

# Energy Potential Detection for Autarkic Smart Object Design in Facility Logistics

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**Abstract**—In order to design energy autarkic Smart Objects powered by Micro-Energy-Harvesters a systematic detection of possible energy sources in the environment is needed. All possible energy sources can be detected and evaluated by the novel Micro-Energy-Harvesting potential detection system in facility logistics. The detection system consists of containers equipped with a probe and a evaluation system. The probes are connected in a Wireless Sensor Network and transfer the sensor data online to the evaluation system. Finally, the evaluation software analyzes the acquired sensor data and calculates the average power which could be harvested from the environment. With this information the user can identify the most promising energy source considering the level of efficiency of Micro-Energy-Harvesters.

**Keywords**—Micro-Energy-Harvesting, Energy Potential Detection, Facility Logistics, Smart Objects, Smart Carrier, Monitoring System

## I. INTRODUCTION

The future trends and developments of the Internet-of-Things (IoT) will tremendously shape industrial control, communication and transportation tasks. Wireless Sensor Networks (WSN), RFID-Technology and decentralized control systems will enable the automated production and individualization of products and decrease the handling complexity of these systems. The actual *Internet of Things - Strategic Research Roadmap* of the European Commission describes industrial and research goals and needs prior to 2010, until 2015 and beyond 2020. Part of this roadmap are monitoring systems and the distribution of Smart Objects in the environment to meet the industrial, economical and societal needs. Aerospace and aviation, Automotive, Telecommunications, Intelligent Buildings, Retail, Logistics, Supply Chain Management, Manufacturing, Product Lifecycle are only some application domains. It shows the clear demand for an improvement of the actual energy sources for Smart Objects in the IoT environment [1]. Mobile Smart Object's capabilities should not be limited by their energy supply and should work at most autarkically. Due to these requirements the Fraunhofer Institute for Material Flow and Logistics in Dortmund focusses their research activities on the systematic detection of potential energy sources and energy storage for Smart Objects. Notably, novel energy storage and harvesting technologies like Micro-Energy-Harvesting (MEH), mini fuel cells, 2D and 3D-Microbatteries and microcapacitors are alternatives for the power supply of Smart Objects in logistics. This contribution shows the elements of the detection of potential energy in facility logis-

tics environments in order to develop energy autarkic Smart Objects with the capability of sensing, acting, identifying and communicate to meet the requirements of IoT in facility logistics [2]. During the research project *AWiDalog - Active Wireless Data Acquisition in Intralogistics* [3] the research activities were focussed on the concept and design of the energy potential detection system for autarkic smart object design in facility logistics.

### A. Internet-of-Things

As a part of the future Internet, the Internet-of-Things can be defined as a decentralized interoperable global network environment with self configuration capabilities based on standard protocols. In this network physical and virtual “things” have identities, attributes, services and interfaces which integrate them seamlessly in the IoT network. So the Internet-of-Things allows entities (e.g. people or things) to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service. This implies addressing elements such as Convergence, Content, Collections, Computing, Communication, and Connectivity in the context where there is seamless interconnection between people and things and/or between things and things [1], [4].

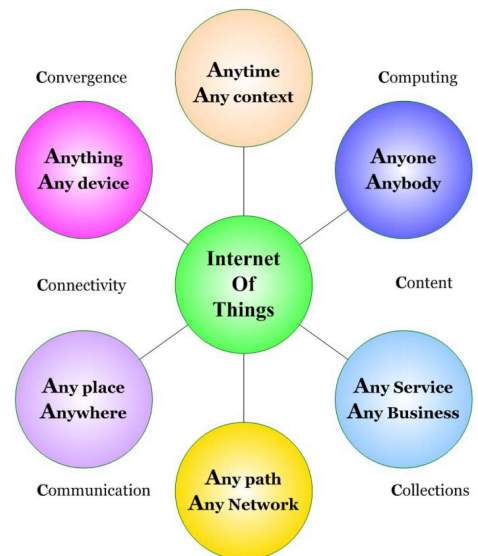


Fig. 1. Internet-of-Things [1]

### B. Smart Objects

Smart Objects are building blocks for the Internet-of-Things. Considered as entities they are able to understand and react on their (intelligent) environment (cf. 1). A Smart Object in an industrial workspace consists of a tool/thing equipped with a communication unit, an actuator and sensors. Additionally, RFID-technology is widely deployed in many industries, so Smart Object often use RFID-technology for communication and identification. Ordinarily, Smart Objects in facility logistics are divided in groups of devices like actuators, readers, triggers, listeners, etc. [5].

