

A number of electronic sensors are built into SenseCam. These sensors are monitored by the camera's microprocessor, and changes in sensor readings can be used to automatically trigger a photograph to be taken. For example, a significant change in light level or the detection of a person in front of the camera can be used as triggers. In addition, by default an internal timer is used to automatically trigger a photograph every 30 seconds. SenseCam also has a manual trigger button that lets the wearer take pictures in the more traditional fashion, a privacy button which causes the camera to stop taking photos for four minutes at a time, and an on-off button. Three LED lights and an internal sounder are used to give the wearer feedback.

Fig. 1. The SenseCam shown close-up and as typically worn, using an adjustable lanyard. The two side buttons are visible on the left, and there is an additional on-off button on the top of the device. There are three LED lights to indicate various aspects of operation.

Fig. 2. Example images captured by SenseCam.

The device is called SenseCam because two of the main components of its operation are sensing the environment and using its camera to record images; ‘Cam’ is also significant because the camera was conceived and realised in Cambridge, UK. The images captured and stored by SenseCam during the course of an event may subsequently be uploaded onto a desktop or laptop computer via a USB connection. A custom SenseCam Image Importer application facilitates the transfer of images in this way. The images can then be viewed either one-by-one or in an animated sequence using a SenseCam Image Viewer application. This animation technique is rather like watching a movie of the event, but because the sequence of images can be displayed much more rapidly than they were captured, it's far quicker and easier than reviewing a video of the day.

2 A Brief History of the SenseCam Project

The SenseCam device has undergone a number of iterations since its inception in 2003. The original motivation for SenseCam was the idea of a "human black box recorder" [3] – like the devices used in aeroplanes and some cars which continually record information from a variety of sensors in case it is useful subsequently. In 2003 such a notion was becoming a practical possibility for the first time, as the cost, size and power consumption of the relevant electronic components continued to reduce, and the first SenseCam prototype incorporating a digital camera along with various other electronic sensors was made viable.
On a visit to Microsoft Research Cambridge towards the end of 2003, Narinder Kapur, Consultant Clinical Neuropsychologist at Addenbrooke's Hospital in Cambridge was shown a SenseCam prototype and he saw its potential to alleviate severe memory impairment in his patients. The following year Microsoft Research and Addenbrooke's Hospital initiated a clinical trial of SenseCam with a patient with severe memory impairment following a brain infection, who we refer to as Mrs B [4, 1]. This trial lasted many months, and as it went on it became increasingly clear that the use of SenseCam to capture digital images of events, coupled with the subsequent periodic review of these images, had a powerful effect on Mrs B's ability to recall the same events. It appeared that Mrs B had true autobiographical recollection of events that had occurred weeks and months earlier. She described thoughts, feelings and happenings that were not depicted in the images themselves. What's more, even when the images were taken away from Mrs B so that she was unable to view them, she was still able to describe the events many months later. Therefore SenseCam images may provide such a powerful cue that reviewing them is sufficient to reinforce consolidation of the episode into a retrievable long term memory store. By contrast, a written diary does not appear to provide powerful enough cues to overcome the hippocampal deficit (5).

On the basis of this preliminary clinical data from the Mrs B trial, in 2005 Microsoft Research started to design a more refined SenseCam prototype known as the v2.3 device [1] and described in detail in Section 4. The v2.3 SenseCam research prototype enabled further trials in Cambridge to be started and was also made available to the research community thereby seeding a network of collaborations across the world [6]. In the years that followed, Microsoft Research continued to produce SenseCam devices to the same v2.3 research prototype design and disseminated around 300 of these to researchers and clinicians interested both in the technology itself and in a wide range of potential applications. Microsoft Research was also able to fund a number of collaborative projects in two tranches, firstly in 2005 and then another in 2007. An annual meeting for those working with SenseCam was initiated to facilitate the sharing of ideas, experiences and results. The first of these, held in the summer of 2007, was quite small, but by 2009 the "Annual SenseCam Symposium" was attracting an international attendance. The ever-growing interest in SenseCam in an increasing number of application areas has also enabled the commercialisation of SenseCam. The first product, the Vicon Revue [7], is based on the v2.3 SenseCam research prototype. A brief history of SenseCam can be found in Table 1.

2003	SenseCam was born. The notion of a 'black box' accident recorder motivated the first prototype. Addenbrooke's Hospital expresses interest.
2004	Initiation of trial with first amnesia patient, Mrs B.
2005	Initial results from Mrs B are very encouraging. New v2.3 SenseCam hardware developed. Microsoft Research initiates collaborations with academia.
2006	Interest grows as the Mrs B trial becomes more widely known. Trials with Alzheimer's patients initiated in Cambridge.
2007	Several more collaborations between Microsoft Research and academics and clinicians initiated. First meeting of SenseCam collaborators in Cambridge, UK.
2008	Second SenseCam collaborators meeting, again in Cambridge, UK.
2009	First annual "SenseCam Symposium" in Chicago, US attracts an international audience. Vicon announce commercial version of SenseCam, the Vicon Revue.
2010	Vicon Revue becomes available. Over 50 research institutions and labs worldwide are using SenseCam in their research.

