European Journal of Electrical Engineering
Vol. 23, No. 4, August, 2021, pp. 321-326
Journal homepage: http://iieta.org/journals/ejee

Animate Prime Movers: A Prototype Based Methodology for Estimation of Renewable Power Production

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https://doi.org/10.18280/ejee.230405

Received: 1 April 2021
Accepted: 11 June 2021

Keywords:
animate prime mover, animal power, exercise energy generation, renewable energy, distributed generation

ABSTRACT

The world is shifting towards renewable energy sources most notably solar and wind power. Besides these two, there are other sources of renewable power which are relatively less exploited. Among these, a rather unexplored field is that of animate prime movers. The current paper intends to present hardware prototype based methodology for evaluation of the potential of generatable power from an exercising animate prime mover – which in the current case is a male caprine subject. MATLAB environment has been used for an attempt to track the center of mass (COM) motion of the subject subsequent to its movement on a retrofitted treadmill. These COM motion trajectories can be used to evaluate the potential of generatable power – wherein the vertical COM motion upon the treadmill with an incline is compared with the corresponding COM motion on the machine when it is flat, and thus the power expended for vertical propulsion of the body is evaluated. This power is potentially generatable if the machine is kept flat and an energy harvesting mechanism is attached to it. Furthermore, the paper includes a relevant literature review section for this relatively unorthodox field.

1. INTRODUCTION

Amongst a variety of options for generation of renewable electric power, maybe the least talked about is the somatic energy of animate prime movers. Some might not even consider this as a (formal) source of energy. But then how did the unit ‘horse power’ come into existence? It came into existence when horses, which were a source of (mechanical) energy, were replaced by the (more convenient to understand) mechanical energy source namely the steam engine. An animate prime mover was replaced by an in-animate option and an inter-conversion unit was coined. After decades of rule of the in-animate prime movers, the case of animate prime movers is surfacing once again – although, the scale (energy or power) is definitely much less than that of the in-animate option.

Why should living beings be subjected to generate power? The answer is simple – exercise. Renewable power is a by-product of the exercise plan, which should be benefitting the health and wellbeing of an animal. So, for example, if a dairy cow takes a daily stroll for about 45 minutes or so on a treadmill, it may add to its own health while at the same time generate a fair amount of energy. Now, even if this is conditionally extrapolated (with conditions such as a limited number of exercise machines and only a certain percentage, say 40 – 50%, of the animals can exercise daily) to a farm of hundreds of cows, the resultant energy may easily be estimated to be something non-negligible.

The current paper intends to present a methodology to evaluate the potential of renewable energy generatable by quadruped mammals exercising on dry-type treadmills. To this end, a male goat is used as a representative of the quadruped mammal family. The potential of energy generation can be evaluated via tracking the center of mass (COM) of the quadruped body – this will be elaborated in the text. The next section presents a relevant literature review that builds upon this apparently unorthodox research.

2. LITERATURE REVIEW

A variety of literature, including research articles [1-8], patents [9-14] and web articles [15-17] may be found related to the concept of animate prime movers. It should be mentioned that this literature review neither defines the scope of various inventions/research efforts nor does it provide a compact summary which encompasses all the inner details of these inventions/research efforts.

In Ref. [1], the authors mention human and animal power as a forgotten source of renewable energy. They say that “the paper makes the case that human and animal power be seen as renewable sources of energy”. In regards to why this power is not mentioned in the commonly discussed renewable sources of power, one of the reasons given is that human and animal powered technologies are not very fashionable. However, it should be noted that this paper is not targeted towards generation of electrical energy from the human or animal power. Wijethunge and Priyadarshana [2] are presenting a micro- hybrid power plant that uses animal draft power as well as biogas. It has been estimated that 12 oxen can produce a total of 18 kWh/day (without including electrical component losses). The work in Ref. [3] mentions a human treadmill which is coupled with a 200 Watts permanent magnet DC generator. Furthermore, this treadmill is also coupled mechanically with a specially designed washing machine. The research effort presented by Ali et al. [4] is another research article intended towards presenting generation of electricity from a human treadmill. The authors mention that the generated electricity may be used for low voltage CFL or for charging of a battery.

