

Mechanical energy converter study for lotic water sensor applications

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Abstract—Wireless sensor systems can help to improve or to expand instrumentation for environmental monitoring systems. A mechanical converter solution will be proposed to convert energy using the Kármán vortex street within lotic water. Within the system design process the focus of this contribution will be in the investigation of the mechanical coupling of turbulences and a mechanical energy converter.

Index Terms—lotic water monitoring, wireless sensor node, mechanical energy converter

I. INTRODUCTION

For a better understanding or controlling of environmental events like climate phenomena, pollution in general or human effected processes wireless sensor systems provide an attractive opportunity to improve or to expand existing instrumentation in an economical way. And extended data base supports a better analysis, a better modelling of still mentioned phenomena for a better prediction allowing a better preparation to prevent civil disasters in the future. Furthermore, additional information provides the opportunity to react quickly and more precise for example in cases the contamination of lotic water, to prevent the spread of pollution.

Within this context, the design of a wireless sensor node (WSN) approach will be proposed to monitor as an example lotic water quantities autonomously for small and medium streams with low flow rates. One major challenge thereby is the realization of a mechanical energy converter for a selforganized power supply using the Kármán vortex street. The study contains of an evaluation of possible energy sources within this context, a study of methods to couple the mechanical energy of the lotic water including FEM analysis and empirical investigations using a flow passage and the system design of a WSN including an energy management, low power sensors and the wireless communication. Within this contribution the focus will be on the investigation of the mechanical coupling of the Kármán vortex street to a proposed converter of mechanical energy sources.

II. CONCEPT OF THE SENSOR SYSTEM

The concept of a wireless sensor node is shown in Fig. 1. One or multiple harvesters provide the energy for the system. The energy flow into the and out of the system is controlled by the energy management. If the amount of energy harvested is not enough to power the system permanently, an energy storage has to be employed. The energy consumer

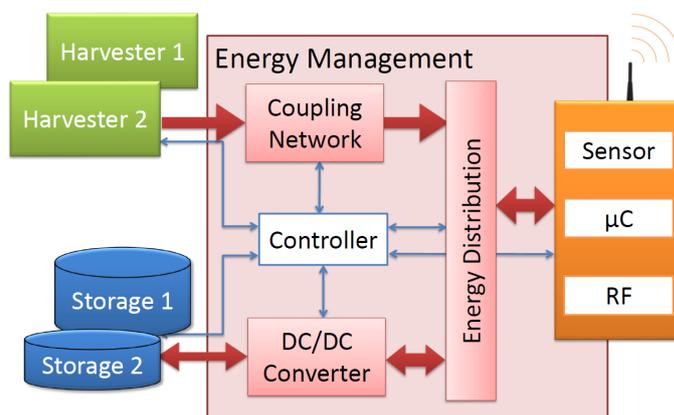


Fig. 1. Concept of a wireless sensor node

is the sensor, microcontroller and RF section. The energy harvester Fig. 1. Concept of a wireless sensor node part (conversion of mechanical to electrical energy) and the sensor, microcontroller and RF part will be discussed in detail in section III.

The proposed WSN will work in lotic water environments with a flow velocity over 0.5 ms^{-1} and water levels above 10 cm. It will include a unidirectional, wireless data transmission to deliver the sensor data to a central receiver station. First evaluations of available electrical components in the energy management section have shown that a continuous power of $10 \mu\text{W}$ is needed. This power has to be generated by the energy harvester. The system should measure the pH value, the temperature and the flow velocity, which is possibly dependent on the amount of harvested power.

