Body Tracking in Healthcare

Synthesis Lectures on Assisstive, Rehabilitative, and Health-Preserving Technologies

Ronald M. Baecker, *University of Toronto*

Advances in medicine allow us to live longer, despite the assaults on our bodies from war, environmental damage, and natural disasters. The result is that many of us survive for years or decades with increasing difficulties in tasks such as seeing, hearing, moving, planning, remembering, and communicating.

This series provides current state-of-the-art overviews of key topics in the burgeoning field of assistive technologies. We take a broad view of this field, giving attention not only to prosthetics that compensate for impaired capabilities, but to methods for rehabilitating or restoring function, as well as protective interventions that enable individuals to be healthy for longer periods of time throughout the lifespan. Our emphasis is in the role of information and communications technologies in prosthetics, rehabilitation, and disease prevention.

Body Tracking in Healthcare
Kenton O'Hara, Cecily Morrison, Abigail Sellen, Nadia Bianchi-Berthouze, Cathy Craig
March 2016

Fieldwork for Healthcare: Guidance for Investigating Human Factors in Computing Systems
Dominic Furniss, Aisling Ann O'Kane, Rebecca Randell, Svetlena Taneva, Helena Mentis, and Ann Blandford
2014

Designed Technologies for Healthy Aging
Claudia B. Rébola
2014

Fieldwork for Healthcare: Case Studies Investigating Human Factors in Computing Systems
Dominic Furniss, Aisling Ann O'Kane, Rebecca Randell, Svetlena Taneva, Helena Mentis, and Ann Blandford
2014

Interactive Technologies for Autism
Julie A. Kientz, Matthew S. Goodwin, Gillian R. Hayes, Gregory D. Abowd

2013

Patient-Centered Design of Cognitive Assistive Technology for Traumatic Brain Injury Telerehabilitation
Elliot Cole
2013

Zero Effort Technologies: Considerations, Challenges, and Use in Health,Wellness, and Rehabilitation
Alex Mihailidis, Jennifer Boger, Jesse Hoey, and Tizneem Jiancaro
2011

Design and the Digital Divide: Insights from 40 Years in Computer Support for Older and Disabled People
Alan F. Newell
2011

Body Tracking in Healthcare
Kenton O'Hara, Cecily Morrison, Abigail Sellen, Nadia Bianchi-Berthouze, Cathy Craig
www.morganclaypool.com

ISBN: 9781627054560 print
ISBN: 9781627059503 ebook

DOI 10.2200/S00702ED1V01Y201602ARH009

A Publication in the Morgan and Claypool Publishers series
SYNTHESIS LECTURES ON ASSISTIVE, REHABILITATIVE, AND HEALTH-PRESERVING TECHNOLOGIES, #9
Series Editors: Ronald M. Baecker, University of Toronto

Series ISSN 2162-7258 Print 2162-7266 Electronic

Body Tracking in Healthcare

Kenton O'Hara
Microsoft Research, Cambridge
Cecily Morrison
Microsoft Research, Cambridge
Abigail Sellen
Microsoft Research, Cambridge
Nadia Bianchi-Berthouze
University College London
Cathy Craig
Queens University, Belfast

SYNTHESIS LECTURES ON ASSISTIVE, REHABILITATIVE, AND HEALTH-PRESERVING TECHNOLOGIES #9

MORGAN & CLAYPOOL PUBLISHERS

ABSTRACT

Within the context of healthcare, there has been a long-standing interest in understanding the posture and movement of the human body. Gait analysis work over the years has looked to articulate the patterns and parameters of this movement both for a normal healthy body and in a range of movement-based disorders. In recent years, these efforts to understand the moving body have been transformed by significant advances in sensing technologies and computational analysis techniques all offering new ways for the moving body to be tracked, measured, and interpreted. While much of this work has been largely research focused, as the field matures, we are seeing more shifts into clinical practice. As a consequence, there is an increasing need to understand these sensing technologies over and above the specific capabilities to track, measure, and infer patterns of movement in themselves. Rather, there is an imperative to understand how the material form of these technologies enables them also to be situated in everyday healthcare contexts and practices. There are significant mutually interdependent ties between the fundamental characteristics and assumptions of these technologies and the configurations of everyday collaborative practices that are possible them. Our attention then must look to social, clinical, and technical relations pertaining to these various body technologies that may play out in particular ways across a range of different healthcare contexts and stakeholders. Our aim in this book is to explore these issues with key examples illustrating how social contexts of use relate to the properties and assumptions bound up in particular choices of body-tracking technology. We do this through a focus on three core application areas in healthcare—assessment, rehabilitation, and surgical interaction—and recent efforts to apply body-tracking technologies to them.