Table 1. A brief history of SenseCam.

3 The SenseCam Device

3.1 SenseCam design requirements

Experience with early prototypes showed that the form factor of SenseCam – its size and shape – is important. It must be convenient to put on and take off, and reasonably small and light so that it is comfortable whilst being worn. In work to date, users have almost exclusively worn the camera on a lanyard around their neck, which appears to meet these two criteria for most people, most types of clothing, and in most conditions. Our experience shows that ideally the camera should be worn reasonably high-up as this reduces unwanted movement and is closer to the eye-line.

In addition to the form factor of the device, other important practical issues include battery lifetime, storage capacity and ease of use. It was critical that the device could operate for an entire day (i.e. around 12 hours of continuous operation), and ideally for two to three days in case the patient forgets to recharge it or does not have a charger with them. A related requirement is enough storage for at least one day's worth of data, and ideally in excess of one week. With enough on-board storage, it is possible to travel without needing a computer to upload the images to every evening.

3.2 SenseCam electronics

The 'brain' of the SenseCam is an embedded microcontroller which communicates with and controls a number of external sensors. The images and sensor data are stored on a standard 1GB SD card. Unlike most consumer digital cameras, the SD is not designed to be removed by the user – it is hidden within the device. Instead, a USB connection is used to copy data from the camera. The 0.3 megapixel (VGA resolution) images recorded by SenseCam are stored as compressed JPEG files on the internal SD memory card. The typical image size (around 30k bytes) allows for around 30 thousand images to be stored on a 1GB SD card. Although digital stills cameras with very much higher resolutions are commonplace today, at the time the v2.3 SenseCam was designed it was much easier to use a lower resolution off-the-shelf image capture module. The low resolution also has the side-effect of requiring less power when storing images.

In addition to image data, the memory card is used to store a log file which records the data from the sensors every few seconds. The log file also records the reason for taking each photograph (e.g. manual shutter press, timed capture or significant change in sensor readings, see Section 3.3). The SenseCam has a built-in real-time clock that ensures the timestamps of all files on the storage card are accurate.

The main components in SenseCam are listed in Table 2, along with a summary of their technical specifications. Figure 3 depicts the front and the back of the SenseCam circuit board and the main hardware components.

Component	Specification
Flash memory	Standard SD card up to 2GB.
Camera module and wide-angle lens	VGA (640x480 pixel) resolution with 119º diagonal wide-angle lens.
Accelerometer	Tri-axis, range ±2g.
Temperature	Range -55 to +125ºC, ±2ºC.
Light level	Independent measurement of red, green and blue intensity.
Passive infrared (PIR) body heat detector	Miniature form factor, low power operation, wide-angle detection.
Push buttons	Three in total, configurable operation.
Sounder/buzzer	Simple tones for feedback to wearer.

Table 2. The main components in SenseCam in addition to the microcontroller, with a summary of their specification.

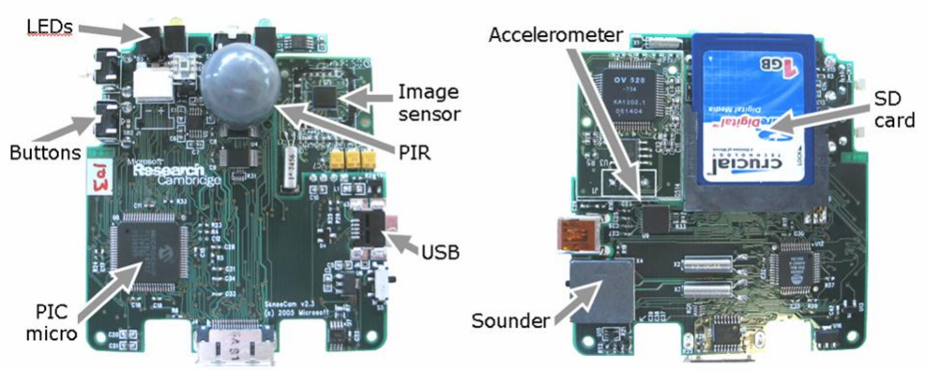

Fig. 3. The front (left) and back (right) of the SenseCam circuit board.

SenseCam is powered from a 980mAh 3.7V lithium-ion rechargeable battery, a similar size and capacity to those commonly used in mobile phones. This battery is recharged from a PC or from a mains power adapter over the USB connection, typically taking around three hours from 'flat' to 'fully charged'. The battery lifetime of SenseCam depends on how frequently images are taken; the most power is consumed by capturing images and saving them to memory. The graph in Figure 4 shows that capturing images at the maximum rate of one approximately every 5 seconds can yield a battery life just below 12 hours. Typically SenseCam captures images every 30 seconds or so, giving a battery life close to 24 hours of continuous operation. SenseCam will maintain its real-time clock for up to nine months without use.