III. DISCUSSION OF THE SYSTEM COMPONENTS

A. Mechanical to electrical energy conversion

There are multiple possibilities for the conversion of the fluid energy of the lotic water to electrical energy [1]–[3], [5]–[8]. One possibility is the use of turbines, which are known from large hydroelectric power plants. On a small scale, which is the case for the proposed system, problems occur which are not known from large-scale applications, for example, the contamination or blocking of the turbine by carried debris. Because of this, another possibility of using the fluid energy has to be found. One solution is the use

of turbulences within the water. For this work, a Kármán vortex street behind a bluff body and a piezoelectric bimorph is employed. The vortices, which are generated behind the bluff body, cause pressure differences and can be used for bending a piezoelectric bimorph, see Fig. 2. Another example is the use of piezoelectric foils [1], [2], shown in Fig. 4. The vortices can be simulated in a CFD (Computational Fluid Dynamics) environment. Some simulations have been carried out, an example is shown in Fig. 3. One can see the detachment of the vortices behind the bluff body. Another possibility is the use of turbulences which are already present within the water. This is especially the case for lotic water, which flows around numerous obstacles.

The advantage of all these principles is that they are insensitive to contaminants or debris carried with the water. For the use in lotic water for a long time (years to decades) a redundant construction is needed. In the following a new concept is proposed, which can be built redundant and bases on a Kármán vortex street. The concept proposed in the literature is depicted along with the new concept in Fig. 5. In the new concept, additional objects are employed, which are attached to the piezoelectric bimorph with a string. This yields two essential advantages:

- Redundant construction possible
- The sensitive piezoelectric material is not exposed to the water anymore.

If applicable, no bluff body is needed and the existing turbulences in the water can be used. The second concept with an additional object attached is investigated in section IV.

B. Microcontroller, wireless data transmission and pH measurements

Fig. 6 shows the schematic setup of the microcontroller and RF section. First datasheet investigations [9] yielded a Fig. 6. Schematic diagram of the microcontroller and RF section power consumption of the unidirectional transsion module of around 100 mW in transmitting mode. This power is orders of magnitude higher than the power consumption of the other components, such as the microcontroller and the analog frontend for the sensors. However, the system as a whole cannot be powered permanently. Based on the power consumption of the transmission module and a continuous

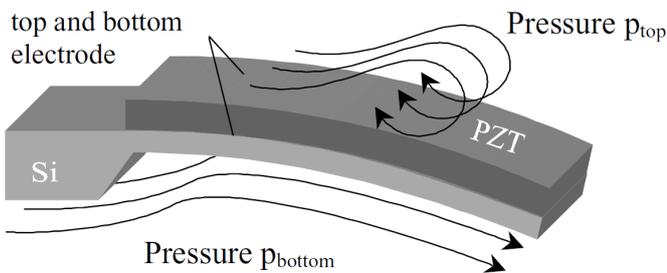


Fig. 2. Piezo bimorph generator [2]

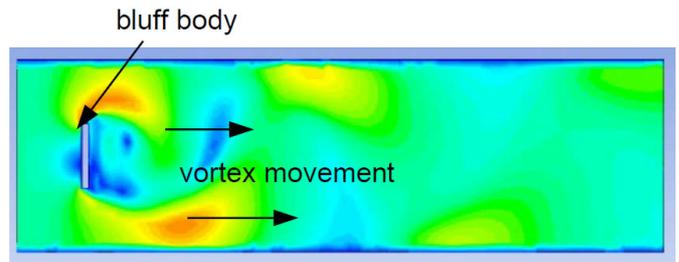


Fig. 3. Exemplary simulation of a Kármán vortex street

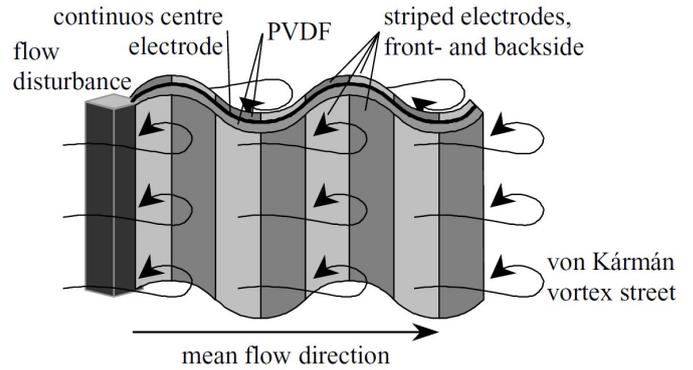


Fig. 4. Energy harvesting in a kármán vortex street with a piezoelectric foil [2]

