

A Smart Cycling Platform for Textile-Based Sensing and Wireless Power Transfer in Smart Cities [†]

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[†] Presented at the International Conference on the Challenges, Opportunities, Innovations and Applications in Electronic Textiles (E-Textiles 2019), London, UK, 12 November 2019.

Published: 4 December 2019

Abstract: This paper proposes an integrated smart cycling system for assisted cycling, energy harvesting and wireless power transfer systems on a bicycle, an enabling platform for autonomous e-textiles-based sensing. The cyclist is assisted by a switched reluctance motor, which also acts as a switched reluctance generator that harvests a peak power of 7.5 W, at 10% efficiency during cycling to power on-body sensors. To demonstrate wearable on-body sensing, a thin flexible CO₂ gas sensor filament, which can be woven in fabric, is presented and evaluated. Wearable inductive resonant wireless power transfer (WPT) is achieved using textile embroidered coils on the bicycle's handle and cycling gloves, achieving more than 80% WPT efficiency from the bicycle to the cyclist's clothing, useful for powering mobile on-body sensors.

Keywords: Internet of things; smart cities; e-bicycle; wearable electronics; wireless power transfer

1. Introduction

Cars and motorcycles are the predominant transportation method in urban environments. This dependence has increased city congestion and levels of air and noise pollution [1], problems the smart cities/IoT (Internet of things) paradigm seeks to address [2]. This work provides a solution, integrating bicycling into the smart city platform for monitoring and reducing the pollution from motor vehicles, and as an empowering platform for on-body e-textile autonomous sensors.

Figure 1 shows an integrated smart bicycle concept proposed in this paper for realising this transduction using a switched reluctance motor (SRM) [3], a harvester generator (SRG) for assisted cycling, and energy harvesting for e-textile sensors. The proposed SRG is cheaper and lightweight when compared to traditional dynamos. It is more environmentally friendly, requiring no permanent magnet, whilst providing greater cyclist comfort, a higher efficiency, and power density. A wireless power transfer (WPT) module enables high-efficiency transmission of the harvested cycling energy to textile-based sensors. A gas sensor, integrated on an e-textile flexible circuit filament, is proposed as a demonstrator.

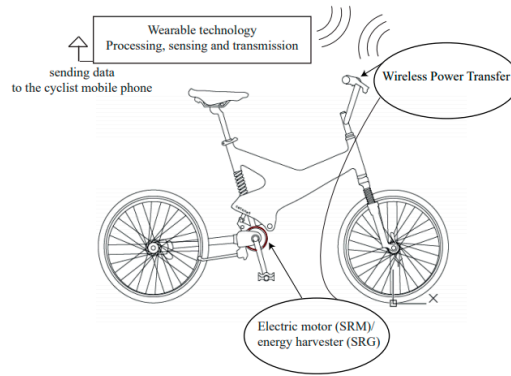


Figure 1. Block diagram of a smart cycling energy harvesting system.

2. Energy Harvesting from Cycling

Traditional bicycle energy harvesting systems use dynamos. Although dynamos offer good efficiency, they reduce cycling comfort, as the cyclist must contribute significantly more energy to move, which is particularly difficult when cycling uphill. The cyclist’s effort can be reduced by disengaging the dynamo manually prior to strenuous cycling, which is cumbersome. One commercial example of smart bicycle technology is the Copenhagen Wheel [4]. The system is controlled only through pedaling with one remote for choosing one of three modes, off, motor assist, and pedal assist (regeneration or exercise mode). The wheel harvests energy dissipated during braking and pedaling.

To minimise these disadvantages, a mid-motor type switched reluctance (SR) machine is proposed. The SR machine can be used both as a switched reluctance motor (SRM), and a switched reluctance generator (SRG) that offers assistance to the cyclist for strenuous cycling and harvests energy, respectively. Although the configuration of a magnet and coil is simple and more efficient for energy generation, it cannot function as a motor whilst configured as a generator. This limitation is avoided in the SR machine, enabling it to function as a motor or a generator with good efficiency. The SR machine is tunable, providing a number of choices to the cyclist, for example, turning on the energy harvester when cycling downhill. Harvesting energy in this way would have minimal impact on the cyclist’s comfort, especially with the use of motor assistance during uphill cycling.