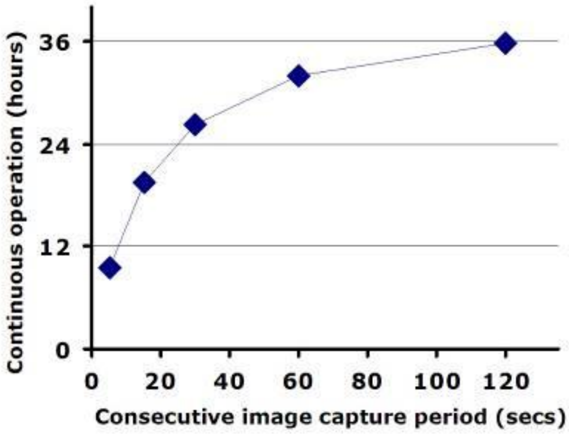

Fig. 4. Graph showing how battery life is affected by frequency of image capture. Note that this data was collected from a SenseCam which had the latest, lowest-power version of the camera module fitted; some SenseCam devices have earlier versions which seem to be more power hungry. Battery capacity and hence battery lifetime will also decrease as the battery ages.

3.3 SenseCam operation

The SenseCam device uses a very simple algorithm to trigger its camera: a photo will be taken every 30 seconds by default (this interval is configurable), and an extra photo will be taken every time the ambient light level changes significantly. In addition, if the camera is stationary and the passive infra red (PIR) sensor detects a person passing in front of the camera, a photo will be taken. Finally, an image may be captured manually at any time by pressing the 'shutter' button on the device. In the case of manual capture SenseCam makes an audible 'beep' to indicate that a photo has been successfully taken, but in all other cases it is silent in operation. A yellow light on the top of the device illuminates whenever a photo is being recorded.

It is also possible to temporarily stop taking pictures for a period of about four minutes by pressing the 'privacy' button. When this button has been pressed, a red light comes on and the camera suspends operation; a beep sounds 15 seconds before the camera automatically starts taking pictures again. In order to extend the pause for another four minutes, the privacy button can be pressed again. On the other hand, pressing the manual shutter button at any time when the camera is suspended will cause the camera to resume taking photographs.

The aim of SenseCam is to capture enough images to record the significant elements of an event, without capturing an excessive number. In theory, it would be possible for SenseCam to simply capture images as quickly as possible and then to select the best ones from these at a later time. However, there are a number of disadvantages to this approach: it would use significantly more power and memory, and would place an onus on the wearer or researcher to look through a great many more images than would otherwise be the case. Also, a device that captures snapshots every 30 seconds may arouse less concern than a device that captures images much more frequently.

The sensors can be individually enabled or disabled through the use of a configuration file on the SD memory card. It is also possible to configure many other aspects of the SenseCam device operation, such as what effect each push button has and how frequently photos are captured by default. Not only does this configurability aid testing and development, but it enables researchers, clinicians and patients to tune device operation for specific needs.

3.4. SenseCam software

Whilst the SenseCam device provides a convenient way of recording images and sensor data relating to an event, it provides no way of reviewing or analyzing this information and only provides a relatively limited storage capacity (suitable for a few weeks of daily use). These limitations are overcome by connecting SenseCam to a computer via a USB cable. The images can be viewed on a PC-based SenseCam Image Viewer application we have developed that displays individual images and also replays image sequences and displays sensor data captured by the device. Figure 5 gives an example screenshot of the version of the Viewer application which has been used most extensively in clinical trials to date.

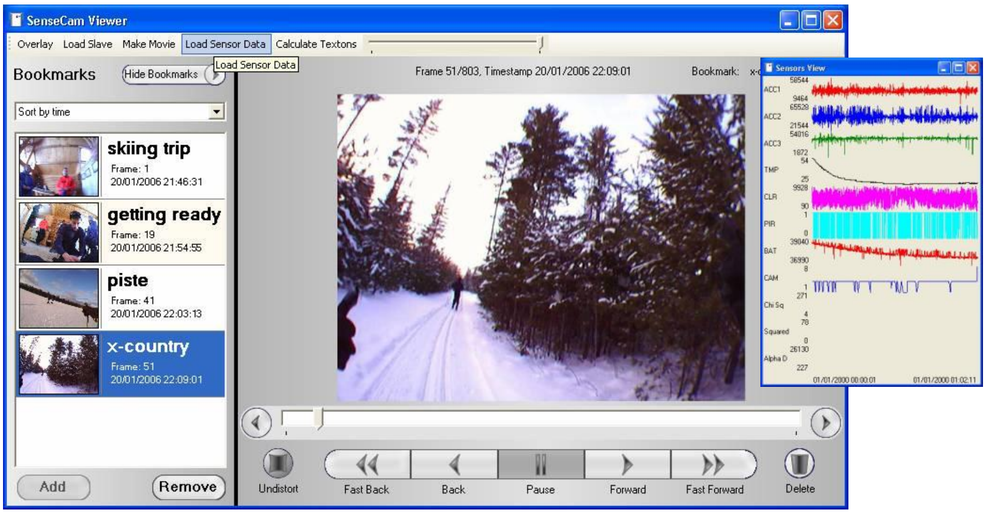

Fig. 5. The SenseCam Image Viewer application, allowing playback and review of SenseCam images and (inset) associated sensor readings.

