Poster: Physical Games in K-12 despite COVID-19

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ABSTRACT

In this poster, we present the potential of extending 6Fit-a-Part, our recently proposed physical distancing platform, to enable interactive physical games in school campuses despite COVID-19 restrictions. To minimize the risk of infection, traditional physical games must be modified such that the inter-player distance remains beyond 6 feet at all times. Our wearable electronic gadget that beeps when it approaches another similar device can facilitate such games, however, it must first solve 3 fundamental challenges: high accuracy, low delay, and high robustness. We highlight that 6Fit-a-Part adopts an improved two way ranging protocol using ultra-wideband radio (UWB) which can provide accurate inter-player distance measurements in real-time. Furthermore, 6Fit-a-Part leverages wireless channel features to perform occlusion detection continuously so that erroneous measurements caused by human occlusions can be corrected. 6Fit-a-Part is designed to be a lightweight wearable device making it a suitable accessory even during games. By compromising rules of traditional physical games, we show that 6Fit-a-Part is capable of seamlessly re-enabling physical games while still enabling physical distancing.

CCS CONCEPTS

• **Computer systems organization** → **Embedded hardware**; **Sensor networks**; • **Networks** → *Network protocol design.*

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1 INTRODUCTION

The COVID-19 pandemic has significantly impacted all of us, including children. While cautious reopening of some K-12 schools is on-going, it is still difficult for children to go back to normal campus life and interact as usual. For instance, students are typically not allowed to play physical games to avoid coming in close contact with each other, and are prevented from touching shared surfaces like balls, Frisbees etc. Schooling experience thus remains incomplete, and valuable interpersonal skills learned on a playing field remain underdeveloped. While asking children to keep safe distance in a game seems possible, potentially by altering the rules of physical games, practically conducting a multiplayer game such that no one comes within 6-feet of each other is extremely difficult.

We have recently developed a physical distancing platform [1], called 6Fit-a-Part, that warns if two devices come within 6-feet of each other. 6Fit-a-Part's target applications are in grocery stores, hospitals, warehouses, etc. where such a warning system can be effective at reducing the risk of infections. The 6Fit-a-Part device can indeed be seen as a solution to the practical issues of maintaining distancing when playing physical games, as well. However, the leap, from designing a platform for relatively slow movements in a grocery store, to games played by children, is non-trivial. Designing such a platform, involves answering a series of questions first:

(1) How to perform distance measurements with high accuracy?
(2) Can the distance measurement be quick enough to provide seamless notification?
(3) Will the accuracy of distance measurement be influenced by the environment? If so, how to mitigate the influence?
(4) How will the platform interact with children to offer the real-time physical distance in the game?

6Fit-a-Part has a UWB chip, an acceleometer, a buzzer and three LEDs. 6Fit-a-Part uses ultra-wideband radios (UWB) to measure the inter-player real-time distance in a certain area with only $cm-$level error with two way ranging (TWR) protocol [2]. To minimize the delay in distance measurement, 6Fit-a-Part broadcasts certain messages instead of unicasting them, as performed by the original TWR protocol. In addition, 6Fit-a-Part runs a blockage detection algorithm to distinguish three types of blockage scenario: no blockage, human blocking and physical object blocking to correct the potential error resulting from occlusions. While such a device is certainly useful for physical distancing, in this poster, we explore if it can also be further used as a platform to enable physical games. We have armed 6Fit-a-Part with 3 colored lights and a beeper which serves as a distance-triggered user notification system. Additionally, we have included an on-device accelerometer to detect movements and not just distances. With these additional features, we believe 6Fit-a-Part can become a generic platform for physical games—potentially remaining useful even post COVID-19.

2 PROBLEM STATEMENT

Our platform is designed to be customizable and flexible without force-fitting a specific game. The fundamental purpose of our platform is to enable playing a game safely while ensuring physical distancing. Fig. 1 presents the general idea. By feeding distance measurements and accelerometer data into a "game rule" box, we

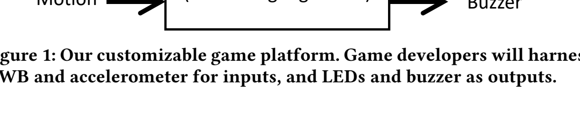

Figure 1: Our customizable game platform. Game developers will harness the UWB and accelerometer for inputs, and LEDs and buzzer as outputs.

