A Tactile Sensing System for Underwater Manipulators

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ABSTRACT

A tactile camera is a sensing system allows robotic systems to orientate and explore their surroundings by purely relying on tactile information. Real world application scenario for such devices are hazy water conditions where underwater robotic systems need to work.

Building up such a system for underwater includes several challenges which need to be considered while chosing appropriate sensors.

We describe our sensor system, the electronical interface and show that local sensor data preprocessing is necessary in this system and how we want to realise this.

Keywords

tactile sensing, underwater, local preprocessing, multi-modal, processing architecture

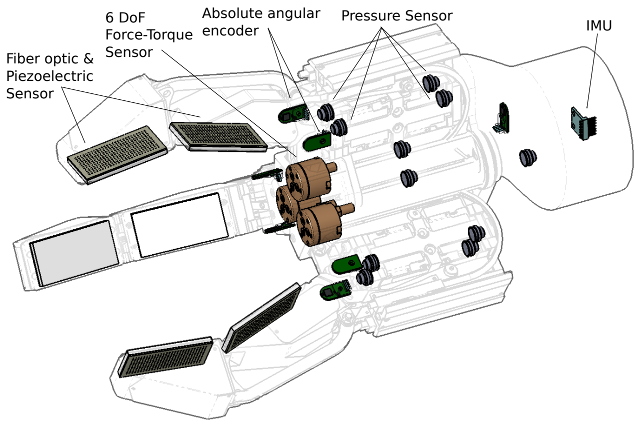

Figure 1: The sensing system of the SeeGrip underwater manipulator

1. INTRODUCTION

Humans use their tactile senses in utter darkness in order to identify nearby objects and navigate around obstacles. Similar conditions apply to robots that have to work in turbid water.

Hazy water conditions limit the capabilities of current underwater manipulation systems as the only feedback from the manipulation area which is mostly available are cameras. As state-of-the art sonar technology is not capable to be used in the near field, underwater robotic systems are a realistic example where robots have to face the previously mentioned scenario.

Our goal is to develop a tactile sensing system that can be understood as a *tactile camera*. This sensing device should enable robots to orientate and perform manipulation tasks in environments where traditional sensors for localisation like cameras and laser scanners fail.

To achieve this goal, feasible sensor principles are selected, appropriate electronics are presented and their combination is discussed. Specific challenges of the integration and use of tactile sensors in robotic systems, as mechanical integration, cabling complexity and data processing, are presented in detail.

2. SENSING PRINCIPLE SELECTION

The realization of a tactile device as a system for orientation and manipulation requires sensing of many different modalities of touch. As mechanoreceptors in the human skin are sensitive to different modalities, several sensing principles need to be combined for the use in robotics to achieve a good sensitivity to a broad range of inputs.

Besides the selection for different modalities, sensor working principles are needed that are capable of working in deep-sea environments. As many sensing devices work as absolute force- or pressure sensors those devices would measure the force induced by the water-column acting on the gripper that increases with depth. Thus, relative force and pressure sensors are preferable which do not have the drawback of becoming insensitive witch increasing depth which would happen using sensors working as an absolute measurement device.

Figure 1 shows the sensor setup of the designed gripper system. The gripper itself is a three-fingered multi-limb manipulator which is actuated using micro-hydraulic valves [9] and a brushless-dc motor.

Humans perform systematic actions in order to identify grasped objects solely by their sense of touch [8]. These movements include the identification of texture, hardness, temperature, weight, volume, shape, the investigation of special functionality of the grasped object and moving parts.

The proposed sensor system features the sensing modalities to get the information about the mentioned object properties.

The piezoelectric sensor modules at the limbs of the gripper can be used for identifying object textures. By moving along a structure vibrational feedback can be processed in order to gain knowledge about the surface properties. Piezo-electric sensors are known to be working well in deep-sea environments. Common applications are sonar transducers, pressure sensors, flow meters [2] or underwater robotic systems [7].

The materials stiffness and their weight can be gained from the six-axis force-torque sensors which are integrated in the fingers of the gripper system. Strain gauge sensors, which mostly are the base for realising force-torque sensors haven been used in underwater environments. Applications are depth measurement [10] and robotic applications [3].

Tactile sensor fields have their strength in sensing geometric properties like and force distributions of objects which are in contact of the sensor. In the literature no tactile sensor element can be found which has proven its functionality in deep-sea before. In [6] we show that using a fiber-optic tactile element is capable of working in deep-sea. The sensor principle is shown in figure 2.