The basis of the SenseCam Image Viewer, which is designed to be straightforward for people with no experience of computers to use, is a window in which images are displayed and a simple VCR-type control which allows an image sequence to be played slowly (around two images/second), quickly (around twelve images/second), re-wound and paused. The animated sequence of images displayed in the ‘quick’ mode creates a kind of ‘flip-book’ movie effect and has been referred to previously as rapid-serial-visual presentation (RSVP) [8]. It turns out to be a quick but very effective way of reviewing a large number of images captured from the first person perspective.

The viewer allows the user to delete images and to correct for the 'fish-eye' lens effect. With long sequences of images, it can be useful to associate named 'bookmarks' with individual images or sequences. Once created, bookmarks can be used to help navigate a long image sequence – clicking on the thumbnail of a bookmark automatically advances or rewinds to that particular image in the sequence.

There are several viewer options. It is possible to display an analogue clock to indicate at what time of day the image displayed was originally taken and to load and display the raw sensor data associated with an image sequence – an example of this is shown inset in Figure 5.

4 The future of SenseCam Technology

4.1 The Camera

Although the device has proven to be well-suited for research into a wide range of applications, there are many ways in which SenseCam could be improved.

One of the most visible improvements which could be made to the SenseCam would be a size reduction. Given the improvements in electronic device technology over the five years since the original design, this is a very realistic proposition. The SenseCam research prototype includes an expansion port which exposes various electrical signals to allow additional sensors to be connected, and the firmware to be modified. To date, two external sensors have been prototyped: an external image sensor and a digital compass. The external image sensor connects to the SenseCam via a flying lead and can be used in place of the built-in camera – so that the SenseCam unit itself can be worn inside a pocket for example, to protect it from rain. Alternatively, the external camera may be used as a second image capture device, to generate a larger field of view. The design of a plug-in digital compass was motivated by the observation that it's beneficial to capture as many images as possible. If a wearer turns to face a new direction resulting in a new vista for themselves and the SenseCam, this is readily sensed by the compass since the SenseCam will rotate too [9].

Many other sensors are natural choices for integration with SenseCam. One example is a GPS location tracker, which would allow the SenseCam to record its location when worn and 'geo-tag' captured images accordingly. Another idea is to record physiological data from the wearer, such as heart rate and galvanic skin response. Although we have used separate, standalone GPS and physiological data loggers in conjunction with SenseCam, and synchronized the time-stamped data subsequently, we have not designed a more integrated hardware solution. It is possible that future commercially available incarnations of SenseCam will do this.

4.2 Companion devices

SenseCam is designed to be small, low powered and unobtrusive in use, and therefore does not include any kind of display for reviewing captured images or sensor data. However, it would be useful to review images without the need for a PC and one can imagine a purpose-built plug-in companion device to do this. It would also be possible to build an interface into SenseCam for transferring images to a mobile phone, either via a cable or wirelessly via Bluetooth, so that a simple image viewer application on the phone could be used. Finally, another idea which has been suggested is a dedicated SenseCam "docking station" which makes the uploading of SenseCam data and recharging of the device even easier than it is using a USB connection to a computer. Whilst we have no concrete plans for such devices, we see no technical impediment to building them given suitable demand.

5 SenseCam Research: Memory and Beyond

5.1 Why are SenseCam images such a powerful cue for recall?

We do not yet know why SenseCam images cue recall of events so powerfully. Anecdotally, both healthy users and memory impaired patients have experienced so-called 'Proustian' moments of recall when viewing SenseCam images of personally experienced events. Particular images often trigger an autobiographical recollection, where the thoughts, feelings and emotions at the time the event was experienced come 'flooding back'. Researchers experimenting with SenseCam themselves, healthy people and memory impaired patients have consistently reported this effect; they state that something in the image – often the apparently mundane or trivial – triggers a memory for a private thought or feeling they had at the time, and this seems to enable access to the rest of the memory for the event. We therefore propose that one of the secrets of SenseCam is quite simple – it takes hundreds of images and at least one of these images is likely to have captured a moment when encoding of a memory took place. When the patient subsequently views that image, taken from their viewpoint at the time of encoding, recall of the event is triggered. This has important implications for rehabilitation because it suggests that in order for the patient to gain maximum benefit from the device, he or she should have the opportunity to view all of their images. Figure 6 shows some example images which have triggered recall in patients the authors have worked with; on the face of them, none of these images are obvious candidates for cueing detailed and vivid recall.

