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Prototyping A Unidirectional Horizontal and Vertical Distance Measurement Apparatus Using Trigonometric Ratio and Laser Beam: A Comprehensive Study

Abhijeet Kumar[1*], Uday Kumar[2]

[1, 2] Science Section, Bihar Bal Bhawan, Department of Education, Government of Bihar, Bihar, India
E-mail: abhijeetkr.sci@gmai.com

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Abstract- This paper presents the design and the prototype of an embedded laser system with a semi-automatic unidirectional laser-based height and distance measuring apparatus based on trigonometric elevation measurement profile fundamentals. The proposed apparatus measures the distance in horizontal and vertical directions, adjacent side/distance and opposite side/height. Results of its testing in every possible scenario, proves its high measurement accuracy. Moreover, it necessitates neither the use of any electronic component for the feedback data, nor any other form of data before the actual measurement. Furthermore, it requires no prior knowledge or specialized abilities. For all of the aforesaid reasons, we believe that the presented apparatus will contribute to the commercial scales used for dual-axis measurement in a stationary and less expensive manner.

Keywords - Trigonometric calculations; Distance and height measurement; Trigonometric ratio; Tangent function; Laser meter.

1. INTRODUCTION

Measuring is the first step in any attempt. Without modern measuring tools, it is impossible to build modern infrastructure in this three-dimensional environment. As a result, the ongoing demand for equipment reflects the ability to accurately and quickly measure any height or distance. There are considerable differences in the distance and height necessary in various fields of study, which have a wide range of applications such as maintenance, construction, surveying, leveling, railroads, sewerage, bridges, infrastructure, etc. The evolution of measurement techniques has a lengthy history. It took thousands of years to establish proper units and precision measurement technologies. One of the most critical topics in this curriculum is trigonometry. Following its inception, application-based measuring became significantly more accessible. Furthermore, contemporary surveying uses trigonometric leveling to represent this occurrence. Geometric leveling and global positioning system (GPS)/leveling are two more approaches developed with trigonometric leveling. These can be classed based on the instruments or procedures employed and their benefits and drawbacks. Works regarding distance, height and height difference measurement methods are available on leveling technologies and their comparison [1]. Various applications currently available for android allow the estimation of tree heights by using the 3D accelerometer on smartphones. Some make the estimation using the image on the screen, while others point to the edges of the terminal [2]. The errors obtained using traditional forestry Hypsometers are similar to the findings of other studies. The maximum (7.6%), mean (2.96%) values of the modulus of the relative error of the Blume Leiss in this work are similar to the results of the study on Fagus sylvatica by [3], which found values

* Corresponding author
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between 10% and 1%, respectively [2]. Different Hypsometers have different accuracy limits. A comparative test of the accuracy and efficiency of two hypsometers investigated the efficiency of the ultrasonic Vertex hypsometer in tree height measurements concerning some of the most commonly used hypsometers in Croatian forestry [4]. The authors in [5, 6] conclude - through theoretical analysis and experimental results - that fast and accurate range measurement is possible, with hazardless small power laser Telemeter, for medium ranges well fitted to instrumentation and process control. Today, there are many sophisticated methods to measure and analyse a bridge during load tests, such as GPS, Photogrammetric measurements, laser scanning, leveling with digital or laser levels, etc. Nevertheless, classical techniques such as Trigonometric heightening are still suitable for the most demanding field observations and demand accuracy [7]. Because of modern technological developments for high-tech instruments, research on precision trigonometric leveling has been required once again [8]. The author in [9] concluded that an error in GPS height is 3.569 m and an error in GPS height difference is 0.213. This research aims to design an embedded laser system with a semi-automatic unidirectional laser-based height and distance measuring application based on trigonometric elevation measurement profile fundamentals. All existing literature and products have relied on devices that rely on feedback systems and require specific data such as base length, among other things. The device's functionality is complicated by this production cycle, increasing the number of pieces per unit. However, the configurable device employed in this study contains two intelligence qualities that set it apart from other market devices. It does not necessitate the use of any electronic component for the feedback data, nor does it necessitate any other form of data before the actual measurement. This research expands on the unique method, and unlike typical Hypsometers, Telemeters and similar equipment, this technique requires no prior knowledge or specialized abilities. Furthermore, this research contributes significantly to the commercial scales used for dual-axis measurement in a stationary and less expensive manner than other technologies.