KEYWORDS

body tracking, healthcare, rehabilitation, assessment, motion tracking, technology, computer vision, computing, human-computer interaction, touchless interaction, data, algorithms, health, sensors, gait analysis, mobile, gesture, medical imaging, accelerometer, depth sensor, force sensors, inertial measurement unit, balance board, body-worn sensors, interactive technology, physiotherapy, doctor, patient, multiple sclerosis, chronic pain, stroke, fall risk, Parkinson's disease, cameras, activity monitoring, collaboration, teamwork, kinematics, kinetics, robotics, wearable computing, exergames, surgery, natural user interfaces, exercise, older adults, natural user interface, speech, movement disorder

Dedication

To Dylan and Darby

Contents

List of Figures

Figures 2.1, 2.3, and 2.5 are from an article by the authors published in *Human-Computer Interaction*, 2016 (copyright Taylor and Francis), available online at www.tandfonline.com/10.1080/07370024.2015.1093421.

Figures 2.2 and 2.6 are from an article by the authors published in *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2014*, Volume 8674 of the series Lecture Notes in Computer Science, 2014 (copyright Springer), available online at http://link.springer.com/10.1007/978-3-319-10470-6_54.

Figure 3.1 is from an article by the authors published in *CHI 2014* (copyright ACM), available online at http://dx.doi.org/10.1145/2556288.2557268 and from an article by the authors published in *Human-Computer Interaction*, 2015 (copyright Taylor and Francis), available online at http://www.tandfonline.com/10.1080/07370024.2015.1085310.

Figure 3.2 is from an article by the authors published in *Games for Health Journal*, 2015 (copyright Mary Ann Liebert, Inc), available online at http://online.liebertpub.com/doi/full/10.1089/g4h.2015.0006.

Figures 4.1 and 4.6 are from an article by the authors published in *Transactions on Computer Human Interaction*, 2013 (copyright ACM), available online at http://dl.acm.org/citation.cfm?doid=2442106.2442111.

Figure 4.2 is from article by the authors published in *CHI '11, 2011*, (copyright ACM), available online at http://dl.acm.org/citation.cfm?id=1979436&CFID=591545870&CFTOKEN=33599456.

Figures 4.3, 4.4, 4.7, and 4.8 are from an article by the authors published in *Journal of Computer Supported Cooperative Work*, 2014 (copyright Springer), available online at http://link.springer.com/article/10.1007/s10606-014-9203-4.

Figure 4.9 reproduced with kind permission from Mithun Jacob and Juan Wachs.

CHAPTER 1

Introduction

Understanding the posture and motion of the human body has been an enduring interest and concern within healthcare settings. For well over a century now, gait analysis work has sought to systematically characterize and quantify different aspects of the body in locomotion (e.g., Whittle, 1996a, 1996b). In particular, these efforts have looked to articulate the patterns and parameters of a normal healthy gait as well as the deviations from a normal gait that are characteristic of particular forms of clinical movement disorders from neurological conditions through to musculoskeletal conditions. Augmenting the observational methods of experts, our understanding of the moving body has been furthered through evolving forms of technological development and instrumentation. The early photographic techniques pioneered by Eadweard Muybridge (1893) and Étienne-Jules Marey (1890) gave rise to important advances in the science and understanding gait analysis over and above what was possible with unaided observational approaches. Following this came the widespread introduction of the video camera, which again opened more sophisticated ways in which characteristics of human movement could be systematically measured, analyzed, and understood. In more recent decades, the field has witnessed even more dramatic technological developments with the emergence of a wide variety of sophisticated computational sensing technologies and techniques. Accelerometers, gyroscopes, goniometers, smart fabrics, force plates, and electro-magnetic sensors, as well as a marker-based and marker-free computer-vision techniques, all offer new ways in which different features of bodily posture and locomotion can be tracked, measured, and interpreted.