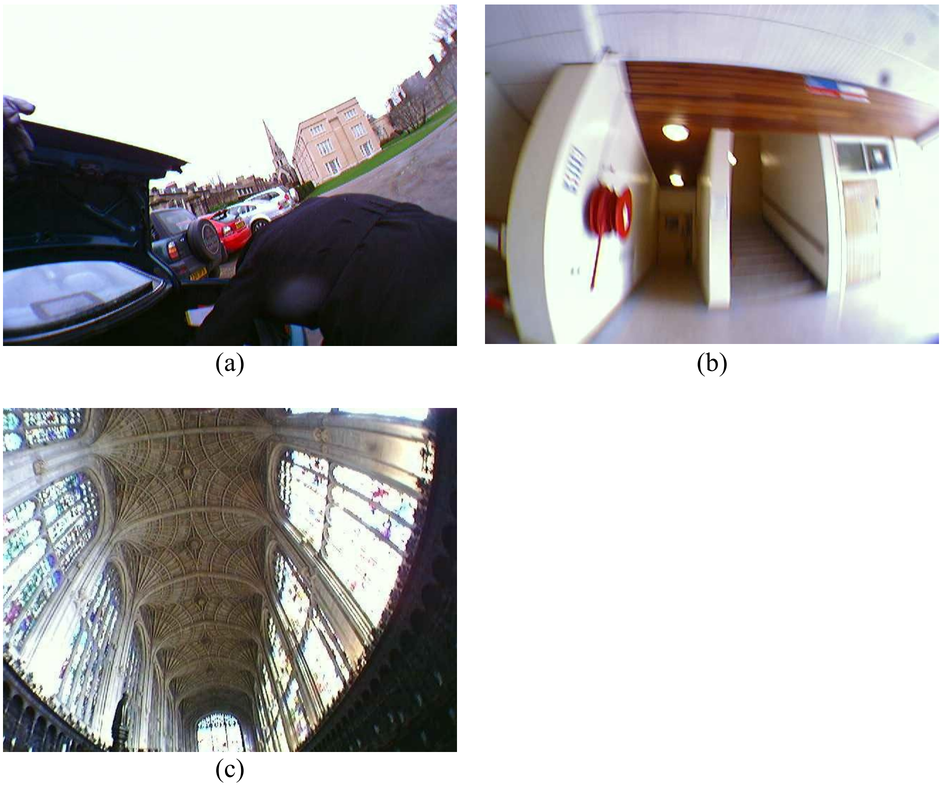

Fig 6. Example SenseCam images that led to autobiographical recall in different patients. (a) The mix of new, pale stonework and old, dirty stonework in the set of buildings in the background led a patient with moderate Alzheimer's disease to ponder the incongruence; a private thought at the time which she subsequently recalled. (b) Despite the extremely low image quality, a TBI patient remembered having to go up a flight of stairs to use the lavatory, and this triggered recall of subsequent events. (c). An image of the vaulted roof in King's College chapel, Cambridge. On viewing this image a patient with Alzheimer's disease remembered what he had thought at the time he was there: "This should be one of the Seven Wonders of the World!"

Another theory why SenseCam images so powerfully cue recall is that the sequences closely resemble normal autobiographical memories (10, 11). Properties of SenseCam images that may be similar to episodic memory images are that they represent short time slices of experience, they are temporally ordered, they are visual, but samples rather than continuous, they are not taken intentionally (i.e. they are formed outside awareness), they have a field or viewer's perspective, and they are triggered by sensory changes that may correspond to event boundaries. That is, episodic memories may be formed at goal junctions of action sequences when there is major change in the predominating goal. It is possible therefore that the detection of changes in the wearer's activity and in their environment through onboard sensors could cause the SenseCam to trigger at junctions of goal processing. For these reasons it could well be possible that SenseCam produces images that are close in nature to visual autobiographical memories. This quality of the images along with the frequency of image capture may combine to provide a strong stimulus for recall.

Not only does the review of SenseCam images seem to cue recall more effectively than other approaches, such as the review of a written diary, but it also appears to be more enjoyable for the subject. Both anecdotal feedback and more formal assessment indicate that patients feel more confident, less stressed and more able to cope with their impairment when using SenseCam compared to keeping and reviewing a written diary or using no intervention at all [4].

5.2 Neurological implications of SenseCam image review

Since the initial study with Mrs B was undertaken [3, 1] we have carried out a functional magnetic resonance imaging (fMRI) study which shows that when Mrs B views SenseCam images she has recently reviewed it causes activation in parts of her brain associated with normal autobiographical remembering [5]. Other authors have found similar results with memory impaired patients [Ref from Martin - 12]. Moreover there is evidence that the hippocampus activates in healthy controls when they are either viewing SenseCam images or when they are remembering events that they have rehearsed with SenseCam (13).