2. MEASUREMENT PRINCIPLE AND METHOD

2.1. Mathematical Functions

The right triangle trigonometry understanding was applied in the device, allowing it to work only for acute angles or $0° < \theta < 90°$. The tangent is defined as the ratio of the opposite side to the adjacent side.

2.2. Algorithm and Variables

The software is written in C++, an object-oriented and compiler-based programming language that allows for dynamic memory allocation, integrate and extend the system.

```
// Variables
float angleX ; // Servo angle
double Distance ;  // Distance
double Height ;  //  Height
const int standheight = 1; // Stand Height (meters)
```

```
// variable for reading the pushbutton status
int heightState;
int distanceState ;
double Cal_Distance(float theta, double opposite)
{
// function to calculate distance/adjacent side
const float rad = 0.0174533; // constant (angle*rad = angle in radians)
double adjacent; // final distance
double Tan; // tan theta of angle
theta = abs(theta); // absolute value of theta (angle)
Tan = tan((theta) * (rad)); // converting angle into radians then into tan
adjacent = opposite / Tan; // adjacent = opposite/tan
return adjacent;
}
double Cal_Height(float theta, double adjacent)
{
// function to calculate height/opposite side
const float rad = 0.0174533; // constant (angle*rad = angle in radians)
double opposite; // final height
double Tan; // tan theta of angle
theta = abs(theta); // absolute value of theta (angle)
Tan = tan((theta) * (rad)); // converting angle into radians then into tan
opposite = adjacent * Tan; // opposite = opposite/tan
return opposite;
}
void setup ()
{
Serial.begin(9600); // Debugging console
myservo.attach(9);// servo on GPIO 9 (pwm)
pinMode(heightPin, INPUT_PULLUP); // button pin's as input
pinMode(distancePin, INPUT_PULLUP);
}
```

The laser beam attached to a servo is exact in measuring angles and positioned or pointed toward the object - as needed by the observer - using a controller or a Potentiometer. Angle data are stored in a separate variable and sorted from (-90^o to +90^o). The system considers and incorporates the instrument's typical height. It is the initial input in determining the distance and adjacent side. The standard height is the measurement from tip to toe of the instrument, which is now one meter. Three variables were assigned to store $\tan\theta$ value-based on these methods. It automatically recognizes the mode of operation by comparing the acquired angle. The declarative programming approach was adopted for this study and it attempted to be bind everything in the form of pure mathematical functions. These functions are invoked repeatedly in the main code as needed. Except for the standard height of the instrument, all variables and parameters started at 0. It includes all the necessary functions such as angle measurement, PWM output for the servomotor, etc. Void loop is used to execute repeatedly the main code.

2.3. Control Structure

The algorithm's flow is divided into multiple conditions that need to be satisfied in a sequence for successful completion (see Fig. 1 which depicts the flow chart).

```
 /*
* Case One
* When the object is Smaller than the laser meter, Primary part of Height measurement
* Calculate and display Distance between object and meter
* Calculate the Height of Object when it is smaller than laser meter
* With Angle of Depression because value of angle X is in negative (due to mapping format)
* Calculating distance/adjacent side, taking Stand Height as opposite side (1 meter)
 */
Void loop ()
{
if (angleX < 0) { //  angle < 0 (negative)
        if ( distanceState == LOW)
        { // button pressed
        Distance = Cal_Distance(angleX, standheight);  //call distance function, with
        parameters
         }
        if ( heightState == LOW)
        { // button pressed
        Height = Cal_Height(angleX, Distance); // call height function
        Height = standheight - Height ; // subtracting Stand Height form opposite side
        }
 }
 /*
* Case Two
* When the object is bigger than the laser meter, Secondary part of Height measurement
* Calculate the Height of Object when it is bigger than laser meter
* With Angle of Elevation because value of angle X is in positive (due to mapping format)
* Calculating height/opposite side, taking Distance as adjacent side
 */
if (angleX > 0)
{ //  angle > 0 (positive)
        if (heightState == LOW)
        { // button pressed
        Height = Cal_Height(angleX, Distance); // call height function with parameters
        Height = Height + standheight; // Adding Stand Height to opposite side
        }
 }
```

