Integral Kinematics (Time-Integrals of Distance, Energy, etc.) and Integral Kinesiology

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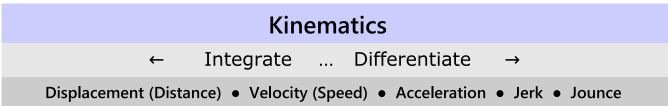

Fig. 1. **Derivatives of Displacement:** Kinematics generally only considers positive derivatives of displacement, i.e. it often fails to consider also the negative derivatives (integrals) of displacement. Figure from Wikipedia.org

***Abstract*—This paper introduces the MannFit™System, a physical fitness concept, regimen, philosophy, and praxis, based on Integral Kinematics (e.g. time integrals of distance or displacement), rather than the Differential Kinematics (distance and its derivatives: speed, acceleration, etc.) that are commonly used in fitness, gaming, sports, and the like.**

Integral Kinematics gives rise to a new kind of fitness training, assessment, scoring, and gaming that puts emphasis on "dextrength" (combining strength with dexterity and fine motor control). Rather than maximizing distance, speed, and acceleration (derivatives of distance or displacement) the goal of the player is to minimize absement (time-integral of distance).

We demonstrate a number of gaming scenarios based on Integral Kinematics, with or without other biofeedback and other gaming apparatus such as the Foc.us tDCS headset for gamers, and other health monitors (EEG, ECG, etc.).

I. Introduction

Concepts like distance, speed, and acceleration appear commonly in sport and fitness. Speed is the time-derivative of distance, and is thus measured in units of distance divided by time (e.g. metres per second or kilometers per hour).

Kinematics is the study of classical mechanics and the word "kinematics" comes from the Greek word "kinema" which means "movement". Typically the study of kinematics involves displacement (and its magnitude, distance), and its time-derivatives: velocity (and its magnitude, speed), acceleration, etc., which form an ordered list of "derivatives of displacement", as shown in Fig 1. In this context we refer to traditional kinematics as "differential kinematics".

We propose a more complete "two-sided" conceptualization of kinematics that includes also the time-integrals of displacement. See Fig. 3.

II. Integral Kinematics

Previously we introduced absement, the time-integral of displacement, and demonsrated how it arises in flow-based processes such as water-based musical instruments [1]. See Fig 2.

Others have also built upon the concept of integrated kinematics and applied it to the field of electrical engineering [2]. More recently, concepts of integral kinematics, such as absement (the time-integral of displacement) have entered the mainstream high school curriculum and are being explored through science fairs and the like [3].

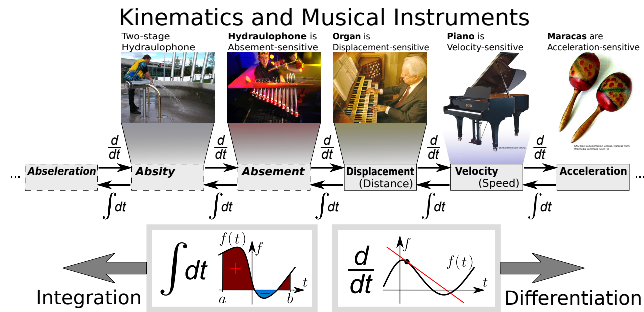

Fig. 2. The study of integral kinematics originated with water flow [1]. The hydraulophone (underwater pipe organ) exhibits the phenomenon of absement. The two-stage hydraulophone exhibits the phenomenon of absity (the double-integral of displacement).

