Review

Technologies That Assess the Location of Physical Activity and Sedentary Behavior: A Systematic Review

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Abstract

Background: The location in which physical activity and sedentary behavior are performed can provide valuable behavioral information, both in isolation and synergistically with other areas of physical activity and sedentary behavior research. Global positioning systems (GPS) have been used in physical activity research to identify outdoor location; however, while GPS can receive signals in certain indoor environments, it is not able to provide room- or subroom-level location. On average, adults spend a high proportion of their time indoors. A measure of indoor location would, therefore, provide valuable behavioral information.

Objective: This systematic review sought to identify and critique technology which has been or could be used to assess the location of physical activity and sedentary behavior.

Methods: To identify published research papers, four electronic databases were searched using key terms built around behavior, technology, and location. To be eligible for inclusion, papers were required to be published in English and describe a wearable or portable technology or device capable of measuring location. Searches were performed up to February 4, 2015. This was supplemented by backward and forward reference searching. In an attempt to include novel devices which may not yet have made their way into the published research, searches were also performed using three Internet search engines. Specialized software was used to download search results and thus mitigate the potential pitfalls of changing search algorithms.

Results: A total of 188 research papers met the inclusion criteria. Global positioning systems were the most widely used location technology in the published research, followed by wearable cameras, and radio-frequency identification. Internet search engines identified 81 global positioning systems, 35 real-time locating systems, and 21 wearable cameras. Real-time locating systems determine the indoor location of a wearable tag via the known location of reference nodes. Although the type of reference node and location determination method varies between manufacturers, Wi-Fi appears to be the most popular method.

Conclusions: The addition of location information to existing measures of physical activity and sedentary behavior will provide important behavioral information.

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KEYWORDS
wearable camera; global positioning system; real-time locating system; sitting; context
Introduction

Physical activity has a long-established relationship with several chronic conditions including diabetes, heart disease, and certain forms of cancer [1]. Recent evidence suggests that sedentary behavior carries deleterious effects on health outcomes independent of moderate-to-vigorous physical activity (MVPA) in young people [2] and adults [3], although this is not a uniform finding [4]. Sedentary behaviors are defined as any waking activity with an energy expenditure of ≤1.5 metabolic equivalents (METs) while in a sitting or reclining position [5].

A paradigm shift is underway toward an increasing appreciation of the importance of reducing sedentary time alongside increasing physical activity [6].

Within the behavioral epidemiology framework [7], the location of a behavior may influence the correlates of the behavior and the intervention strategies needed to change behavior. Discerning the varying contribution of multiple locations to physical activity and sedentary time will allow researchers to target interventions to locations which are associated with the lowest levels of physical activity or highest levels of sedentary time. Understanding the contribution of multiple locations to health behaviors first requires the accurate measurement of location, as suggested by the behavioral epidemiology framework [7,8].

Sedentary behavior and physical activity differ in the domains and locations in which they are likely to occur. Sedentary time is likely, though not exclusively, to occur indoors at the home, at work or school, or in leisure pursuits such as eating a meal or going to the cinema. Conversely, MVPA may occur through active transport, housework, or purposeful exercise. This can be illustrated through the close link between adults, on average, spending approximately 90% of time indoors [9,10] and approximately 60% of time in sedentary activities [11]. The large proportion of time spent indoors and the increasing research focus on sedentary behavior suggest that an accurate measure of where behavior occurs indoors would be particularly valuable.

Determining where physical activity and sedentary time are performed will provide valuable information in isolation; however, it can also act in a synergistic manner. For example, much recent effort has focused on the use of complex pattern recognition techniques to determine the mode or type of activity being performed from raw acceleration data. Depending on the classification method used, classification accuracies between 50% and 90% have been achieved [12]. Given the probabilistic nature of these activity classification methods, the inclusion of location-based data into the current algorithms may provide greater levels of accuracy. For instance, the likelihood of stair climbing is greatly increased if an individual is near a staircase. Similarly, context-sensitive questioning via ecological momentary assessment (EMA) [13] can be enhanced by using location to trigger desirable questions in place of time-based cues.

Furthermore, measurement of indoor location could benefit research into the correlates of physical activity or sedentary behavior. For example, the presence of a television set in a child’s bedroom may be a correlate of higher screen time [14]; however, this may be a stronger correlate for those who spend more time in their bedrooms. Establishing how much time a child spends in their bedroom via objective indoor location could, therefore, fully elucidate the strength of this correlate. Thus, the accurate measurement of location could greatly enhance several areas within physical activity and sedentary behavior research, both in and of itself and as an adjunct to other research areas.

Individuals may be able to accurately report the broad location of their physical activity and sedentary behavior [15]; however, self-report location instruments are unable to provide detailed and temporally patterned location information. Objective monitoring could, therefore, provide a more robust means to measure the location of physical activity and sedentary behavior. To date, time indoors has been inferred through the lack of a global positioning system (GPS) signal [16] or through the use of a light (lux) sensor incorporated into activity monitors [17]. However, these methods are only able to differentiate indoor from outdoor and do not provide room- or subroom-level location. Alongside measures of outdoor location, there is, therefore, a need for measures of room- and subroom-level indoor locations, which are feasible for use in this field of research. This review aims to provide an overview of devices and technology currently used, or that could potentially be used, to assess the indoor or outdoor location of physical activity and/or sedentary behavior.

Methods

Search Strategy

Search strategies to identify potentially relevant articles were built around three key groups of keywords: behavior, measurement, and context. Key terms were as follows: sedentary lifestyle, sedentary lifestyles, sedentary behav*, screen time, seden*, sitting time, motor activity, motor activities, physical activity, or activities of daily living; measur*, assess*, patterns, monitor, or sensor; and context*, setting, location, mode, domains, or environment. Scopus, Web of Science, PubMed, Institute of Electrical and Electronics Engineers (IEEE), and OpenGrey were searched using the key terms up to February 4, 2015. Subsequently, forward and backward searching of included articles (ie, references and articles citing the included article) was conducted to identify any further eligible articles. In addition, manual searches of personal files were conducted.

Inclusion and Exclusion Criteria

To be included in this review, studies were required to meet the following criteria: (1) be published in the English language, (2) either describe a tool used to measure the location of physical activity and/or sedentary behavior or provide sufficient information to discern whether the instrument could be modified to measure location, and (3) be a portable/wearable tool. Technologies were required to be portable or wearable to ensure that the technology is always with the participant and that the scope of the review was not so broad as to be unmanageable by including nonwearable technologies (eg, closed-circuit television [CCTV]). A minimum of one part of the measurement system, not the whole system, was required to be wearable/portable for

http://www.jmir.org/2015/8/e192/
inclusion. For example, GPS systems consist of a wearable unit and orbiting satellites (ie, one part of the system is wearable but the whole system also consists of unwearable components). Wearable technologies is also an area which is experiencing rapid growth in the consumer sector, as technology increasingly becomes smaller, more powerful, and multi-purpose. Wearable technologies, therefore, give this review a contemporary positioning. No date restriction was placed on search results. Studies erroneously defining sedentary behavior as the absence of sufficient physical activity rather than activities undertaken in a sitting or reclined position [5], were treated as physical activity studies.

Identification of Relevant Studies

Titles and abstracts of identified articles were screened to determine eligibility based on the above inclusion criteria. Titles and abstracts which did not meet the inclusion criteria were excluded. Following this, the full text of any potentially relevant article was obtained for full reading to determine conformity to the inclusion criteria. A subsample of potentially relevant articles retrieved for full-paper screening were extracted by a second author (JPS) to determine interrater agreement. If any discrepancies arose, these were resolved by discussion between authors. Interrater agreement was high (Cohen’s kappa = .81).

Data Extraction and Synthesis

Data of eligible papers was extracted via standardized forms developed for this review. All available information was extracted. Identified devices which assessed where physical activity and sedentary behavior occur were tabulated to highlight the available literature in this research area and to showcase the array of measurement technologies.

Internet Search Engines

To ensure that the widest possible range of devices were included, systematic searches of Internet search engines were performed for devices and technologies that are able to measure location but may not have made their way into the published research to date. This was necessary due to the relatively slow pace of research and publication compared to the pace of technological advance (ie, new research papers may use old technology which has been surpassed by newer models). Google, Bing, and Yahoo were searched using the following key terms: RTLS (real-time locating system), GPS tracking device, RFID (radio-frequency identification) tracking, wearable camera, wearable GPS, and wearable RFID. These search terms were chosen based on the results of the academic literature searches. Specialized software was used to export the first 300 results of each search to Microsoft Excel. This ensured that the results were unaffected by the changing algorithms of search engines. Searches were completed on February 4, 2015. The retrieved website addresses were screened to determine eligibility. Only manufacturer websites were included to ensure the accuracy of the information. All other websites, including blogs and consumer review websites, were excluded. Eligible websites were then browsed for location monitoring devices. Only devices and full integrated systems which are ready to use (ie, not bespoke) were included in an attempt to address the practicalities of deployment to assess where physical activity and sedentary time occur. The specifications of these devices were then extracted using standardized forms developed for this review. If available, specifications were obtained from device manuals. If device manuals were not available, any specifications shown on the website regarding the device were extracted. Only available information was extracted (ie, gaps in tables indicate a lack of available information). By note of caution, readers should be mindful that device characteristics, as supplied by manufacturers, are often generated under ideal conditions. Real-world pilot-testing with participants may, therefore, be required to establish real-world device characteristics.

Results

The number of research papers included and excluded at each stage of the systematic review process is shown in Figure 1. This review began with 61,009 potentially eligible papers, eventually resulting in the full inclusion of 98 papers. A further 90 papers were then identified through reference searching, citation tracking, and the searching of personal files.

A breakdown by year and technology is depicted in Figure 2. This review found 12 types of technology capable of assessing where physical activity and sedentary behavior occur. GPS was the most widely used location monitoring technology, comprising 119 (63.3%) [16,18-134] of the total 188 papers. Wearable cameras and RFID were the second- and third-most popular forms of location technology, contributing 23 (12.2%) [18,19,135-156] and 20 (10.6%) [157-177] studies, respectively, out of 188. The remaining 9 technologies each contributed a small number of studies (8 [4.3%] or less) to the total sample [178-200]. GPS has the longest history of use, initially being used within sports science in 1997. Conversely, wearable cameras and Wi-Fi-based localization technologies appear to be the most recent debut within research.

Selective details of devices used within research are shown in Table 1 (wearable cameras), Table 2 (GPS), and Table 3 (other). A complete version of Table 2 is available as Multimedia Appendix 1.

Tables 4-6 show selective characteristics of the results of the Internet search engine searches for wearable cameras, RTLS, and GPS, respectively. Complete versions of Tables 5 and 6 are available as Multimedia Appendices 2 and 3. These searches found 21 wearable cameras [201-214], 78 RTLS tags from 35 companies [215-249], and 81 GPS devices [250-286]. GPS devices were marketed for a variety of purposes, including the tracking of children by parents, elder monitoring to limit wandering, and the tracking of young drivers. RTLS companies positioned their products as suitable for asset management applications in warehouses and, to a lesser extent, equipment and patient tracking in health care settings. Wearable cameras were targeted toward extreme sports, life logging, and law enforcement applications.
Table 1. Summary of wearable camera systems used in published research to date.

| Model                        | Wear site | Weight, kg or g | SF, FPS | Refs*, notes |
|------------------------------|-----------|-----------------|---------|--------------|
| Natural-Point, Inc OptiTrack-Prime 17W | Indoor | 1.32 kg | N/A | 30-360 | [135] |
| Vicon Motion capture system | Both (most indoor) | N/A | 1.7 | N/A | ≤1000 | [136,137] |
| Prototype eButton | Both | N/A | ~10 | 42 g | Pin onto shirt | 10 | [138-140] |
| Prototype Wrist-Sense | Both | N/A | ~7 | 6.2 diameter | Wrist | 6 | [141,142] |
| Microsoft SenseCam (Vicon Revue) | Both | N/A | ≤16 | N/A | Lanyard around neck | Change in sensor readings | [18,19,143-155] |
| Looxcie 2 | Both | 22 g | 1-4 | 2.31x1.70 x8.46 | N/A | 15/30 | [156] |

*a: Man: manufacturer
b: I/O: Indoor/outdoor
c: BL: battery life
d: CR: camera resolution
e: Dim: dimensions
f: SF: sampling frequency
f: FPS: frames per second
h: Refs: references
i: N/A: not applicable
### Table 2. Summary of Global positioning systems used to date in published research (see Multimedia Appendix 1 for the full version of this table).

| Man<sup>a</sup> | Model                  | Battery life, h, days, or weeks | Dim<sup>b</sup> <sup>c</sup>, cm or mm | Weight, g | Wear site | Cold start time, s or Hz | Storage, points, MB, or, GB | References                                      |
|-----------------|------------------------|---------------------------------|----------------------------------------|-----------|-----------|--------------------------|--------------------------------|-----------------------------------------------|
|                  | Garmin Foretrex 201    | 15 h                            | 8.4x4.3x 1.8 cm                        | 78        | Wrist     | 45 s                     | 10,000 points                   | [16,20-31]                               |
|                  | Garmin Forerunner 305  | Typically 10 h                   | 5.3x 6.8x 1.7 cm                      | 77        | Wrist     | 45 s                     | N/A<sup>c</sup>                 | [32-35]                                   |
|                  | Garmin Forerunner 205  | 10 h                            | 53x69x 18 mm                           | 77        | Wrist     | 45 s                     | 72,000 points                   | [25,30,42-45]                            |
|                  | Garmin 60              | N/A                             | N/A                                    | N/A       | Pocket of backpack       | 0.5 Hz                   | N/A<sup>c</sup>                 | [46,47]                                   |
|                  | Telespial Systems Trackstick II | 16-36 h, 2 days-1 week in power save | 11.4x3.1x 1.9 cm                   | N/A       | N/A       | 52 s                     | 1 MB                           | [52,53]                                   |
|                  | GlobalSat DG100        | 20-24 h                         | N/A                                    | N/A       | Waist     | 5, 15, or 30 s           | 50,000 points                   | [25,47,54-59]                            |
|                  | GPSports SPI ELITE     | N/A                             | N/A                                    | N/A       | Back harness | 1 Hz                   | N/A<sup>c</sup>                 | [60-69]                                   |
|                  | GPSports SPI PRO       | N/A                             | N/A                                    | N/A       | Back harness | 5 Hz                   | N/A<sup>c</sup>                 | [71-74]                                   |
|                  | GPSports SPI 10        | N/A                             | N/A                                    | N/A       | Back harness | 1 Hz                   | N/A<sup>c</sup>                 | [65,66,73,75-77]                        |
|                  | Catapult Innovations MinimaxX | 5 h                             | 8.8x5.0x 1.9 cm                       | 67        | Back harness | 1 GB                   | N/A<sup>c</sup>                 | [62,73,78-87]                            |
|                  | Telespial Systems Super | 4-8 days                      | N/A                                    | N/A       | Waist     | 5 or 15 s                | N/A<sup>c</sup>                 | [88,89]                                   |
|                  | Qstarz BT1000X         | 42 h                            | 72x47x 20 mm                           | 65        | Pouch on belt | 35 s, 5 s, or 15 s | 400,000 points                  | [18920580-10131]                        |
|                  | GlobalSat BT335        | 25 h                            | N/A                                    | N/A       | Waist     | 30 s                    | N/A<sup>c</sup>                 | [110-114]                                 |