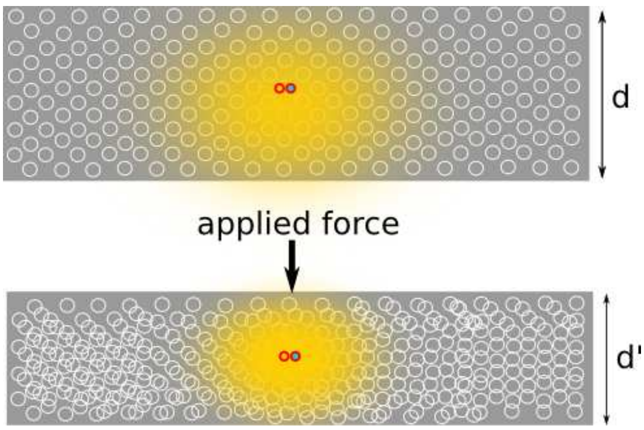

Figure 2: Sensing principle of the fiber-optic tactile sensor

Two polymer-optical fibers form a tactile element. One of those fibers emits light into an open-cell foam structure that is fixed around the fibers. The reflection of the light in the foam structure is sensed by the second optical fiber. When applying force, more light is reflected by the foam which can measured by a brightness increase. The brightness signal is converted into digital processable data using miniature CMOS cameras [5]. The sensing principle has been originally developed for automotive purposes [11] but due to the fact that the open cell structure does not compress at high ambient pressures when used in a pressure neutral setup it is also usable for underwater applications.

As tactile sensors need to be in direct contact with the grasped object, sensing different modalities at the same area becomes an integration challenge. For our gripper system we need to integrate piezoelectric sensor modules and the fiber-optic tactile sensor module on the same area in the limb structures of the gripper. The result is a multi-modal sensing module where both sensing principles are placed on the same area.

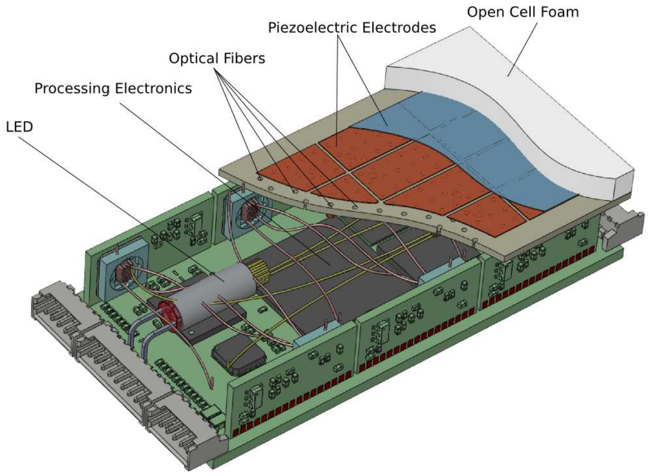

Figure 3: Multi-modal tactile sensing system

A standard FR4 plate which is normally used for PCB design serves as a carrier for the polymer-optical fibers of the fiber-optic tactile sensor. A segmented layer of piezoceramic material with drilled holes for the optical fibers is deposited on top of the FR4 plate. While this approach does not affect the sensitivity of the fiber-optic sensor, it will probably dampen the identation of the piezoelectric sensor. This issue will be part of further research.

3. ELECTRONIC SENSOR INTERFACES

To reduce the amount of wiring and to distribute the processing load from a central processing unit to local embedded processors, each sensor module has its own PCB for signal processing.

Figure 4 shows the gripper system and the integrated processing units. For the analog preprocessing of the piezoelectric sensors and the force-torque sensors programmable system-on-chip electronic modules haven been chosen. These modules integrate a reconfigurable analog and a digital part together with a microcontroller in one chip.

Six camera modules the interface to the fibers of the tactile sensor. Those cameras are controlled by a FPGA in order to be able to process them in parallel. All sensor information coming from the fingers is merged on the *Sensor Fusion Board* to reduce data bandwidth and perform signal preprocessing steps.

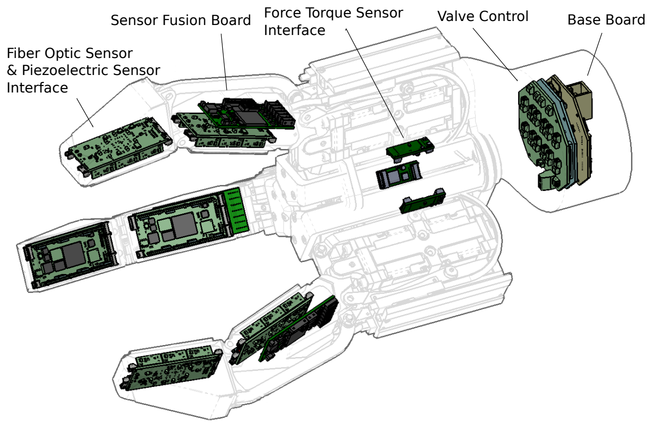

Figure 4: The electronic system of the SeeGrip underwater manipulator

Separate PCBs for the actuation and the connection to higher processing levels are placed in the wrist of the gripper. The processing on the *Base Board* is realised by a multi-purpose DSP.