Actual trends show the demand for Smart Carriers e.g. containers or bins with the abilities of sensing, actuating and communicating with the conveyor environment and external systems. The instant ability of monitoring, tracing and tracking of goods along the entire supply chain enables the detection of environmental stress on the transported good, interruptions of the cold chain, anticipatory process planning and decentralized conveyor control on item level [6], [7].

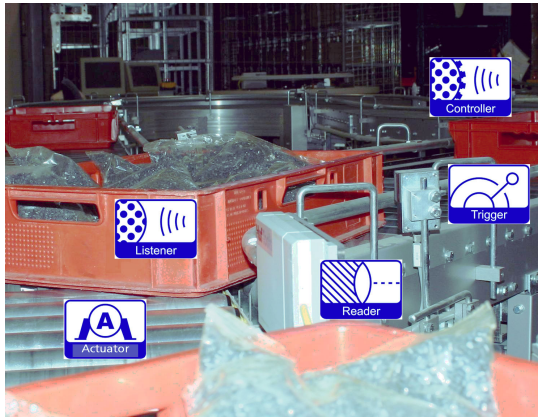


Fig. 2. Smart Objects in Facility Logistics [5]

### C. Energy Supply

Implementations of different types of energy supply are capable to power Smart Objects. Wired energy supplies, (rechargeable) batteries, capacitors are state-of-the-art solutions. Micro-Energy-Harvesters pave the way for autarkic, respectively maintenance-free, systems. Energy autarkic systems call high demands on the included electronics. In contrast to systems with batteries these systems have to consider Micro-Energy-Harvester specific properties and consumer load specific properties.

Smart objects driven by MEH also require integrated converter electronics, such as boost converters to match the impedance between harvester and the load circuit. Furthermore, MEH do not deliver energy continuously, factually only in times when energy sources are available. Effectively, they should produce more energy than needed. To guarantee long term operation of the autarkic system, this surplus of energy has to be stored to be used at another time. For that purpose an energy buffer and energy management circuits have to be implemented.

## II. BACKGROUND

### A. Wireless Sensor Nodes

A Wireless Sensor Network is a network consisting of a number of electronic devices. These devices are composed of a wireless communication interface, a microcontroller and a variety of sensors. Typical network topologies, such as star, mesh and tree are applied by different communication standards. Ideally, the sensor data is routed through the network in a quick, intelligent and power saving manner. WSN are used for condition and facility monitoring, medical surveillance and logistic purposes. The sensor data is used to retrieve qualitative and quantitative information or state changes of the observed system. The main focus of autarkic WSN is on the reduction of power draining activities and the perpetuation of the network. Furthermore special techniques of energy management support the durability of the WSN. Duty cycling and time-slot operations reduce awake time of the nodes, hence the energy consumption [8], [9].

### B. Micro-Energy-Harvesting Principles

Alternative energies for Smart Objects can be found in Micro-Energy-Harvesting technologies. Micro-Energy-Harvesting is based on the use of special physical effects. These effects enable according converter systems to harvest energy from environmental influences. These conditions may be acceleration/vibration of the system, solar irradiance or thermal differences between the system and the environment. The photoelectric effect (cf. figure 3) is utilized already for many years to convert energy from sunlight or artificial light sources. The photoelectric effect transfers electrons from the valence to the conduction band by the absorption of photons. So the solar cell converts solar energy into a usable amount of direct current [10].

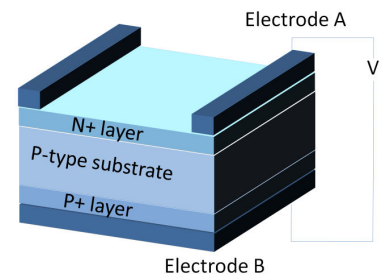


Fig. 3. Solar Micro-Energy-Harvesting

The piezoelectric effect (cf. figure 4) is used to transform mechanical energy to electrical energy. Mechanical force applied to a piezoelectric crystal results in a change of voltage. When using electromagnetic induction small conductible masses are moved through a magnetic field. An electric current is induced in a closed circuit. Thus acceleration forces like vibrations or shocks can be converted to usable energy [9]. Vibration harvesters operating in wide frequency bands have lower efficiency than small band

frequency harvesters.