Exercise and energy generation has been mentioned in Refs. [5-7], wherein the works [5] mentions a treadmill for exercise as well as energy generation whereas the other two references mention exercise bikes and power production. The study by Yang et al. [5] states that, "In the era of green energy, any approach of harvesting energy, even a small one, would be regarded as meaningful and welcome…". They propose energy harvesting via a grid-connected treadmill (for humans) which can automatically transfer operating modes between a motor and a generator – wherein an infrared sensor will be signaling the control loop about the user position on the treadmill. The paper mentions hardware implementation as well and presents various related waveforms. The research effort presented by Strzelecki et al. [6] mentions generation of electric power via a stationary exercise bicycle. They mention that for the average speed of 20 kph, their unit can produce around 250 Watts of power. The research in Ref. [7] proposes DC power system inside a home for ease of integration of renewable energy resources and proposes an exercise bike retrofitted with an electrical generator to produce and then supply electrical power for the house-hold use. Prototype model has been used and the author mentions a value of 125 W with one set of the so-called HPG (human power generation) system.

The work presented in Ref. [8] is an effort by two of the authors of this paper. It is an effort to evaluate the potential of renewable power generatable from the dry-type equine treadmill if the incline is replaced by an equivalent energy generation mechanism. The approach makes use of oxygen uptake and plasma lactate values, which have been employed to calculate the aerobic and an-aerobic contributions of the generatable power.

Looking at patented inventions, Al-Zamil [9] presents the idea of a multi-stage (five stages) mechanical platform. It will be used to convert energy from animals such as camels/horses into electrical power. A rotating base, air compression mechanism and a dynamo for electricity generation are included in the multiple stages of this invention. Gomez-Nacer [10] presents a treadmill like device that can tap the energy of horses and can convert it into electrical power. The inventor mentions this device to be intended for rural areas with little or non-existent electricity.

The concept of exercise for animals may be seen in the 'Bovine Treadmill' patent presented in Ref. [11]. It is a device including hoof abrasion and treadmill cleaning systems. It has been mentioned that exercise can benefit dairy cows, similar to the way humans benefit from exercise. One embodiment of the invention includes a power generation system as well. Besides these, the works [12-14] are patents which also present the concept of animate prime movers in one way or the other.

Looking at web articles it's mentioned in Ref. [15] that a horse treadmill which may be used for splitting wood, grinding corn and pumping water. The machine is made mostly of wood and the equine speed on the machine is slow – in the author's word the horse is a-ploddin' on the machine. The works [16] is another web article mentioning the use of a cow on an electricity producing treadmill. The title of the article appears to be quite promising - 'Cows on Treadmills Could Produce Six Percent of the World's Power', wherein, the article mentions an estimation that if 1.3 billion cattle in the world used treadmills for eight hours a day, then this feat could be achieved. The article also mentions that it may seem unethical to make cows walk on machine, however, the machine workout is quite similar to the animal's normal routine, where the animals walk around eight hours for daily grazing. One cow has been mentioned to produce 2 kW of electricity – and this is a substantial figure. In another interesting web article [17], it's mentioned that the use of a horse treadmill for powering a machine is a far from new idea. The article mentions an 1880's issue of the magazine 'Scientific American' which gives an illustration of a horse (and also a cow/bull) on a treadmill. The article goes on to say that it has been mentioned in the magazine that the animal treadmill could perform many functions such as pumping water or generating electricity for lighting.

In favor of the concept of exercising animals, the patent [18] mentions in its 'Background' section that in livestock and poultry breeding enterprises, the (animal) body quality is weak and the resistance to disease is low. Some livestock/poultry enterprises use Clenbuterol drug, violating the rules. This drug as well as other antibiotics (which may be used for decreasing rate of animal fatality) cannot be completely degraded in animal bodies and can thus enter human bodies causing health issues. The section goes on to say that research related to exercise physiology has shown that good exercise can provide various benefits such as improving the muscle mass, consumption of body fat as well as increasing immunity (for animals) – and various individuals and companies are beginning to understand the significance of movement for enhancing the quality of livestock/poultry meat products.

Energy from animals' waste has been the area of interest since decades [19-25]. As compared to the existing models for renewable energy generation from animals' waste; the idea of animate prime-movers will definitely open new horizons of research in future.