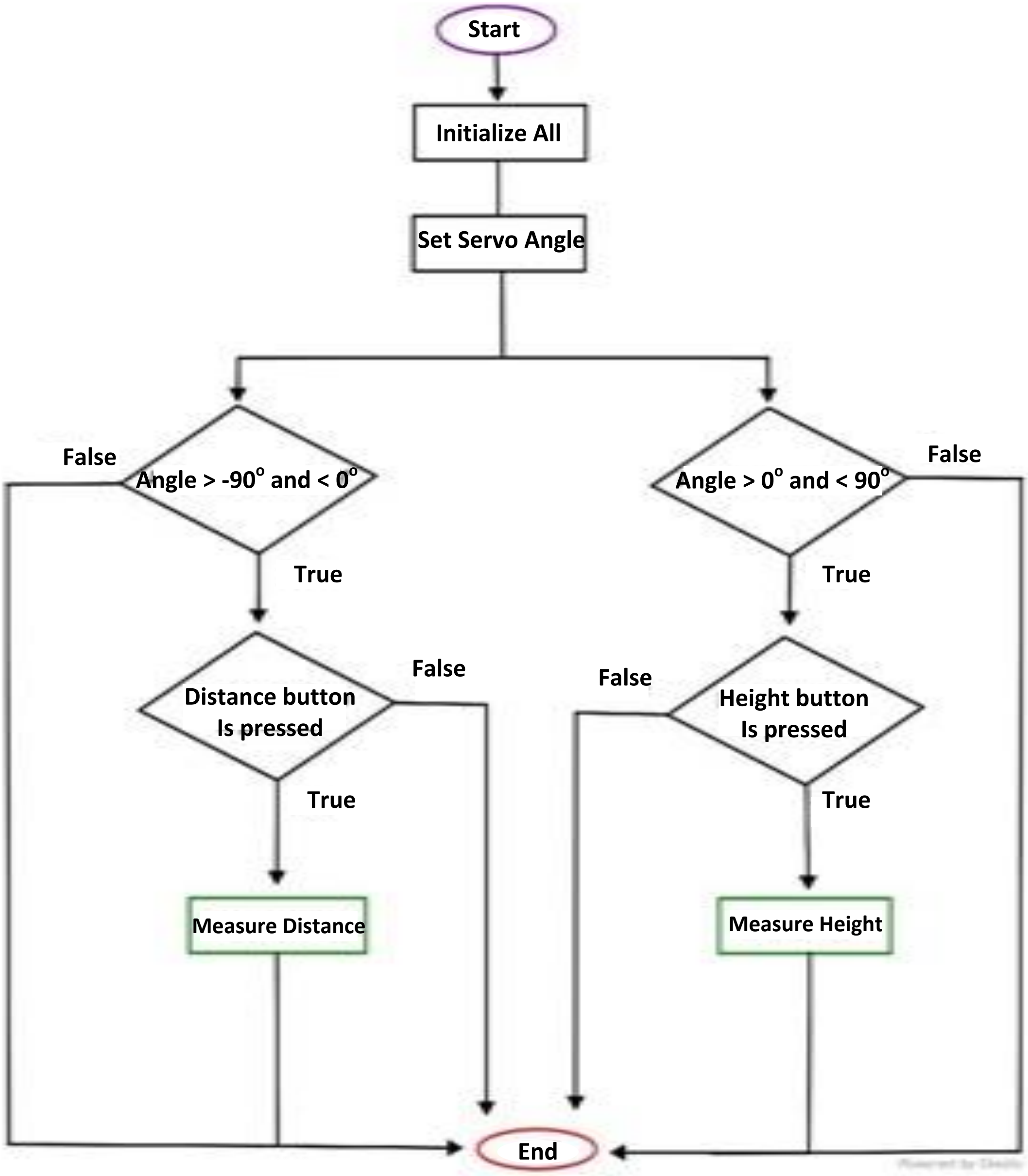

Fig. 1. Flow chart of the utilized algorithm.