A tentative hypothesis arising from these studies is that if it is true that SenseCam causes increased activation of regions of the brain associated with autobiographical memory, then stimulating these brain regions through the use of SenseCam may lead to improved memory and cognition more generally in healthy and impaired populations. This hypothesis has yet to be empirically tested but is nevertheless an exciting possibility. The evidence from these studies and others also suggests that SenseCam may be valuable as a tool for investigating normal memory through behavioural and neuroimaging means.

5.3 Combining SenseCam images with physiological data

Some of our collaborators have investigated the use of physiological measures in conjunction with SenseCam images [14]. In the clinical setting, doing so can enhance the ability of brain-injured patients to develop awareness of, and therefore improve, emotional regulation. Improvement in emotional regulation is especially important to participation in everyday life after a brain injury; it may facilitate the return to social and professional activities thereby reducing the likelihood of contact with mental health services and the criminal justice system.

Work to date has focused on collaboratively reviewing SenseCam image sequences and related biometric information with the patient, and identifying emotional trigger situations. However, practical difficulties such as a lack of clinician time and the technical challenges of combining images and sensor data have made it difficult to develop these potential applications further. We hypothesise that the development of a robust, easy to use software application that combines SenseCam images with physiological markers such as heart-rate, galvanic-skin response and skin temperature data will allow clinicians and researchers to quickly identify in a valid and reliable way the triggers or events that lead to emotional arousal.

Moreover, it has been suggested that combining SenseCam imagery with physiological measures could be used within standard cognitive behavioural therapy settings to treat a range of psychological disorders such as depression, anxiety and psychosis. For example, SenseCam images might help in the treatment of depressed patients, by enhancing therapeutic interventions which aim to alter negative bias by helping subjects to remember and elaborate positive events.

5.4 Exploiting SenseCam image content

The SenseCam Image Importer and Viewer software (described in Section 3.4 above) provides the basic image-handling functionality required for much of the current clinical work. However, there is also research underway using more sophisticated image processing techniques to expand and improve the range of research applications of SenseCam.

One of our collaborators has worn a SenseCam every day since June 2006, amassing in excess of 5 million images in that time [15]. These images have been used as part of an even larger data set for developing and testing algorithms that allow image content to be categorized automatically, thereby inferring the activity of the wearer [16, 17]. Examples of activities that may be established in this way include socialising, eating (and what types of food), travel behaviours, the environments that people experience (urban or rural), whether they are working at a desk or computer and the movement of the user (whether they are walking, standing or sitting). The combination of SenseCam as an automatic data collection tool which requires no conscious input from the wearer, with the subsequent automatic analysis of the images, provides a light-weight, continuous way of collecting data relating to many aspects of daily life. The applications to outcome measurements in medical and other settings are potentially numerous.

Work has also been carried out to explore ways of automatically detecting unusual and pertinent images from large data sets [18]. Given people's natural tendency to forget the routine or mundane, a way of detecting images which fall broadly into that category is likely to be valuable, whether it's used to hide those images (since they may be less relevant to the user) or to promote them (since they are less likely to be memorable). The categorization and prioritization of recorded images can be used to alter the way in which images and sequences are presented to the user [19], an area of research which will become increasingly important as the size of SenseCam images collections continues to grow. A final area of research highlighted here is work which uses information relating to the names of geographical places and iconic landmarks gathered from the Internet to provide additional context when viewing SenseCam image sequences [20].

5.5 Further applications

In addition to its value as a memory aid, many other applications have been proposed for SenseCam technology. The authors have noted that experience with SenseCam in one domain has a tendency to generate enthusiasm for its application in many others. For example, there is interest in using SenseCam as a tool to assist in the assessment of physical and mental health problems such as autism, learning disabilities and neurological conditions. Examples include assessing how much physical activity a patient undertakes or monitoring the number of face-to-face interactions a patient has in a typical week. This type of assessment can be continued for months or even years after an intervention to determine long-term outcomes.

Monitoring travel behavior and exercise with SenseCam is also likely to be beneficial in programmes designed to improve fitness and/or reduce the weight of patients. Using standard techniques such as questionnaires, accurately monitoring the extent and nature of exercise that people partake in throughout the day is difficult. SenseCam provides a way to unobtrusively monitor daily activities [21], and ultimately the computer vision and machine learning techniques outlined in Section 5.4 may be able to categorise these automatically. A related use of SenseCam is monitoring the type, amount and frequency of food, drink or medication intake. SenseCam provides ground truth data which is otherwise difficult to obtain, and in the longer term we hope that manual analysis of the data will be replaced by automated image analysis techniques.

SenseCam may be useful in emergency settings. It has been suggested that this approach could be useful in a variety of scenarios, including use by the ambulance service for correlating the speed and nature of treatment at the scene of a road traffic accident with long-term patient outcome, and deployment in natural disaster situations such as the recent earthquake in Haiti where SenseCam was trialed during a search and rescue mission. Law enforcement, military and security organisations have suggested that SenseCam might be useful both as a tool for documenting situations in the field and as a way of eliciting vivid recall by personnel during subsequent debriefing.