These developments have been significant for a number of reasons. In part, this evolving instrumentation offers an increasingly diverse set of ways that features of body movement can be sensed, measured, classified and represented. These may include the spatio-temporal properties of individual joints and limbs (e.g., position, acceleration, rotation), spatio-temporal measures of particular actions (such as stride length, gestures), tracking and representations of complete action trajectories, kinetic forces, and outcome measures such as achievement of particular motion end goals (e.g., successfully reaching for an object). Their significance lies also in efficiencies that they can bring to the analysis of body motion data, reducing the cost and time of data capture and making such data accessible to richer more sophisticated mathematical analysis. This has led to accelerated developments in the fundamental understanding of normal human motion as well as in our understanding and assessment of the movement abnormalities and symptomatic movement patterns (e.g., tremor, freezing) manifest in clinical conditions such as cerebral palsy (CP), Parkinson's disease, multiple sclerosis (MS), chronic pain, and stroke (e.g., Dobson et al., 2007; Hass et al., 2005;

Rodda et al., 2004; Salarian et al., 2004; Morris et al., 1996; Socie and Sosnoff, 2013; Ferrarin et al., 2014). This understanding is important both for diagnostic assessments and treatment planning but also to enable us to understand the impact of particular interventions on the disease progression.

The above significances relate well to the core aims of traditional gait analysis work within the healthcare domain in the sense that they are concerned primarily with notions of measuring and analyzing the body with a view to achieving some form of clinical interpretation. But there is additional significance in this digital instrumentation of gait and motion analysis that can be found in the interactive opportunities that have opened up. The digital sensing and tracking of the body in motion now presents opportunities for computational behaviors and responses to be made contingent upon digitally represented patterns of human motion. In this respect the moving body is no longer just a quantifiable object of analysis and classification in itself as it might be conceived within more traditional orientations to gait analysis and clinical assessment. Rather, the body can be transformed in profound ways by the ability to digitally infer and dynamically respond to its patterns of motion. This further opens up the ways in which we need to understand the properties of these body-tracking technologies in healthcare because of the system behaviors that can now be attached to their output. Here then, it is not just what aspects of the body in motion can be tracked and quantified but also what the system can action on the basis of this data. It is the data in application that opens a broader scope of enquiry in relation to these technologies and for which there is a larger set of socio-technical concerns at play.

If we think about the use of body-tracking technology within rehabilitation scenarios for example, the more traditional focus of gait analysis has been with the assessment of particular movement disabilities displayed by a particular individual. Such assessment then forms the basis of planning appropriate and bespoke treatment regimes or evaluating the success of particular clinical intervention on movement disability severity (e.g., Kuan et al., 1999; Salarian et al., 2004; Stokic et al., 2009; Lopez-Meyer et al. 2011). But with the widening scope enabled by the interactive capabilities of these body-tracking technologies, we are now seeing growing interest in rehabilitation scenarios that extend beyond the analytic offerings of earlier forms of gait analysis. So, for example, rehabilitative treatment interventions have been developed that provide various forms of feedback to a patient based on particular forms of clinically relevant bodily motion with a view to facilitating the patient's understanding and awareness of their movement (e.g., Singh et al., 2014). Similarly, numerous examples of interactive serious games and exercise programs have been explored to exploit motion-based tracking control as a means to encourage particular forms of body movement in the context of a patient's movement rehabilitation (Alankus et al. 2010; Geurts et al., 2011; Jaume-i-Capó, 2014).

Other examples opened up by the possibilities for actively responding to the tracked body include everyday *activity monitoring*. Here, rather than using the body-tracking technology for clinical assessment, the opportunities are in ongoing sensing of movement in everyday life and

inferring particular forms of behavioral action states from the sensor data. An example here would be fall monitoring in older adults where body worn accelerometers can be used to infer when the characteristic patterns of a fall have occurred. On detection of the characteristic data pattern various things are consequently triggered such as sending a notification to a caregiver or clinician. The impact of this on the everyday practices and lives of the patients in question extends beyond the more traditional realms of gait analysis and this need to be understood in new ways. Other clinically significant patterns of movement disorder have the potential to be inferred in the context of everyday living. For example, the gait initiation and freeze states associated within Parkinson's disease may be inferred in ways that could allow the triggering of new forms of interactive clinical intervention.

But such digital instrumentation of body movement analysis also offers opportunities in healthcare contexts that extend even further outside the bounds of more traditional gait analysis. More specifically here, we can shift our attention from patient-centric application of these technologies (where the form and motion of the patient's body is of central concern) to new forms of clinician-centric applications. Here it is the body of the clinician, not the patient, which can be also considered as a focal point for body-tracking technologies to enable new forms of body and motion-based interactive possibilities in healthcare scenarios. Of particular interest here has been the context of the operating room where body tracking of the clinician offers the potential to overcome the specific constraints of these environments imposed on more traditional interaction techniques. By tracking the body movements of the clinician as opposed to the patient in these contexts, control of surgical equipment, for example, can be achieved touchlessly with these technologies without compromising sterility.