2.4. Instrumentation

Although the conventional green laser pointer (5 mW) is utilized in this investigation, any visible laser light can be used. It is worth mentioning that only the visible light laser is appropriate since the human eye functions as a feedback receiver as shown in Fig. 2.

The term "LP" refers only to devices that use a frequency-doubling diode-pumped architecture (laser pointer). Consequent to the study's requirements, the laser was replaced. A laser driver with a reliable power supply and heat dissipation system is also used for long-term operations. The device incorporates an MG996R, digital high torque metal gear dual ball bearing servo with a rotation of 0–180°. The laser beam is attached to the servo motor shaft and positioned or aimed toward the item as needed by the observer, using a controller or a potentiometer as shown in Fig. 3.

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Fig. 2. The experimental setup and measurement steps.

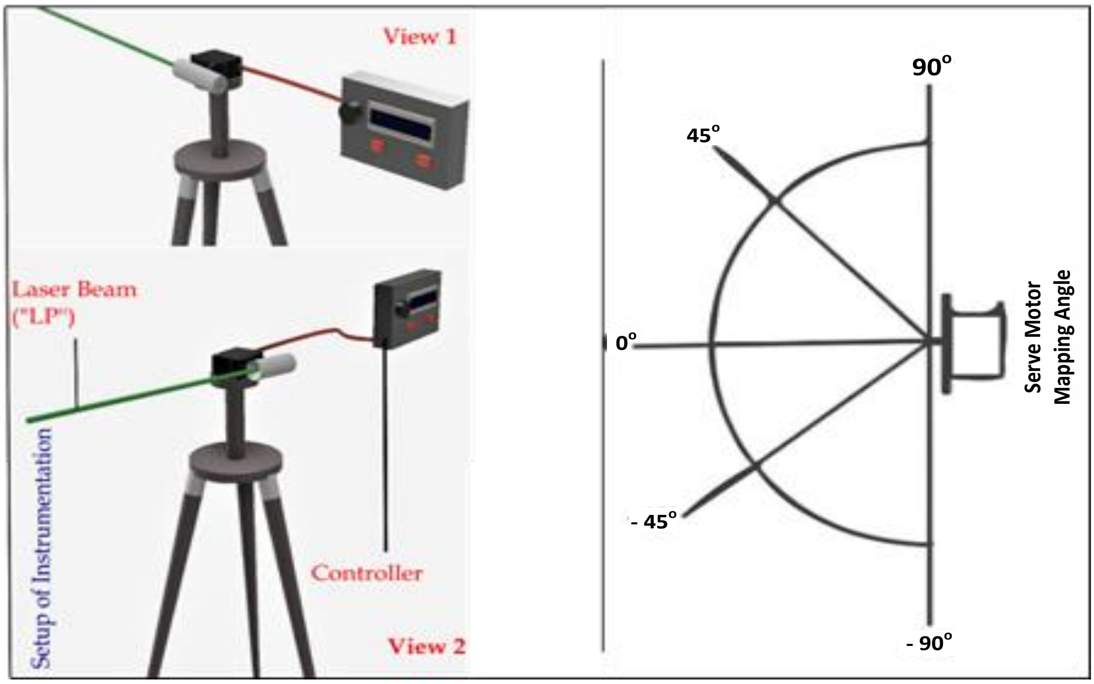

Fig. 3. Physical appearance of the proposed device with angle notation.

2.5. Circuit Schematics

The ATmega328P microcontroller has six analog inputs, fourteen digital inputs, and six PWM outputs. It cycles at 16 MHz and accurately performs the proposed function. Servo motor is a substantial output device controlled by a microcontroller using a PWM signal. The controller has two primary functions: height and distance measurement and as a switch. The user adjusts the angle between 0-180° navigated using a rotary encoder to target the laser pointer on an item with a comparable base. The log data with their parameters – distance, height, and the value of $tan\ \theta$ for the various acute angles – are shown on an LCD screen. All components are powered by a 5 V, 1 A portable DC power source as shown in Fig. 4.

