AFRL-RH-WP-TR-2013-0135

IS "PATTERN OF LIFE" SIZE-INVARIANT? RECOVERING THE UNDERLYING INTENT OF A WALKER FROM HUMAN WALKING TRAJECTORY DATA

Brian Tsou
Human Analyst Augmentation Branch
Human-Centered ISR Division
Wright-Patterson AFB, OH 45433

Jeffrey Smigelski
Jack Jean
Wright State University
3640 Colonel Glenn Hwy
Dayton, OH 45435

INTERIM REPORT
JULY 2013

AIR FORCE RESEARCH LABORATORY
711TH HUMAN PERFORMANCE WING
HUMAN EFFECTIVENESS DIRECTORATE
WRIGHT-PATTERSON AFB, OH 45433
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

NOTICE AND SIGNATURE PAGE

AFRL-RH-WP-TR-2013-0135 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//signature//	//signature//
RICHARD WARREN Work Unit Manager Human Analyst Augmentation Branch	LOUISE CARTER, Ph.D. Chief, Human-Centered ISR Division Human Effectiveness Directorate 711th Human Performance Wing Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01-JUL-2013

2. REPORT TYPE
Interim

3. DATES COVERED *(From - To)*
7 June 2011 – 7 June 2013

4. TITLE AND SUBTITLE
Is "Pattern of Life" Size-Invariant? Recovering the Underlying Intent of a Walker from Human Walking

5a. CONTRACT NUMBER
In-House

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Brian Tsou Jeffrey Smigelski Jack Jean

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
H09F (2313HX04)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

Human Analyst Augmentation Branch
Human-Centered ISR Division
7ll^th Human Performance Wing
Human Effectiveness Directorate
Wright-Patterson AFB, OH 45433

Wright State University
3640 Colonel Glenn Hwy
Dayton, OH 45435

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
711th Human Performance Wing
Human Effectiveness Directorate
Human-Centered ISR Division
Human Trust and Interaction Branch Wright-Patterson AFB OH 45433

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S):
AFRL-RH-TR-WP-2013-0135

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A. Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
88ABW-2013-0135; Cleared 26 March 2014

14. ABSTRACT
The motivation for this proposed research is that the volume, variety, and complexity of data being collected by the intelligence, reconnaissance, and surveillance community have far exceeded traditional signal extraction procedures for anomaly detection. Knowing the proper signature (defined as an ensemble of features that correspond to a given target or activity) to extract from a signal or image is the key to all intelligence data processing. However, most signatures found relevant for one scale or resolution might lose their meaning when the resolution is changed, which is typically the case when the sensing field-of-view or area of coverage changes.

15. SUBJECT TERMS
GPS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Richard Warren
U	U	U	SAR	14	19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

THIS PAGE INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The motivation for this proposed research is that the volume, variety, and complexity of data being collected by the intelligence, reconnaissance, and surveillance community have far exceeded traditional signal extraction procedures for anomaly detection. Knowing the proper signature (defined as an ensemble of features that correspond to a given target or activity) to extract from a signal or image is the key to all intelligence data processing. However, most signatures found relevant for one scale or resolution might lose their meaning when the resolution is changed, which is typically the case when the sensing field-of-view or area of coverage changes. For example, a visually familiar posture or gesture will change or even become invisible when viewed from far away. Under the Air Force Research Laboratory's (AFRL) Layered-Sensing construct, target size can vary greatly depending on the particular sensor that is collecting data. It is very possible that a signature that is useful in extracting target or activity in one sensor resolution may become useless in another. A size-invariant signature would make data collection and processing more efficient.

2.0 OBJECTIVE

For the first time, we can see all the rhythms and melodies of day-to-day human activities under one view for very long duration. This capability of a sensor to loiter persistently over the same area creates an opportunity to observe and find possible anomalous activities that need a further look by a higher resolution sensor, which might possibly result in a corresponding change of the observable signature. In these wide-area staring sensors, a person would subtend at most a few pixels on the image plane without showing any spatial features. However, everyone's movements could still be registered as trajectories. Assuming a trajectory is the physical manifestation of one's underlying intent (either malicious or non-malicious), it could be used as the basis for a suitable "behavior signature" for the underlying intent. (A behavior signature is defined as an activity or activities that can be geo-spatially connected to an event and which, in turn, can be used to mathematically determine the source event.) Thus, a person's motion trajectory, no matter how registered by a sensor or how many pixels are involved, might directly reflect that person's malicious intent or anomalous activity, and thereby allow harvesting more than just pictorial information from wide-area persistent sensors. In general, the path or position of any object in time is a result of the underlying process or processes that generate the motion.