With these developments in technology, then, we have greater number of ways that body movement can be captured, measured, and interpreted, but also a much broader scope of potential application areas for the healthcare domain. Understanding these technologies and their clinical significance raises a diverse set of concerns. On the one hand, one might look to understand these technologies in the terms of particular characteristics of movement that they capture and measure and the performance parameters of the technologies relating to these—for example their accuracy, precision, resolution and reliability with respect to different types of movement representation. While this provides a useful first basis for thinking about these technologies, it is quickly apparent that such characterizations are not sufficient in and of themselves. One cannot simply consider the performance attributes of these technologies in terms of their relative distance from an ideal way of representing the body in the richest and most accurate way possible. So while greater motion tracking performance in terms of resolution, reliability, and accuracy may open up new opportunities they are not end goals in themselves. The more pertinent concern here is what needs to be measured and how well for a particular clinical scenario at hand—be that understanding the movement patterns of a clinical disorder or sensing movement necessary to achieve particular interactive outcomes. Each of these contexts, uses, and clinical conditions may demand more or less

of particular forms of body tracking and may be robust in different ways to the respective limitations and characteristics of these technologies. One of the goals of the book is to highlight some of the complex interdependencies between the technical readings of the body's motion and clinical perspectives. The aim here is to allow a greater reflection on some of the assumptions bound up in body-tracking technologies and algorithms with a view to understanding their clinical significance.

1.1 ENABLING TECHNOLOGIES

To help us further these discussions, we first take a look at some of the key technological approaches for measuring and understanding different aspects of the body in motion. One of the key approaches concerns *Kinematic* characterizations of the moving body, which articulate geometrical features of body motion such as limb/joint position, orientation, displacement, velocity, and acceleration. These geometrical features of motion may be articulated in two and three dimensions depending on the requirements of the scenario and may apply to specific limbs and joints or the moving body as a whole.

1.1.1 CAMERA-BASED SYSTEMS

Many kinematic systems for tracking and measuring the moving body rely on some form of *camera-based* set-up. Simple systems can be based around single camera set-ups though these can present certain limitations in terms of orientation flexibility and in terms of opportunities for tracking in three dimensions. Many of the more sophisticated commercial set-ups used in high end gait laboratories though rely on multi camera set-ups to enable orientation flexibility and full 3D capture of limb and joint movement. While there are variants in the different systems, these high-end systems generally rely on some form of marker tracking. Here different types of markers are attached to the joints and limbs in standardized configurations such as the Helen Hayes (Vaughan et al., 1992) and CAST (Cappozzo et al., 1995) marker sets. These may be passive systems in which retro-reflective markers reflect infrared or visible light back to the sensing camera. Alternatively, some systems use active marker systems such as opto-electronics that employ light emitting diodes (LEDs) as markers. The advantage of the active systems is that they can more reliably identify and track the individual markers from one frame to the next leading to a much less noisy and stable tracking of the markers.

Generally speaking, most of the commercial camera based systems offer good accuracy in terms of position data, somewhere in the region of 1–3 mm in all dimensions. Measurements of acceleration and velocity can suffer when there is even a small amount of noise in the original data, though these can often be compensated for through the application of appropriate filtering of the data if this is not detrimental to a particular clinical scenario. Other challenges arise from the requirements for accurate positioning of the markers correctly on the body that can require a certain

level of expertise on the part of the operator. Estimation techniques for this positioning are subject to certain errors while there are also sources of error arising from the movement of markers relative to their intended position with respect to the bone.