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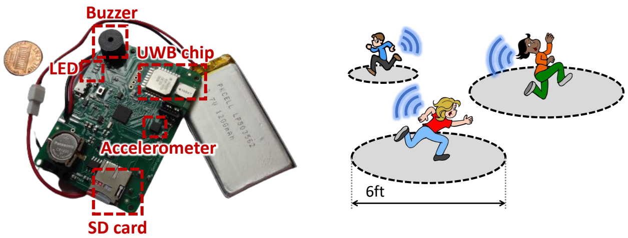

Figure 2: (a) 6Fit-a-Part Hardware prototype. (b) The distanced-tag game.

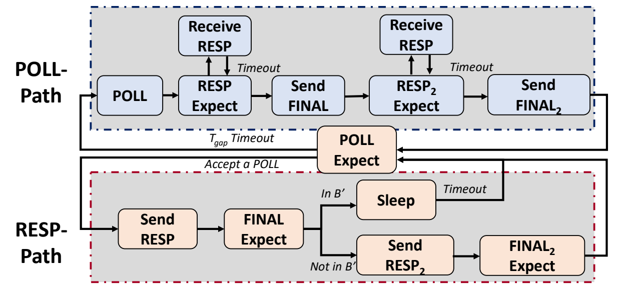

Figure 3: The original 6Fit-a-Part state machine [1]. Node A follows POLL-path, while B_i follow RESP-path, in tandem. Alternative state-machines are possible, and can improve performance in gaming applications.

expect to generate customized interactive feedback with buzzer and LEDs for safe physical gaming. As an example, we use a simple game of "tag" to model the requirements of this platform for ease in understanding. Imagine a group of children playing tag, where a child attempts to virtually "touch" the other players to mark them out, within a time limit. Our aim is to replace the notion of "touch" with the notion of being within 6-feet from one other[1]. With each player carrying a 6Fit-a-Part device, a player becomes "it" if the current "it" player comes within the given distance from him/her. An LED light on the device representing the "it" designation would turn on at the new distantly-tagged player and would turn off at the previous "it" player to indicate the success of the tag. This scenario highlights three technical requirements: (i) highly accurate distance measurements; (ii) fast ranging; and (iii) distance compensation during human-body blocking. If these requirements are met, even more complex games can be designed.

3 OUR ENABLING PLATFORM

6Fit-a-Part presents a potential solution to enable physical games while maintaining physical distancing. Fig. 2(a) shows our hardware prototype. It is lightweight and small in size, ($7.5cm \times 5cm$), making it easy to wear like an ID badge. Each child would wear a 6Fit-a-Part device (called a node). Every node emits a UWB signal, over which 6Fit-a-Part performs two-way-ranging (TWR) for obtaining time-of-flight (ToF) measurements. This provides pair-wise distances between players. Continuously monitoring the distance from self to other nodes, 6Fit-a-Part gives a visual-audio alarm when tag happens, i.e, when a distance smaller than the pre-set threshold is detected. This threshold, from safety perspective, should be larger than 6 feet. Next, We will analyze in detail how 6Fit-a-Part satisfies the requirements of accuracy, delay, and robustness.

3.1 Ranging accuracy

6Fit-a-Part measures ToF and multiplies it by the speed of the light to calculate the distance. Benefiting from the large bandwidth of UWB signals and fine-grained internal clocks, 6Fit-a-Part facilitates nano-second precision ToF measurements, which correspond to a cm-level resolution. To compensate for clock offsets and drifts, 6Fit-a-Part adopts TWR, a widely used protocol in measuring ToF [2]. At a high level, the TWR algorithm functions by exchanging 3 messages between two nodes A and B. Initially, A sends a POLL packet at $t_{A,1}$. When B receives the POLL at $t_{B,1}$, it replies with a RESP packet at $t_{B,2}$. This forms the first way of ranging. When A receives the RESP at $t_{A,2}$, it returns a FINAL packet to B at $t_{A,3}$ which is then received by B at $t_{B,3}$, which forms the second way of ranging. The four resulting timestamps $t_{A,2}-t_{A,1},\ t_{A,3}-t_{A,2},\ t_{B,2}-t_{B,1},\ t_{B,3}-t_{B,2}$ produce the ToF [3]. Because of the high time-resolution in UWB transceivers, the resulting distance error is $\approx 10cm$ with two way ranging, alleviating ranging accuracy concerns.