<sup>a</sup>Man: manufacturer  
<sup>b</sup>Dim: dimensions  
<sup>c</sup>N/A: not applicable

### Table 3. Summary of other measures used in published research to date.

| Type of measure                                    | Indoor/outdoor | References |
|----------------------------------------------------|----------------|------------|
| Radio-frequency identification                      | Indoor         | [157-177]  |
| Wireless localization                               | Indoor         | [178-183]  |
| Technology-assisted ecological momentary assessment/experience sampling | Both           | [184-191]  |
| Integrated circuit tags                             | Indoor         | [192,193]  |
| Ultrasonic (Bat system)                             | Indoor         | [194]      |
| Cellular networks                                   | Outdoor, but works indoor | [195]      |
| Bluetooth                                           | Indoor         | [196]      |
| Social media check-in                               | Both           | [197]      |
| Ultrasound                                          | Indoor         | [198,199]  |
| Pedestrian dead reckoning system                    | Indoor         | [200]      |
Table 4. Summary of commercially available wearable cameras unused in research to date.

| Manufacturer, reference | Model | Battery life of wearable component, h or min | Dimensions, mm, in, or cm | Weight, g or oz | Wear site |
|-------------------------|-------|---------------------------------------------|---------------------------|-----------------|-----------|
| Autographer [201]       | N/Aa  | 10 h                                        | 37.40x90.00x 22.93 mm     | 58 g            | Clip or lanyard |
| Narrative (formally Memoto) [202] | Clip | N/A                                        | 36x36x9 mm               | 20 g            | Clip or lanyard |
|                         | Clip 2 (released spring 2015) | N/A                                        | N/A                      | N/A             | N/A N/A |
| MeCam [203]             | Classic | 80 min continuous                          | 1.75x0.50 in             | 1 oz            | Clip or necklace |
|                         | MeCam HD | 60-120 min continuous                      | 2x2 in                   | 2.5 oz          | N/A       |
| uCorder [204]           |-Pockito IRDC260-R | ≤75 min                                    | 2.50x1.25x0.50 in        | N/A            | N/A       |
|                         | Pockito IRDC260-B | ≤75 min                                    | 2.50x1.25x0.50 in        | N/A            | N/A       |
|                         | Pockito IRDC150 | ≤2 h                                       | 1.1x0.6x3.5 in           | N/A            | N/A       |
|                         | Pockito IRDC250 | ≤2 h                                       | 1.1x0.6x3.5 in           | N/A            | N/A       |
|                         | Pockito IRDC250 | ≤2 h                                       | 1.1x0.6x3.5 in           | N/A            | N/A       |
|                         | 2.1 | N/A                                        | 45x4x15 mm               | 1.5 oz          | Clip      |
| Spy Emporium [206]      | Spy hidden camera glasses | 1-2 h                                      | 160x40x40 mm            | N/A            | Glasses/ on face |
| VIEVU [207]             | VIEVU 2 | 2.5 h recording, 1.5 h streaming           | 1.90x1.90x0.75 in        | 2.4 oz          | Clip      |
|                         | LE3 | ≤5 h                                       | 3.00x2.10x0.85 in        | 2.8 oz          | Clip      |
| Panasonic [208]         | WV-TW310L | 5 h continuous                           | 45x75x41 mm             | 210 g           | Clip      |
|                         | WV-TW310S | 5 h continuous                           | 45x75x41 mm             | 160 g           | Clip      |
| meMINI [209]            | N/A | 3.5 h                                      | N/A                      | N/A             | Lanyard   |
| Pivothead [210]         | N/A | N/A                                       | N/A                      | N/A             | Glasses/ on face |
| Nixie [211]             | N/A | N/A                                       | N/A                      | N/A             | Wrist (detaches to become camera) |
| CA7CH [212]             | Lightbox | N/A                                      | 38x38x10 mm              | 30 g            | Clip      |
| ELMO USA [213]          | QBIC-MSI | 2 h                                      | 2.14x2.40x1.57 in        | 95 g            | Lanyard   |
| Vidcie [214]            | Lookout QUB | 1 h (8 h with battery pack)             | 4.8x4.8x1.5 cm           | 37 g            | Clip      |

aN/A: not applicable
Table 5. Summary of commercially available real-time locating systems unused in research to date (see Multimedia Appendix 2 for the full version of this table).

| Manufacturer, reference | Model | Infrastructure/ method | Dimensions, mm, in, or cm | Accuracy, m, cm, or ft |
|-------------------------|-------|------------------------|---------------------------|------------------------|
| **Ekahau [215]**        | A4    | Wi-Fi, RSSI\(^a\) and triangulation | 45x55x19 mm | 1 m |
|                         | B4    | Wi-Fi, RSSI and triangulation | 60.0x90.0x8.5 mm | 1 m |
|                         | W4    | Wi-Fi, RSSI and triangulation | 51.5x50.0x17.5 mm | 1 m |
| **Ubisense [216]**      | Series 7000 industrial | UWB\(^b\), TOA\(^c\), AOA\(^d\) | 71x64x47 mm | 15 cm |
|                         | Series 7000 compact | UWB, TOA, AOA | 38.0x39.0x16.5 mm | 15 cm |
|                         | Series 7000 slim tag | UWB, TOA, AOA | 83x42x11 mm | 15 cm |
|                         | Series 700 intrinsically safe tag | UWB, TOA, AOA | 38.0x39.0x25.5 mm | 15 cm |
|                         | Series 9000 compact tag | UWB, TOA, AOA | 38.0x39.0x16.5 mm | 15 cm |
| **Zebra [218]**         | WhereTag IV | Wi-Fi, TDOA\(^e\) | 43.7x66.0x21.3 mm | 2 m |
|                         | WhereTag III | Wi-Fi, TDOA | 21x66x44 mm | |
| **Sonitor [222]**       | Whole system | Wi-Fi, ultrasound, RSSI | N/A\(^f\) | 1 ft |
| **Secure Care [225]**   | ENVisionIT | Wi-Fi | N/A | 30 cm |
| **Mojix [226]**         | eLocation | Passive RFID\(^g\) | N/A | Within 1 m |
| **TempSys [228]**       | Fetch System | RF\(^h\) and ultrasound, TDOA | N/A | 0.5 m |
| **Awarepoint [229]**    | Asset tags | ZigBee | 1.8x1.3x0.5 in | Up to bay level |
|                         | Wearable tag | ZigBee | 1.8x1.3x0.5 in | |
| **Nebusens [232]**      | Sirius Quantum | ZigBee | 22.00x32.72x5.00 mm | 1 m |
| **Essensium [233]**     | Mobile nodes | Wide over narrowband RF, TWR\(^i\), TOF\(^j\) | 19.8x8.8 cm | Typically 50 cm |
| **PLUS Location [234]** | R1 badge tag | UWB, TDOA | 38.0x78.0x9.6 mm | <1 m |
|                         | R2 tags | UWB, TDOA | 87x42x10 mm | <1 m |
| **Purelink [239]**      | Personnel tracking tag | RFID | 85x54x4 mm | 2 m |
| **Sanitag [240]**       | Staff tag | RF, RSSI, TOF | 90x61x5 mm | 2.5 m |
|                         | Patient tag | RF, RSSI, TOF | 43x36x10 mm | 2.5 m |
| **OpenRTLS [242]**      | Tag | UWB, TDOA, TWR | 66x44x17 mm | 10 cm |

\(^a\)RSSI: received signal strength indicator
\(^b\)UWB: ultra wide band
\(^c\)TOA: time of arrival
\(^d\)AOA: angle of arrival
\(^e\)TDOA: time difference of arrival
\(^f\)N/A: not applicable
\(^g\)RFID: radio-frequency identification
Table 6. Summary of commercially available global positioning systems unused in research to date (see Multimedia Appendix 3 for the full version of this table).

| Manufacturer                       | Model            | Battery life of wearable component, days, weeks, months, or h | Dimensions, in, cm, or mm |
|------------------------------------|------------------|---------------------------------------------------------------|---------------------------|
| **Trackstick [250]**               |                  |                                                               |                           |
| Trackstick mini                    |                  | 3-14 days                                                     | 3.50x1.50x0.38 in         |
| Trackstick II                      |                  | 16 h-2 days (AAA)                                             | 4.50x1.25x0.75 in         |
| Super Trackstick                   |                  | 3 days-3 weeks (AAA)                                          | 4.50x1.25x0.75 in         |
| Trackershop-UK [251]               | Pro-pod5         | 14-15 days                                                    | 6.35x4.00x2.50 cm         |
| **Gotek7 [252]**                   |                  |                                                               |                           |
| Prime 1.0                          |                  | 10 days normal; ≤12 months with 1 update per day              | N/A                       |
| Prime 2.0                          |                  | 15 days normal; ≤14 months (1 per day)                       | 65x42x25 mm               |
| **Trackinapack [256]**             |                  |                                                               |                           |
| Advanced                           |                  | ≤10 days                                                      | 2.63x1.38x0.79 in         |
| Advanced plus                      |                  | ≤15 days                                                      | 2.50x1.50x0.79 in         |
| **TracLogik [259]**                |                  |                                                               |                           |
| Guardian GPS                       |                  | 100-220 hours                                                 | 67.8x37.0x20.0 mm         |
| Guardian pro GPS                   |                  | 2-14 days                                                     | 62.5x40.0x25.0 mm         |
| Covert 2000                        |                  | 10-15 days                                                    | 61x34x31 mm               |
| **Loc8tor [261]**                  |                  |                                                               |                           |
| N/A                                |                  | ≤9 months in power save; 3-14 days normally                  | 68x36x20 mm               |
| **LandAirSea [269]**               |                  |                                                               |                           |
| Silvercloud realtime GPS tracker   |                  | 5-6 days at 2 h per day                                       | 3.90x2.26x0.90 in         |
| Tracking key pro                   |                  | 2 weeks (4 h), 4 weeks (2 h), 6 weeks (1 h per day)          | 3.01x1.95x1.40 in         |
| **GTX Corp [273]**                 |                  |                                                               |                           |
| Prime AT                           |                  | ≤16 days                                                      | 67x37x20 mm               |
| Smart sole                         |                  | 2-3 days                                                      | Depends on show size      |
| **Nike [276]**                     | Sportwatch GPS   | 8 h with average use                                          | 1.5x10.1x0.6 in           |
| **Garmin [277]**                   |                  |                                                               |                           |
| Forerunner 620                     |                  | 6 weeks (watch) 10 h (training)                               | 45.0x45.0x12.5 mm         |
| Forerunner 220                     |                  | 6 weeks (watch) 10 h (training)                               | 45.0x45.0x12.5 mm         |
| Tactix                             |                  | 50 h (5 weeks in watch mode)                                 | 49x49x17 mm               |
| Fenix 2                            |                  | 20 h (5 weeks in watch mode)                                 | 49x49x17 mm               |
| Trax [280]                         |                  | 1 day                                                        | 38x55x10 mm               |
| **Personal GPS Trackers [282]**    |                  |                                                               |                           |
| Personal GPS Tracker               |                  | ≤7 days                                                       | 65x40x18 mm               |
| Mini GPS Tracker                   |                  | 2-4 days                                                      | 58x22x11 mm               |

N/A: not applicable
Figure 1. Flowchart of study selection process.

Figure 2. Number of studies published each year covering different types of technology. A total of 12 kinds of technology were found during the course of this review.
Discussion

Principal Findings

This systematic review sought to identify tools which have been used, or could be modified for use, to assess where physical activity and sedentary behaviors occur. This review identified 188 research papers which used 12 different types of technology. The most widely used technology was GPS with 119 publications [16,18,134], followed by wearable cameras and RFID with 23 [18,19,135-156] and 20 [157-177] publications, respectively. The remaining 9 types of technology each contributed a small number of studies to the total sample [178-200]. However, it should be noted that a number of these were bespoke or prototype systems; this is particularly true of RFID, integrated circuit (IC) tag systems, and various communication protocols for wireless localization.

Systematic grey searches identified 21 wearable cameras [201-214], 78 RTLS tags [215-249], and 81 GPS devices [250-286]. By only including devices which are "ready to use," we sought to address the practicalities of deployment and limit the inclusion of bespoke technologies. Combined with the devices used within research papers to date, we identified a total of 263 devices. The history, principles of use, and the applications for GPS, RTLS, and wearable cameras will now be discussed in greater detail.

Global Positioning System

Originally developed by the United States Department of Defense, the GPS system consists of 24 satellites orbiting Earth. These satellites transmit signals to GPS receivers and are able to determine the location, direction, and speed of the receiver based on trilateration between three or more satellites [287]. Due to the original military application of GPS, a deliberate error was embedded into the system to reduce the risk of enemy forces using the system. This deliberate error was removed in the year 2000, thus making the system available to civilian users. The use of GPS has since proliferated into areas such as criminal offender tracking, vehicle tracking, and vehicle navigation. Such has been the widespread adoption of GPS, that the European Union is currently investing substantial amounts of money into its own satellite system to ensure it is not reliant on American satellites. Early GPS devices possessed limited battery life and memory capacity and form factors unsuitable for long periods of wear. Thus GPS devices were first used for sports applications before making their way into health research.