It is hypothesized that, by knowing the 2D path and temporal trajectory of an object and converting it to a 1D time series, the process(es) responsible for different human activities may be deduced from the quantitative representation of the trajectory in both the time and frequency domains as a mathematical signature characterized by a series of transfer function equations and associated scaling exponents.

3.0 APPROACH/ANALYSIS

As a proof of concept of the ability of human-motion trajectory-only data to yield information about the nature of the underlying activity without prior knowledge about who or how someone is moving, time-series data were collected for four different walking scenarios: normal walking, walking around picking up sticks, walking while stalking another person, and walking openly while surveilling an area but avoiding being conspicuous.

3.1 Data Collection

Specifically, in order to better understand the classification of different kinds of movement using the scaling exponent, four scripted walking actions were recorded using a Global Positioning System (GPS)-enabled BlackBerry (BB) smartphone. GPS data, consisting of latitude and longitude information, was recorded at approximately two-second intervals capturing the total path of a subject, and was converted to a time series as the change in step size (distance) per unit time. Two open-air locations were selected with two scripted walking tasks occurring at each location. At each location, the second walking task immediately followed the first walking task, but both events at a location were recorded as one data set. However, each walking task was entirely independent. That is, there was no overlap, and the transition from one walking task to the next was abrupt. Further, at no time after transitioning to the second scripted walking task did the script revert to the first task.

Data Analysis. Once the data were recorded, the latitudes and longitudes were converted to a single time series. Although the 2D bird's-eye view of the path and trajectory time-series appear uniform (especially when the points are connected), the conversion to a 1D time series (dropping location data and substituting distance-travelled per time interval) offers both visual and mathematical cues of two distinct behaviors. For each location, the first part of the time series representing one scripted action appears visually distinguishable from the second part representing a new motion type (see Figures 2 and 3). The visual difference can be expressed mathematically. In turn, the mathematical change in time-series behavior indicates a change in the physical process or purposeful intent behind the generation of the time series. This physical change is reflected in a change in the observed scaling behavior in the data. If the data of two behaviors are combined, the more dominant behavior will have a greater influence on the measured scaling exponent. Therefore, a sliding window approach is preferred in which a time series is passed through a preset window which is constantly evaluating the time series over the length of the window and looks for a change in the scaling exponent as an indication of a change to a new behavior.

4.0 RESULTS

The results for the two locations each containing two scripted walking tasks are as follows:

Location 1 Activity: Two Very Different Sequential Walking Tasks:

Walking Around a Parking Lot / Picking up Sticks (Figure 1): Case 1consists of two grossly different walking patterns, namely, walking around a parking lot versus picking up sticks. The first 338 points representing the walking phase (left side in Figure 2) exhibit a slightly different scaling behavior and scaling exponent than the action of picking up sticks (right side in Figure 2). Using a sliding window, the time series of distance travelled per unit time changes suddenly at Sample Number 338. Note how the minimum distance travelled in each step for the first 338 points is above one meter, on average, per sampling interval suggesting continuous movement (walking). After point 339, the minimum and maximum distance fluctuates more wildly indicating more variable movement (picking up sticks). At some times, there is no movement as the individual stopped, and the distance travelled is 0 m for a sampling interval.