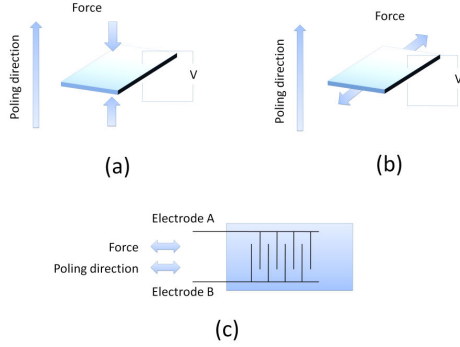


Fig. 4. Vibration Micro-Energy-Harvesting

Thermoelectric harvesters are based on the Seebeck effect. The Seebeck effect (cf. figure 5a) occurs when two different metals are joint at two ends and a voltage is produced by a temperature gradient. The thermoelectric device converts thermal energy into electricity. The opposite effect of the Seebeck effect is the well known Peltier effect. In thermoelectric devices it describes the generation of heat at one junction of two metals and the absorption of heat at the other junction by the application of a voltage [9], [11].

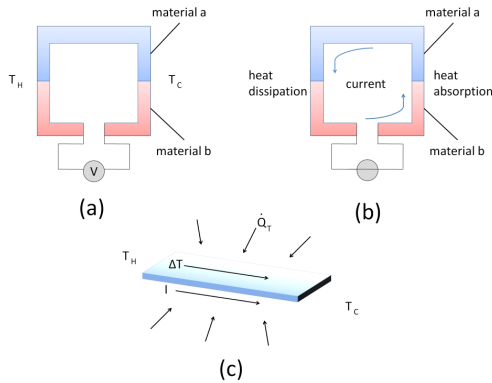


Fig. 5. Thermal Micro-Energy-Harvesting

### C. Detection of Micro-Energy-Harvesting Potentials

Conveyor systems in facility logistics usually consist of roller conveyors, belt conveyors, lifts, turn points, pushers etc. All of these devices cause environmental stress on the transported containers in different ways. Continuous vibrations with variable frequencies caused by roller or belt conveyors or shocks of pushers unintentionally transfers kinetic energy on the transported container or bin. Moreover, the conveyor system could pass through different temperature zones and different illuminance levels. This environmental impact could be used for MEH to power a Smart Object and ensure their energy autarky. Possible identified energy sources are: shocks

and vibrations (kinetic energy), illuminance (radiant energy) and a temperature gradient (thermal energy).

Until today the implementation of an energy source for energy autarkic devices with a Micro-Energy-Harvester is done via the “trial-and-error” principle. Possible energy sources are manually identified and evaluated by existing harvesters - e.g. an electrical machine causes vibrations, so different vibration harvesters are tested and implemented. This process is inefficient and strongly depends on the capabilities of the operator. This clearly shows the demand for a systematic solution.

## III. GENERATED POWER EVALUATION

### A. Idea

Basically, all possible energy sources which are listed in I-C and II-C should be examined and evaluated by the Micro-Energy-Harvesting potential detection system. The whole detection system (cf. III-C) consists of the containers each equipped with a probe and a evaluation system. Finally, the evaluation software analyzes the acquired sensor data and calculates the average power which could be harvested from the environment. With this information the user can identify the most promising energy source considering the level of efficiency of a Micro-Energy-Harvester.

### B. Setup

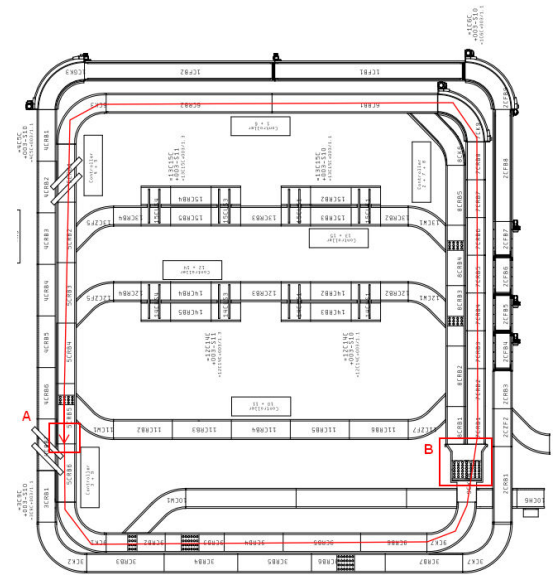


Fig. 6. Layout of the Conveyor System and the Way of the Probe

Referring to the preliminary idea, an existing test facility with continuous conveyors was used for the experimental setup. To mirror the heterogeneous configuration in facility logistics systems, the test assembly contains a number of different elements - for example various turning points, pushers, roller and belt conveyors with different drives to represent most of the used types in the industry. All these modules



are controlled by the “Internet-of-Things” principle. Figure 6 shows the test facilitys conceptual assembly. The conveyor system is illuminated by tube lights and the temperature is constant. Some conveyor elements are partly covered by overhanging elemets like RFID-gates.