The earliest GPS study in a sporting domain was conducted in 1997 [132]. It was found from this initial evaluation that GPS could be used to assess human locomotion [132]. Following this early study, GPS has been used to assess movement characteristics in sports such as Australian football [66], orienteering [49], hockey [63], and rugby [72]. These studies have generally found GPS to be a suitable measure of movement parameters in sport, such as speed and distance. Physiological measures such as heart rate are often included alongside GPS to provide further data on the demands of a particular sport. These devices are often worn on the back via a custom-made vest and are, therefore, unlikely to be suitable for long-term wear. These sports studies, therefore, provide little insight into the applicability of GPS for assessing free-living physical activity.

The earliest study to use GPS to investigate free-living physical activity was conducted in 2005 [22]. The GPS units were found to provide valid and reliable measures of location when compared to a known geodetic point [22]. Following the validation of these units, a small pilot study examined the feasibility of integrating GPS, geographic information system (GIS), and accelerometer data. It was found that GPS and accelerometer data could be successfully integrated, with GPS data available for 67% of all MVPA time [22]. Accelerometer, GIS, and GPS data have since been successfully integrated in further studies to assess active commuting to school [16] and time spent outdoors after school [20].

In reviewing 24 studies which use GPS in physical activity research [288], GPS data loss was found to be highly correlated with device wear time (r=.81, P<.001). Common reasons for data loss include signal dropout, limited battery power, and poor protocol adherence [288]. Due to devices requiring a line of sight to the orbiting satellites, signal dropout can occur when this line of sight is broken. The necessity for GPS devices to have a line of sight to at least three orbiting satellites also results in GPS only receiving signal within certain indoor environments, such as a single-story building with a wooden roof or high-story building with large windows. Even under these circumstances, GPS is unable to determine room- or subroom-level indoor location. Participants are often required to remain stationary outside before commencing a journey to ensure that the GPS device can acquire satellite signal, failure to adhere to this can result in data loss.

While GPS can be used to successfully augment accelerometer measurement of physical activity, several shortcomings need to be addressed. There is currently no established approach to the analysis and interpretation of GPS data [287]. Guidelines and common data analysis programs for the capture and analysis of GPS data, such as the Personal Activity and Location Measurement System (PALMS), are therefore highly useful in standardizing approaches. Due to requiring a clear line of sight to orbiting satellites, GPS is most suitable for assessing outdoor location. However, up to 90% of our time is spent indoors [9,10]. The ability to assess where physical activity and sedentary time occur in an indoor environment would allow the formation of a more comprehensive behavioral profile which incorporates contextual information alongside accelerometry-measured intensity and duration.

Wireless Localization

Wireless localization technology has been commercialized under the umbrella term real-time locating systems. Used in health care [289] and warehouse environments, RTLS systems are able to assess the location of people or assets within an indoor environment. Many RTLS devices are commercially available (see Table 5 and Multimedia Appendix 2). All of these devices function on the principle of determining the location of a mobile component via the known location of fixed components, though the method of determining location and the type of fixed component vary between manufacturers. Interested readers are
referred elsewhere for detailed technological reviews of wireless localization [290-293].

The fixed components of RTLS systems also vary between RTLS manufacturers. Some manufacturers, such as AeroScout, require the installation of proprietary fixed reference points. Others, such as the Ekahau system, are able to utilize existing Wi-Fi points within buildings as fixed reference points and, therefore, do not require the installation of infrastructure. Several manufacturers also provide infrared (IR) location beacons for increased location accuracy in areas of poor signal strength. Hardware of the Ekahau RTLS system is shown in Figure 3. The location of the mobile component of the RTLS system, worn by an individual or placed on equipment, is then relayed back to software supplied with the RTLS system. This software requires a floor plan of the environment being monitored; the location of the mobile component is then viewed on this floor plan or as an x and y coordinate. RTLS systems, therefore, function in much the same manner as GPS: providing x and y coordinates rather than longitude and latitude. The manufacturers of several RTLS systems suggest that their systems are capable of handling hundreds of mobile tags simultaneously. Manufacturers state that RTLS systems are generally accurate to within 2 to 3 meters.

However, RTLS systems are not without limitations. Due to their predominant use in the tracking of patients and equipment, many RTLS systems are configured for real-time monitoring and require slight modification to generate a log of coordinates for any later integration with other data streams. At present, RTLS systems are not being used in physical activity or sedentary behavior research; therefore, the feasibility of incorporating RTLS data with accelerometry is unknown. The RTLS software requires the manual setting of the scale of the floor plan and, therefore, introduces possible human error into the system.

Despite this, RTLS could potentially be used within physical activity and sedentary behavior research to answer a number of research questions which are currently assessed via self-report methods. For example, RTLS, alongside accelerometry, could provide location information to assess whether youngsters in a daycare center are more likely to be active when they are near equipment such as a sandbox or when they are near other active youngsters. Likewise, if researchers are undertaking a standing desk intervention to reduce sitting time, participants are currently often asked to self-report how much time they spend at their desk. The amount of time the participant spends at their desk may impact any possible reduction in sitting time due to the standing desk. With RTLS, researchers would be able to objectively determine the amount of time their participants were at their standing desk and thus determine the success, or otherwise, of the intervention with greater certainty.

Determining the indoor location of physical activity and sedentary behavior via RTLS may also be an important research finding in itself. For example, within an elderly care home environment, RTLS could be used to assess whether individual residents are more sedentary alone in their bedrooms or when mixing with other residents in communal areas. Depending on the findings, some residents may then be best suited to an individual intervention focusing on bedroom-based sedentary behavior while other residents may be more suited to a group intervention focusing on communal area sedentary behavior.
Wearable Cameras

Recent interest has accumulated in the use of wearable cameras in physical activity and sedentary behavior research, mirroring the growth of the life-logging and quantified-self communities. However, several of the wearable cameras identified in this review appear to have limited public health utility due to very short (e.g., 1.5 hours) of battery life. The most popular wearable camera in a research setting is the Microsoft SenseCam. Worn on a lanyard around the neck and containing sensors such as passive infrared, accelerometer, and gyroscope, this device automatically captures a first-person picture at a frequency of approximately 20 seconds. The device has a battery life of approximately 16 hours with sufficient memory capacity to store approximately 32,000 images [294]. From initial small-scale pilot studies, it appears that images generated from wearable cameras are a feasible means of assessing active travel behavior [144,294]. Wearable cameras, therefore, provide broader contextual information; however, they can also be used to infer location. Commercially available wearable cameras, such as the Autographer, also provide GPS coordinates alongside the photograph. Two of the most popular wearable cameras are shown in Figure 4.

Unlike pure location measurement technologies such as GPS and RTLS, wearable cameras are able to provide broader contextual information based on the generated images. For example, a succession of images may show a television set. From this, it could be identified that the participant is watching television. Likewise, a succession of images may show a group of people of a similar age to the participant which researchers may be able to classify as time spent with friends; this is important as an individual’s friends may play a role in shaping physical activity behaviors [295].

Despite the encouragement offered by these initial studies, significant ethical, privacy, and analytical issues remain. There is a possibility that participants may be wearing the device during situations in which they do not wish to be photographed. To overcome this, the device allows the user to turn off the device for several minutes should they require privacy. There is also the possibility that the device may take pictures of an individual that participants encounter who does not wish to be photographed. Linked to this is the possibility that individuals may be wearing the device in situations that are unsuitable for photography, such as dropping off or picking up children from school. In an effort to overcome some of these issues [296], an ethical framework has been proposed for the use of wearable cameras in research. The framework includes the issues of informed written consent from participants, privacy and confidentiality, nonmaleficence, and the autonomy of third parties [296].
Alongside these privacy issues is the issue of data analysis. Current data analysis methods are laborious, involving the manual trawling and coding of images. For long-term monitoring this may prove to be prohibitive in the adoption of wearable cameras. Pattern recognition algorithms to semiautomate this process are available from computer scientists; however, there is a need for these to be integrated into device software in a manner which is suitable for end users. Despite these issues, wearable cameras can be used to assess where behavior occurs both indoors and outdoors and may, therefore, be able to supplement GPS to provide a greater range of contextual information.

The preceding discussion of GPS, RTLS, and wearable cameras highlights the principles, limitations, and use in physical activity and sedentary behavior research of each of these three technologies. GPS is the dominant technology used within research to date to assess where physical activity and sedentary time occur. However, the development of RTLS and wearable cameras offers the possibility to incorporate these technologies alongside GPS and accelerometry to provide a more comprehensive behavioral profile which fully elucidates the context, intensity, and duration of the behavior. The present systematic review also identified several other location monitoring technologies, such as RFID and IC tags, that are less "ready to use" than the three main technologies discussed. While these technologies, particularly RFID, may have a substantial research base behind them, there appears to be no "off the shelf" complete system which is readily purchasable for location tracking.

The ability to assess where behavior occurs in an indoor environment may be particularly elucidating for sedentary time. With the ability to assess where sedentary behavior occurs at work (eg, in a meeting room or at a desk) and at home (eg, sofa, desk, or dining table), behavioral researchers would possess a more comprehensive profile of the context in which sedentary behavior occurs, which could further illuminate the most common modes of sedentary behavior.

It is also worth briefly considering available technologies which were not included in this systematic review, largely due to a lack of wearability. Bluetooth low energy (BLE) proximity systems have recently gained in popularity in certain applications. Many of these systems are primarily aimed toward retail applications for the purpose of proximity marketing. In this scenario, small BLE beacons are placed around a retail environment. The customer, as they are perusing the store with a BLE-enabled device such as a mobile phone, then receives targeted marketing and discount offers to their phone based on their proximity to the beacons. For example, when the customer is perusing the carbonated drinks aisle in a supermarket, an offer may be sent to their phone for a particular brand of drink. These systems offer the potential to install BLE beacons within an indoor environment and determine location based on proximity to the beacons.

Of particular note is the recent miniaturization of BLE beacons to the size of a sticker, so suitably small that it may unobtrusively be attached to items such as chairs, bicycles, and sports equipment. This novel "nearables" equipment offers the potential to assess the location and type of behavior.
Conclusions

This systematic review sought to identify tools which have been used or could be used to assess where physical activity and sedentary time occur. We identified 188 research papers, of which 119 used GPS and 23 used wearable cameras. A total of 76 location tracking devices or systems were used. Systematic Internet search engine searches found 21 wearable camera models, 78 RTLS tags, and 81 GPS devices. This gave a cumulative total of 263 location tracking devices or systems. GPS is the dominant form of location tracking used within physical activity research to date. While GPS is a valid measure of outdoor location, it is unable to be used within an indoor environment.

Recent developments in wearable cameras and RTLS systems have ensured that tools are now available which offer the potential to assess where physical activity and sedentary behaviors occur indoors. Thus, these tools can provide further contextual information, alongside GPS, when used in conjunction with measures of physical activity and sedentary behavior such as accelerometers. Issues and limitations of each technology were identified, including privacy, data analysis and interpretation, and common data processing methodologies. The integration of accelerometry, GPS, and a technology capable of assessing indoor location would provide researchers with the ability to assess the indoor and outdoor location of physical activity and sedentary behavior. Future research should, therefore, investigate the feasibility of incorporating these technologies, with particular reference to the wearability of the devices, the integration of data streams, and the generation of meaningful behavioral outcomes.

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Authors’ Contributions

AL, LBS, and DWE conceived and planned the review. AL completed data acquisition and drafted the manuscript. LBS, JPS, PWS, and DWE provided critical comments and insights. All authors read and approved the final manuscript.
Conflicts of Interest
None declared.

Multimedia Appendix 1
Full version of Table 2.

[PDF File (Adobe PDF File), 11KB - jmir_v17i8e192_app1.pdf]

Multimedia Appendix 2
Full version of Table 5.

[PDF File (Adobe PDF File), 11KB - jmir_v17i8e192_app2.pdf]

Multimedia Appendix 3
Full version of Table 6.