A three-phase 18/12 SR machine configuration is considered and modelled in MagNet software to compare the performance of the SR machine on a bicycle based on the cycling profile presented in [3]. The cyclist power is calculated using $P(W) = T_{av}\omega$, where T_{av} is the average cycling torque over the complete pedal crank revolution and ω is the angular speed. Figure 2 shows the harvested power when the cycling schedule time is arbitrarily fixed at 10% duty cycle, that is, only 10% of cycling power is harvested by the SRG. Results indicate that a cyclist harvests more energy during uphill cycling because the cyclist pedals more and expends more energy in this phase.

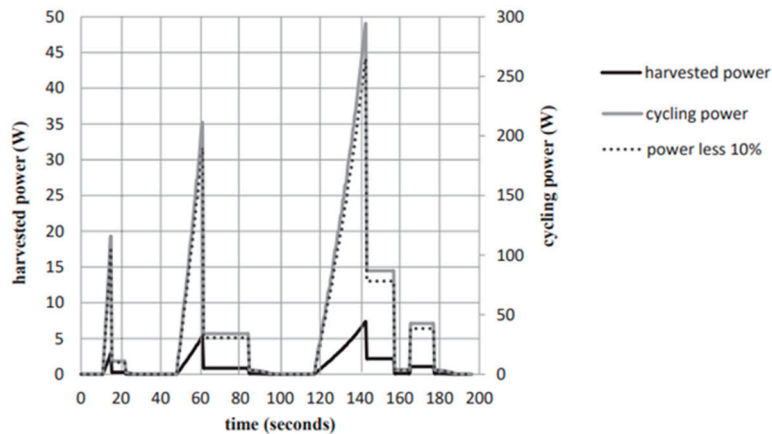


Figure 2. Simulation results of a switched reluctance (SR) motor. The harvested power levels as a function of the cycling schedule time for the fixed 10% duty cycle. The black line indicates the harvested power during cycling and the gray line shows the power put out by the cyclist and the motor. The dotted line indicates the total power after a portion of energy is harvested. The power from the cyclist has increased during uphill cycling.

3. Wearable Wireless Power Transfer

Flexible textile coils have been previously demonstrated for on- and in-body WPT with high efficiency over a short distance, for wearable and body-planar applications [5,6]. To transfer the power wirelessly to the user, near-field non-radiative WPT is proposed using inductive coupling [6,7]. Conductive textile threads (40 μm thick) were embroidered into a woven-polyester fabric substrate (280 μm thick), forming planar spiral coils for transmitting and receiving power.

The inductance of the coil is measured using an impedance analyzer and tuned to resonate at 6.78 MHz (the license-free band used for most WPT applications) based on $F_{Resonance} = 1/2\pi\sqrt{LC}$. Two identical coils are proposed for the bicycle’s handle and for the cyclist’s glove in Figure 3. The measured coil inductance and resistance at 1 MHz are 4.9 μH and 0.480 Ω, respectively.



Figure 3. Integration of embroidered 10-turns wireless power transfer (WPT) coils (left) on the glove and bicycle handle (right) respectively. Coil dimensions: $D_{inner} = 20$ mm, $D_{outer} = 50$ mm diameter, pitch = 0.5 mm, where D = coil diameter.