Such set-ups, while producing good quality data, can be cumbersome and expensive to set-up, requiring large amounts of dedicated space that is difficult to reconfigure and move. For many application possibilities that may be less sensitive to fine grained accuracy requirements, these may be well beyond the scope of what is necessary. An intriguing shift in recent years has been the rise of much cheaper camera-based alternatives derived from commercial camera-based computer gaming systems such as, most recently, Sony's PlayStation camera and Microsoft's Kinect. The Kinect system in particular has received particular interest in the clinical communities that has begun to assess its feasibility for a range of rehabilitation, assessment, monitoring, and control scenarios (e.g., Gabel et al., 2012; Stone and Skubic, 2011a, 2011b). Significant here is that it is offers a much more affordable alternative to the high-end gait laboratory tracking set-ups. Similarly, while it is fixed during actual use, it is relatively portable making it suitable for easy deployment in a wider range of environments than more high end gait lab set-ups (e.g., home). The Kinect system combines VGA and depth sensing cameras and, as well as producing a raw depth image of any scene and body sampled, software is used to infer and extract a virtual skeleton model of the scanned body to be tracked in real time (Shotton et al., 2011). The inferred skeleton in the Kinect SDK comprises 20 points based on rough estimations of the center of the major joints in the human body meaning that tracking is not dependent upon the placement of external markers on the body—the set-up effort and costs entailed by marker-based set-ups. Such inferred estimates of the major joints though do come with certain compromises in terms of the precision. Such precision may be suitable for coarse-grained gestural interaction and simple quantifications of motion parameters (Bonnechère et al., 2014). The inferred skeleton of the Kinect is also a planar representation so it does not constitute a full 3D representation of the human body which again creates certain constraints in the ways such technology might be deployed. This also has implications for the organization of body movement in the sense that the tracked body assumes the body is facing toward the camera. In its out-of-the-box form, it may be less suited to visualizing and understanding of the complex motion patterns associated related to the pathologies associated with cerebral palsy, stroke, chronic pain, etc. Such constraints though may be overcome by supplementing the inferences with anatomically correct motion modeling data from validated biomechanical studies of complex movements (Bonnechère, et al., 2013). The important point highlighted by Bonnechère is that the characteristics of any enabling technology for motion tracking is in part related to the fundamental sensing capabilities, and in part related to the assumptions and inferences of the associated computing algorithms. Both of these need to be understood in relation to the application opportunities of the particular body-tracking technology.

1.1.2 BODY WORN SENSORS

A significant alternative to vision-based approaches to kinematic motion tracking in healthcare can be found in the use of body worn sensors (e.g., Morris, 1973). Such sensor-based approaches are of appeal in the sense that they are relatively inexpensive and impose fewer constraints on the area of movement. There are a number of commonly used sensors such as accelerometers, gyroscopes, and goniometers that are either held, worn, or attached to particular parts of the body such as the leg, foot, arm, waist, etc. (e.g., Crea et al., 2014). *Accelerometers* are a form of inertial sensor that measures acceleration along a particular axis of movement and from which velocity and positional data can be derived—although there are generally accepted problems of "drift" with accelerometers since errors in measurement accumulate from point to point and build up over time. There are three common variants of accelerometer, piezoelectric, piezoresistive, and capacitive with capacitive generally having higher levels of sensitivity and resolution (Wong et al., 2007). In order to enable the sensing and measurement of rotational movements, accelerometers are often combines with *gyroscopes*, a form of inertial sensor that measures angular velocity. Again, when attached to particular parts of the body, this angular motion velocity can be used to measure and classify key features of body movement (e.g., Ayrulu-Erdem and Barshan, 2011; Tuncel et al., 2009). These can also be complemented with data from *magnetometers*, which essentially allow position and orientation of the sensor relative to the magnetic field (Graham et al., 2004). While magnetometers are relatively poor for accurate assessment of fast movements they do not suffer from the same levels of drift over time and thus can compensate for some of the drawbacks of the other two types of sensor in helping to determine accurate orientation and position. Advances in microelectronics now means that these sensors scan be combined in a single unit. As with some of the marker-based camera approaches, wearable sensors can suffer some similar challenges in terms of the accuracy with which they can be placed relative to corresponding body parts.

A further kinematic characteristic of movement concerns the relative motion between different body segments. The continuous measurement of the angle of a joint between two body segments can be achieved using various forms of *electrogoniometers*, based on strain gauges, potentiometers, and mechanical flexible techniques. While a single goniometer will measure angles in one plane it is possible to mount multiple goniometers in different planes for multiaxial tracking requirements.

With advances in material sciences, sensing fabrics (e.g., de Rossi et al., 2001; Sawhney et al., 2006; Scilingo et al., 2003; Mazzoldi et al., 2002) also offer an intriguing way to track measure characteristics of body posture and motion. Here fabrics are imbued with particular sensing attributes by depositing different forms of polymers and materials onto or into the fabric. The deposited materials can have different resistive and capacitive qualities that dynamically change as the fabric is stretched. While these systems vary in their responsiveness they are important in the ways that they begin to highlight some of the more practical elements of sensing activities in particular for

adoption in more every day healthcare scenarios. The fabrics offer a lightweight and ergonomically comfortable way of getting sensing on the body and thus may have benefit for body-tracking applications that take place in everyday contexts over longer periods of time.