[PDF File (Adobe PDF File), 13KB - jmir_v17i8e192_app3.pdf]

References
1. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I. American College of Sports Medicine. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc 2011 Jul;43(7):1334-1359. [doi: 10.1249/MSS.0b013e318213f1eb] [Medline: 21694556]
2. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act 2011;8:98 [FREE Full text] [doi: 10.1186/1479-5868-8-98] [Medline: 21936895]
3. Grøntved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. JAMA 2011 Jun 15;305(23):2448-2455 [FREE Full text] [doi: 10.1001/jama.2011.812] [Medline: 22673296]
4. Ekelund U, Luan J, Sherar LB, Esliger DW, Griew P, Cooper A, International Children's Accelerometry Database (ICAD) Collaborators. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. JAMA 2012 Feb 15;307(7):704-712 [FREE Full text] [doi: 10.1001/jama.2012.156] [Medline: 22337681]
5. Sedentary Behaviour Research Network. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab 2012 Jun;37(3):540-542. [doi: 10.1139/h2012-024] [Medline: 22540258]
6. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev 2010 Jul;38(3):105-113 [FREE Full text] [doi: 10.1097/JES.0b013e3181e373a2] [Medline: 20577058]
7. Sallis J, Owen N. Physical Activity and Behavioral Medicine. Thousand Oaks, CA: Sage Publications; 1999.
8. Marshall SJ, Ramirez E. Reducing sedentary behavior: a new paradigm in physical activity promotion. Am J Lifestyle Med 2011 Feb 16;5(6):518-530. [doi: 10.1177/1559827610395487]
9. Indoor Air Division, Office of Atmospheric and Indoor Air Programs. Report to Congress on Indoor Air Quality. Volume 2. Washington, DC: United States Environmental Protection Agency; 1989 Aug 01. URL: http://nepis.epa.gov/Exe/ZyPDF.cgi/9100LMBU.PDF?Dockey=9100LMBU.pdf [accessed 2015-07-31] [WebCite Cache ID 6aOwaHuww]
10. European Commission, Eurostat. How Europeans Spend Their Time: Everyday Life of Women and Men. Luxembourg City, Luxembourg: Office for Official Publications of the European Communities; 2004. URL: http://bookshop.europa.eu/en/how-europeans-spend-their-time-pbKS5804998/downloads/KS-58-04-998-EN-C/KS5804998ENC_002.pdf?FileName=KS5804998ENC_002.pdf&SKU=KS5804998ENC/pdf&CatalogueNumber=KS-58-04-998-EN-C [accessed 2015-07-31] [WebCite Cache ID 6aOwv3Gr]
11. Dunstan D, Healy G, Sugiyama T, Owen N. Too much sitting and metabolic risk has modern technology caught up with us? European Endocrinology 2010;6(1):19-23. [doi: 10.17925/EE.2010.06.01.19]
12. Preece SJ, Goulermas JY, Kenney LP, Howard D, Meijer K, Crompton R. Activity identification using body-mounted sensors---a review of classification techniques. Physiol Meas 2009 Apr;30(4):R1-R33. [doi: 10.1088/0967-3334/30/4/R01] [Medline: 19342767]
13. Intille S, Rondoni J, Kukla C, Ancona I, Bao L. A context-aware experience sampling tool. In: Proceedings of the Conference on Human Factors in Computing Systems. New York, NY: ACM; 2003 Presented at: Conference on Human Factors in Computing Systems; April 5-10, 2003; Fort Lauderdale, FL p. 972-973.
14. Hoyos CI, Jago R. Systematic review of correlates of screen-viewing among young children. Prev Med 2010 Jul;51(1):3-10. [doi: 10.1016/j.ypmed.2010.04.012] [Medline: 20417227]
15. Kozeys, K.L., Lyden K., Hickey A., Ray EL., Fowke JH., Freedson PS., et al. Validation of a previous day recall for measuring the location and purpose of active and sedentary behaviors compared to direct observation. Int J Behav Nutr Phys Act 2014;11:12 [FREE Full text] [doi: 10.1186/1479-5868-11-12] [Medline: 24940619]

16. Cooper AR, Page AS, Wheeler BW, Grief P, Davis L, Hillsdon M, et al. Mapping the walk to school using accelerometry combined with a global positioning system. Am J Prev Med 2010 Feb;38(2):178-183. [doi: 10.1016/j.amepre.2009.10.036] [Medline: 20117574]

17. Tandon PS, Saelens BE, Zhou C, Kerr J, Christakis DA. Indoor versus outdoor time in preschoolers at child care. Am J Prev Med 2013 Jan;44(1):85-88. [doi: 10.1016/j.amepre.2012.09.052] [Medline: 23253655]

18. Lam M, Godbole S, Chen J, Oliver M, Badland H, Marshall S, et al. Measuring time spent outdoors using a wearable camera and GPS. In: Proceedings of the 4th International SenseCam and Pervasive Imaging Conference. New York, NY: ACM; 2013 Presented at: 4th International SenseCam and Pervasive Imaging Conference; November 18-19, 2013; San Diego, CA p. 1-7. [doi: 10.1145/2526667.2526668]

19. Carlson JA, Jankowski MM, Meseck K, Godbole S, Natarajan LA, Raab F, et al. Validity of PALMS GPS scoring of active and passive travel compared with SenseCam. Med Sci Sports Exerc 2015 Mar;47(3):662-667. [doi: 10.1249/MSS.0000000000000446] [Medline: 25010407]

20. Cooper AR, Page AS, Wheeler BW, Hillsdon M, Grief P, Jago R. Patterns of GPS measured time outdoors after school and objective physical activity in children: the PEACH project. Int J Behav Nutr Phys Act 2010;7:31 [FREE Full text] [doi: 10.1186/1479-5868-7-31] [Medline: 20412582]

21. Lachowycz K, Jones AP, Page AS, Wheeler BW, Cooper AR. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? Health Place 2012 May;18(3):586-594 [FREE Full text] [doi: 10.1016/j.healthplace.2012.01.006] [Medline: 22365385]

22. Rodríguez DA, Brown AL, Troped PJ. Portable global positioning units to complement accelerometry-based physical activity monitors. Med Sci Sports Exerc 2005 Nov;37(11 Suppl):S572-S581. [Medline: 16294120]

23. Rodríguez DA, Cho G, Elder JP, Conway TL, Evenson KR, Ghosh-Dastidar B, et al. Identifying walking trips from GPS and accelerometer data in adolescent females. J Phys Act Health 2012 Mar;9(3):421-431 [FREE Full text] [Medline: 21934163]

24. Wheeler BW, Cooper AR, Page AS, Jago R. Greenspace and children's physical activity: a GPS/GIS analysis of the PEACH project. Prev Med 2010 Aug;51(2):148-152. [doi: 10.1016/j.ypmed.2010.06.001] [Medline: 20542493]

25. Wieters KM, Kim J, Lee C. Assessment of wearable global positioning system units for physical activity research. J Phys Act Health 2012 Sep;9(7):913-923. [Medline: 21975729]

26. Cho G, Rodríguez DA, Evenson KR. Identifying walking trips using GPS data. Med Sci Sports Exerc 2011 Feb;43(2):365-372. [doi: 10.1249/MSS.0b013e3181ebec3c] [Medline: 20581721]

27. Southward EF, Page AS, Wheeler BW, Cooper AR. Contribution of the school journey to daily physical activity in children aged 11-12 years. Am J Prev Med 2012 Aug;43(2):201-204. [doi: 10.1016/j.amepre.2012.04.015] [Medline: 22813686]

28. Zenk SN, Schulz AJ, Odoms-Young AM, Wilbur J, Matthews S, Gamboa C, et al. Feasibility of using global positioning systems (GPS) with diverse urban adults: before and after data on perceived acceptability, barriers, and ease of use. J Phys Act Health 2012 Sep;9(7):924-934 [FREE Full text] [Medline: 21952361]

29. Zenk SN, Schulz AJ, Odoms-Young AM, Wilbur J, Wezgryn L., et al. Activity space environment and dietary and physical activity behaviors: a pilot study. Health Place 2011 Sep;17(5):1150-1161 [FREE Full text] [doi: 10.1016/j.healthplace.2011.05.001] [Medline: 21696995]

30. Duncan S, Stewart TI, Oliver M, Mavoa S, MacRae D, Badland HM, et al. Portable global positioning system receivers: static validity and environmental conditions. Am J Prev Med 2013 Feb;44(2):e19-e29. [doi: 10.1016/j.amepre.2012.10.013] [Medline: 23332343]

31. Rodríguez DA, Cho G, Evenson KR, Conway TL, Cohen D, Ghosh-Dastidar B, et al. Out and about: association of the built environment with physical activity behaviors of adolescent females. Health Place 2012 Jan;18(1):55-62 [FREE Full text] [doi: 10.1016/j.healthplace.2011.08.002] [Medline: 21945985]

32. Collins P, Al-Nakeeb Y, Nevill A, Lyons M. The impact of the built environment on young people's physical activity patterns: a suburban-rural comparison using GPS. Int J Environ Res Public Health 2012 Sep;9(9):3030-3050 [FREE Full text] [doi: 10.3390/ijerph9093030] [Medline: 23202669]

33. Fjortoft I, Löfman O, Halvorsen TK. Schoolyard physical activity in 14-year-old adolescents assessed by mobile GPS and heart rate monitoring analysed by GIS. Scand J Public Health 2010 Nov;38(5 Suppl):28-37. [doi: 10.1177/140349481084909] [Medline: 21062837]

34. Maddison R, Jiang Y, Vander HS, Exeter D, Mhurchu CN, Dorey E. Describing patterns of physical activity in adolescents using global positioning systems and accelerometry. Pediatri Exerc Sci 2010 Aug;22(3):392-407. [Medline: 20814035]

35. Tan H, Wilson AM, Lowe J. Measurement of stride parameters using a wearable GPS and inertial measurement unit. J Biomech 2008;41(7):1398-1406. [doi: 10.1016/j.jbiomech.2008.02.021] [Medline: 18423472]

36. Duncan MJ, Mummery WK. GIS or GPS? A comparison of two methods for assessing route taken during active transport. Am J Prev Med 2007 Jul;33(1):51-53. [doi: 10.1016/j.amepre.2007.02.042] [Medline: 17572312]
37. Duncan MJ, Mummery WK, Dascombe BJ. Utility of global positioning system to measure active transport in urban areas. Med Sci Sports Exerc 2007 Oct;39(10):1851-1857. [doi: 10.1249/mss.0b013e3181ff31e] [Medline: 17909415]

38. Oreskovic NM, Blossom J, Field AE, Chiang SR, Winickoff JP, Kleinman RE. Combining global positioning system and accelerometer data to determine the locations of physical activity in children. Geospat Health 2014;2(2):263-272. [doi: 10.4081/gh.2012.144] [Medline: 22639128]

39. Fjortoft I, Kristoffersen B, Sageie J. Children in schoolyards: tracking movement patterns and physical activity in schoolyards using global positioning system and heart rate monitoring. Landsc Urban Plan 2009 Dec;93(3-4):210-217. [doi: 10.1016/j.landurbplan.2009.07.008]

40. Seeger C, Welk G, Erickson M. Assessing the built environment using gps, physical activity monitors and geospatial surveys. International Journal of Geoinformatics 2009;5(1):41-48.

41. Seeger C, Welk G, Erickson S. Using global position systems (GPS) and physical activity monitors to assess the built environment. J Urban Reg Inf Syst Assoc 2008;20(2):5-12.

42. Webber SC, Porter MM. Monitoring mobility in older adults using global positioning system (GPS) watches and accelerometers: a feasibility study. J Aging Phys Act 2009 Oct;17(4):455-467. [Medline: 19940324]

43. Coombes E, van Sluijs E, Jones A. Is environmental setting associated with the intensity and duration of children's physical activity? Findings from the SPEEDY GPS study. Health Place 2013 Mar;20:62-65 [FREE Full text] [doi: 10.1016/j.healthplace.2012.11.008] [Medline: 23376730]

44. Jones AP, Coombes EG, Griffin SJ, van Sluijs E. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. Int J Behav Nutr Phys Act 2009;6:42 [FREE Full text] [doi: 10.1186/1479-5868-6-42] [Medline: 19615073]

45. Lee C, Li L. Demographic, physical activity, and route characteristics related to school transportation: an exploratory study. Am J Health Promot 2014;28(3 Suppl):S77-S88. [doi: 10.4278/ajhp.130430-QUAN-211] [Medline: 24380470]

46. Le Faucheur A, Abraham P, Jaquinandi V, Bouyé P, Saumet JL, Noury-Desvaux B. Study of human outdoor walking with a low-cost GPS and simple spreadsheet analysis. Med Sci Sports Exerc 2007 Sep;39(9):1570-1578. [doi: 10.1249/mss.0b013e3180ce28c7] [Medline: 17805900]

47. Noury-Desvaux B, Abraham P, Mahé G, Sauvaget T, Leftheriotis G, Le Faucheur A. The accuracy of a simple, low-cost GPS data logger/receiver to study outdoor human walking in view of health and clinical studies. PLoS One 2011;6(9):e23027 [FREE Full text] [doi: 10.1371/journal.pone.0023027] [Medline: 21931593]

48. Larsson P, Henrikssoon-Larsén K. Combined metabolic gas analyser and dGPS analysis of performance in cross-country skiing. J Sports Sci 2005 Aug;23(8):861-870. [doi: 10.1080/02640410400022078] [Medline: 16195038]

49. Larsson P, Henrikssoon-Larsén K. The use of dGPS and simultaneous metabolic measurements during orienteering. Med Sci Sports Exerc 2001 Nov;33(11):1919-1924. [Medline: 11689744]

50. Hongu N, Orr BJ, Roe DJ, Reed RG, Going SB. Global positioning system watches for estimating energy expenditure. J Strength Cond Res 2013 Nov;27(11):3216-3220. [doi: 10.1519/JSC.0b013e31828bae0f] [Medline: 23439338]

51. Nielsen RO, Cederholm P, Buist I, Sørensen H, Lind M, Rasmussen S. Can GPS be used to detect deleterious progression in training volume among runners? J Strength Cond Res 2013 Jun;27(6):1471-1478. [doi: 10.1519/JSC.0b013e3182711e3c] [Medline: 22990565]

52. Badland HM, Duncan MJ, Oliver M, Duncan JS, Mavoa S. Examining commute routes: applications of GIS and GPS technology. Environ Health Prev Med 2010 Sep;15(5):327-330 [FREE Full text] [doi: 10.1007/s12199-010-0138-1] [Medline: 21435262]

53. Oliver M, Badland H, Mavoa S, Duncan MJ, Duncan S. Combining GPS, GIS, and accelerometer: methodological issues in the assessment of location and intensity of travel behaviors. J Phys Act Health 2010 Jan;7(1):102-108. [Medline: 20231761]

54. Abraham P, Noury-Desvaux B, Gernigon M, Mahé G, Sauvaget T, Leftheriotis G, et al. The inter- and intra-unit variability of a low-cost GPS data logger/receiver to study human outdoor walking in view of health and clinical studies. PLoS One 2012;7(2):e31338 [FREE Full text] [doi: 10.1371/journal.pone.0031338] [Medline: 22363623]

55. Quigg R, Gray A, Reeder AI, Holt A, Waters DL. Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. Prev Med 2010;50(5-6):235-240. [doi: 10.1016/j.ypmed.2010.02.002] [Medline: 20153361]

56. Kang B, Moudon AV, Hurvitz PM, Reichley L, Saelens BE. Walking objectively measured: classifying accelerometer data with GPS and travel diaries. Med Sci Sports Exerc 2013 Jul;45(7):1419-1428 [FREE Full text] [doi: 10.1249/MSS.0b013e318285f202] [Medline: 23439414]

57. Hurvitz PM, Moudon AV, Kang B, Fesinmeyer MD, Saelens BE. How far from home? The locations of physical activity in an urban U.S. setting. Prev Med 2014 Dec;69:181-186. [doi: 10.1016/j.ypmed.2014.08.034] [Medline: 25285750]