3. BACKGROUND AND CURRENT WORK

Figure 1. Male caprine subject on inclined treadmill

The current work is the first project at the newly arranged 'Site for Research in Animate Prime Movers/Biomechanics for Power Generation' at the FSD campus of the university. For the current work, a manual (human) treadmill was purchased from a local supplier. The treadmill was fitted with an Induction Motor in order to make it motorized. A set of pulleys was attached to the front shaft of the treadmill – the pulleys reduce the speed as well as interface the motor with the shaft.

A male caprine subject – a male goat, has been used for this study, as shown in Figure 1. The choice of the subject may be regarded as notional i.e. to convey the idea; whereas use of a cow or buffalo would be giving higher energy production estimates. The highest pulley size was selected that gave a walking motion to the subject on the treadmill.

4. METHODOLOGY TO ESTIMATE POTENTIAL OF RENEWABLE POWER

4.1 The Main theme and contribution of the current effort

This section presents the proposed methodology for evaluating the generatable power via exercise of animate prime movers. The basic idea is that inclined treadmills are used/proposed for animals at different places [8, 11, 13, 16] if the power expended by the animal for the vertical propulsion can be estimated, and an equivalent energy generation system is attached to the flat mill, then the animal exercise gets coupled with renewable power production.

To this end, the current work attempted to determine this estimate of generatable power – and although, the current work remained unable to obtain suitable results, still it presents the methodology, mentions a number of its own shortcomings in the form of detrimental factors, and thus provides guidance to future work in this direction.

4.2 Methodology – Hardware based work

After setting up the treadmill, the next thing is to locate the COM point of the animal subject. The current work used an estimated COM point – which may be one of the detrimental factors. The estimate of vertical COM line was made via balancing the subject on a see-saw arrangement – and the midpoint of the COM line was roughly estimated to be the COM point of the subject. Figure 1 shows the subject on the machine and the estimated COM point location. Further studies, may use more sophisticated methods for locating the COM point. The hair was cut a little and a black marker was put on the subject's body – here again, a detrimental factor may be the ignoring of the movement of skin and hair. The subject was weighed to be around 16.5 kg in mass and estimated age was less than a year. Subsequently, the treadmill slope was adjusted to be roughly around 10%. The subject was then walked upon the machine – with a stride speed of roughly around 1 stride/second. Initially, it was planned to prevent the cranio-caudal motion of the subject on the treadmill; but for the final experiment, this was given up and the subject could move cranio-caudally to some extent. This may be regarded as another detrimental factor – as the cranio-caudal motion may affect the vertical motion of the COM point. This gets augmented when the subject is in walking mode – as walk is relatively less pattern following when compared to trot or gallop.

For the inclined treadmill work, a video of the subject was made which was further processed to extract COM motion trajectories. The machine was then flattened i.e. slope almost 0% and the same experiment was performed again.

4.3 Methodology – Software based work

For the video processing and tracking of the COM point, MATLAB environment has been used. Firstly, a video of the treadmill work was cut into single stride segments. Three such strides were selected – wherein, the hoof strike of the right fore (RF) leg was roughly taken as the start point of a stride. Subsequently, each stride video was processed separately for tracking of the COM point. The area around COM point was selected to extract interest points – these were then tracked and later plotted to roughly give the motion of COM in the xy plane; z axis motion of these points was not included, which may be another detrimental factor.