1.1.3 FORCE AND PRESSURE-BASED SYSTEMS

As well as articulating the basic patterns of motion posture in *kinematic* terms, there are also important elements of body tracking that can be grounded in more *kinetic* terms. Such kinetic characterizations are concerned with how movement manifests in terms of force and pressure. Force platforms, for example, are commonplace within gait labs. Such platforms consist of a rigid upper surface layer. Beneath this layer is a set of transducers positioned appropriately to measure small displacements of the upper surface in three axes. What is of interest in such systems is while the foot is the point of contact with the system, the recorded forces actually pertain to the motion of the body as a whole, representing the acceleration of the center of gravity of the whole body. From such analysis of the end points of motion we can determine something more holistic about the ongoing posture, sway and balance of the body. This information can be important for diagnostic purposes, rehabilitation, and interactional control. Interestingly, derivatives of this technology have found their way into commercial gaming systems such as the Wii Balance Board. As with the Kinect system discussed earlier, the significance of this lies in making these tracking and measuring capabilities available at a much lower cost and in a way that is accessible in a wider range of environments outside of high end gait laboratories, such as the home. Other force sensors may be worn on the body and, in particular, embedded into footwear (e.g., Faivre et al., 2004) creating opportunities for kinetic sensing of movement within an even broader range of everyday circumstances.

While these sensing technologies form the fundamental basis for tracking the body, the captured data is actually only the starting point. In order to make sense out of the captured data, additional analytic techniques need to be applied. For example, various forms of algorithmic filters may be applied in to compensate for particular features and shortcomings of particular sensing technologies in relation to certain forms of body motion. Such filters discard or transform selected unwanted elements of the data while maintaining other relevant parts.

1.2 BODY TRACKING IN CONTEXT

As we suggested above, presenting an overview of the enabling technologies in this way allows us to get an initial sense of the possibilities. But the driving concern in such treatment remains with the centrality of body measurement and analysis as the end in itself. That is, what can be reliably sensed and inferred with a view to how these tracked and measured actions might align with symptomatic properties and clinical indicators or with forms of interaction techniques appropriate to particular clinical settings. In many senses this has been an appropriate focus for the field of gait analysis as

it has been dominated by its research efforts. But in relatively recent years, these research efforts of gait analysis and body tracking have started to find more significant application in routine clinical and every day practice. For example, we see it commonly in the clinical management of cerebral palsy where is may be requested as part of orthopaedic surgical planning processes as well as post surgical analysis. We also see its use being more routinely requested in the assessment of an individual's motor dysfunction post stroke. This shift is all set to increase as research matures but also as various forms of body-tracking sensors pervade ever more areas of our everyday lives beyond the bounds of traditional clinical contexts. One only needs to consider the ubiquity of smart phone technology and the recent growth in smart wearable health bands to get a sense of how widespread body-tracking technologies such as accelerometers and gyroscopes have become. In addition, with the ability of digital body-tracking systems to functionally respond in real time to the sensed data streams, we will see wider applications and uses being situated in everyday clinical and life practices.

The shift from research to more routine everyday practice has important consequences for how we need to consider these various technologies in healthcare contexts. While the nature and form of bodily movement and its inferred representation remains a central concern, there is now an additional imperative to consider how the material form of these tracking and assessment opportunities can be situated within the larger systems of clinical workflows, environmental contexts, social and collaborative practices and the everyday contexts of routine living. Much of the concerns of these shifts into practice remain relatively unexplored in gait research but, as we will discuss later in the book, there are profound and mutually interdependent ties between the fundamental characteristics and assumptions of these technologies and the configurations of everyday collaborative practices with them. The field is now at a point where greater attention to these concerns is becoming of critical importance to the ways that these technologies can be appropriated.

Such a practice-centric perspective points to a number of key socio-technical considerations in the understanding of these body-tracking technologies. In the first instance there is an important consideration about how we conceptualize data and measurement of the body derived from these technologies. Rather than conceiving the data and measures derived from these technologies purely as self-explicating representations of the objective reality of the moving body, it is important to consider how they are embedded in practice and how the actions on this data render them meaningful in particular contexts. Such arguments are derived from key thinkers in *Social Studies of Science* and technology (e.g., Lynch, 1985, 1990a, 1990b; Goodwin, 1994, 2000). But increasingly these arguments are finding significance in more healthcare contexts and design oriented disciplines in ways that not only situates them closer to our domain of concern but also offers the basis for reasoning about particular technological approaches in terms of their practical implications (e.g., Hartswood et al., 2003; Mentis and Taylor, 2013; O'Hara et al., 2014a). In their arguments about medical imaging technologies and the visual representation of the body, Mentis and Taylor (2013) highlight the importance of moving away from simply "privileging image fidelity and detail" toward a greater

privileging of the "active use of images." Likewise, as Lynch (1985) argues, we need to consider data in terms of a "*representational adequacy*" that is not fixed but dependent upon a "*coherence of actions established in the social environs*" of a setting (p. 60).