58. Brown BB, Wilson L, Triby CP, Werner CM, Wolf J, Miller HJ, et al. Adding maps (GPS) to accelerometer data to improve study participants' recall of physical activity: a methodological advance in physical activity research. Br J Sports Med 2014 Jul;48(13):1054-1058 [FREE Full text] [doi: 10.1136/bjsports-2014-093530] [Medline: 24815545]

59. Hurvitz PM, Moudon AV, Kang B, Saelens BE, Duncan GE. Emerging technologies for assessing physical activity behaviors in space and time. Front Public Health 2014;2:2 [FREE Full text] [doi: 10.3389/fpubh.2014.00002] [Medline: 24479113]
60. Barbero-Alvarez JC, Coutts A, Granda J, Barbero-Alvarez V, Castagna C. The validity and reliability of a global positioning satellite system device to assess speed and repeated sprint ability (RSA) in athletes. J Sci Med Sport 2010 Mar;13(2):232-235. [doi: 10.1016/j.jams.2009.02.005] [Medline: 19446495]

61. MacLeod H, Morris J, Nevill A, Sunderland C. The validity of a non-differential global positioning system for assessing player movement patterns in field hockey. J Sports Sci 2009 Jan 15;27(2):121-128. [doi: 10.1080/02640410802422181] [Medline: 19058089]

62. Duffield R, Reid M, Baker J, Spratford W. Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. J Sci Med Sport 2010 Sep;13(5):523-525. [doi: 10.1016/j.jams.2009.07.003] [Medline: 19853507]

63. Portas MD, Harley JA, Barnes CA, Rush CJ. The validity and reliability of 1-Hz and 5-Hz global positioning systems for measuring distance travelled in team sport specific running patterns. Int J Sports Physiol Perform 2010 Sep;5(3):328-341. [Medline: 20861523]

64. Johnston RJ, Watsford ML, Pine MJ, Spurrs RW, Murphy AJ, Pruyn EC. The validity and reliability of 5-Hz global positioning system units to measure team sport movement demands. J Strength Cond Res 2012 Mar;26(3):758-765. [doi: 10.1519/JSC.0b013e318225f161] [Medline: 22310508]
83. Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. J Sports Sci 2012;30(2):121-127. [doi: 10.1080/02640414.2011.627941] [Medline: 22122431]

84. Molinos Domene A. Evaluation of movement and physiological demands of full-back and center-back soccer players using global positioning systems. Journal of Human Sport and Exercise 2013;8(4):1015-1028. [doi: 10.4100/jhse.2013.84.12]

85. White AD, MacFarlane N. Time-on-pitch or full-game GPS analysis procedures for elite field hockey? Int J Sports Physiol Perform 2013 Sep;8(5):549-555. [Medline: 23412758]

86. Dwyer DB, Gabbett TJ. Global positioning system data analysis: velocity ranges and a new definition of sprinting for field sport athletes. J Strength Cond Res 2012 Mar;26(3):818-824. [doi: 10.1519/JSC.0b013e3182276555] [Medline: 22310509]

87. O'Hara JP, Brightmore A, Till K, Mitchell I, Cummings S, Cooke CB. Evaluation of movement and physiological demands of rugby league referees using global positioning systems tracking. Int J Sports Med 2013 Sep;34(9):825-831. [doi: 10.1055/s-0033-1333694] [Medline: 23444093]

88. McMinn D, Rowe DA, Cuk I. Evaluation of the trackstick super GPS tracker for use in walking research. Res Q Exerc Sport 2012 Mar;83(1):108-113. [doi: 10.1080/02701367.2012.10599831] [Medline: 22428418]

89. McMinn D, Oreskovic NM, Aitkenhead MJ, Johnston DW, Murtagh S, Rowe DA. The physical environment and health-enhancing activity during the school commute: global positioning system, geographical information systems and accelerometry. Geospat Health 2014 May;8(2):569-572. [doi: 10.4081/gh.2014.46] [Medline: 24893034]

90. Kerr J, Marshall S, Godbole S, Neukam S, Kerr J, Ersbøll AK, Troelsen J. The relationship between outdoor activity and health in older adults using GPS. Int J Environ Res Public Health 2012 Dec;9(12):4615-4625 [FREE Full text] [Medline: 23330225]

91. Christian WJ. Using geospatial technologies to explore activity-based retail food environments. Spat Spatiotemporal Epidemiol 2012 Dec;3(4):287-295. [doi: 10.1016/j.sste.2012.09.001] [Medline: 23149325]

92. Dessing D, Pierik FH, Sterkenburg RP, van Dommelen P, Maas J, de Vries SI. Schoolyard physical activity of 6-11 year old children assessed by GPS and accelerometer. Int J Behav Nutr Phys Act 2013;10:97 [FREE Full text] [Medline: 23945145]

93. Epstein DH, Tyburski M, Craig IM, Phillips KA, jobes ML, Vahabzadeh M, et al. Real-time tracking of neighborhood surroundings and mood in urban drug misusers: application of a new method to study behavior in its geographical context. Drug Alcohol Depend 2014 Jan 1;134:22-29 [FREE Full text] [doi: 10.1016/j.drugalcdep.2013.09.007] [Medline: 24332365]

94. Klinker CD, Schipperijn J, Christian H, Kerr J, Ersbøll AK, Troelsen J. Using accelerometers and global positioning system devices to assess gender and age differences in children's school, transport, leisure and home based physical activity. Int J Behav Nutr Phys Act 2014;11:8 [FREE Full text] [doi: 10.1186/1479-5868-11-8] [Medline: 24457029]

95. O'Connor TM, Oreskovic NM. Comparing self-identified and census-defined neighborhoods among adolescents using GPS, and focus groups. J Phys Act Health 2014 Nov;11(8):1517-1524. [doi: 10.1123/jpah.2012-0420] [Medline: 23733298]

96. Evenson KR, Wen F, Hillier A, Cohen DA. Assessing the contribution of parks to physical activity using global positioning system and accelerometer. Med Sci Sports Exerc 2013 Oct;45(10):1981-1987 [FREE Full text] [doi: 10.1249/MSS.0b013e318293330e] [Medline: 23531716]

97. Robinson AI, Oreskovic NM. Comparing self-identified and census-defined neighborhoods among adolescents using GPS and accelerometer. Int J Health Geogr 2013;12:57 [FREE Full text] [doi: 10.1186/1476-072X-12-57] [Medline: 24325342]

98. Prins RG, Pierik F, Elman A, Sterkenburg RP, Kamphuis CB, van Lenthe FJ. How many walking and cycling trips made by elderly are beyond commonly used buffer sizes: results from a GPS study. Health Place 2014 May;27:127-133. [doi: 10.1016/j.healthplace.2014.01.012] [Medline: 24603010]

99. Dessing D, de Vries SI, Graham JM, Pierik FH. Active transport between home and school assessed with GPS: a cross-sectional study among Dutch elementary school children. BMC Public Health 2014;14:227 [FREE Full text] [doi: 10.1186/1471-2458-14-227] [Medline: 24597513]

100. Harrison F, Burgoine T, Corder K, van Sluijs E, Jones A. How well do modelled routes to school record the environments children are exposed to? A cross-sectional comparison of GIS-modelled and GPS-measured routes to school. Int J Health Geogr 2014;13:5 [FREE Full text] [doi: 10.1186/1476-072X-13-5] [Medline: 24529075]

101. Klinker CD, Schipperijn J, Kerr J, Ersbøll AK, Troelsen J. Context-specific outdoor time and physical activity among school-children across gender and age: using accelerometers and GPS to advance methods. Front Public Health 2014;2:20 [FREE Full text] [doi: 10.3389/fpubh.2014.00020] [Medline: 24653983]

102. Ellis K, Godbole S, Marshall S, Lanckriet G, Staudenmayer J, Kerr J. Identifying active travel behaviors in challenging environments using GPS, accelerometers, and machine learning algorithms. Front Public Health 2014;2:36 [FREE Full text] [doi: 10.3389/fpubh.2014.00036] [Medline: 24795875]

103. Moore HJ, Nixon CA, Lake AA, Douthwaite W, O'Malley CL, Pedley CL, et al. The environment can explain differences in adolescents' daily physical activity levels living in a deprived urban area: cross-sectional study using accelerometer, GPS, and focus groups. J Phys Act Health 2014 Nov;11(8):1517-1524. [doi: 10.1123/jpah.2012-0420] [Medline: 23733145]

104. Panter J, Costa S, Dalton A, Jones A, Ogilvie D. Development of methods to objectively identify time spent using active and motorised modes of travel to work: how do self-reported measures compare? Int J Behav Nutr Phys Act 2014;11:116 [FREE Full text] [doi: 10.1186/s12966-014-0116-x] [Medline: 25231500]
105. Terrier P, Ladetto Q, Merminod B, Schutz Y. High-precision satellite positioning system as a new tool to study the biomechanics of human locomotion. J Biomech 2000 Dec;33(12):1717-1722. [Medline: 11006399]
106. Terrier P, Ladetto Q, Merminod B, Schutz Y. Measurement of the mechanical power of walking by satellite positioning system (GPS). Med Sci Sports Exerc 2001 Nov;33(11):1912-1918. [Medline: 11689743]
107. Tropef PJ, Oliveira MS, Matthews CE, Cromley EK, Melly SJ, Craig BA. Prediction of activity mode with global positioning system and accelerometer data. Med Sci Sports Exerc 2008 May;40(5):972-978. [doi: 10.1249/MSS.0b013e318164e407]
108. Tropef PJ, Wilson JS, Matthews CE, Cromley EK, Melly SJ. The built environment and location-based physical activity. Am J Prev Med 2010 Apr;38(4):429-438 [FREE Full text] [doi: 10.1016/j.amepre.2009.12.032] [Medline: 20307812]
109. Krenn PJ, Oja P, Titze S. Route choices of transport bicyclists: a comparison of actually used and shortest routes. Int J Behav Nutr Phys Act 2014;11(1):31 [FREE Full text] [doi: 10.1186/1479-5868-11-31] [Medline: 24597725]
110. Almanza E, Jerrett M, Dunton G, Seto E, Pentz MA. A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data. Health Place 2012 Jan;18(1):46-54 [FREE Full text] [doi: 10.1016/j.healthplace.2011.09.003] [Medline: 22423906]
111. Dunton GF, Liao Y, Almanza E, Jerrett M, Spruitt-Metz D, Chou C, et al. Joint physical activity and sedentary behavior in parent-child pairs. Med Sci Sports Exerc 2012 Aug;44(8):1473-1480 [FREE Full text] [doi: 10.1249/MSS.0b013e31825148e9] [Medline: 22367744]
112. Dunton GF, Liao Y, Almanza E, Jerrett M, Spruitt-Metz D, Pentz MA. Locations of joint physical activity in parent-child pairs based on accelerometer and GPS monitoring. Ann Behav Med 2013 Feb;45 Suppl 1:S162-S172 [FREE Full text] [doi: 10.1007/s12160-012-9417-y] [Medline: 23011914]
113. Jerrett M, Almanza E, Davies M, Wolch J, Dunton G, Spruitt-Metz D, et al. Smart growth community design and physical activity in children. Am J Prev Med 2013 Oct;45(4):386-392. [doi: 10.1016/j.amepre.2013.05.010] [Medline: 24050413]
114. Dunton GF, Almanza E, Jerrett M, Wolch J, Pentz MA. Neighborhood park use by children: use of accelerometry and global positioning systems. Am J Prev Med 2014 Feb;46(2):136-142 [FREE Full text] [doi: 10.1016/j.amepre.2013.10.009] [Medline: 24439346]
115. Paz-Soldan VA, Reiner RC, Morrison AC, Stoddard ST, Kitron U, Scott TW, et al. Strengths and weaknesses of Global Positioning System (GPS) data-loggers and semi-structured interviews for capturing fine-scale human mobility: findings from Iquitos, Peru. PLoS Negl Trop Dis 2014 Jun;8(6):e2888 [FREE Full text] [doi: 10.1371/journal.pntd.0002888] [Medline: 24922530]
116. Feng T, Timmermans HJ. Transportation mode recognition using GPS and accelerometer data. Transp Res Part C Emerg Technol 2013 Dec;37:118-130. [doi: 10.1016/j.trc.2013.09.014]
117. Neven A, Janssens D, Alders G, Wets G, Van Wijmeersch B, Feys P. Documenting outdoor activity and travel behaviour in persons with neurological conditions using travel diaries and GPS tracking technology: a pilot study in multiple sclerosis. Disabil Rehabil 2013 Sep;35(20):1718-1725. [doi: 10.3109/09638288.2012.751137] [Medline: 23343357]
118. Clark RA, Wergodana N, Paterson K, Telianidis S, Williams G. A pilot investigation using global positioning systems into the outdoor activity of people with severe traumatic brain injury. J Neuroeng Rehabil 2014;11:37 [FREE Full text] [doi: 10.1186/1743-0003-11-37] [Medline: 24645752]
119. Doherty ST, Oh P. A multi-sensor monitoring system of human physiology and daily activities. Telemed J E Health 2012 Apr;18(3):185-192. [doi: 10.1089/tmj.2011.0138] [Medline: 22480300]
120. MacLellan G, Baillie L. Development of a location and movement monitoring system to quantify physical activity. In: Proceedings of the Conference on Human Factors in Computing Systems. New York, NY: ACM; 2008 Presented at: Conference on Human Factors in Computing Systems; April 5-10, 2008; Florence, Italy p. 2889-2894. [doi: 10.1145/1358628.1358779]
121. Minarik T, Hofer C, Schrempf A. A novel activity monitoring device for home rehabilitation applications. In: Proceedings of the 9th IASTED International Conference on Biomedical Engineering. 2012 Presented at: 9th IASTED International Conference on Biomedical Engineering; February 15-17, 2012; Innsbruck, Austria p. 400-407. [doi: 10.2316/P.2012.764-120] [Medline: 21288235]
122. Li I, Dey AK, Forlizzi J. Using context to reveal factors that affect physical activity. ACM Trans Comput Hum Interact 2012 Mar 01;19(1):1-21. [doi: 10.1145/2147783.2147790]
123. Rainham DG, Bates CJ, Blanchard CM, Dummer TJ, Kirk SF, Shearer CL. Spatial classification of youth physical activity patterns. Am J Prev Med 2012 May;42(5):e87-e96. [doi: 10.1016/j.amepre.2012.02.011] [Medline: 22516507]
124. Schenk AK, Withbrod BC, Hoarty CA, Carlson RH, Goulding EH, Potter JF, et al. Cellular telephones measure activity and lifestyle in community-dwelling adults: proof of principle. J Am Geriatr Soc 2011 Feb;59(2):345-352 [FREE Full text] [doi: 10.1111/j.1532-5415.2010.03267.x] [Medline: 21288235]
125. Schutz Y, Herren R. Assessment of speed of human locomotion using a differential satellite global positioning system. Med Sci Sports Exerc 2000 Mar;32(3):642-646. [Medline: 10731007]
126. Sposaro F, Daniels J, Tyson G. iWander: An Android application for dementia patients. Conf Proc IEEE Eng Med Biol Soc 2010;2010:3875-3878. [doi: 10.1109/IEMBS.2010.5627669] [Medline: 21097072]
127. Wiehe SE, Carroll AE, Liu GC, Haberkorn KL, Hoch SC, Wilson JS, et al. Using GPS-enabled cell phones to track the travel patterns of adolescents. Int J Health Geogr 2008;7:22 [Full text] [doi: 10.1186/1476-072X-7-22] [Medline: 18495025]

