Demo Abstract: Gondola - a Parametric Robot Infrastructure for Repeatable Mobile Experiments

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ABSTRACT

When deploying a testbed infrastructure for Wireless Sensor Networks (WSNs), one of the most challenging features is to provide repeatable mobility. Wheeled robots, usually employed for such tasks, strive to adapt to the wide range of environments where WSNs are deployed, from chaotic office spaces to neatly raked potato fields. For this reason, wheeled robots often require an expensive customization step in order to adapt, for example, their localization and navigation systems to the specific environment. To avoid this issue, we present Gondola, a parametric robot infrastructure based on pulling wires, rather than wheels. Gondola avoids the most common problems of wheeled robots and easily adapts to many WSNs' scenarios. Different from existing solutions, Gondola can easily move in 3-dimensional space, with no need of a complex localization system and with an accuracy that is comparable to off-the-shelf traditional robots.

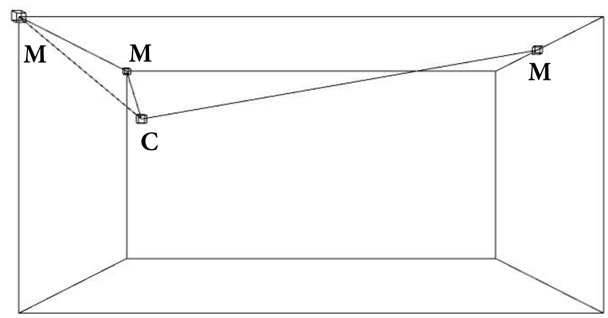

Figure 1: Example of Gondola infrastructure in a 3-dimensional space. In this example the Sensor Carriage (C) is attached to three spooling motors (M) mounted on the room ceiling.

1. INTRODUCTION

Providing a repeatable movement is essential for a wide range of WSN's applications, from automated testing to optimal sensors placement. To this end, several mobile infrastructures for WSNs couple wireless sensors with wheeled, small-scale robots that are cheap and easily available on the market. Unfortunately, wheeled robots present several drawbacks that practically limit the range of mobile experiments that researchers can run. First, in order to navigate, affordable wheeled robots often require a localization infrastructure that accurately estimates the robot's position and heading: from simple black lines on the ground [4] to complex tracking systems based on cameras [2]. Second, these mobile robots run on batteries, limiting the maximum duration of an experiment and requiring a cumbersome and periodic recharging task. Finally, wheeled robots can only move on a horizontal 2-dimensional plane (possibly free of obstacles such as furniture and stairs), heavily limiting the movement space of the experiment.

To avoid the aforementioned problems, we present the design of Gondola, a robotic infrastructure that moves through cables, rather than wheels. Inspired by plotters based on polar coordinates [1, 3, 5] our robotic system embeds the mobile wireless sensor in a carriage (*Sensor Carriage*), which is connected trough thin wires to one or more spooling motor, depending on the required degree-of-freedom of the movement (see Fig. 1). Because the Gondola infrastructure is completely parametric (both the location and the number of spooling motors), it can be easily adapted to different environments (small rooms, halls, outdoor) and needs (1-, 2- and 3-dimensional movement). Typical applications of the Gondola infrastructure are, for example, visualizing the operating range of NFC and RFID technologies and testing wireless network protocols in the presence of moving nodes.

2. THE GONDOLA PLATFORM

The architecture of Gondola, shown in Fig. 2, is composed of four modules: a *System Controller*, a *Motor Controller*, a set of *Spooling Motors* (M1 ... M4), and a *Sensor Carriage* (C). By controlling the length of the wire spooled by each motor, the two controllers are able to move the Sensor Carriage and its payload (the sensor node WS1) in space. We now analyze in detail each element of the Gondola system[1].

System Controller. This module gets a sequence of 3-dimensional positions and timings and translates each into a set of 1-dimensional spooling movements. One for each spooling motor.

[1]The design files of both hardware and software are available at http://github.com/iprotonotarios/gondola.

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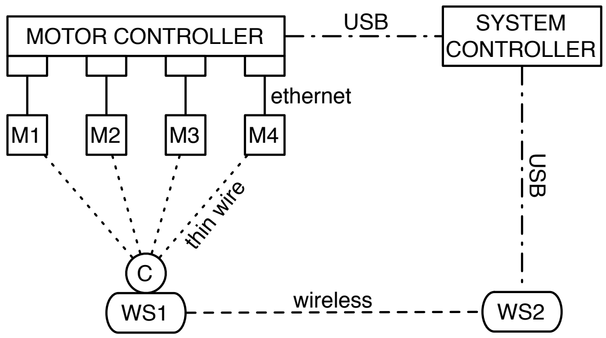

Figure 2: The system architecture of Gondola. The Sensor Carriage (C) moves by controlling the length of the wire spooled by each motor (M1 . . . M4).