### C. Detection System

1) *Overview of the Detection System:* The overview of the detection system is given in figure 7. The detection system consists of three parts:

- Container with Probes: n containers with wireless transceiver and sensors for recording of acceleration, illuminance and temperature gradient
- Data Acquisition Unit: one coordinator node, which polls the sensor nodes periodically and sends the data to the evaluation system
- Evaluation System: PC with recording and evaluation software for online and offline data analysis

was built up. The sensor nodes communicate in a Wireless Sensor Network using star topology.

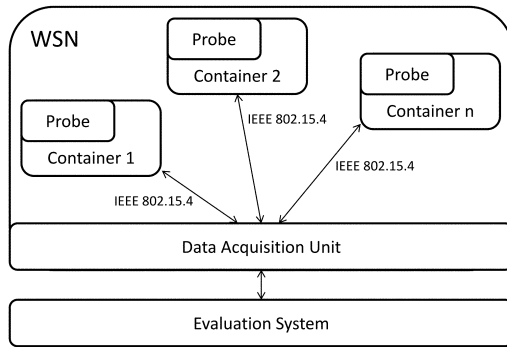


Fig. 7. Conceptual Overview of the Micro-Energy-Harvesting Potential Detection System

The detection is started by the introduction of the probe containers into a material flow system. So they cycle through the system like usual transport containers. During the transportation environmental influences are recorded by the sensor nodes and periodically sent to the coordinator node, which provides the data to the evaluation system. The evaluation system calculates the average power which could be harvested from the environment. The required a priori knowledge and the parameters for the calculation are decribed in III-C3.

2) *Probe:* The probe container is composed of a wireless sensor node equipped with the following sensors and parameters:

Type	Range	Accuracy	Sampling Rate
3-Axis Accelerometer	-16...+16 g	±1%	600Hz
Temperature 1 & 2	-40...+85C	±0,4°C	40Hz
Illuminance	1...65535 klux	±5%	40Hz

TABLE I  
BUILT-IN SENSORS

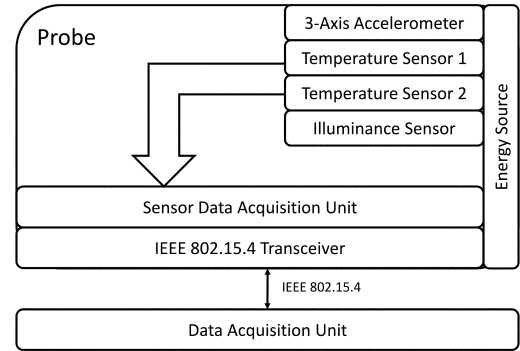


Fig. 8. Structural Overview of Probe

The figure 9 shows the container with the build-in sensor node on the conveyor system of the Fraunhofer Institute for Material Flow and Logistics in Dortmund.

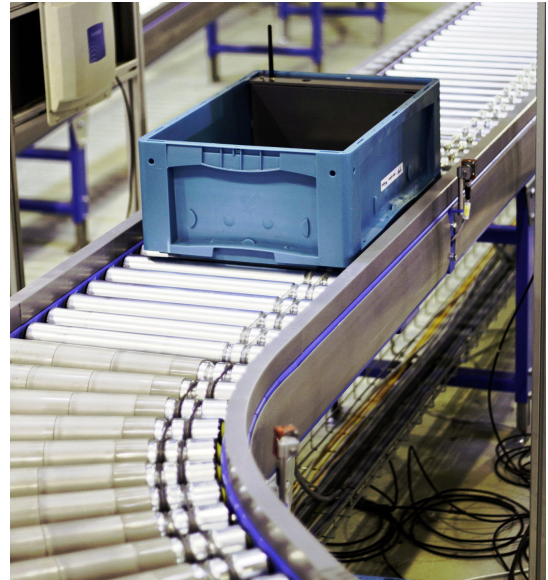


Fig. 9. Container equipped with Measurement Devices

The accelerometer offers the oppurtunity to detect vibrations lower than 300Hz which is the eigenfrequency of the used plastic containers. The temperature sensors are wired and could be mounted on the transported good inside the container or on the container in order to measure the temperature gradient. The illuminance sensor measures the photometric quantity, so a priori knowledge of the light spectrum is needed to recalculate the radiometric quantity (cf. III-C3). All data is sent via radio based on the IEEE 802.15.4 standard to the coordinator node. If more than one measurement node is used the sampling decreases because of the shared bandwidth. The probe itself is powered by lithium batteries.

