

Phantom Study of Arterial Localization using Tactile Sensor Array and a Normal Vs. Shear Pulse Pressure Propagation Method

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Abstract— Objective: Locating the radial artery reliably is a key challenge in reducing patient risks from complications in Trans-Radial Access, which is an important clinical method for catheterization, cardiac monitoring, and neuroendovascular procedures. New tactile sensing technology is being developed to bridge the skill, cost, and performance gap between ultrasonic needle guidance, and manual palpation, for use in developing countries. This paper further develops tactile artery localization with a novel algorithm for arterial localization based on the properties of a curved tactile sensor array. **Methods:** Using tactile sensor insensitivity to shear loading, coupled with a radial pulse wave propagation path, the position of the artery can be found at the intersection of a normal and tangential vector from the array corresponding to maximum and minimum pulse pressure measurement locations respectively. This was validated in a simple silicone phantom study **Results:** The proposed method measured with $MAE = 0.58 \pm 0.25 \text{mm}$ whilst the artery is within range of the tactile array, compared with $0.81 \pm 0.57 \text{mm}$ for a comparative method of simple pulse localization. This showed improvement in arterial localization and repeatability, and was within 1 arterial radius, expected to reduce the risk of missing the artery, or perforating the side wall.

Clinical Relevance— Robust and repeatable arterial localization is important for reducing the failure rate of trans-radial (and other arterial) procedures, and thus reducing the risk of harmful complications.

I. INTRODUCTION

Trans-radial Access (TRA) is preferred for performing coronary angiography and percutaneous coronary intervention over other sites [1], as well as being used for catheterization [2] and providing A-line blood pressure (BP) standards. It is preferred for its generally lower risk of complications compared with other arterial sites [3], however it is not completely without risk. Complications exist, such as finger necrosis [4], hematoma, arterial puncture, and arterial occlusion [5] amongst other complications [2]. The TRA failure rate is in the order of 6.8% [6], where failure either causes complications or requires a second attempt, and although there are medical predictors of failure many come down to poor needle application [7]. While ultrasonic needle guidance does help with this [8], ultrasound has a relatively high skill burden, on top of the high upfront cost of the equipment. This is fine for developed healthcare systems, but developing systems still rely on manual palpation, bringing patient complications as well as risk of accidental injury to the

clinician. New needle guidance technology based on capacitive tactile imaging [9] is under development as a low cost alternative to ultrasound in this application as in other clinical applications for the developing healthcare world [10].

A. Tactile Arterial Localization

Tactile arterial localization is an alternative to ultrasound [8] that is more sensitive than manual palpation, and is currently under development in the form of SmartTouch (Medical Tactile Inc., US-CA). This is shown in Figure 1. SmartTouch is a system that uses a tactile array to detect arterial pulse pressure on the skin, thus localizing the artery. It then indicates the position to the clinician using an LED marker, whilst also acting as a finger guard to protect the clinician from accidental injury.

It has been observed that this still led to failed application in some cases, particularly when the array is badly aligned and so a more robust localization method is to be developed. For this, the flat array used in early versions of SmartTouch is substituted for a curved 2x9 array, SN9490 (PPS UK Limited – GB) to allow for greater flexibility. For repeatability, the array is to be mounted on a robot manipulator for this work.

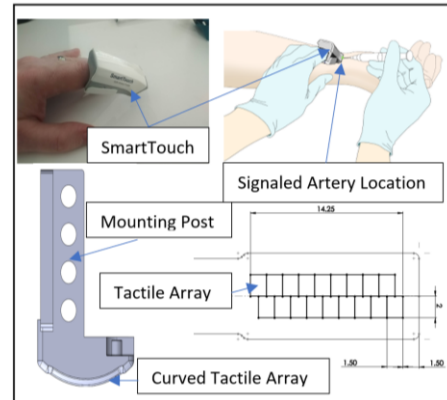


Figure 1 - SmartTouch artery finder. Fingertip mounted tactile sensor used to locate radial artery. (PPS UK Limited, - GB).

II. SCOPE AND OBJECTIVE

This paper shall introduce a new method of tactile arterial localization, taking advantage of capacitive tactile element properties which will be tested in a robotically controlled phantom study replicating a needle guidance application. This work will not cover clinical TRA, focusing on localization.

*Research supported by PPS UK Limited (GB) and Medical Tactile Inc. (US -CA)

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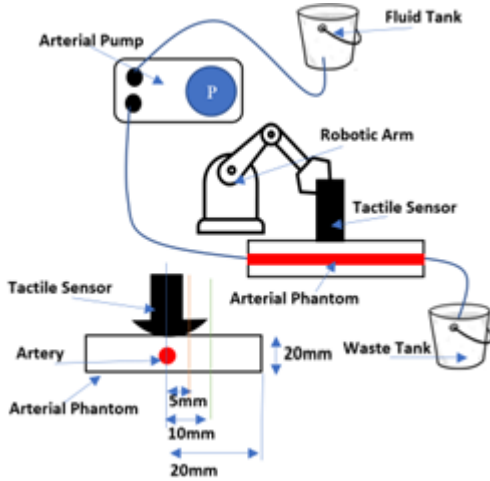


Figure 3 - Experimental Setup Diagram. The tactile sensor is pressed into the phantom in 3 different locations w.r.t. the artery by the robot arm: Centered, 5mm offset, and 10mm misaligned.