[1]"it" is a tag-game terminology.

3.2 Ranging delay

The second concern is that unmodified TWR is time-consuming. When multiple nodes exist in the same area, all-to-all pair-wise rangings will experience a significant delay. Such delay affects a tag game substantially since children can run fast, quickly changing the inter-player topology. If the distance cannot be obtained quickly, there will be a risk of breaching the safe distance. We propose to reduce the ranging delay by: (i) improving original TWR protocol to increase efficiency; (ii) limiting the ranging network size by filtering unnecessary nodes. Our improved TWR protocol is depicted in Fig. 3 and was first developed in [1].

Efficient TWR protocol: The key insight of the efficient TWR protocol is to leverage the broadcasting nature of wireless signals to merge multiple individual TWR messages into one, saving transmission time. When Device A initialises a POLL to measure the distance with B, other devices also receive a copy of this POLL. Therefore, A can broadcast only one POLL to initialise the measurement process for all nodes. However, one issue of naive broadcasting is that it inherently increases the possibility of collisions as all nodes accept the POLL and might send their respective RESP almost simultaneously, yielding heavy packet loss. Hence, a collision avoidance scheme is required to ensure the success of ranging.

Specifically, at the very beginning, A will initialise a POLL and broadcast it to all close-by nodes $B = \{B_1, B_2, \cdots, B_n\}$ and enter the RESP EXPECT state awaiting the RESPs. The POLL carries an extra field s to represent the maximum available time slots. When B_i receives the POLL, instead of entering the send-RESP state immediately, it randomly picks a slot s_i in $[1, s]$ and sends RESP in that slot to avoid collision. Once sending out the RESP, B_i enters the FINAL-expect state. On reception of a RESP from some B_i, A puts the node ID into a set B' and awaits other RESPs. After the pre-set time runs out, A enters the send-FINAL state. At this time, we have $B' \subset B$ because some RESPs might still run into collisions. In the send-FINAL state, A broadcasts the reception list B' inside the FINAL packet to complete ranging. Note that at this time A can only complete the ranging with those $B_i \in B'$. The distance with $B_i \notin B'$ still remains unmeasured.

To range with $B_i \notin B'$, 6Fit-a-Part adds a respond-again scheme for RESP re-transmission. When A assembles the FINAL message, it adds an extra field s' to represent the available time slots in the

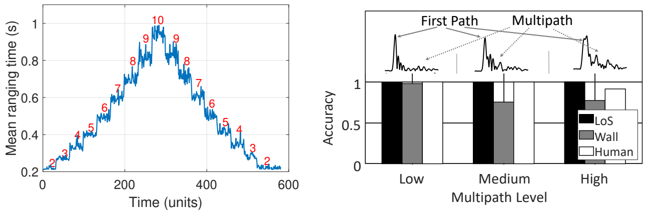

Figure 4: (a) 10 devices range with each other in one second; (b) The accuracy of occlusion detection remains high even in significant multipath.

respond-again round. Once FINAL is sent out, A enters the RESP_2-expect state. When B_i receives the FINAL message, it firstly check if its ID is included in B'. If its ID is included, the node simply computes the distance with all timestamps and goes to the sleep state. Otherwise, it will assume this FINAL message as a new POLL. As a reply, it randomly picks a time slot in $[1, s']$ to re-send the new RESP and enters the FINAL_2-expect state. Once A times out, it sends a FINAL_2 for the remaining nodes to complete the ranging. The respond-again round is extremely beneficial to reduce collision since only unsuccessful nodes from the previous round, participate in the second round. We refer readers to [1] for more details.

Once A completes this process, it relinquishes its initiator role and awaits POLL from others. Some B_i will become an initiator and broadcast its POLLs continuing the ranging. Fig. 4(a) shows the efficiency of the protocol—when we perform ranging in a 10-node network, it takes less than 1 second to complete all-to-all ranging.