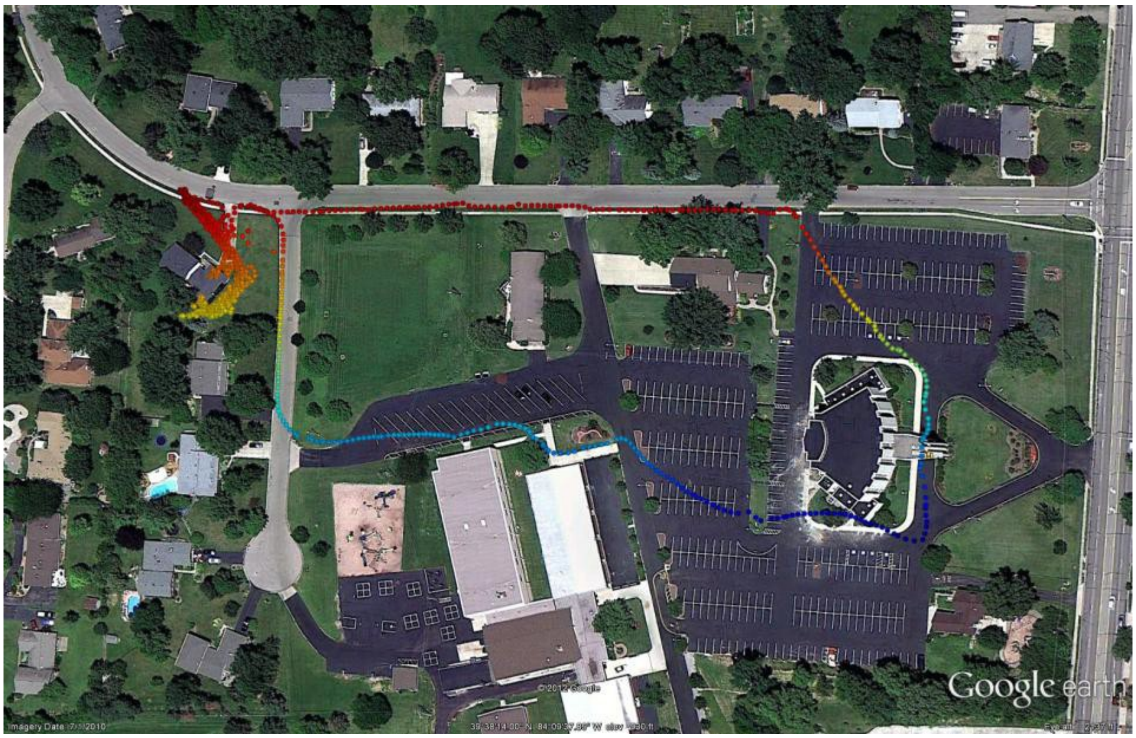

Figure 1: Overhead View of Case 1 Scenario

Blue dots are normal walking path locations and red dots are locations of picking up sticks activity