128. Duncan JS, Badland HM, Schofield G. Combining GPS with heart rate monitoring to measure physical activity in children: a feasibility study. J Sci Med Sport 2009 Sep;12(5):583-585. [doi: 10.1016/j.jsams.2008.09.010] [Medline: 19036637]

129. Rainham D, Krewski D, McDowell I, Sawada M, Liekens B. Development of a wearable global positioning system for place and health research. Int J Health Geogr 2008;7:59 [Full text] [doi: 10.1186/1476-072X-7-59] [Medline: 19032783]

130. Townshend AD, Worringham CJ, Stewart IB. Assessment of speed and position during human locomotion using nondifferential GPS. Med Sci Sports Exerc 2008 Jan;40(1):124-132. [doi: 10.1249/mss.0b013e3181590bc2] [Medline: 18091013]

131. Witte TH, Wilson AM. Accuracy of WAAS-enabled GPS for the determination of position and speed over ground. J Biomech 2005 Aug;38(8):1717-1722. [doi: 10.1016/j.jbiomech.2004.07.028] [Medline: 15958230]

132. Schutz Y, Chambaz A. Could a satellite-based navigation system (GPS) be used to assess the physical activity of individuals on earth? Eur J Clin Nutr 1997 May;51(5):338-339. [Medline: 9152866]

133. Moayeri PG, Troped P, Evans J. Environment feature extraction and classification for Context aware Physical Activity monitoring. In: Proceedings of the IEEE Sensors Applications Symposium (SAS). 2013 Presented at: IEEE Sensors Applications Symposium (SAS); February 19-21, 2013; Galveston, TX p. 123-128. [doi: 10.1016/SAS.2013.6493570]

134. Oreskovic NM, Perrin JM, Robinson AI, Locascio JJ, Blossom J, Chen ML, et al. Adolescents' use of the built environment and sedentary travel behaviour? Results from a pilot study. Int J Behav Nutr Phys Act 2011;8:44 [FREE Full text] [Medline: 10.1186/1479-5868-8-44]

135. Zhu C, Sheng W. Real-time recognition of complex human daily activities using dynamic Bayesian network. In: Proceedings of the 8th International Conference on Intelligent Robots and Systems. Berlin, Germany: IEEE; 2010 Presented at: 8th International Conference on Intelligent Robots and Systems; September 25-30, 2011; San Francisco, CA p. 3395-3400.

136. Zhu C, Sheng W. Real-time recognition of complex human daily activities using motion and location data. IEEE Trans Biomed Eng 2012 Sep;59(9):2422-2430. [doi: 10.1109/TBME.2012.2190602] [Medline: 22434793]

137. Zhang H, Li L, Jia W, Fernstrom JD, Sclabassi RJ, Sun M. Recognizing physical activity from ego-motion of a camera. Conf Proc IEEE Eng Med Biol Soc 2010;2010:5569-5572. [doi: 10.1109/IEMBS.2010.5626794] [Medline: 21096480]

138. Li L, Zhang H, Jia W, Mao Z, Sun M. Indirect activity recognition using a target-mounted camera. In: Proceedings of the 4th International Congress on Image and Signal Processing (CISP). Washington, DC: IEEE; 2011 Presented at: 4th International Congress on Image and Signal Processing (CISP); October 15-17, 2011; Shanghai, China p. 487-491.

139. Zhang H, Li L, Jia W, Fernandez JD, Sclabassi RJ, Mao Z, et al. Physical activity recognition based on motion in images acquired by a wearable camera. Neurocomputing 2011 Jun 1;74(12-13):2184-2192 [Free Full text] [doi: 10.1016/j.neucom.2011.02.014] [Medline: 21779142]

140. Maekawa T, Yanagisawa Y, Kishino K, Kamei K, Sakurai Y, et al. Object-based activity recognition with heterogeneous sensors on wrist. In: Proceedings of the 8th International Conference, Pervasive Computing. Berlin, Germany: Springer Berlin Heidelberg; 2010 Presented at: 8th International Conference, Pervasive Computing; May 17-20, 2010; Helsinki, Finland p. 246-264. [doi: 10.1007/978-3-642-12654-3_15]

141. Maekawa T, Kishino Y, Yanagisawa Y, Sakurai Y, WristSense: wrist-worn sensor device with camera for daily activity recognition. In: Proceedings of the IEEE International Conference on Pervasive Computing and Communications Workshops. 2012 Presented at: IEEE International Conference on Pervasive Computing and Communications Workshops; March 19-23, 2012; Lugano, Switzerland p. 510-512. [doi: 10.1109/PerComW.2012.6197551]

142. Mavoa S, Oliver M, Kerr J, Doherty A, Witten K. Using SenseCam images to assess the environment. In: Proceedings of the 4th International SenseCam and Pervasive Imaging Conference. New York, NY: ACM; 2013 Presented at: 4th International SenseCam and Pervasive Imaging Conference; November 18-19, 2013; San Diego, CA p. 84-85. [doi: 10.1145/2526667.2526683]

143. Kelly P, Doherty AR, Hamilton A, Matthews B, Batterham AM, Nelson M, et al. Evaluating the feasibility of measuring travel to school using a wearable camera. Am J Prev Med 2012 Nov;43(5):546-550 [Full text] [doi: 10.1016/j.amepre.2012.07.027] [Medline: 23079179]

144. Wang P, Smeaton AF. Using visual lifelogs to automatically characterize everyday activities. Inf Sci 2013 May;230:147-161. [doi: 10.1016/j.ins.2012.12.028]

145. Kelly P, Doherty A, Berry E, Hodges S, Batterham AM, Foster C. Can we use digital life-log images to investigate active and sedentary travel behaviour? Results from a pilot study. Int J Behav Nutr Phys Act 2011;8:44 [Full text] [doi: 10.1186/1479-5868-8-44] [Medline: 21599935]
147. Doherty AR, Kelly P, Kerr J, Marshall S, Oliver M, Badland H, et al. Using wearable cameras to categorise type and context of accelerometer-identified episodes of physical activity. Int J Behav Nutr Phys Act 2013;10:22 [FREE Full text] [doi: 10.1186/1479-5868-10-22] [Medline: 23406270]

148. Kerr J, Marshall SJ, Godbole S, Chen J, Legge A, Doherty AR, et al. Using the SenseCam to improve classifications of sedentary behavior in free-living settings. Am J Prev Med 2013 Mar;44(3):290-296. [doi: 10.1016/j.amepre.2012.11.004] [Medline: 23415127]

149. Marinac C, Merchant G, Godbole S, Chen J, Kerr J, Clark B, et al. The feasibility of using SenseCams to measure the type and context of daily sedentary behaviors. In: Proceedings of the 4th International SenseCam and Pervasive Imaging Conference. New York, NY: ACM; 2013 Presented at: 4th International SenseCam and Pervasive Imaging Conference; November 18-19, 2013; San Diego, CA. p. 42-49. [doi: 10.1145/2526667.2526674]

150. Oliver M, Doherty AR, Kelly P, Badland HM, Mavoa S, Shepherd J, et al. Utility of passive photography to objectively audit built environment features of active transport journeys: an observational study. Int J Health Geogr 2013;12:20 [FREE Full text] [doi: 10.1186/1476-072X-12-20] [Medline: 23575288]

151. Sheats J, Winter S, Padilla-Romero P, Goldman-Rosas L, Grieco L, King A. Comparison of passive versus active photo capture of built environment features by technology naive latinos using the sensecam and stanford healthy neighbourhood discovery tool. In: Proceedings of the 4th International SenseCam and Pervasive Imaging Conference. New York, NY: ACM; 2013 Presented at: 4th International SenseCam and Pervasive Imaging Conference; November 18-19, 2013; San Diego, CA. p. 8-15. [doi: 10.1145/2526667.2526669]

152. O'Loughlin G, Cullen SJ, McGoldrick A, O'Connor S, Blain R, O'Malley S, et al. Using a wearable camera to increase the accuracy of dietary analysis. Am J Prev Med 2013 Mar;44(3):297-301. [doi: 10.1016/j.amepre.2012.11.007] [Medline: 23415128]

153. Barr M, Signal L, Jenkin G, Smith M. Using SenseCam to capture children's exposure to food marketing: a feasibility study. In: Proceedings of the 4th International SenseCam and Pervasive Imaging Conference. New York, NY: ACM; 2013 Presented at: 4th International SenseCam and Pervasive Imaging Conference; November 18-19, 2013; San Diego, CA. p. 50-51. [doi: 10.1145/2526667.2526675]

154. Thomaz E, Parmami A, Essa I, Abowd G. Feasibility of identifying eating moments from first-person images leveraging human computation. In: Proceedings of the 4th International SenseCam and Pervasive Imaging Conference. New York, NY: ACM; 2013 Presented at: 4th International SenseCam and Pervasive Imaging Conference; November 18-19, 2013; San Diego, CA. p. 26-33. [doi: 10.1145/2526667.2526672]

155. Gemming L, Doherty AR, Kelly P, Utter J, Ni Murchee C. Feasibility of a SenseCam-assisted 24-h recall to reduce under-reporting of energy intake. Eur J Clin Nutr 2013 Oct;67(10):1095-1099. [doi: 10.1038/ejcn.2013.156] [Medline: 24002044]

156. Zariffa J, Popovic MR. Hand contour detection in wearable camera video using an adaptive histogram region of interest. J Neuroeng Rehabil 2013;10:114 [FREE Full text] [doi: 10.1186/1743-0003-10-114] [Medline: 24354542]

157. Hong Y, Kim I, Ahn S, Kim H. Activity recognition using wearable sensors for elder care. In: Proceedings of the 2nd International Conference on Future Generation Communication and Networking (FGCN). Washington, DC: IEEE; 2008 Presented at: 2nd International Conference on Future Generation Communication and Networking (FGCN); December 13-15, 2008; Hainan Island, China p. 302-305. [doi: 10.1109/FGCN.2008.165]

158. House S, Connell S, Milligan I, Austin D, Hayes TL, Chiang P. Indoor localization using pedestrian dead reckoning updated with RFID-based fiducials. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). Washington, DC: IEEE; 2011 Presented at: Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); August 30-September 3, 2011; Boston, MA. p. 7598-7601. [doi: 10.1109/EMBS.2011.6091873]

159. Hsu C, Chen J. A novel sensor-assisted RFID-based indoor tracking system for the elderly living alone. Sensors (Basel) 2011;11(11):10094-10113 [FREE Full text] [doi: 10.3390/s111110094] [Medline: 22346651]

160. Lin C, Hsu Y. IPARS: Intelligent Portable Activity Recognition System via Everyday Objects, Human Movements, and Activity Duration. Palo Alto, CA: American Association for Artificial Intelligence; 2006. URL: https://www.aaai.org/Papers/Workshops/2006/WS-06-13/WS06-13-007.pdf [accessed 2015-07-31] [WebCite Cache ID 6aR4aDAzo]

161. Lin Y, Su M, Chen S, Wang S, Lin C, Chen H. A study of ubiquitous monitor with RFID in an elderly nursing home. In: Proceedings of the International Conference on Multimedia and Ubiquitous Engineering (MUE). Washington, DC: IEEE; 2007 Presented at: International Conference on Multimedia and Ubiquitous Engineering (MUE); April 26-28, 2007; Seoul, South Korea p. 336-340. [doi: 10.1109/MUE.2007.55]

162. Stikic M, Huỳnh T, Laerhoven K, Schiele B. ADL recognition based on the combination of RFID and accelerometer sensing. In: Proceedings of the 2nd International Conference on Pervasive Computing Technologies for Healthcare. Washington, DC: IEEE; 2008 Presented at: 2nd International Conference on Pervasive Computing Technologies for Healthcare; January 30-February 1, 2008; Tampere, Finland p. 258-263. [doi: 10.1109/PCTHEALTH.2008.4571084]

163. Morton T, Weeks A, House S, Chiang P, Scaffidi C. Location and activity tracking with the cloud. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). Washington, DC: 2015.
164. Jin G, Lu X, Park M. An indoor localization mechanism using active RFID tag. In: Proceedings of the IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing. 2006 Presented at: IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing; June 5-7, 2006; Taichung, Taiwan p. 4. [doi: 10.1109/SUTC.2006.1636157]

165. Ni L, Liu Y, Lau Y, Patil A. LANDMARC: indoor location sensing using active RFID. In: Proceedings of the 1st IEEE International Conference on Pervasive Computing and Communications. Washington, DC: IEEE; 2004 Presented at: 1st IEEE International Conference on Pervasive Computing and Communications; March 26, 2003; Fort Worth, TX p. 701-710. [doi: 10.1109/PERCOM.2003.1192765]