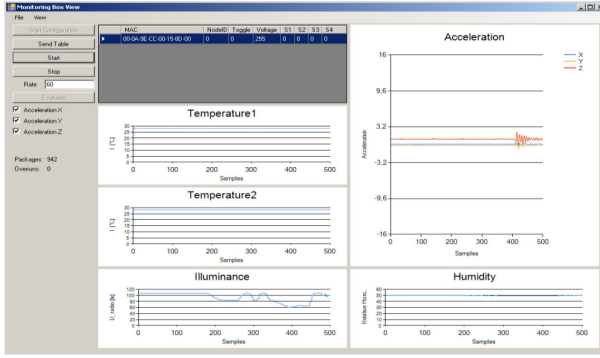


Fig. 10. Management View

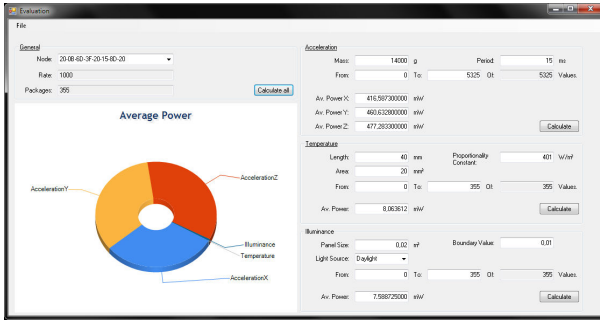


Fig. 11. Evaluation View

3) *Evaluation Software*: The evaluation software manages the mobile sensor nodes, it stores the obtained sensor data and it calculates the energy potential of the system to be examined. By the use of a proprietary communication protocol, it is possible to configure, activate and deactivate each sensor node. The user is able to select specific sensor nodes from the whole set of nodes and include these in the measurement. The user starts and stops the measurement manually or timer controlled. After the measurement is finished the whole set of measured data is calculated into potential energy values of each node and each type of sensor using the specific formulas of the physical interrelation. Various constant values contribute to the calculation and are considered as a priori knowledge. They specify physical conditions of the environment and configurations of intended hardware to be used. Exemplarily named shall be the sampling rate of the sensors, assumed weight of the container, available space for thermo harvester, spectrum of the prevalent light source and the available panel size of the solar harvester. The software shows the resulting data as nominal values and in a chart where each potential MEH is rated in percent of the overall energy contribution. The calculated results show the pure potential and do not represent the energy being gained by the use of MEH. Due to the specific degree of efficiency of each MEH, the real available energy can be obtained by the help of the efficiency factors.

#### D. Measurements

First experimental measurements have been performed at the Fraunhofer Institute of Material Flow and Logistics

in Dortmund, Germany. One small load container has been equipped with the described probe and passed into the conveyor system being examined. Section 'A' in Figure 6 shows the start and end point of the container's cycle through the system. Section 'B' shows a pusher where lanes can be switched. The evaluation software has been configured with the parameters from a priori knowledge as depicted in table II.

Parameter	Value	Description
Sampling Rate	600	samples per second
mass	14kg	container mass plus load
length	40mm	assumed length of the thermo harvester
area	20mm <sup>2</sup>	assumed area of the thermal harvester
$\lambda$	401	thermal conductivity constant
panel size	0.02m <sup>2</sup>	area of the photodetector
light source	tube light	spectrum of the light source