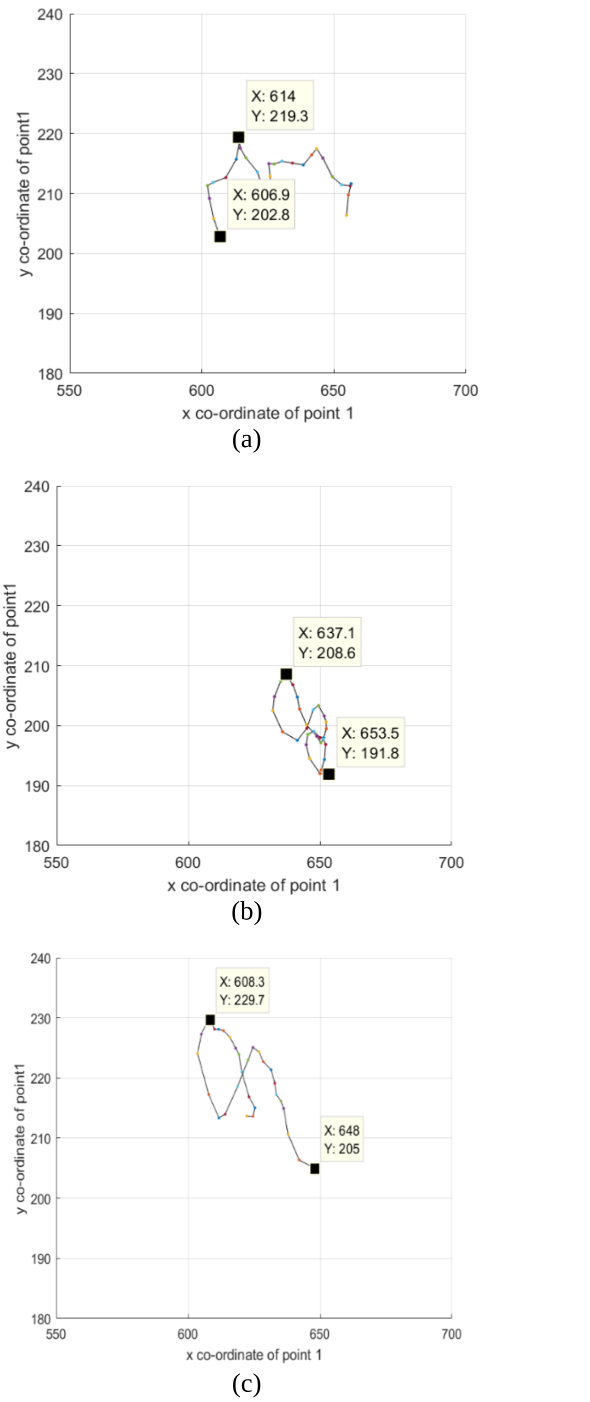

Figure 2. Video Processing Results – (a), (b), (c) are for the three selected strides of inclined treadmill work

For tracking purpose, a MATLAB example was modified to suit our needs, and the tracking methodology may be explained as: In the first frame, a Region-of-Interest (RoI) is selected using PC mouse, subsequently, minimum eigen value features are calculated (Shi-Tomasi Algorithm) for the RoI – the features are saved as points and then point tracker algorithm (Kande-Luca-Tomasi, KLT Algo) is initiated at the feature locations. The tracker keeps tracking the feature locations in each subsequent frame of the video.

The resultant video processing results have been plotted and are shown in Figure 2. Also, the coordinates of the lowest and highest points are shown. The coordinates are in pixels, and in order to come to know the size of vertical and horizontal pixels, two additional points were placed on the subject's body with known distance between them. These are shown in Figure 3 and the subsequent image processing showed that for the vertical points, a single pixel represents almost 0.035 inches of the subject's body, both for the inclined and the flat treadmill– the horizontal sizing was not used.

Subsequently, the plots of Figure 4 present the image processing results for the flat treadmill workout.

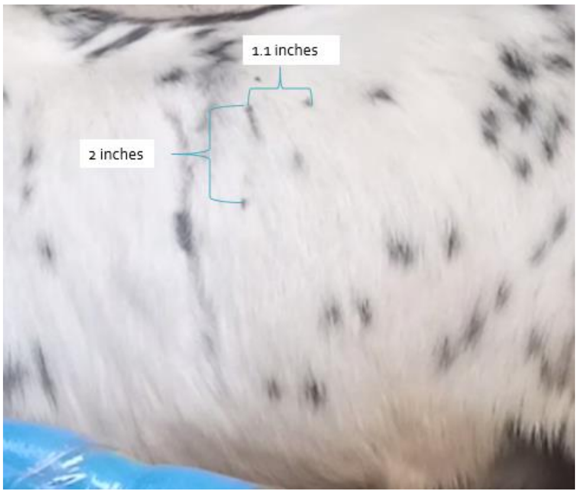

Figure 3. Sizing the horizontal and vertical pixels

Now to compare the vertical movement of the COM in the inclined and the flat treadmill, the vertical movement for three strides is averaged.