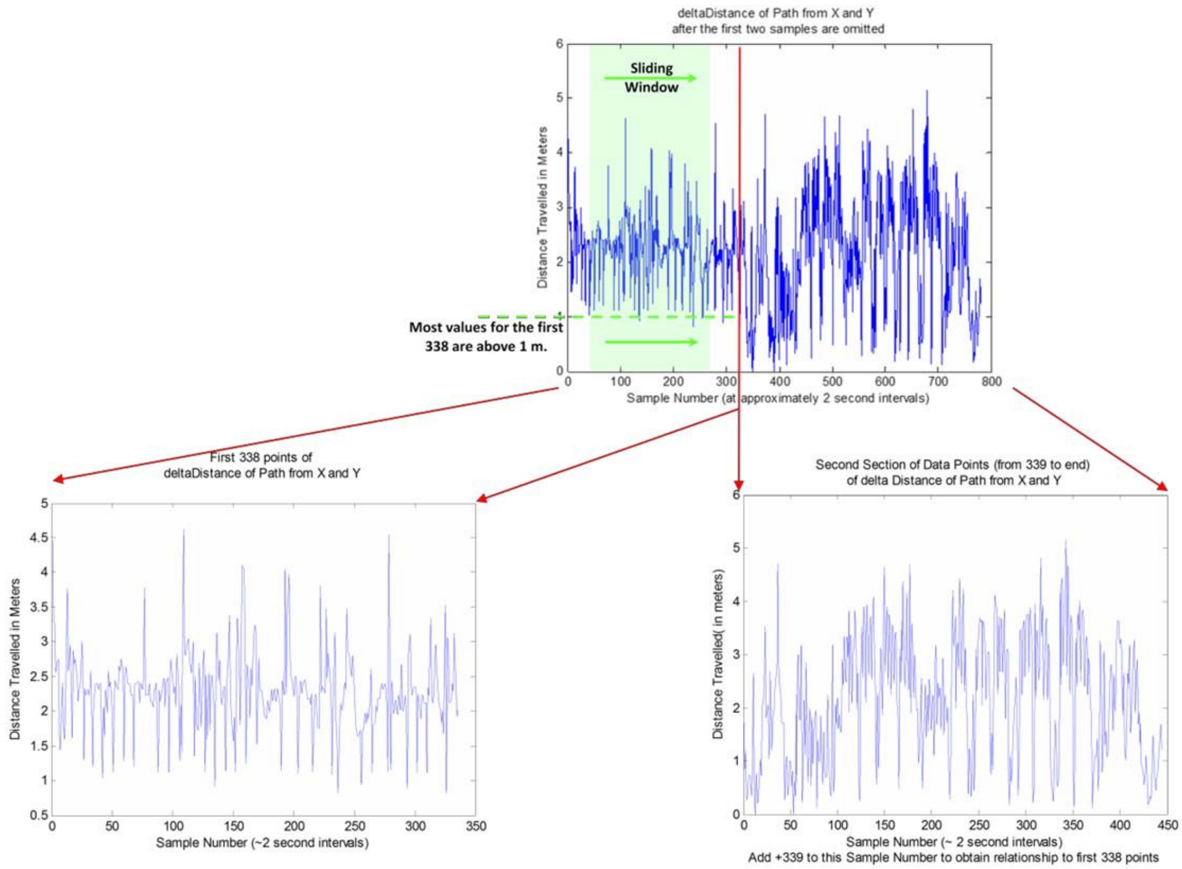

Figure 2: Time Series of Distance Travelled at each Two-Second Interval for the Normal Walking and Picking Up Stick Phrases of Case

The mechanism that is causing the observed change in scaling behavior needs to be addressed. In walking, movement does not come to a complete stop and is the continuous integration of more or less a relatively constant velocity. As a consequence, the step size rarely falls below 1 m per 2 second interval. Continuous movement may have noise at only the high frequencies: movement at an average or fixed speed is considered "normalized" around that speed so that a constant velocity is stable as fluctuations around a constant velocity consist of low amplitude, high frequency noise. The result is that the scaling exponent is low and close to that which is considered to be the completely random behavior of Gaussian white noise. However, this is not to say that action of walking or the purposeful intent (input velocity) of walking is random.

Instead, the interpretation is that any constant velocity spectrum is nearly the same as that for Gaussian white noise with small high frequency fluctuations. The motion is otherwise unchanging with frequency and therefore generates a remarkably flat spectrum similar to that of random behavior.

The change in the scaling exponent of the second scripted motion (right side in Figure 2) in the latter half of the Location 1 activity indicates a change in the behavior of the individual performing the movement. In an activity such as picking up sticks on a property, there is increased variability based on the location of the stick and the pile to which the stick is moved combined with the stuttered back and forth movement of the work. The increased variability, at this resolution, is through reduced randomness, since there is more purpose and hence coordinated movement behind the task of picking up sticks. From the change in step size per unit time, a change point was able to be determined corresponding to an abrupt change in scaling behavior at Point 338 indicating a different physical process taking place in the time series.

From a filtering perspective, from the change in the scaling exponent alone, the two scripted actions within the data can be accurately separated with the first 338 points defining a continuous walk around the parking lot and the second portion from Point 339 to the end of the time series defined as picking up sticks on a property. Additionally, the duration of each activity can easily be calculated. For example, the first 338 points at approximately 2- second intervals translates to a total of 676 seconds or a walk around the parking lot that took roughly 11 minutes and 16 seconds (if the sampling interval was constant). Potentially, in knowing the scaling exponent, the transfer function, and the duration of an activity, a catalog of actions may be created as a filter bank for unknown data.