SenseCam has been used in innovative ways to get a first-hand account of the lives of certain groups of people for whom this would otherwise be difficult. For example research is underway in which children with autism and people with learning disabilities wear the device during the course of a day. The images are reviewed by their carers to better understand how they experience daily life [22, 23]. Similar research has been suggested for other situations, for example as a way to understand how both doctors and patients experience their time in Accident and Emergency.

Researchers have used SenseCam as a tool for ethnography since it provides a way of unobtrusively recording behavior both of the wearer and people the wearer interacts with [24]. In education settings SenseCam provides a way for teachers to enhance the reflective practice techniques sometimes used during on-the-job development [25]. Research into the obvious questions surrounding the privacy implications of SenseCam and other recording devices has also been published [26].

Finally, since its inception SenseCam technology has been associated with the burgeoning field of life-logging, first mooted over 60 years ago [27] and now a practical possibility [28]. The prime tenet of life-logging is that advances in technology will allow us to record every aspect of our daily lives and the minutiae of our interactions with others, and that this will greatly improve our lives by freeing us from the constraints and fallibilities of human memory. But there is also considerable skepticism about the feasibility of this ideal and about its desirability [29]. Our research both informs and sidesteps this debate by demonstrating clear value of a specific life-logging technology to a number of important applications.

5.6 Remaining questions

Despite the wide range of research already undertaken, there are still a great many outstanding questions about SenseCam and its role in cognition. These include: 'How often and at what interval are patients required to view images in order for the memories to become consolidated?', 'Is mass practice as effective as spaced rehearsal?', 'For how long are memories retained?', 'How do different classes of patient or injury respond differently to the images, or is the effect highly heterogeneous, even amongst patient types?', 'What is the importance of first-person image capture?', 'Do only 'important' images need to be viewed or is it necessary that these images are contained within their temporally ordered sequence?', 'Does audio or annotation improve memory recall and retention?', 'What is the effect of improved autobiographical recollection on a patient's well-being?', 'Can SenseCam be used effectively to improve semantic memory, prospective memory or executive functioning?' and 'Are the sensors important and if so, how and why?'

Work with SenseCam in research laboratories and clinics around the world is beginning to address many of these questions, and we encourage people to participate in the SenseCam research community, both online [30] and via the Annual SenseCam Symposium.

7 Conclusions

SenseCam is a small digital camera designed to take photographs regularly and passively without user intervention, whilst being worn. The photos can subsequently be uploaded via USB onto a PC and viewed using a simple interface. Preliminary research indicates that SenseCam aids the recall of episodic memories in patients with severe memory impairment and that early repeated viewing of SenseCam images may reinforce consolidation of the episode into a long term memory store. Neuroimaging studies indicate that viewing SenseCam images of personally experienced events activates parts of the brain involved in normal autobiographical memory in both healthy and impaired populations.

It appears that SenseCam is particularly suited to people with memory or cognitive impairment because it captures images autonomously, enabling patients to record their experiences without conscious thought, meaning that the wearer can truly participate in an event without having to pause to capture the moment. SenseCam also appears to be less burdensome than the use of a regular camera or written diary.

A great many research questions remain. We do not yet know why SenseCam is such a powerful memory aid: it may be that the sheer volume of images means that even in severely impaired patients one of the images is bound to cue recall, or that the first-person viewpoint of the images stimulates recollection because they are similar to normal episodic memory.

New research in the computer science domain applies computer vision techniques to the content of the images, thereby enabling the activity of the wearer to be inferred. Work to automatically label, segment and present pertinent images and image sequences is also underway and is likely to enable numerous additional applications for SenseCam in both clinical and non-clinical areas. Worldwide, research continues into the potential of this simple yet intriguing device.

References

1. Hodges, S., Williams, L., Berry, E., Izadi, S., Srinivasan, J., Butler, A., Smyth, G., Kapur, N., and Wood, K. (2006). SenseCam: a Retrospective Memory Aid. In Dourish and A. Friday (Eds.): Ubicomp 2006, LNCS 4206, pp. 177 – 193,
2. Microsoft Research SenseCam website, http://research.microsoft.com/sensecam
3. Wood, K., Fleck, R., Williams, L. Playing with SenseCam, UbiComp, 2004.
4. Berry, E., Kapur, N., Williams, L., Hodges, S., Watson, P., Smyth, G., Srinivasan, J., Smith, R., Wilson, B. and Wood, K. The use of a wearable camera, SenseCam, as a pictorial diary to improve autobiographical memory in a patient with limbic encephalitis. Special issue of Neuropsychological Rehabilitation 2007, 17 (4/5), 582-681, "Encephalitis: Assessment and Rehabilitation Across the Lifespan". ISBN: 978-1-84169-836-6.
5. Berry, E., Hampshire, A, Rowe, J., Hodges, S., Kapur, N., Watson, P., Browne, G., Smyth, G., Wood, K. and Owen, A. The neural basis of effective memory therapy in a patient with limbic encephalitis. Journal of Neurology, Neurosurgery, and Psychiatry with Practical Neurology, 2009.
6. Laursen, L. (2009). A Memorable Device. Science, 323, 13th March 2009.
7. Vicon Revue website, http://viconrevue.com

