I am a Smartwatch, and I can Track my User's Arm

Sheng Shen, He Wang, Romit Roy Choudhury

The Problem Definition:

With advancements in technology, the research and development in the field of smart devices have become quite vast. Many software applications, as well as smart devices, have been popularized over years, which aim to promote a smart lifestyle. Most of these applications/devices are improved to an extent to be used for healthcare and quick health solutions. These devices/applications track the user's movement with the help of the embedded sensors and notify them to walk or run and other customized healthcare tips and tricks which they either recognize using the user's pattern of walking, sleeping, eating, etc. or based on the user's set preferences. But a lot of work (both research as well as development) goes into the backend to reach such solutions as, tracking the user movements, not only walking, running, and biking but also gestures, and then using that data over time to detect patterns, etc. This paper presents the idea of solutioning tracking of the postures of human-arm with the help of just a smartwatch, which usually rests on the wrist of the user. The paper's main aim is to track the arm posture by just using the motion and magnetic sensors in the watch instead of using machine learning algorithms, with the vision that this solution can further be used as a generic platform for gesture-based applications.

Key Idea:

The solution ArmTrak works on the idea of using the IMU sensors (i.e., accelerometer, gyroscope, and magnetometer) along with the compass in the smartwatch and human anatomy to detect the arm's posture. But the core problem is to detect the human's facing direction from these sensors in the watch. The author uses the information about the orientation of the shoulder to know about the orientation of the elbow and states that if the orientation or the position of the elbow is known then we can also detect the orientation and position of the wrist with the help of static shift, equal to the length of the forearm. But as there is no pre-defined pattern or any way to benefit from the prior (or pre-defined absolute data) therefore to reset the estimates which translates this problem to the Bayesian tracking problem in continuous space as the search space of the elbow is vast. But then the author tried to limit the search space of the elbow by using the anatomical models. With ground truth evaluated using Kinetic 2.0, the median error is stated to be 9.2 cm for free-posture and 13.3cm for the real-time version.

Important Details:

1. Arm posture is defined as a function of elbow location, wrist location, and wrist rotation, for the fixed shoulder location.
2. A modified Hidden Markov model (HMM) framework is used for elbow tracking with point cloud as the prior.
3. Viterbi Decoding is used for offline processing of the posture.

4. Watch's orientation and compass are used to opportunistically estimate the user's facing direction.
5. Torso Coordinate System (TCS) is used to define the posture of the arm. Although, Earth coordinate system (ECS) is used for situations like a user pointing to the TV screen with a remote, or when a user is performing a punching gesture.
6. The Elbow location and Wrist location are static shifts of each other, with the static shift as the length of the forearm. Hence the elbow and wrist point clouds show a 1.1 mapping.

My Thoughts and Criticism:

The paper presents a different view of the problem of tracking human arm posture with relevant observations, limitations, and proof. However, after reading the paper I felt that if machine learning makes the work efficient and quick why would one wish to use geometric data from sensors, given the smartwatch already has limited space(memory), processing capacity, and power? Use of the Viterbi algorithm seems highly inefficient as the complexity of the runtime goes $O(|S|^2 T)$, which if the system is scaled (especially with limited memory on a smartwatch) will surely cause significant delay.:

A few of the assumptions and scenarios that led me to further questions and thinking are:

1. The limitation of ArmTrak is that it won't be effective if the user is moving very fast (as it is mentioned in the paper this case is side-stepped), but the majority of the people will be moving at variable speeds and a major target section of the audience for arm posture tracking will be sports people or athletes who wish to improve their skills example say javelin throw. Then ArmTrak might not match the user's expectations.
2. The number of subjects on which the experiment is done is limited, hence the data for observation is limited. The subjects should be selected from different dimensions and fields (as right now all subjects are graduate students for EE/CS).
3. The testbed uses the Samsung Gear smartwatch which is a highly sophisticated device with great sensors and power efficiency. Other models of devices should be used as well which are noisier as compared to the Samsung Gear.
4. The energy factor is overlooked, which is a major setback in the solution design.
5. ArmTrak can show unexpected results if the user tries to constrain the arm motion or perform unexpected actions like getting the shoulder beyond the directions (left, forward, down).
6. If the device is offline, a lot of data need to be stored in the memory (in limited space) which means the hardware needs to be compatible with such a huge computation dataset.
7. ArmTrak is tested on a limited number of user orientations and might not show the expected results when the user is in situations when their arm's posture remains the same, but orientation keeps changing (and that orientation is detected via the noisy sensors of the smartwatch).

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