Location 2 Activity: Two Similar Sequential Walking Tasks:

Stalking Target / Active Walking Surveillance (Figure 3): Location 2 activity consists of two subtly similar scripted actions representing stalking behavior (left side in Figure 4) and active walking surveillance (right side in Figure 4) in and around the parking lot to assess the area. Although the distinction between the scaling exponents is small, the scaling exponent does distinguish between the two distinct scripted actions which are very similar behaviors involving movement. The difference between the two behaviors is how one moves when stalking someone so as not to be seen by the target versus how one moves when assessing an area and performing surveillance after the target has left the area.

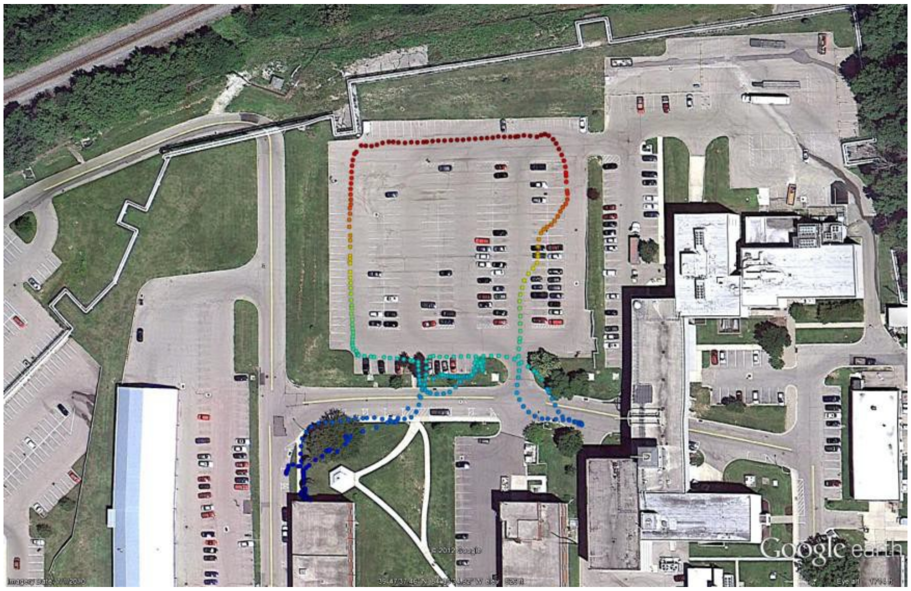

Figure 3: Overhead View of Case 2 Scenario

Blue dots are stalking path locations and red dots are locations surveillance walking while trying to be inconspicuous