8. Spence, R (2001). Rapid, serial and visual: A presentation technique with potential. Information Visualisation (pp. 13 – 19). Harlow, UK: Addison Wesley.
9. Ignas Budvytis, James Scott and Alex Butler. Compass-Based Automatic Picture Taking using SenseCam. In Adjunct Proceedings of Pervasive 2008, Sydney, Australia, May 2008.
10. Conway, M.A.: Memory and the self. Journal of Memory and Language, 53: 594-628 (2005).
11. Brewer, W. F. (1986). What is autobiographical memory? In D. Rubin (Ed.), Autobiographical Memory (pp. 25-49). Cambridge: Cambridge University Press.
12. fMRI with Claire from Martin/Catherine
13. St. Jacques PL, Conway MA, Lowder M, Cabeza R. Watching My Mind Unfold vs. Yours: An fMRI Study Using a Novel Camera Technology to Examine Neural Differences in Self-Projection of Self vs. Other Perspectives. In Press, Journal of Cognitive Neuroscience.
14. Brindley et al. this issue
15. Doherty A, Pauly-Takacs K, Gurrin C, Moulin C and Smeaton A.F., Three Years of SenseCam Images - Observations on Cued Recall. Invited speech at: SenseCam 2009 Symposium at the 39th Annual Meeting of the Society for Neuroscience: Neuroscience 2009, Chicago, USA, 16-17 October 2009.
16. Byrne D, Doherty A.R., Snoek C.G.M., Jones G.F., and Smeaton A.F. Validating the Detection of Everyday Concepts in Visual Lifelogs. SAMT 2008 – 3rd International Conference on Semantic and Digital Media Technologies, Koblenz, Germany, 3-5 December 2008.
17. Doherty A.R, Ó Conaire C, Blighe M, Smeaton A.F, and O'Connor N. Combining Image Descriptors to
18. Effectively Retrieve Events from Visual Lifelogs. MIR 2008 – ACM International Conference on Multimedia Information Retrieval, Vancouver, Canada, 30-31 October 2008.
19. Doherty, Aiden R. (2009) Providing effective memory retrieval cues through automatic structuring and augmentation of a lifelog of images. PhD thesis, Dublin City University.
20. Lee H, Smeaton A.F, O'Connor N, Jones G, Blighe M, Byrne D, Doherty A.R, & Gurrin G. (2008). Constructing a SenseCam Visual Diary as a Media Process. Multimedia Systems Journal, Special Issue on Canonical Processes of Media Production, Vol. 14, No. 6, 2008 pp341-349
21. Kelly, P and Foster, C. A new technology for measuring our journeys: Results from a pilot study. Early Career Investigator Prize. 2010 Annual Conference of the International Society of Behavioral Nutrition and Physical Acitivity, Minneapolis, 9-12 June, 2010.
22. Gabi Marcu – emailed for reference.
23. Buchanan, M, Frith, H and Conboyhill, S. Towards utilizing SenseCam and positive psychology to increase subjective wellbeing in adults with learning disabilities. SenseCam 2009 Symposium at the 39th Annual Meeting of the Society for Neuroscience: Neuroscience 2009, Chicago, USA, 16-17 October 2009.

24. Byrne D, Doherty A, Smeaton A.F, Jones G, Kumpulainen S and Jarvelin K. (2008). The SenseCam as a Tool for Task Observation. HCI 2008 - 22nd BCS HCI Group Conference, Liverpool, U.K., 1-5 September 2008.
25. Fleck, R & Fitzpatrick, G., (2006). Supporting reflection with passive image capture. Supplementary proceedings of COOP'06, Carry-le-Rouet, France. pp.41-48.
26. Nguyen, D.H., Marcu, G., Hayes, G.R., Truong, K.N., Scott, J., Langheinrich, M., Roduner, C. Encountering SenseCam: Personal Recording Technologies in Everyday Life. In the Proceedings of UBICOMP 2009: The 11th International Conference on Ubiquitous Computing (September 30-October 3, 2009, Orlando, FL), 2009.
27. Bush, V. As We May Think, Life Magazine, September 1945.
28. Bell, G. and Gemmell, J. A Digital Life, Scientific American, March 2007.
29. Viktor Mayer-Schönberger - Delete: The Virtue of Forgetting in the Digital Age. Princeton, NJ: Princeton University Press, 2009. 199 pp. (ISBN 978-0-691-13861-9).
30. SenseCam wiki, http://www.clarity-centre.org/sensecamwiki/