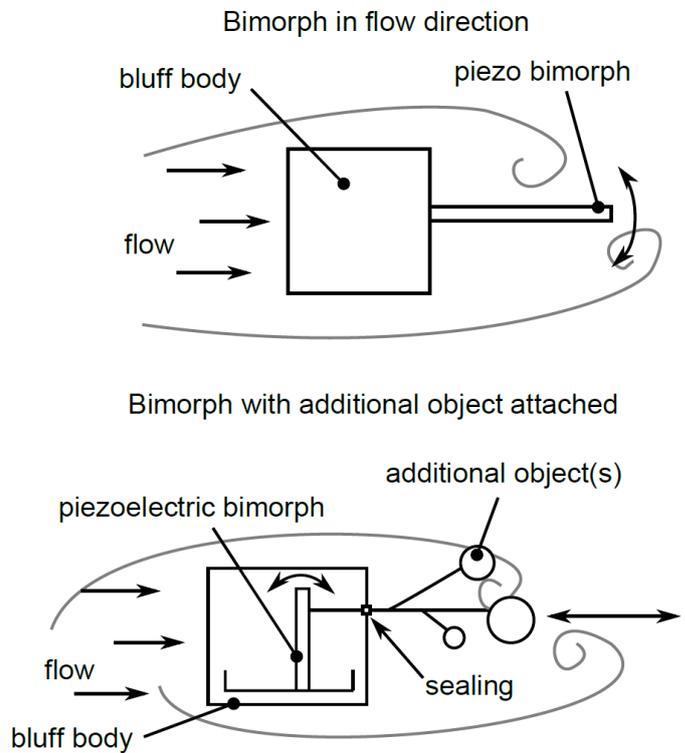


Fig. 5. Comparison of solutions without and with additional attached object

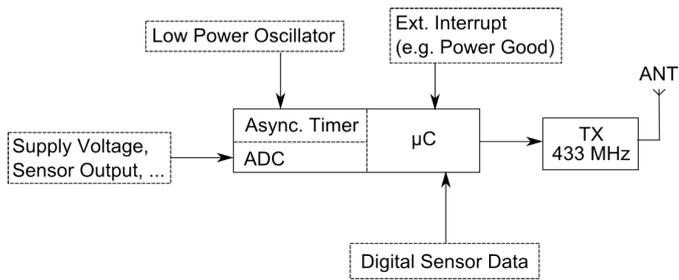


Fig. 6. Schematic diagram of the microcontroller and RF section

input power of $10 \mu\text{W}$, a puls/pause ratio of 1 : 10.000 can be achieved.

One interesting parameter of lotic waters is the pH value. The pH value shall be measured with the proposed system. For pH measurements, two solutions are currently on the market: Glass electrodes and ion sensitive field effect transistors (ISFETs). The advantage of glass electrodes is their availability on the market and the low costs. But they are not easy to integrate, as they are very brittle considering the glass membrane and they are relatively large. ISFETs are easy to integrate and relatively robust but at this moment more expensive than glass electrodes. However, they will probably be employed in the system because of their integrability. A third possibility is the use of pH sensitive Carbon Nanotubes (CNT) [10], but this method is not market-ready yet.

IV. EXPERIMENTAL RESULTS

Fig. 7 shows the schematic of the experimental setup, Fig. 8 the real setup in a flow passage. The piezoelectric bimorph is equipped with an extension in a way that it is not in contact with the water and no sealing is necessary. A string with a water-filled table tennis ball is attached to the extension. Through this chain the movement of the table tennis ball caused by the periodic (Kármán vortices) or chaotic (natural turbulences) pressure differences is converted to a bending of the piezoelectric bimorph.