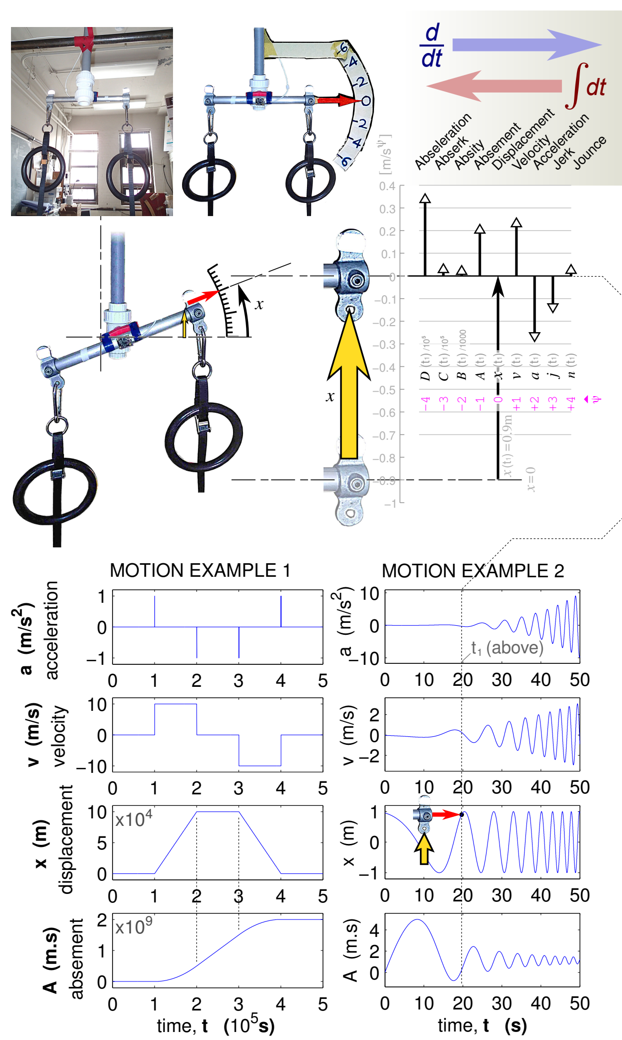

Fig. 3. Two-sided Kinematics (differential AND integral) of an object (e.g. ball valve T-handle) undergoing motion. The amount of water flowing through the valve (instrumented with an angle sensor) is the absement of the tilt. Tilt is the distance of one end from center position, approximately proportional to angle (for small angles). We integrate the absolute value of angle, distance. The bar swings freely through an angle of $\pm\otimes/6 = \pm\pi/3$. (Phoenician, Hebrew, or Greek letter teth, or theta, ⊗, ʊ, ⊖, or θ, once meant, and evolved from a hieroglyph for, "wheel", so let it be the full circle = ● = 2π. Let ʊ/2 = ◓ = ◓ = π, and ʊ/4 = ◔ = ◔ = $\pi/2$, and so on, for any fraction thereof.)

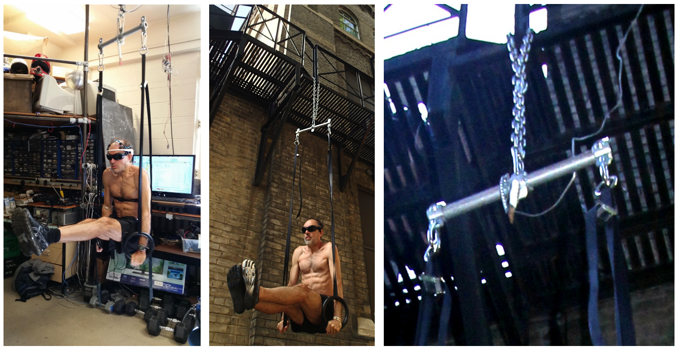

Fig. 4. Example of the MannFit™System consisting of fitness rings attached to a destabilizing bar to increase the difficulty of keeping stable on the rings. The bar pivots, and also rotates, swinging, tilting, and twirling around to introduce further degrees of freedom. The destabilizing bar is equipped with tilt, vibration, and position sensors and is suspended from a load cell for further data sensing. (Leftmost) Training using biofeedback from an InteraXon Muse EEG sensor, and a heart sensor (chest strap), with output to a Foc.us tDCS headset for gamers. The amount of stimulation (i.e. the amount of required Focus) can be delivered in proportion to the error (tilt of the bar). (Center) Field deployment from fire escape stairs. (Rightmost) Closeup of the destabilizing bar.

A number of related concepts, also introduced by author S. Mann, include: momentement, as in the following ordered list (each being the time derivative of the one before it): *momentement; momentum; force; yank; tug; snatch; shake*, and also actergy (or "total action" or "Hamiltonian action"), as in:

Power	Energy	Actergy (Total Action)
Watts	Joules (Watt Seconds)	Joule Seconds
Strength	Endurance	Longevity,

where power is roughly analogous to strength (i.e. short-term "burst mode" output), energy is roughly analogous to endurance (i.e. longer-term output), and the new concept, actergy, as measured in J.s, is roughly analogous to longevity (i.e. overall health) on a much longer time-scale. We thus introduce "Integral Kinesiology" as the use of integral kinematics in the study of human movement, toward the goal of long-term health and wellness, based on developing lean muscle mass and combining strength, endurance, and fine control, with stability and absemental stability.

III. Absement-based fitness training, evaluation, scoring, and gaming

Most sport and fitness training and evaluation is based on differential kinematics, but we wish to explore also integral kinematics. In order to do this, we constructed an apparatus that requires steadiness rather than speed. In particular, we took an existing stability-demanding apparatus — fitness rings — and added an even greater challenge by incorporating a destabilizing bar, hung from a single chain, from which both fitness rings hang, as shown in Fig 4.

