

# Intermittently-powered Battery-free Robot

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## I. INTRODUCTION

Low cost robotic platforms have been developed to tackle a variety of challenges anonymously. Miniature robots can be used for inspection in difficult to reach places, operating like mobile sensing units. Hardware modularity is a way to make the robot adapt its resources to different environments and sensing operations. By separating out power, computation, motor control and sensing a verity of capabilities can be tested [1], [2]. Microrobots typically use infrared-based neighbor to neighbor distance sensing and communication [3]. While controlling a swarm or collective is mainly accomplished by means of active low power transceivers [1], [2].

Choosing the right locomotion resource can depend on different factors, moving in the most energy efficient way on a particular surface is often the determining factor. On a flat surface, robots commonly use a two-wheeled differential drive design to not only move but allow for steering as well [1], [2]. The GRITSBot does not use conventional DC motors, requiring encoders to estimate their speed. Instead by using stepper motors the speed can be set by changing the delay between steps. Estimating it's position therefore is reduced to simply counting steps [2]. Overall cost can be a decisive factor, therefore the Kilobot uses two vibrating motors for locomotion combined with three thin legs. When the motors are activated the centripetal forces will generate a forward movement, which can be explained using the slip-stick principle [3]. Other locomotion types are biologically inspired, the HARM-VP is small scale piezoelectric driven quadrupled robot[4]. Each leg as two degrees of freedom and move up and down as well as forward and backward.

Typically the operation time is extended by regularly checking the remaining energy in the battery and move to a recharging station before the robot runs out of energy [2], [3]. As an alternative to quickly recharging, the battery can also be swapped automatically when the robot moves into the docking station [5]. Another work shows a robot that is able to swap it's primary battery using a six degree-of-freedom manipulator, used to grab the dead battery and plug it into a wireless recharging charging station [6]. Using direct wireless power to replace or supplement to a batteries energy is shown in [7], however the robot can only operate or recharge while remaining in close proximity to a transmitter. In these cases the robots are highly reliant on an infrastructure to allow for continuous autonomous operation. This can be a severe constraint if the robot moves out of reach or needs to operate in a area where this infrastructure is not present.

To capture the optimal amount of solar energy along the

way, a map of the expected solar power can be used to compute the optimal path. To distinguish sunny or shaded two methods are proposed in [8], one being a simple datadriven Gaussian Process and the other estimates the geometry of the environment as a latent variable. Energy aware path planning is commonly used in combination with mission planning. In [9], an analysis of the solar radiation is used to generate a time-optimized motion plan and power schedule using a cascaded particle swarm optimization algorithm.

Comparing batteries with super-capacitors there are some Reincarnation in the Ambiance: Devices and Networks with Energy Harvesting [10]

All the previous work assumes that a operation is only possible when there is sufficient energy to complete a task. This research will explore the feasibility of a battery-less robot, allowing persistent operation while having a very small and intermittent source of energy. Intermittently powering robots creates new challenges in control, navigation and collaboration.

## II. RELATED WORK

In resent years the devices used for this telemetry have become low cost and battery less. Fully programmable platforms have been developed to exploring the combination of sensing, computation and communication, while operating battery-less by making use of RF energy harvesting [?].

## III. DESIGN REQUIREMENTS

## IV. ROBOT DESIGN

Should the subsections more or less reflect the columns in the table?

A. *Hardware*

B. *Software*

## V. LOCALIZATION ALGORITHM

## VI. EXPERIMENTAL RESULTS

## VII. LIMITATIONS AND FUTURE WORK

## VIII. CONCLUSIONS

TABLE I

AN COMPARISON OF SMALL ROBOTIC PLATFORMS

Robot	Cost	Scalability	Odometry	Sensors	Locomotion	Size [cm]	Weight [g]	Battery life [h]
IPR	TBD	charge, program	stepper motors	distance	wheel, 3cm/s	3	15g	0.0001
Zooids [11]	\$50	??	none/external	position, touch	wheel, 50cm/s	2.6	12	1-2
GRITSBot [2]	\$50 <sup>1</sup>	charge, program calibrate	stepper motors	distance, earing, 3d accel., 3d gyro	wheel 25cm/s	3	??	1-5
Kilobot [3]	\$50 <sup>1</sup>	charge, program	other agents	distance, ambient light	vibration, 1cm/s	3.3	??	3-24
TinyTerp [1]	\$50	none	none/extrnal	3d gyro, 3d accel.	wheel, 50cm/s	1.8	??	1

<sup>1</sup> Cost of parts

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