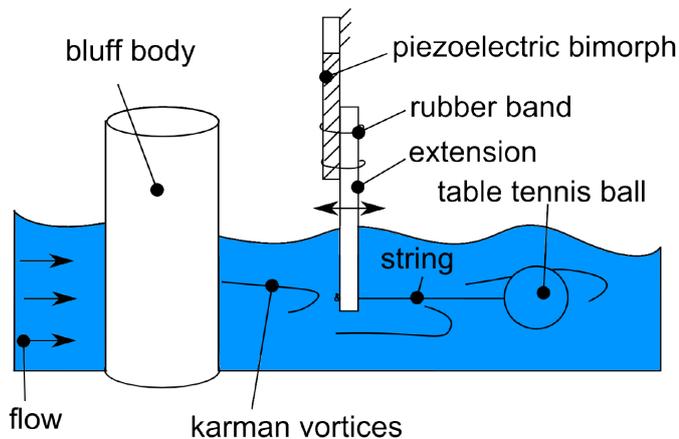


Fig. 7. Schematical setup for the mechanical to electrical energy conversion

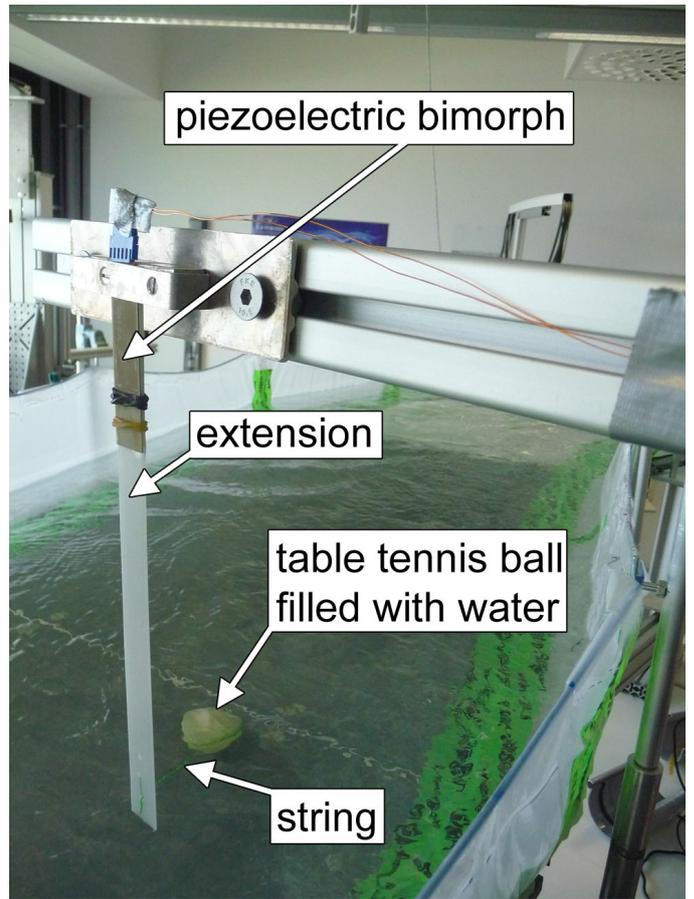


Fig. 8. Setup in a flow passage

In the experiment, a power of circa $1 \mu\text{W}$ at a flow velocity of 0.2 ms^{-1} and a load impedance (ohmic) of $1 \text{ M}\Omega$ could be reached. This is not sufficient to power the electronics of the system. But one has to keep in mind that the proportionality

$$E_s \propto v^3 \quad (1)$$

holds, meaning that the energy ES is proportional to the cube of the flow velocity. It is not possible to get flow velocities over 0.2 ms^{-1} in the used flow passage. As the system should work at flow velocities above 0.5 ms^{-1} , it is possible that enough power (around $15 \mu\text{W}$ at 0.5 ms^{-1}) will be generated if the equation (1) holds for this particular setup. Other bluff body shapes beside a cylindrical shape were investigated in the CFD simulation. No significant improvements could be found.

V. NEXT STEPS

Experiments at higher flow velocities ($\geq 0.5 \text{ ms}^{-1}$) and a field test have to be carried out. It is expected that the present turbulences within the lotic water obviate the need for a bluff body and more power can be generated. A housing has to be engineered, which enables a modular setup and the integration of different sensors (i.e. pH, temperature).

VI. CONCLUSION

In this work a new possibility of conversion from mechanical flow energy to electrical energy was proposed. This possibility follows the concepts proposed in the literature. In addition, a system was introduced, which is powered by the energy harvester.

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