Participants were invited to perform standard fitness activities, such as dips, leg-raises, and sustained (held) leg-raises (the "L-seat" static holding of position shown in Fig 5), while sensors in the destabilzing bar provided data to a National Instruments analog to digital converter, with a microcontroller simultaneously sending the data to Android and IOS smartphone apps, as well as to a and a portable computer doing realtime analysis and display, as well as a data logger for fitness training.

Fig. 5. (leftmost) Participants and group dynamics while using the apparatus. (rightmost) Stephanie Mann (Age 8) invented some new exercises and taught them to the group. Here co-author Pete puts one of them into practice.

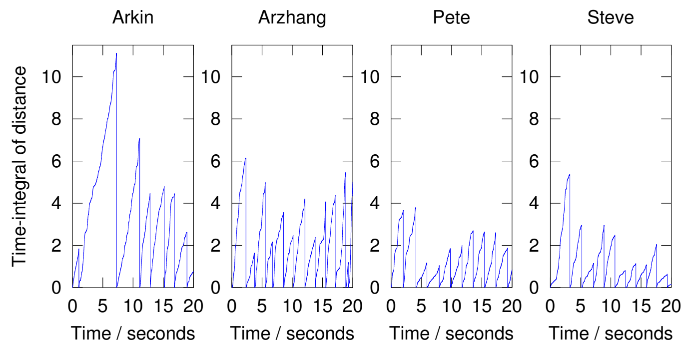

Fig. 6. **Results:** Unlike traditional sports metrics which have a goal of maximum speed or acceleration, here the goal of this game is to obtain the lowest absemement (lowest time-integrated distance from the stable position) during each cycle (repetition) of the periodic exercise (here, leg-raises). The integral is reset at the beginning of each repetition, and grows as distance (from stable point) is integrated. The goal is to minimize the height of each peak. Average absements (average height over all peaks for each player) were: Arkin: 5.2;Arzhang: 3.56; Pete: 2.34; Steve: 2.07. Here Steve won this match. These numbers were consistent with the amount of experience each of the players previously had with the fitness rings (e.g. Steve having been the most experienced on the rings, then Pete, etc.).

See Fig 6 for results. **Note that while traditional sports and fitness metrics are based on MAXIMIZING speed or acceleration (i.e. maximizing derivatives of distance), our goal here is MINIMIZING absement (i.e. minimizing the integral of distance from a cenral resting point).**

We are also using absement as a feedback mechanism for a variety of fitness tasks, to create a fun and playful yet effective fitness training program.

IV. Going Further

A simple implementation of the MannFit system is based on a bar attached to a ball valve, or a ball valve metaphor (e.g. a simulated ball valve running on a smartphone). When the bar is straight across, the valve is closed and no fluid flows through the valve. When the bar tips away from the horizontal, fluid flows through the ball valve to a greater degree when there is a greater tilt.

A ball valve is a valve that controls the flow of water using a ball that has a hole drilled through the ball. When the ball is turned so the hole is at a right angle (90 degrees) from the flow pipe, the water is shut off, as shown in Fig 7 (leftmost). When the ball is turned so the hole runs along the pipe, the valve is turned on, as shown rightmost in Fig 7.

A long metal bar attached to the ball valve, together with a flow sensor or virtual flow sensor (e.g. tilt sensor), is shown in

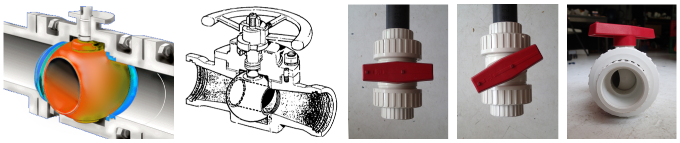

Fig. 7. **Ball Valves:** (1) Ball valve in the closed position. Figure adapted from http://www.franklinvalve.com/DURASEAL/advantages.html (2) Ball valve in the open position. Figure adapted from http://www.tpub.com/fireman/69.htm **(3-5) Ball Valve with "T-handle":** (3) T-handle ball valve in the closed position. (4) T-handle ball valve in a partially open position. (5, rightmost) View looking into the end of the valve when it is partially open.