TABLE II  
A PRIORI PARAMETERS

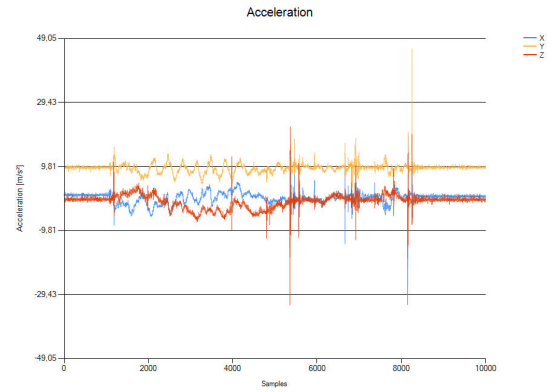


Fig. 12. Acceleration of the Container During the Cycle

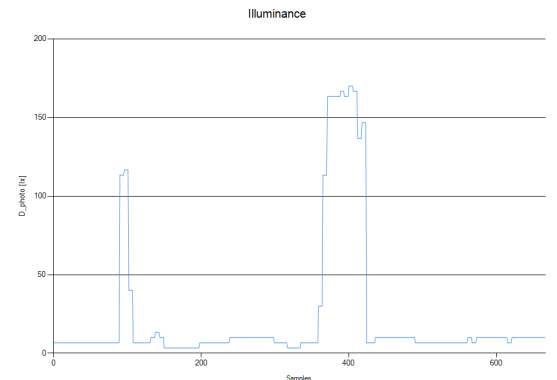


Fig. 13. Illuminance of the Container During the Cycle

In the management view the probe has been prepared for the measurement. The measurement has been started approx. 2 seconds before the conveyor system started operating and the measurement stopped approx. 3 seconds after the conveyor.

Figure 12 shows the acceleration sensor data and figure 13 indicates the illuminance sensor data. The data states different conditions of the moving container caused by acceleration in all 3 degrees of freedom, shocks and different illumination. In this test field the temperature sensor data can be disregarded due to uniform thermal conditions in the environment. After the calculation of the sensor data a potential energy distribution amongst the investigated sources of energy can be obtained denoted in figure 14.

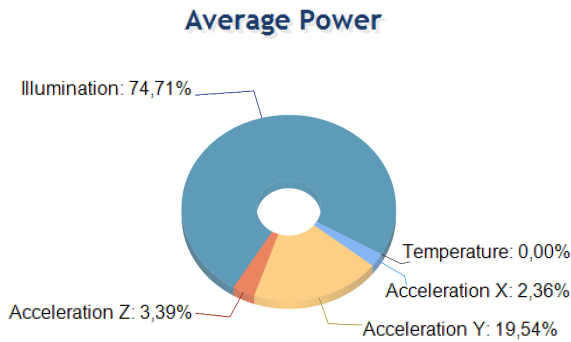


Fig. 14. Offline Calculated Pie Diagramm

Source	$P_{det}$	Eff.[9]	$P_{eff}[mW]$	$I_{@3.3V}[mA]$
Acceleration X	61,28	1 %	0,6128	0,1857
Acceleration Y	508,03	1 %	5,0803	1,5395
Acceleration Z	88,15	1 %	0,8815	0,2671
Illumination	19,42	15 %	2,9131	0,8828

TABLE III  
EXPERIMENTAL RESULTS

#### IV. CONCLUSION AND OUTLOOK

The results (cf. table III) show the feasibility of the proposed detection system to discover energy potentials for Smart Objects in facility logistics. Roller conveyors deliver an acceptable average in power, where belt conveyors do not. Heavy shocks by pushers purely provide more power but are not transformable by MEH because of the limited bandwidth of the harvesters. Future evaluation has to include Fourier transformation to find energy peaks over all detected frequencies.

The most promising energy source in the test field is generated by the lighting, since acceleration harvesters do not operate over the whole frequency band. By the use of adequate energy harvesters, the test environment including the conveyor system provides enough energy to power Smart Objects. Especially in this case it is shown that also a combination of harvesters, the test environment including the conveyor system provides enough energy to power Smart Objects. Especially in this case it is shown that also a combination of harvesters leads the way to success. The evaluation is based on a sleep current of 0.1mA, active current of 10mA and a transmit current

of 20mA [9]. For instance a Smart Carrier [12] with an active control and monitoring unit can be realized as an energy autarkic device with limited transmission cycles and by using sophisticated power management (energy buffering) techniques.

This work presents a systematic way to find indicators for the utilization of Micro-Energy-Harvesters. For the final selection of the appropriate harvesters, a database with efficiency factors for different types of Energy Harvester is essential. The creation and maintenance of this database is part of future work at the Fraunhofer Institute for Material Flow and Logistics. Energy storage and buffer technologies are still necessary to power energy autarkic and maintenance-free systems.

Further studies on different types of communication systems for smart object are also desired and will push forward the increasing use of autarkic systems. Finally, for the detection system it is favourable to use the ZigBee communication stack to enable mesh network topologies and hence allow a wider area to be examined.

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