$$\begin{aligned} S_{v-A-inc} &= 219.3 - 202.8 = 16.5\ pixels \\ S_{v-B-inc} &= 208.6 - 191.8 = 16.8\ pixels \\ S_{v-C-inc} &= 229.7 - 205 = 24.7\ pixels \end{aligned} \tag{1}$$

where, $S_{v\text{-}A\text{-}inc}$ represents the vertical movement (distance) in pixels for an inclined stride. The corresponding averaged value is given in Eq. (2).

$$S_{v-average-inc} = \frac{S_{v-A-inc} + S_{v-B-inc} + S_{v-C-inc}}{3} = 19.33\ pixels \tag{2}$$

Similarly, for the flat strides,

$$\begin{aligned} S_{v-A-flat} &= 204.2 - 157.4 = 46.8\ pixels \\ S_{v-B-flat} &= 197.3 - 175.1 = 22.2\ pixels \\ S_{v-C-flat} &= 205.8 - 171.9 = 33.9\ pixels \end{aligned} \tag{3}$$

and the averaged value is given in Eq. (4).

$$S_{v-average-flat} = \frac{S_{v-A-flat} + S_{v-B-flat} + S_{v-C-flat}}{3} = 34.3\ pixels \tag{4}$$

These results are showing more vertical movement in the flat stride than the inclined stride, and this clearly indicates the presence of some sort of abnormality in the procedure. The next section presents a critique to our own work and then recommendations for future work in this direction.

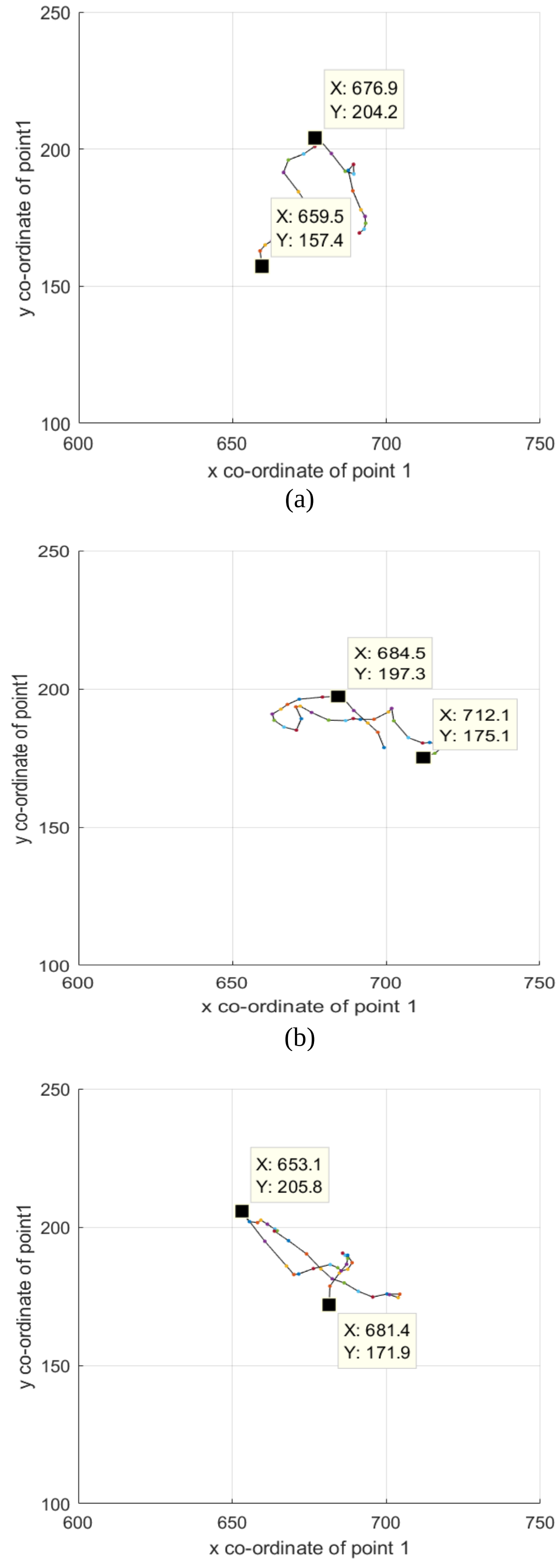

Figure 4. Video Processing Results – (a), (b), (c) are for the three selected strides of flat treadmill work