The "privileging [of] image fidelity and detail" arguments in Mentis and Taylor (2013) relate nicely to the "*centrality of body measurement*" perspectives highlighted above in relation to the currently narrow ways of talking about body-tracking technologies. In part, this points us to the need to attend further to the *in situ* and interactional organization of any body-tracking data that can be collected through this varied array of sensing technologies; the ways it can be visualized, constructed, attended to, pointed at, oriented to, manipulated, and discussed in the context of particular clinical activity. That is, what can be done by the human actors in clinical setting that are, in Lynch's (1985) terms, *disciplining* the data? This practical achievement of how such data is given meaning in practice is arguably one strand of work that is under articulated within the more traditional realms of gait analysis but is starting to gather attention within fields such as Human-Computer Interaction.

What this points to, then, is a greater need to think about these technologies in terms of the opportunities they create for reconfiguring routine practices which entails detailed understanding of the socio-technical context in which they are embedded. As a simple high level illustration of these issues let us consider how much of the early gait assessment and body-tracking work has been reliant upon specialized and dedicated gait assessment labs. While these labs are optimal from the perspective of enabling the very highest quality of gait and body movement data to be collected, such a privileging of high quality quantification comes with particular consequence in terms of practice. So, for example, these set-ups are enormously costly from a financial perspective. In addition, they are complex and time consuming to set-up, and demand a high levels of expertise to run. Such characteristics ultimately constrain and shape the ways these technologies can be appropriated in particular clinical trajectories, workflows, and practice. If we take the simple issue of cost, this factor alone is prohibitive to a more ubiquitous deployment of these technologies in other forms of clinical setting or indeed in the home or on the move. Being a high cost resource means they are also a more scarce and limited resource. The consequence of this is that any quantification of patients' posture and motion requires them to travel to a particular place at a particular narrow time windows. Already then we can start to see how this limits opportunities for where and how often such tracking can be carried out preventing more frequent and ongoing tracking over the course of time and particular disease/condition progression. What this begins to do is turn our attentions to a different set of factors and trade-offs that are important to consider in relation to these technologies over and above the centrality of body measurement concern. So, for example, one might consider trading representational precision and accuracy for lower-cost sensing technology because of the potential to open up usage of such technologies outside specialist centers—e.g., in health centers, and in the home.

The significance of this may go beyond simply making the availability and accessibility of these technologies more widespread. Indeed, in many practical applications of these technologies, key elements of their success arise by virtue of the practices being situated in a particular social setting. This may be the case for example, with the issue of rehabilitative gaming using body-tracking technologies. Here while body-tracking technologies and games can be designed to promote particular forms of rehabilitative movements, this in itself may be pointless if the patient does not have the appropriate motivation and incentive to perform the movements in the first place. As we discuss later, such motivational requirements may be achieved by situating the technologie,s in particular social contexts such as a care home where a game-based rehabilitation regime can be performed in the company of other residents. Such an opportunity only really becomes plausible when the sensing technology is low cost and portable enough to be deployed in these kinds of social contexts. If a sensor, too, is something that can be worn comfortably for hours and even days, this opens up the possibility for the continuous or more frequent capture of body movement data in the context of everyday living relative to the rather artificial setting of a gait lab. This is not simply a question of ecological validity of gait data but more of an important realization of the ways in which the motor capabilities, performance, and dysfunctions may be manifest, constrained, and managed in very different ways depending on the social, physical, and environmental circumstances.

Consideration of the tracked body as a *social body* in the presence of other actors is an important shift that reveals many different implications in relation to particular forms of body tracking. For example, there may be issues of social acceptability of particular forms of tracking technologies that may be conspicuous in the presence of others. Irrespective of how well certain technologies may operate in principle, if they lead to various forms of social discomfort, this will ultimately shape their patterns of use in practice. Of further interest too is how various forms of body-tracking technologies impose particular influence not just on an individual being tracked but on the movements and actions of other people in the vicinity of the tracked body. For example, the algorithms in computer-vision tracking systems may demand that the moving bodies remain visibly separated or may demand particular orientations to a camera rather than a collaborating actor. In this respect, the tracking characteristics can affect the interpersonal configurations and relations of the multiple actors making up different healthcare contexts as the actors work together to make the sensing systems work. This could include, among many others, the relationship between doctor and patient during assessment, or the relationship between collaborating clinicians during a surgical procedure. If we take the doctor patient relationship as an example here we will discuss later how these considerations become a very real issue in the organization of assessments of patients with movement disorders. With such patients often finding difficulty performing certain movements unaided, the clinician may offer support bringing the body of the clinician together with the body of the patient. Treating these connected bodies as distinct entities can pose a particular challenge for computer-vision-based body-tracking systems that rely on the visual separation of the bodies.