166. Shiraiishi T, Komuro N, Ueda H, Kasah H, Tsuibo T. Indoor location estimation technique using UHF band RFID. In: Proceedings of the International Conference on Information Networking. Washington, DC: IEEE; 2008 Presented at: International Conference on Information Networking; January 23-25, 2008; Busan, South Korea p. 1-5. [doi: 10.1109/ICOIN.2008.4472808]

167. Tesoriero R, Tebar R, Gallud J, Lozano M, Penichet V. Improving location awareness in indoor spaces using RFID technology. Expert Syst Appl 2010 Jan;37(1):894-898. [doi: 10.1016/j.eswa.2009.05.062]

168. Bouchard K, Fortin-Simard D, Gaboury S, Bouchard B, Bouzouane A. Accurate RFID trilateration to learn and recognize spatial activities in smart environment. International Journal of Distributed Sensor Networks 2013;2013:1-16. [doi: 10.1155/2013/936816]

169. Smith L, Ucci M, Marmot A, Spinney R, Laskowski M, Sawyer A, et al. Active buildings: modelling physical activity and movement in office buildings. An observational study protocol. BMJ Open 2013;3(11):e004103 [FREE Full text] [doi: 10.1136/bmjopen-2013-004103] [Medline: 24227873]

170. Ni L, Liu Y, Lau Y, Patil A. LANDMARC: indoor location sensing using active RFID. Wireless Networks 2004;10(6):701-710. [doi: 10.1109/PERCOM.2003.1192765]

171. Kim S, Jeong Y, Park S. RFID-based indoor location tracking to ensure the safety of the elderly in smart home environments. Pers Ubiquit Comput 2013;17(8):1699-1707. [doi: 10.1007/s00779-012-0604-4]

172. Almudevar A, Leibovici A, Tentler A. Home monitoring using wearable radio frequency transmitters. Artif Intell Med 2008 Feb;42(2):109-120. [doi: 10.1016/j.artmed.2007.11.002] [Medline: 18215512]

173. Frencken WG, Lemmink KA, Delleman NJ. Soccer-specific accuracy and validity of the local position measurement (LPM) system. J Sci Med Sport 2010 Nov;13(6):641-645. [doi: 10.1016/j.jsams.2010.04.003] [Medline: 20594910]

174. Ogris G, Leser R, Horsak B, Kornfeind P, Heller M, Baca A. Accuracy of the LPM tracking system considering dynamic position changes. J Sports Sci 2012;30(14):1503-1511. [doi: 10.1080/0264042X.2012.712712] [Medline: 22906154]

175. Sathyan T, Shuttleworth R, Hedley M, Davids K. Validity and reliability of a radio positioning system for tracking athletes in indoor and outdoor team sports. Behav Res Methods 2012 Dec;44(4):1108-1114. [doi: 10.3758/s13428-012-0192-2] [Medline: 22477436]

176. Stelzer A, Fischer A, Vossiek M. A new technology for precise local position measurement-LPM. In: Proceedings of the IEEE MTT-S International Microwave Symposium Digest. Washington, DC: IEEE; 2004 Presented at: IEEE MTT-S International Microwave Symposium Digest; June 6-11, 2004; Fort Worth, TX p. 655-658. [doi: 10.1109/MWSYM.2004.1360722]

177. Stelzer A, Pourvoyeur K, Fischer A. Concept and Application of LPM- A Novel 3-D Local Position Measurement System. IEEE Trans Microw Theory Tech 2004 Dec;52(12):2664-2669. [doi: 10.1109/TMTT.2004.838281]

178. Pei L, Guinness R, Chen R, Liu J, Kuusniemi H, Chen Y, et al. Human behavior cognition using smartphone sensors. Sensors (Basel) 2013;13(2):1402-1424 [FREE Full text] [doi: 10.3390/s130201402] [Medline: 23348030]

179. Stratton G, Murphy R, Rosenberg M, Ferguson P, Attwood A. Creating intelligent environments to monitor and manipulate physical activity and sedentary behavior in public health and clinical settings. In: Proceedings of the IEEE International Conference on Communications. Washington, DC: IEEE; 2012 Presented at: IEEE International Conference on Communications; June 10-15, 2012; Ottawa, ON p. 6111-6115. [doi: 10.1109/ICC.2012.6364974]

180. Stroiescu F, Daly K, Kuris B. Event detection in an assisted living environment. In: Proceedings of the Annual International Conference on Medicine in Engineering and Biology Society (EMBC). Washington, DC: IEEE; 2011 Presented at: Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); August 30-September 3, 2011; Boston, MA p. 7581-7584. [doi: 10.1109/IEMBS.2011.6091869]

181. Pei L, Chen R, Chen Y, Leppakoski H, Perttula T. Indoor/outdoor seamless positioning technologies integrated on smart phone. In: Proceedings of the International Conference on Advances in Satellite and Space Communications. Washington, DC: IEEE; 2009 Presented at: International Conference on Advances in Satellite and Space Communications; July 20-25, 2009; Colmar, France p. 141-145. [doi: 10.1109/SPACOMM.2009.12]

182. D’Souza M, Wark T, Karunanithi M, Ros M. Evaluation of realtime people tracking for indoor environments using ubiquitous motion sensors and limited wireless network infrastructure. Pervasive Mob Comput 2013 Aug;9(4):498-515. [doi: 10.1016/j.pmcj.2012.03.007]
183. Villarrubia G, De PJ, Bajo J, Corchado J. Real time positioning system using different sensors. In: Proceedings of the International Conference on Information Fusion. Washington, DC: IEEE; 2013 Presented at: International Conference on Information Fusion; July 9-12, 2013; Istanbul, Turkey p. 604-609.

184. Dunton GF, Whalen CK, Jamner LD, Floro JN. Mapping the social and physical contexts of physical activity across adolescence using ecological momentary assessment. Ann Behav Med 2007 Oct;34(2):144-153. [doi: 10.1080/08836610701566803] [Medline: 17927553]

185. Dunton GF, Liao Y, Intille S, Wolch J, Pentz MA. Physical and social contextual influences on children's leisure-time physical activity: an ecological momentary assessment study. J Phys Act Health 2011 Jan;8 Suppl 1:S103-S108. [Medline: 21350250]

186. Dunton GF, Kawabata K, Intille S, Wolch J, Pentz MA. Assessing the social and physical contexts of children's leisure-time physical activity: an ecological momentary assessment study. Am J Health Promot 2012 Feb;26(3):135-142. [doi: 10.4278/ajhp.100211-QUAN-43] [Medline: 22208410]

187. Dunton GF, Intille SS, Wolch J, Pentz MA. Investigating the impact of a smart growth community on the contexts of children's physical activity using Ecological Momentary Assessment. Health Place 2012 Jan;18(1):76-84 [FREE Full text] [doi: 10.1016/j.healthplace.2011.07.007] [Medline: 22439009]

188. Liao Y, Intille S, Wolch J, Pentz MA, Dunton GF. Understanding the physical and social contexts of children's nonschool sedentary behavior: an ecological momentary assessment study. J Phys Act Health 2014 Mar;11(3):588-595. [doi: 10.1123/japh.2011-0363] [Medline: 23493261]

189. Spook JE, Paulussen T, Kok G, Van Empelen P. Monitoring dietary intake and physical activity electronically: feasibility, usability, and ecological validity of a mobile-based Ecological Momentary Assessment tool. J Med Internet Res 2013;15(9)e214 [FREE Full text] [doi: 10.2196/mir.2617] [Medline: 24067298]

190. Liao Y, Intille SS, Dunton GF. Using ecological momentary assessment to understand where and with whom adults’ physical and sedentary activity occur. Int J Behav Med 2015 Feb;22(1):51-61. [doi: 10.1007/s12529-014-9400-z] [Medline: 24639067]

191. Engelen L, Bundy AC, Lau J, Naughton G, Wyver S, Bauman A, et al. Understanding patterns of young children's physical activity after school - it’s all about context: a cross-sectional study. J Phys Act Health 2015 Mar;12(3):335-339. [doi: 10.1123/japh.2013-0152] [Medline: 24828415]

192. Greiner C, Makimoto K, Suzuki M, Yamakawa M, Ashida N. Feasibility study of the integrated circuit tag monitoring system for dementia residents in Japan. Am J Alzheimers Dis Other Demen 2007 May;22(2):129-136. [doi: 10.1177/1533317507299414]

193. Yamakawa M, Suto S, Shigenobu K, Kunimoto K. Comparing dementia patients' nighttime objective movement indicators with staff observations. Psychogeriatrics 2012 Mar;12(1):18-26. [doi: 10.1111/j.1479-8301.2011.00380.x] [Medline: 22416825]

194. Hay S, Rassia S, Beresford A. Estimating personal energy expenditure with location data. In: Proceedings of the 8th IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops). Washington, DC: IEEE; 2010 Presented at: 8th IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops); March 29-April 2, 2010; Mannheim, Germany p. 304-309. [doi: 10.1109/PERCOMW.2010.5470650]

195. Ramulu PY, Chan ES, Loyd TL, Ferrucci L, Friedman DS. Comparison of home and away-from-home physical activity indicators with staff observations. Psychogeriatrics 2012 Mar;12(1):18-26. [doi: 10.1111/j.1479-8301.2011.00380.x] [Medline: 22416825]

196. Kelly D, McLoone S, Logan B, Dishongh T. Single access point localisation for wearable wireless sensors. In: Proceedings of the 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Washington, DC: IEEE; 2008 Presented at: 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society; August 20-25, 2008; Vancouver, BC p. 4443-4446. [doi: 10.1109/IEMBS.2008.4650197]

197. Ben-Harush O, Carroll J, Marsh B. Using mobile social media and GIS in health and place research. Continuum: Journal of Clin Neurological Sci 2013;19(4):4781-4810 [FREE Full text] [doi: 10.1002/1556-9527.EBCite2010.06430] [Medline: 21530250]

198. Yeh S, Chang K, Wu C, Chu H, Hsu JY. GETA sandals: a footstep location tracking system. Pers Ubiquit Comput 2007 Feb 1;11(6):451-463. [doi: 10.1007/s00779-006-0098-z]

199. Shahid B, Kannan AA, Lovell NH, Redmond SJ. Ultrasound user-identification for wireless sensor networks. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). Washington, DC: IEEE; 2010 Presented at: Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); August 31-September 4, 2010; Buenos Aires, Argentina p. 5756-5759. [doi: 10.1109/EMBS.2010.5470650]

200. Lan K, Shih W. On calibrating the sensor errors of a PDR-based indoor localization system. Sensors (Basel) 2013;13(4):4781-4810 [FREE Full text] [doi: 10.3390/s130404781] [Medline: 23575036]

201. Autographer. URL: http://www.autographer.com/ [accessed 2015-05-04] [WebCite Cache ID 6YGw4cjlu]

202. Narrative. URL: http://getnarrative.com/narrative-clip-1 [accessed 2015-05-04] [WebCite Cache ID 6YGw4jqfDX]

203. MeCam. URL: http://www.mecam.me/collections/all-products/products/mecam?variant=388052188 [accessed 2015-05-04] [WebCite Cache ID 6YGw4cFkC]

204. uCorder. URL: http://www.ucorder.com/IRDC260r-pocket-camcorder.html [accessed 2015-05-04] [WebCite Cache ID 6YGw4cZ9p]
205. Parashoot. URL: http://theparashoot.com/ [accessed 2015-05-04] [WebCite Cache ID 6YGwmeZsC]

206. Spy Emporium. URL: http://www.spyemporium.com/covert-wearable-cameras/5mp-hd-hidden-dvr-spy-camera-eyeglasses/ [accessed 2015-05-04] [WebCite Cache ID 6YGwuU2kEo]

207. VIEVU. URL: http://www.vievu.com/vievu-products/hardware/ [accessed 2015-05-04] [WebCite Cache ID 6YGwujJ9xy]

208. Panasonic. URL: http://security.panasonic.com/pss/security/products/ind/TW310/index.html [accessed 2015-05-04] [WebCite Cache ID 6YGx2RSpJ]

209. meMINI. URL: http://memini.com/ [accessed 2015-05-04] [WebCite Cache ID 6YGxHzYpt]

210. Pivothead. URL: http://www.pivothead.com/technology/originals/ [accessed 2015-05-04] [WebCite Cache ID 6YGxMEy7k]

211. Nixie. URL: http://thynixie.com/ [accessed 2015-05-04] [WebCite Cache ID 6YGxSVJZk]

212. CA7CH. URL: http://www.ca7ch.com/preorder/ [accessed 2015-05-04] [WebCite Cache ID 6YGxXMPkU]

213. ELMO USA. URL: http://www.elmousa.com/qbie/wearable-cameras [accessed 2015-05-04] [WebCite Cache ID 6YGxxRGyH]

214. Vidian. URL: http://www.vidian.com/vidian-cameras-kits/ [accessed 2015-05-04] [WebCite Cache ID 6YGx08gG]

215. Ekahau. URL: http://www.ekahau.com/realt-time-location-system/ [accessed 2015-05-14] [WebCite Cache ID 6YW8hsj88]

216. Ubisense. URL: http://www.ubisense.net/en/products/smart-factory [accessed 2015-05-27] [WebCite Cache ID 6YqK59jbd]

217. AeroScout. URL: http://www.aeroscout.com/12-tag-family [accessed 2015-05-04] [WebCite Cache ID 6YGyOOGFg]

218. Zebra. URL: https://www.zebra.com/us/en/products/location-solutions/wherentag/wheretag.html [accessed 2015-05-04] [WebCite Cache ID 6YGy0V4C]

219. Elpas. URL: http://www.elps.com/Products/Healthcare-Asset-Tracking-Tag.aspx [accessed 2015-05-04] [WebCite Cache ID 6YGyvAlvb]