5. CRITIQUE OF THE RESULTS

Various detrimental factors have been mentioned so far that should/could be improved upon, for future work in this direction. All in all, due to a lack of high-tech facilities and a seamlessly appropriate equipment, the current effort remained unable to bring out the results which it was expecting to reach. The current paper, documents some of these deficiencies while also providing the research community an insight into this relatively new direction for research.

6. WEAK POINTS AND ASSUMPTIONS

Besides, the detrimental factors mentioned earlier, this research is based upon the assumption that the vertical propulsion power for an inclined treadmill is not the same as the corresponding power on an actual inclined terrain. Thus, the COM tracking method is required to estimate the amount of power expended.

7. A LOOK INTO THE EXPECTED RESULTS AND THEIR PROSPECTS/FUTURE WORK

Basically, the expectation was that the study would be able to detect a higher vertical motion for the COM point in the inclined workout as compared to the flat workout i.e. $S_{v\text{-}average\text{-}inc}$ should have been more than $S_{v\text{-}average\text{-}flat.}$. So, for example, if the obtained results showed a net 10 pixel higher movement for the inclined work, then to convert it into power, firstly it would have been converted to a length – in this case, it would have been around.

$$S_{v-net-inches} = 10pixels \text{ x } 0.035in = 0.35in \tag{5}$$

So this gives a 0.35 inches i.e. around 0.9 cm additional vertical movement to the COM in the inclined treadmill workout – and taking a 16.5 kg body weight, this gives energy expended per stride for the additional vertical work to be:

$$Energy_{vertical\ movement} = mgh = 16.5kg \text{ x } 9.8ms^{-2} \text{x } 0.009m \approx 1.45\ Joules \tag{6}$$

Converting to power, assuming the 1 stride per second speed, the same numerical value becomes power, hence,

$$Power_{vertical\ movement} = mgh = 16.5kg \text{ x } 9.8ms^{-2} \text{x } 0.009m \approx 1.45\ Watts \tag{7}$$

This value of 1.45 Watts is the value which is extractable by an energy harvesting mechanism if the treadmill is kept flat, and an equivalent-to-incline energetic exercise is given to the animal.

Furthermore, the value 1.45 Watts naturally appears to be quite low, but it becomes more valuable once this procedure is extrapolated to a larger animal e.g. a cow or a bull. If we assume a 400 kg cow to be exercising in this way, with $S_{v\text{-}net\text{-}inches}$ around 1 inch – then $Power_{vertical\text{-}movement}$ variable jumps to around a 100 Watts at the 1 stride/second speed. A large farm may be able to produce a good amount of energy (the energy conversion losses will nevertheless, also come into play) while also improving the health of the livestock.

As regards the possible future work, various directions are possible – an obvious major direction for future work is to implement the theme of energy harvesting treadmills for livestock and actually generate the power. Designing energy generation devices and ensuring the appropriate movement of livestock may be part of this. The Psychological aspects of such a work may also be explored e.g. stress releasing to humans via animal assisted activities and stress releasing to farm animals via providing good exercise in a congenial, cheerful environment. For instance, for horses, a psychological aspect of Equine Assisted Activities has been mentioned in literature, and coupling power generation with the corresponding effects of this equine involving activity upon university teachers/students or other people can be an explorable work area.

8. APPROVAL OF ETHICAL RESEARCH

The subject was acclimated to inclined treadmill machinery via a number of sessions, and then an approval for research experimentation was obtained from the members of 'Panel for Approval of Ethical Research (PAER)'.

9. CONCLUSION

This paper has presented a methodology for estimation of the renewable power producible from the exercise of livestock/animate prime movers. The estimation is for an energy harvesting mechanism that will extract an equivalent-to-incline energy from a flat treadmill. Despite the fact, that the hardware prototype experimentation mentioned here could not demonstrate the presented methodology, nevertheless, a critique on the implementation of the methodology has been presented and future prospects are hinted as well.

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