Here we see illustrated the intertwining of social and technical circumstances in ways that bears on our understanding of these technologies in context.

There are many such social, clinical, and technical relations pertaining to these technologies that may play out, in particular ways, across a range of different healthcare contexts and across a range of different stakeholders. Critical in the future development and successful adoption of these technologies, by clinicians and patients alike, is a greater emphasis on understanding the socio-technical contexts and implications of these various approaches to body-tracking technologies in different healthcare scenarios. One of the aims of this book is to offer the reader various examples of this kind of discussion and illustrate some key ways in which social contexts of use relate to the properties and assumptions bound up in particular choices of body-tracking technology. In addition, we can see how certain technology characteristics might lead to the collaborative practices of these healthcare scenarios to be configured in particular ways. The intent here is not to offer a complete and comprehensive account of all scenarios of use but, rather, through the examples, offer critical insights and more importantly a perspective that can be brought to bear on a broader set of technologies and scenarios that relate to this exciting field.

1.3 OVERVIEW

In presenting our discussion of these technologies, this book explores three core application areas in healthcare. Each of these application areas offer us different ways of thinking about the body in motion as something that can be tracked and understood toward different ends. Here we are able to articulate how specific demands of the application area and the settings in which they are practiced have particular implications for how a common set of body-tracking technologies can be critically understood. In the first instance we look at the issue of body tracking in the context of clinical assessment. In many ways this has been at the heart of more traditional gait analysis research and practice efforts to date. While there have been a plethora of feasibility studies in the area that point to many ways that body tracking and analysis can be used to infer particular neurological disease states, the practical accomplishment of these assessments remains a richly intriguing challenge for a variety of reasons. Using assessment of multiple sclerosis as a core example, the chapter sets out to reveal the practical challenges faced in using ubiquitous sensing technologies for assessing movement disorder in actual practice.

The second area shifts emphasis to consider these technologies in the context of rehabilitation; more specifically scenarios of self directed rehabilitation and care. Here two different areas of rehabilitative care are considered. The first of these concerns the treatment of chronic pain while the second looks at reducing fall risk in older adults through the bespoke forms of balance training. Of interest in the treatment of chronic pain scenario is the realization that any movement-based disabilities experienced are not simply bound up in physical concerns. Rather, their manifestation

is bound up also with psychological and affective states. In this regard, body-tracking technologies in these scenarios are not simply about how they can encourage particular forms of physical movement but also how systems might be designed to recognize or influence psychological and affective factors. Of significance here are the ways in which the body-tracking approach moves beyond analysis and assessment to consider the role of interactive outcomes tied to specific bodily action. Interactive and motivational concerns are apparent too in the context of the balance training and rehabilitation as well as the ways in which particular forms of balance related movement can be encouraged. Here motivation in rehabilitation is treated as a multi-faceted concern that has implications for how we conceive the role of body-tracking technologies in these scenarios. Rather than just tracking body position and control to understand balance performance, it looks at how balance indicators influence events within a game, which are manipulated to get the patient to move the body in progressively more difficult ways. In this respect there are motivational factors intrinsic to the game and task. But the work also highlights some of the more social aspects of motivation in rehabilitation and how this arises because the form of the technology enables it to be embedded in a particular social setting.

The third theme in this book then takes a rather different turn. Building on some of the interactive opportunities of these technologies, the theme considers how the movement of the body can be used to develop new forms of interaction of relevance to healthcare. More specifically, the significant turn here is to focus on the body of the clinician as also something to be tracked and explore the implications of this in the particular setting of the operating room. Of importance here are some of the unique demands of these settings that lend significance to opportunities for touchless interaction and hands free interaction. In addition, the discussion here is used to highlights ways in which certain task demands as well as the social and collaborative organization of the setting relate to particular characteristics of the motion tracking and inference technologies.

Our aim in this book is not to offer a complete account of these technologies within particular clinical applications and contexts. Rather, through a range of examples, our aim is to introduce a richer set of concerns and perspectives that are important to consider when thinking about these body-tracking technologies in healthcare contexts. The intention is for these examples to be used as a starting point for the reader's own reflections on how new emerging forms of body-tracking technology may come to be used and appropriated in a range of new application areas and settings.