In particular, given a 3-dimensional movement from position A to position B, the 1-dimensional spooling distance of motor i is computed as $S_i = \Delta(A, Mi) - \Delta(B, Mi)$, where Δ is the euclidean distance between two points in space and M_i is the position of motor i. Note that, theoretically, Gondola works with any motor configuration, i.e. any number of motors and any motors' positioning. Nevertheless, because the pulling wires are tensioned only by the force of gravity, to achieve a good range of movements in 3-dimensional space Gondola needs at least three properly positioned motors.

Once the required spooling distances are computed, the System Controller sends this information to the Motor Controller, which in response sends and acknowledgment as soon as the Sensor Carriage reaches its destination, i.e. as soon as all motors spooled the required length. After receiving the acknowledgment, the System Controller starts logging the sensor output until a predefined event occurs, e.g. a timeout or a specific output from the sensor node. Then, the System Controller proceeds with the next planned position.

Motor Controller. This module is in charge of receiving a spooling sequence and properly actuate the Spooling Motors such that the resulting movement (in 3-dimensional space) is smooth and at constant speed[2]. For simplicity and cost effectiveness, we designed the Motor Controller as a shield for the Arduino Mega that can be interfaced with up to four stepper motors via Ethernet cables (Figure 3). Note that the current version of Gondola relies only on the stepper motors to control the spooled length of the wires. To improve this module and avoid spooling inaccuracies, it is possible to provide a feedback to our system by adding a rotary encoder to each one of the spooling motors. The current Motor Controller allows such modification by interfacing four of the eight wires enclosed in the Ethernet cable with the Arduino's GPIO.

Spooling motors. As previously mentioned, our robotic infrastructure moves the Sensor Carriage by changing the length of wire spooled by each motor. The characteristics of these motors are therefore very important for the overall performance of the system. While it is obvious that movement precision is important, it is not obvious that other characteristics, such as the holding torque (the capacity to maintain a position, when the carriage is loaded), are equally important. For our demonstration, we choose three 42BYGHW811 Wantai stepper motors, with 1.8° movement precision and a holding torque of 4800 g-cm. Because each motor drives a wheel of radius 2 cm, the resulting movement precision is $(2\pi\ 2\text{cm})1.8^\circ/360^\circ = 0.062\,\text{cm}$, while the holding force is 2400 g. Preliminary experiments show that, with this spooling precision and in a 6.5×3.9×3.1 meter room, Gondola achieves a positioning error of less than 2 cm. As previously mentioned, this error can be further reduced by adding a feedback mechanism to the spooling motors.

[2]A smooth movement in 3-dimensional space often requires a different rotational speed for each spooling motor.

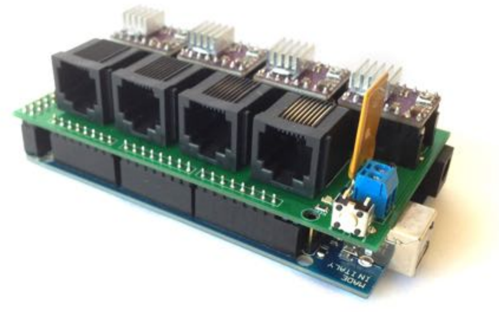

Figure 3: The Motor Controller (green pcb) hosts four ethernet interface and four stepper drivers (violet pcb). Computation and serial communication is performed by the Arduino Mega (blue pcb).

3. DEMONSTRATION

The goal of this demonstration is to show how Gondola performs complex tasks that require repeatable and precise movements. To this end, the live demo will consist of Gondola performing a *volumetric scan* of the environment, a task that requires the following three steps.

Move. Gondola will precisely move the Sensor Carriage to a predefined position.

Sense. Once the position is reached, a couple of wireless sensor nodes (WS1, WS2 in Figure 2) will exchange a strobe of packets and measure the received signal strengths (RSSI).

Log and Visualize. Every RSSI measure will be transmitted over serial to the System Controller, that will store and visualize the sensed information on a display.

When enough samples are collected, Gondola will move the Sensor Carriage to the next predefined position.

4. REFERENCES

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