Node filtering: Notice that 6Fit-a-Part's approach assumes no prior knowledge of the membership of a network and therefore takes the most general approach in designing the modified TWR. However, for enabling physical games, further opportunities exist in the form of distances and inputs from the accelerometer. For example, if some two players are many meters away, it is unlikely that these players would infect each other, enabling sparse measurements between such nodes, and other game-specific optimizations.

3.3 Occlusion detection

The last issue is the influence from the environment. The naive ranging results can be misleading without the right context. For example, when children are physically separated by a wall, there will be no risk of infection even within 6 feet. Moreover, we observe that when a human is blocking the direct path of a ranging pair, the distance measurement becomes erratic. 6Fit-a-Part proposes to leverage low-level UWB channel impulse response signatures to discriminate three types of occlusion: no blockage, physical object blocking, and human blocking. We disable the 6-feet warning when a physical barrier is detected between the ranging pair. For the human blocking case, we additionally build a regression tree to compensate for the error caused by occlusion. This detection result can also be used for more flexible re-ruling of physical games. For instance, in a tag game, such virtual touch through the wall can be assumed as an invalid tag. To extract correct features for effective classification, we make two key observations. First, compared to no-blockage case, the receiving power is much lower when wall-blocking or human-blocking occurs under the same distance. Second, human-blocking can distort the impulse response shape. Such distortion comes from the complicated multi-path effect caused by occlusion. Based on our observation, we extract 9 wireless features from UWB channel impulse response(CIR) to building the tree. These features describe the low-level UWB signature such as power, pulse shape, etc. Fig. 4(b) shows the accuracy of the discrimination of occlusion in scenarios with different multi-path levels. We observe $> 90\%$ mean classification accuracy in the low- and medium-multipath scenario, and 85% accuracy even in the high-multipath scenario.

4 PLANNED EXPERIMENT SETUP

We propose to test and evaluate the performance of 6Fit-a-Part as a platform for physical games in a real game scenario. To perform the experiment safely, we use mobile robots as players in the game. Each mobile robot will be equipped with a 6Fit-a-Part device as well as a SD card to store the data. We schedule the path of robots in advance with publicly available videos of real-life tag games. We plan to place 2-3 cameras to generate the ground-truth inter-robot distance using computer vision algorithm in real-time. When performing the experiment, the robots will "play" the tag game with pre-programmed path decision algorithm as if they are real players. During the game, 6Fit-a-Part continuously runs the ranging protocol and stores the distances in an SD card. We are interested in the following metrics:

Ranging accuracy. We match the distance measurements recorded in every SD-card with camera ground-truth for accuracy.

Ranging delay. We can use the timestamps recorded in SD card to obtain the ranging delay from the host robot to all other robots.

Occlusion detection. We will evaluate the performance of occlusion detection in a tag game. Wall occlusion will be made by separate two mobile robots with physical objects of different materials. Human occlusion will be created by volunteers running across the line of sight path between mobile robots.

Game failure. We define game failures as the times when robots make the wrong decision in playing the game. For example, when two robots are within 6 feet but separated by a wall, if they assume it as a successful tag, it will be a failure.

We are also interested in micro-benchmarks of moving speed of players. We plan to start from low-mobility robots, and gradually increase the moving speed. We will observe how the above metrics change as the robot mobility changes.

5 DISTANCE AS A GAMING PRIMITIVE

Distance measurement capabilities can open up new gaming options. For example, a single-person minesweeper game becomes possible; a few 6Fit-a-Part devices are hidden in a garden (as mines) and kids must walk from start to finish without going too near these mines. Their handheld "detector" devices flash a green light that turns yellow or red based on how close they get to the mines.

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REFERENCES

[1] Y. Cao, A. Dhekne, and M. Ammar. 2020. 6Fit-A-Part: A Protocol for Physical Distancing on a Custom Wearable Device. In *ICNP 2020*.
[2] Jose A. Gutierrez, Edgar H. Callaway, and Raymond L. Barrett. 2003. *IEEE 802.15.4 Low-Rate Wireless Personal Area Networks: Enabling Wireless Sensor Networks.*
[3] Dries Neirynck, Eric Luk, and Michael McLaughlin. 2016. An alternative double-sided two-way ranging method. In *2016 13th workshop on positioning, navigation and communications (WPNC)*. IEEE, 1–4.