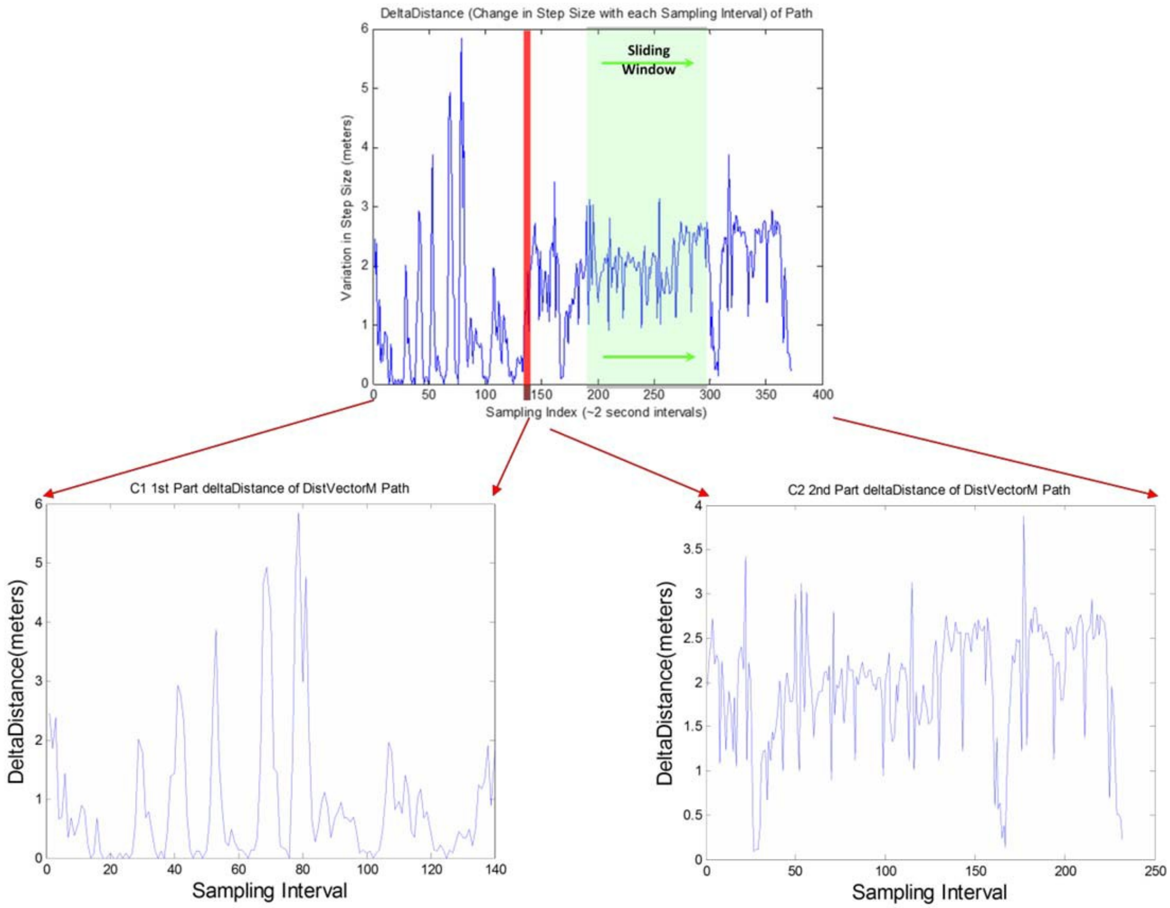

Figure 4: Time Series of Distance Travelled at each Two-Second Interval for the Stalking and Surveillance Walking Phases of Case 2

From the time series of the stalking action, one observes that the change in distance (velocity) with each time increment is very stuttered with sudden increases in velocity to catch up with a target followed by moderately long periods of inactivity (approximately 10 to 20 seconds on average) upon reaching cover. The bursts of velocity result in a change in location as much as 6 m per event and because more time is spent in high frequency but low amplitude situations (under cover) interspersed with sudden large amplitude but lower frequency runs.

Comparatively, in active surveillance when a target is no longer present, the increased freedom of movement moderates the time series allowing more or less an average velocity of around just under 2 m per unit time (or 1 m/s for 2 second intervals). This lowers the scaling behavior as velocity experiences normalization. However, the scaling exponent is higher than that for walking in Case 1 since there are still staggered starts and stops to both acquire information and assess the area without looking conspicuous.

5.0 DISCUSSION OF PRELIMINARY RESULTS

As promising as the results of this proof-of-concept demonstration are for unlocking the information contained in purely trajectory-only data, there are however, some limitations to using the scaling exponent and transfer functions to define human movement.

Specifically, one limitation is the degree to which one is able to deduce intent from pure trajectory data. In order to do so, one would need to assume that for every given type of motion, there could be identified a unique and corresponding state of intention. However, there are likely to exist very similar movement patterns for which the underlying intentions would be very different, such as picking up sticks that were scattered about versus searching for a lost cat. There are also likely to be very similar states of intention for which the corresponding movement patterns would be very different, such as avoiding immanent detection by quickly walking away versus hiding in a building.

Nonetheless, this approach to inferring intent from movement patterns does show promise and it remains to be determined whether the capability to infer intent from pure trajectory-only data might be improved by considering the context within which the movement occurs.

More lines of evidence may be needed to accurately describe a specific behavior such as the duration of an event, the range of the time series, and even the location of an event which defined what behaviors are likely or even possible in an area. For example, dancing and skipping are unlikely along a steep rocky slope. Together, time series movement may be summarized through a combination of some or all of these parameters to ensure the best possible mathematical description of a behavior or the purposeful intent behind a behavior.

Collection and analysis of GPS data for walking three designated routes on the campus of Wright State University by volunteer students are continuing.

LIST OF ACRONYMS

AFRL	Air Force Research Laboratory
BB	BlackBerry
GPS	Global Positioning System