The communication between the different processing units is realized using low-voltage differential signaling (LVDS).

4. SENSOR SIGNAL PROCESSING

Table 1 shows the amount of sensor information generated every second for one finger of the gripper system. Without any preprocessing this amount of information is hardly useable by a central electronic unit that computes higher level grasp and exploration tasks based on the sensor data in realtime.

Therefore, appropriate preprocessing should take place at the earliest possible state in the processing chain in order to reduce the amount of transmitted data as well as the amount of storage.

The most amount of data is generated by the tactile sensing system which is interfaced by six cameras. Figure 5 shows an example for an output of the camera.

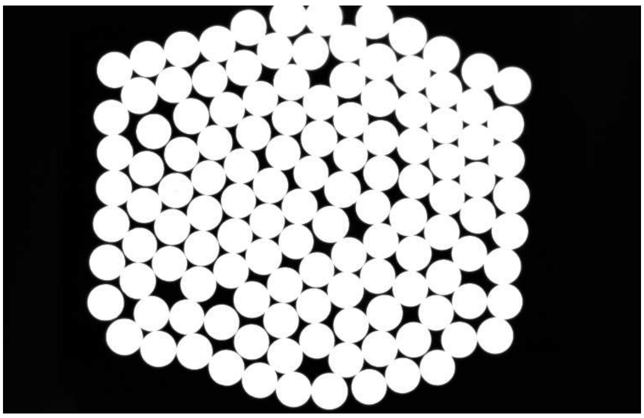

Figure 5: Camera image of the fiber optic sensors

As can be seen, only a small part of the recorded information is actually interesting for sensor processing. For each of the visible optical fibers only an average on the brightness information is needed in order to gain all relevant information from the sensor. This approach would reduce the amount of data that needs to be transmitted from the sensors.

Another straight forward step is using compression techniques for data transmission. Examples for useful approaches are the transfer of sensor values at lower resolution or density as well as the transfer of packets which include only the changes to previous values.

Steps that require some computing on the sensor data is commonly done at early stages of the processing steps [1]. The extraction of geometric properties from tactile images like lines and edges leads to significant data reduction.

Fusioning and reasoning the data at higher processing steps together with tactile sensor information from other sensors is another aspect of preprocessing sensor data. The raw data coming from force-torque sensors can be fusioned into a force vector on each finger or on the complete gripper. An example for sensor data reasoning is the filtering of sensor signal changes that are induced by the movements of the gripper with a grasped object. An inertial measurement unit is integrated into the wrist of the gripper that measures the acceleration of the system in order to identify the described effect.

If a model of the tactile sensor behaviour exists, the information about the pose of the manipulator arm together with knowledge about the object that has to be grasped can be used to pre-calculate the expected sensor feedback when grasping the object. This knowledge can be used to suppress expected tactile information that has to be transmitted to higher processing units. This approach which is known under the term *efference copy* in biology [4] can also be used for exploring the operational area of the manipulator.

5. CONCLUSIONS

Sensing devices that can be integrated into a tactile sensing system that has the modalities to allow us to orientate and explore our environment solely using tactile sensors have been identified. The selection of sensing principles is working under deep-sea conditions but is not limited to purely underwater use.

The calculated amount of sensor information cannot be processed by or even transmitted to a central processing unit without performing decentralized preprocessing steps. Several approaches to realize a decentralized information processing architecture have been proposed. As this research is ongoing work we are proceeding with integrating and implementing the described approaches on real hardware.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Table 1: Generated sensor data for one finger

Sensor Type	Sampling Frequency	Sensor data	Number of Sensors	Output per second
Fiber optic sensor	30 Hz	640x480x8 Bit	12	210.94 MB/s
Piezoelectric sensor	10 kHz	20x16 Bit	2	781.25 kB/s
Force-torque sensor	1 kHz	6x16 Bit	1	11.72 kB/s
Absolute angular encoder	1 kHz	12 Bit	2	2.93 kB/s
Pressure sensor	1 kHz	14 Bit	4	6.84 kB/s
Temperature sensor	1 Hz	12 Bit	4	48 B/s
Total Data				211.72 MB/s

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