The robot arm pressed the sensor array into the 3 locations over a discrete depth range of 2-10mm in 2mm steps. 5 pulses were captured at each depth increment to provide a single measurement. 5 measurements at each location and depth were averaged to obtain the tracking trend. Sensor depth measurement was compared between the robot estimate and the prescribed method at the misaligned position only as it is not affected by pulse propagation, and to avoid interference from the artery. The phantom material was relaxed mechanically between compression runs.

V. RESULTS

The results of the localization and compression depth measurement trials are shown in Figure 4. For the cases where the artery is beneath the tactile array (centred and 5mm offset), the results show that the proposed method is effective in estimating the horizontal distance between the sensor axis and the arterial centre with total errors within the arterial limits indicated by the black lines [13], [14].

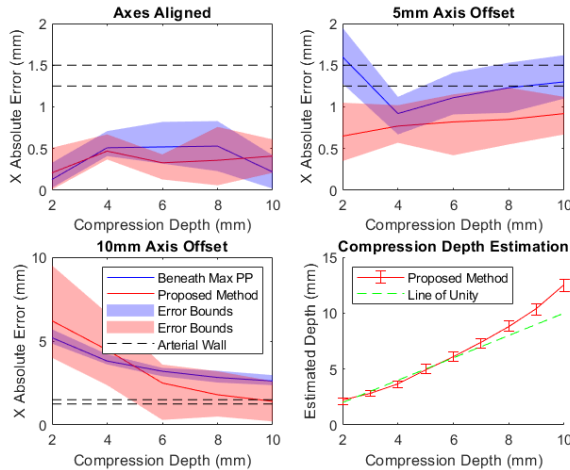


Figure 4 - X axis artery location and compression depth measurement results. Results show that proposed method is a general improvement over estimating location beneath max pulse element. Results below arterial lines indicate a likely hit, above indicates a miss, and between indicates striking the arterial wall.

Where the artery is well centered with the tactile array, both methods perform equivalently well, within an artery radius typically. As the offset increases to 5mm, the error from the previous max pulse element method exceeds the artery dimensions which would lead to missed punctures or perforation of the artery wall. The error from the proposed method is within tolerance for this offset showing the method is effective. In this situation error generally increases with compression depth, likely due to the artery moving horizontally in response to the load.

When the artery is not beneath the array, but is still detectable (10mm offset), both methods perform poorly, however the proposed method is still a general improvement over the max pulse element method. The proposed method has higher error bars than the max pulse method indicating instability. Error improves with compression depth for the proposed method as the angle between the normal and tangential vectors increases. Error improves with compression for the max pulse method as more elements become engaged allowing the max pulsing element to move towards the artery. In reality this measurement would indicate the user to move the array over the artery.

Depth measurement using gaussian fitting is effective up to approximately 6mm of compression, with errors increasing to non-useful values beyond this point. This is likely due to non-linearity in the phantom material, and ‘mounding’ of the material around the array.

VI. DISCUSSION

The results for the proposed method are within an arterial inner diameter [12] whilst the artery is beneath the tactile array, which is an improvement over the max pulse element method, that often had errors outside of 1 artery diameter and this would lead to a miss or a perforation during TRA.

In the axially aligned situation, both methods perform similarly as the artery is directly beneath the array and so does not move horizontally with compression depth. Repeatability is good again because the artery doesn’t move horizontally.

In the 5mm offset situation, error increase with compression due to slight artery motion horizontally. The initially poor measurement from the max pulse pressure method is caused by a lack of engaged elements, meaning the closest valid element is far from the artery.

The 10mm offset situation is of course not realistic for needle guidance as it is out of range, but was tested to see the operational range of the proposed method. The proposed method improved with compression, as the angular resolution of the tactile array improved as more elements engaged. Similarly the max pulse method improved with compression as the max pulsing element moved closer to the artery as more elements engaged, this converged onto the distance between the artery center and the edge of the array.

Given Equation 1, if the ‘x’ coordinate of the artery is located correctly, the proposed method should find the ‘y’ coordinate simply. This was not demonstrated as the competing method has no way of determining this value. Additionally, the compression of the phantom artery will drastically shift the reference location of the artery, making validation of ‘y’ problematic.

In relating this work to other clinical applications, the proposed method required a more severe curvature on the tactile array than that used in radial artery tactile blood pressure measurement applications [15] in order to achieve the necessary tangent and normal elements over a useful range. This BP measurement methods can be applied to this array, but not vice-versa. The depth measurement is likely not to be practical clinically due to interference from surrounding bones and non-linear tissue, however it is expected to have applications in other clinical tactile imaging applications [16].

VII. CONCLUSION

This paper presented a novel method for arterial localization based on the properties of a curved tactile array, validated in simple phantom materials. As the localization was within 1 arterial radius, this suggests that a reduction in failed TRA would be possible in future clinical testing. This method is to be developed into a clinically practical system providing dual functionality of needle guidance, and protecting the operator from accidental injury.

The arterial localization performance is expected to translate well into clinical testing, as accurate tactile measurements are not required for this to work, only relative measurements of the pulse pressure. This coupled with the relatively low cost of tactile sensor systems indicates that this will be a suitable needle guidance method in future following comprehensive clinical trialing.

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