A Vector Network Analyzer (VNA) was used to measure the WPT efficiency in Figure 4 at 6.78 MHz as a function of coil-separation and frequency. The coil demonstrates the highest power transfer efficiency at the selected frequency, due to the lower losses at the low-MHz frequency bands. The reduced WPT efficiency at 0.1 cm separation is a result of detuning due to the coils’ mutual inductance affecting the series inductance, requiring a frequency-tracking circuit at the transmitter. However, more than 80% WPT efficiency is still maintained. Although ultrathin threads of relatively high series resistance were used, the achieved WPT efficiency is similar to state-of-the-art wearable WPT systems [5,6]. As the proposed coils are optimized for short-range WPT, high efficiency can be achieved on-body due to the minimised magnetic field dissipation through the human body. Moreover, higher power levels can be transferred compared to radiative power transfer, due to the lower human absorption, compared to microwave frequencies, and the higher regulation’s transmitted power limits. Table 1 shows a comparison of the proposed WPT coils with reported wearable WPT systems.

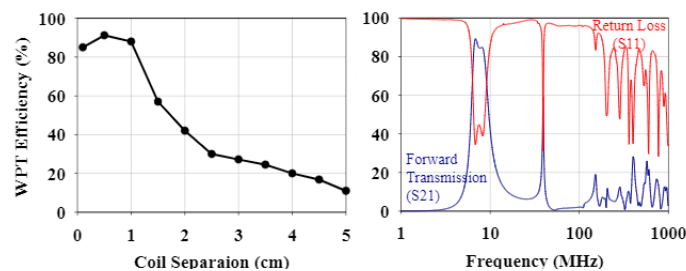


Figure 4. WPT efficiency between the tuned coils at 6.78 MHz over different coils separation (left), and over frequency up to 1 GHz at 1 cm (right).

Table 1. Comparison of the proposed WPT method with the state-of-the-art.

	Distance (mm)	η_{WPT}	WPT Method	Coils
This work	5	82.1%	Inductive coupling	Embroidered copper threads
[5]	10	78.1%	Tuned magnetic resonance	Copper wires
[6]	60	60%	Coupled magnetic resonance	Copper plated textile

4. Requirements for Wearable Sensing

Wearable and textile on-body sensing have attracted recent interest [8]. A textile-based super capacitor has been presented for storing harvested energy for wearable sensors [9]. In addition, flexible Radio Frequency (RF) front ends for wireless nodes have been specifically designed for on-off-body communication using standard license free protocols such as Bluetooth Low Energy [10]. In this work, we investigated a novel wearable gas sensor (Figure 5), fabricated based on the fabrication process in [8]. The sensor was implemented for mobile air pollution sensing on-body using commercial gas sensors packaged for weaving in textiles. The sensor runs at 88 mW. At an 80% WPT efficiency, the average power from the SRG from Figure 2 is 824 mW; sufficient to power multiple gas sensors or other low-power wearable sensors.

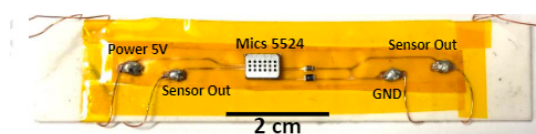


Figure 5. Flexible gas sensor strip containing MiCS-5524 gas sensor chip and surface mount resistors.

5. Conclusions

In this paper, a complete smart-cycling system architecture is proposed. The smart cycling enables the connectivity among cyclists in smart cities. A self-powered sensing system that can be integrated easily to any type of bicycle is considered. To achieve this, a switched reluctance generator to harvest the surplus cycling energy, which is then reused to power on-body sensors, is presented. Moreover, a textile-based wireless power transfer mechanism using inductive coupling and pollution sensing using commercial gas sensors are presented to enable additional use-cases of the harvested cycling energy, empowering crowdsourcing air pollution data through cyclists in smart cities. Future studies will advance from the modular implementation of the architecture proposed in this paper to a full system integration of the SRM/SRG, the inductive power transfer (IPT) and the wearable sensor.

Funding: This work was funded by the UK Engineering and Physical Sciences Research Council (EPSRC) under Grant EP/P010164/1.

Conflicts of Interest: The authors declare no conflict of interest

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