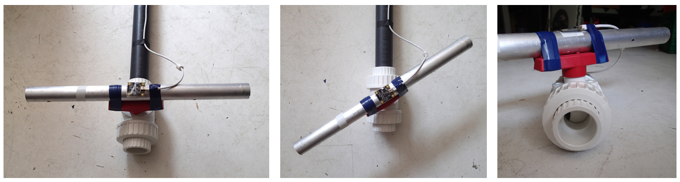

Fig. 8. **Valve Absement metaphor or reality:** Rings supported by the ball valve: creates a fluid minimization reality or metaphor. Real water (or any liquid such as a green slime) drips down on the participant when the bar deviates from horizontal. The more the bar deviates from horizontal, the greater the fluid flow. A goal is to minimize total accumulated fluid flow while performing the exercises.

Fig 8. Doing exercises like pullups, dips, leg raises, etc., from the bar creates an absemental fluid flow metaphor or reality.

In another embodiment, an Android or IOS smartphone app is written for simulating a bucket that fills when the bar tilts away from horizontal. See Fig 9. The participant attempts to stop (or minimize) the filling of the virtual bucket by keeping the bar straight. This provides an easy metaphor to understand.

In another embodiment, the participant attempts to drive a virtual spaceship down a circular tunnel, while steering with a wobbleboard that must never touch the ground at any point along its circumference. To up the ante, the partipant's feet are also on a fitness ball. See Fig 10.

The tipping angle (in absolute value), or equivalently (for small angles) the distance from either end of the bar from

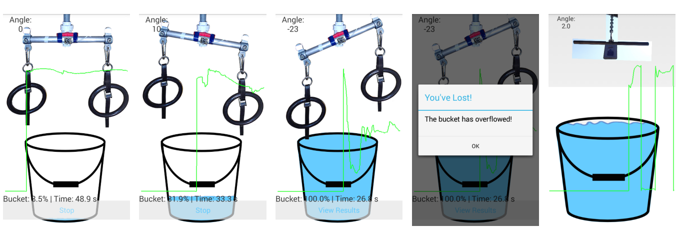

Fig. 9. Screen captures of MannFit app, with virtual bucket as time-integrator running on smartphone. (rightmost) Simplified version with simply a bar hanging from a chain (no rings) and the smartphone attached to the bar.

Fig. 10. Example with multidimensional Integral Kinematics in the form of pushups on wobble board which must not touch the floor along any of its perimeter (sensed, along with time-integrated tilt), while feet are balanced on a fitness ball.

its horizontal position, (or the tilt of the wobble board) is integrated over time to determine the absement (or "anglement"), which, when intgrating absolute value, might more rightly be called "absistance" (or "absangle"). The amount of water in the bucket (virtual) or amount of real liquid that pours out of the valve (Fig 8) is equal to the absement of the distance of deviation. Moreover, in other embodiments the smartphone functions as the tilt sensor, and the valve is entirely virtual, as shown in Fig 9, where the smartphone's IMU (Intertial Measurement Unit) becomes the tilt sensor. The camera phone further uses computer vision to measure or sense each repetition of a periodic exercise, and "clears" the virtual bucket after each repetition. The user attempts to stabilize the bar, thus "spilling" the least water, which amount is used in the scoring.

In other embodiments the metaphor (or reality) is that of air flow into an inflatible toy. Tilting the bar inflates the toy's belly, giving the toy a fat belly. The goal is to keep the toy slender (not fat) by holding the bar straight (level) while performing the exercises (pullups, dips, leg-raises, etc.).

In other embodiments, wearable computing is used with AR (Augmediated Reality) such as with Meta Spaceglass, to provide these metaphors or realities in an AR environment.

Finally, the concept is extended to more dimensions. For example, a board is used instead of the bar. The board pivots on a point that touches the ground, so the board is very unstable. The smartphone and app sense tilt angle and magnitude and the magnitude is represented as a radius. The time integral of the radius is the variable of interest. In on example, the feet are balanced on a fitness ball while the hands are balanced on the board. The user does 3 sets of 25 or more "MannUps™" (fitness ball + wobble board pushups) while trying to minimize the integrated radius (i.e. stay straight). In another embodiment a driving game appears with a tunnel in which the participant needs to keep a virtual spaceship from hitting the sides of the tunnel.

V. Conclusion

The MannFit™System, based on Integral Kinematics, was presented and successfully demonstrated through examples such as fitness rings equipped with an instrumented destabilizing bar, or a wobble board similarly equipped. We found that experienced users of fitness rings were able to maintain low absement (time-ingrated distance from a central mean position) values. We also found that an absement-based feedback mechanism was useful in training, to help develop stability and control. This work suggests that we should consider two-sided kinematics (i.e. both Differential Kinematics AND Integral Kinematics) in sport, fitness, and gaming, not just the traditional one-sided (differential-only) kinematics.

References

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