220. CenTrak. URL: http://www.centrak.com/products/ [accessed 2015-05-04] [WebCite Cache ID 6YGzhsB0Q]

221. TeleTracking. URL: http://www.teletracking.com/ [accessed 2015-05-04] [WebCite Cache ID 6YGzxa6B8]

222. Sonitor. URL: http://www.sonitor.com/ [accessed 2015-05-04] [WebCite Cache ID 6GYzAmB0]

223. Versus. URL: http://www.versustech.com/ [accessed 2015-05-04] [WebCite Cache ID 6YGzv8Cj]

224. Radiance. URL: http://www.radiance.com/ [accessed 2015-05-27] [WebCite Cache ID 6YqKVF6sd]

225. Secure Care. URL: http://www.securitycarehealthcare-rtls [accessed 2015-05-27] [WebCite Cache ID 6YqKLYkwx]

226. Mojix. URL: http://www.mojix.com/products/eloation.php [accessed 2015-05-04] [WebCite Cache ID 6YH07G0Z2]

227. AssetWorks. URL: http://www.assetworks.com/ [accessed 2015-05-04] [WebCite Cache ID 6YH0BLo9Y]

228. Tempsys. URL: http://www.tempsys.net/realt-time-location-systems/ [accessed 2015-05-04] [WebCite Cache ID 6YH0EF015]

229. AwarePoint. URL: http://www.awarepoint.com/ [accessed 2015-05-04] [WebCite Cache ID 6YH0HE015]

230. Comita. URL: http://comita.net/en/comprehensive-security-solution/comita-rtls/ [accessed 2015-05-04] [WebCite Cache ID 6YH0LCdBK]

231. TrackIT. URL: http://www.thetrackit.com/products.php [accessed 2015-05-04] [WebCite Cache ID 6YH004Wl]

232. Nebusens. URL: http://www.nebusens/index.php/en/products/n-core/hardware [accessed 2015-05-04] [WebCite Cache ID 6YH0S9B0]

233. Essensium. URL: http://www.essensium.com/ [accessed 2015-05-04] [WebCite Cache ID 6YH0UQ99]

234. PLUS Location. URL: http://pluslocation.com/ [accessed 2015-06-24] [WebCite Cache ID 6ZW866UB]

235. Technical Life Care. URL: http://www.technicallifecare.com/RTLS-services.php [accessed 2015-05-04] [WebCite Cache ID 6YH0i7Te]

236. AiRISTA. URL: http://www.airista.com/ [accessed 2015-05-14] [WebCite Cache ID 6YWGRxW3]

237. Conduto. URL: http://www.conduco.co.uk/solutions/rtls-real-time-locating-systems/ [accessed 2015-05-04] [WebCite Cache ID 6YH121YAG]

238. Luminosity. URL: http://www.luminosityhealth.com/index.php/luminosity-features/rtls [accessed 2015-05-04] [WebCite Cache ID 6YH10AGDb]

239. PureLink. URL: http://www.purelink.ca/fr/products/equipment-tracking-tag.php [accessed 2015-05-04] [WebCite Cache ID 6YH1652qz]

240. Sanitag. URL: http://www.sanitag.com/ [accessed 2015-05-04] [WebCite Cache ID 6YH190dzC]

241. Aida. URL: http://www.aidafrid.com/index.php/products-solutions/aida-rtls [accessed 2015-05-04] [WebCite Cache ID 6YH1E0S0M5]

242. OpenRTLS. URL: http://www.openrtls.com/shop/product/tag-23 [accessed 2015-05-04] [WebCite Cache ID 6YH1G73N1]

243. BeSpoon. URL: http://bespoon.com/3d-precise-location-rtls/ [accessed 2015-05-04] [WebCite Cache ID 6YH1JRyV]

244. Ecived. URL: http://www.ecived.com/en/product_show.aspx?id=18 [accessed 2015-05-04] [WebCite Cache ID 6YH1M7ZK8]

245. Skytron. URL: http://www.skytron.us/products/pages/gen2ir.html [accessed 2015-05-04] [WebCite Cache ID 6YH1POJOp]

246. LogiTag. URL: http://logi-tag.com/products/rtls/patientflow.html [accessed 2015-05-04] [WebCite Cache ID 6YH1Rz6GG]

247. RedPoint Positioning. Redpoint URL: http://www.redpointpositioning.com/products-services/?prod=radionodes [accessed 2015-05-04] [WebCite Cache ID 6YH1TCh6q]

248. Borda Technology. URL: http://www.bordatech.com/products_hardware.html [accessed 2015-05-04] [WebCite Cache ID 6YH1XpZPC]

249. PointRF. URL: http://pointrf.com/technology.php [accessed 2015-05-04] [WebCite Cache ID 6YH1XpZPC]
250. Trackstick. URL: http://www.trackstick.com/products/mini/index.html [accessed 2015-05-04] [WebCite Cache ID 6YH28d2Em]
251. Trackershop. URL: http://www.trackershop-uk.com/shop/personal-gps-trackers/pro-pod-5-personal-gps-tracker/ [accessed 2015-05-04] [WebCite Cache ID 6YH22nIKQ]
252. Gotek7. URL: http://www.gotek7.com/ [accessed 2015-05-27] [WebCite Cache ID 6YqL0pKwX]
253. CareWhere. URL: http://carewhere.co.uk/ [accessed 2015-05-04] [WebCite Cache ID 6YH2Rrl9d]
254. PocketFinder. URL: http://www.pocketfinder.com/ [accessed 2015-05-04] [WebCite Cache ID 6YH2TAkR]
255. Bluetrack. URL: http://bluetrackgpstrackers.co.uk/shop/gps-trackers/prime-lite/ [accessed 2015-05-04] [WebCite Cache ID 6YH2U4c4t]
256. Trackinapack. URL: http://www.trackinapack.co.uk/advanced-gps-tracking-device [accessed 2015-05-05] [WebCite Cache ID 6YM1ECB6]
257. Protect my kids. URL: http://www.protectmykids.co.uk/gps-tracking-device-kids-monitoring-protect-kids/ [accessed 2015-05-05] [WebCite Cache ID 6YMJii1w]
258. Amber Alert GPS. URL: http://www.amberalertgps.com/ [accessed 2015-05-05] [WebCite Cache ID 6YIMM4Q48]
259. TracLogik. URL: http://www.traclogik.co.uk/product/covert-2000/ [accessed 2015-05-05] [WebCite Cache ID 6YMXshO8]
260. Laipac. URL: http://www.laipac.com/ [accessed 2015-05-27] [WebCite Cache ID 6YqL15gLd]
261. Loc8tor. URL: http://www.loc8tor.com/ [accessed 2015-05-05] [WebCite Cache ID 6YIMp8VEy]
262. Miegtrack. URL: http://www.miegtrack.net/portable-gps-tracker/ [accessed 2015-05-05] [WebCite Cache ID 6YIMrHrX]
263. SonikGPS. URL: http://sonikgps.com/sonik_global_tracking.html [accessed 2015-05-05] [WebCite Cache ID 6YIMvH9KC]
264. Global Tracking Group. URL: http://www.globaltrackinggroup.com/gps-tracking-device-ub5000e.cfm [accessed 2015-05-05] [WebCite Cache ID 6YIMsKCQw]
265. GPsIntegrated. URL: http://gpsintegrated.com/products/personal-tracker/handheld-gps/gsm-tracker-g1202 [accessed 2015-05-05] [WebCite Cache ID 6YIN0HWR]
266. buddi. URL: https://www.buddi.co.uk/ [accessed 2015-05-05] [WebCite Cache ID 6YIN4sVj3]
267. Keytracker. URL: http://www.keytracker.com/products_personnelgps.php [accessed 2015-05-05] [WebCite Cache ID 6YN7inLg]
268. RM Tracking. URL: http://www.rmtracking.com/ [accessed 2015-05-05] [WebCite Cache ID 6YINCZiYk]
269. LandAirSea. URL: https://www.landairsea.com/gps-tracker [accessed 2015-05-05] [WebCite Cache ID 6YNHi1yz]
270. Dynaspy. URL: https://www.dynaspy.com/gps-tracking-devices/real-time-gps-trackers/worldtracker-enduro-pro-gps-tracker [accessed 2015-05-05] [WebCite Cache ID 6YINKLC1w]
271. WheribleGPS. URL: http://www.wheriblegps.com/products/wheritrack-device/ [accessed 2015-05-05] [WebCite Cache ID 6YIOK1FGs]
272. iLOC. URL: https://www.ilocotech.com/triloc/purchase [accessed 2015-05-05] [WebCite Cache ID 6YIOLnr4b]
273. GTX Corp. URL: https://gtxcorp.com/ [accessed 2015-05-27] [WebCite Cache ID 6YqM3n5n]
274. BioSensics. URL: http://www.biosensics.com/shop/pamsys-motion-sensor-with-gps/ [accessed 2015-05-05] [WebCite Cache ID 6YIOY4x8d]
275. Recon Instruments. URL: http://www.reconinstruments.com/products/jet/ [accessed 2015-05-05] [WebCite Cache ID 6YIoa78Hb]
276. Nike. URL: https://secure-nikeplus.nike.com/plus/products/sport_watch/ [accessed 2015-05-05] [WebCite Cache ID 6YIQcS6gr]
277. Garmin. URL: http://www.garmin.com/en-GB [accessed 2015-05-14] [WebCite Cache ID 6YWYKYO9Ns]
278. Revolutionary Tracker. URL: http://www.revolutionarytracker.com/ [accessed 2015-05-05] [WebCite Cache ID 6YIPXPvAz]
279. Everon. URL: http://www.everon.fi/en/solutions/vega-gps-safety-solution-and-bracelet [accessed 2015-05-05] [WebCite Cache ID 6YIPZia4t]
280. Trax. URL: http://traxfamily.zendesk.com/hc/en-gb/articles/200310982-Tracker-specifications [accessed 2015-05-05] [WebCite Cache ID 6YIQ5NeF1]
281. Ninja Tracking. URL: http://www.ninjatracking.co.uk/prime-at-lite [accessed 2015-05-05] [WebCite Cache ID 6YIQ6mio2]
282. Personal GPS Trackers. URL: http://www.personalgpstrackers.co.uk [accessed 2015-05-05] [WebCite Cache ID 6YIQ988PK]
283. Retriever. URL: http://www.retriever.com/pre-order [accessed 2015-05-05] [WebCite Cache ID 6YIQFD6pa]
284. Duotraq. URL: http://www.duotraq.com/ [accessed 2015-05-27] [WebCite Cache ID 6YqMBkJ0Vz]
285. Mindme. URL: http://www.mindme.com/ [accessed 2015-05-05] [WebCite Cache ID 6YIQY6YoY]
286. Bubble Tracker. URL: http://www.bubbletacker.com/ [accessed 2015-05-05] [WebCite Cache ID 6YIQKMIviU]
287. Maddison R, Ni Mhurchu C. Global positioning system: a new opportunity in physical activity measurement. Int J Behav Nutr Phys Act 2009;6:73 [FREE Full text] [doi: 10.1186/1479-5866-6-73] [Medline: 19887012]
288. Krenn PJ, Titze S, Oja P, Jones A, Ogilvie D. Use of global positioning systems to study physical activity and the environment: a systematic review. Am J Prev Med 2011 Nov;41(5):508-515 [FREE Full text] [doi: 10.1016/j.amepre.2011.06.046] [Medline: 22011423]
289. Kamel Boulos MN, Berry G. Real-time locating systems (RTLS) in healthcare: a condensed primer. Int J Health Geogr 2012;11:25 [FREE Full text] [doi: 10.1186/1476-072X-11-25] [Medline: 22741760]

290. Stojanović D, Stojanović N. Facta Universitatis, Series: Automatic Control and Robotics. 2014. Indoor localization and tracking: methods, technologies and research challenges URL: http://casopisi.junis.ni.ac.rs/index.php/FUAutContRob/article/download/208/88 [accessed 2015-07-31] [WebCite Cache ID 6aRElrDiw]

291. Liu H, Darabi H, Banerjee P, Liu J. Survey of Wireless Indoor Positioning Techniques and Systems. IEEE Trans Syst Man Cybern C Appl Rev 2007 Nov;37(6):1067-1080. [doi: 10.1109/TSMCC.2007.905750]

292. Curran K, Furey E, Lunney T, Santos J, Woods D, McCaughey A. An evaluation of indoor location determination technologies. Journal of Location Based Services 2011 Jun;5(2):61-78. [doi: 10.1080/17489725.2011.562927]

293. Koyuncu H, Yang S. A survey of indoor positioning and object locating systems. International Journal of Computer Science and Network Security 2010;10(5):121-128.

294. Kelly P, Doherty A, Berry E, Hodges S, Batterham AM, Foster C. Can we use digital life-log images to investigate active and sedentary travel behaviour? Results from a pilot study. Int J Behav Nutr Phys Act 2011;8:44 [FREE Full text] [doi: 10.1186/1479-5868-8-44] [Medline: 21599935]

295. Macdonald-Wallis K, Jago R, Sterne JA. Social network analysis of childhood and youth physical activity: a systematic review. Am J Prev Med 2012 Dec;43(6):636-642. [doi: 10.1016/j.amepre.2012.08.021] [Medline: 23159259]

296. Kelly P, Marshall SJ, Badland H, Kerr J, Oliver M, Doherty AR, et al. An ethical framework for automated, wearable cameras in health behavior research. Am J Prev Med 2013 Mar;44(3):314-319. [doi: 10.1016/j.amepre.2012.11.006] [Medline: 23415131]

Abbreviations

AOA: angle of arrival
BL: battery life
BLE: Bluetooth low energy
CCTV: closed-circuit television
CR: camera resolution
Dim: dimensions
EMA: ecological momentary assessment
FPS: frames per second
GIS: geographic information system
GPS: global positioning system
IC: integrated circuit
IEEE: Institute of Electrical and Electronics Engineers
I/O: indoor/outdoor
IR: infrared
Man: manufacturer
MET: metabolic equivalent
MVPA: moderate-to-vigorous physical activity
N/A: not applicable
NIHR CLAHRC for EM: National Institute for Health Research Collaboration for Leadership in Applied Health Research and Care—East Midlands
PALMS: Personal Activity and Location Measurement System
Refs: references
RF: radio frequency
RFID: radio-frequency identification
RSSI: received signal strength indicator
RTLS: real-time locating system
SF: sampling frequency
TDOA: time difference of arrival
TOA: time of arrival
TOF: time of flight
TWR: two-way ranging
UWB: ultra wide band