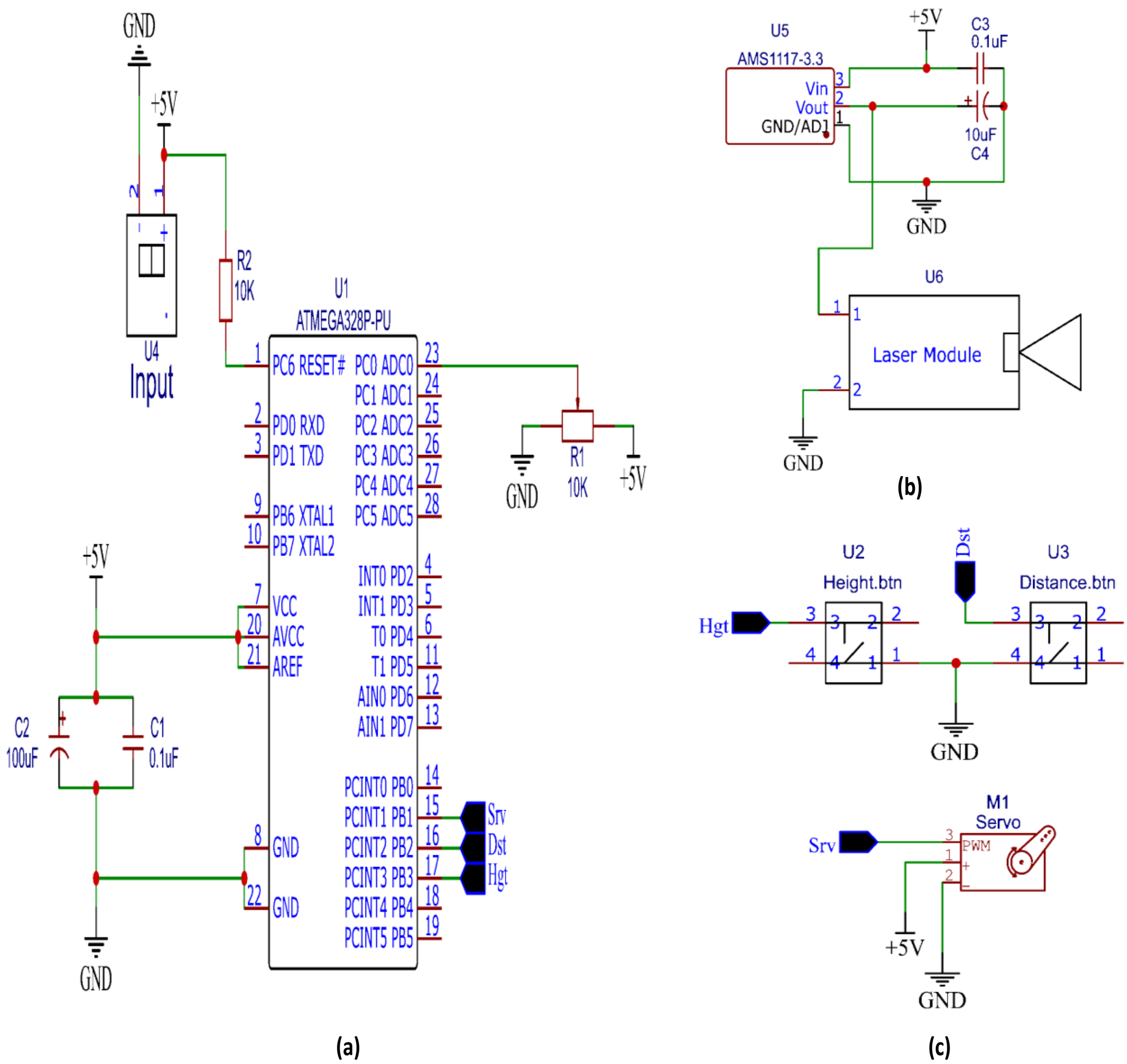

Fig. 4. Logic circuit schematics: a) micro controller unit; b) laser and driver; c) input and output.

3. RESULTS AND DISCUSSION

3.1. Height and Distance Measurement: Experimental Interpretations

The height and distance (H&D) measurement is a straightforward, but effective process that uses a trigonometric ratio of $tan\ \theta$. It is necessary to have a joint base throughout the object and instrument since it will be an adjacent side/base. The measurement of H&D of any object needs to execute in order; the initial phase is to measure the adjacent side reasoned that it would be further used to determine the opposite side.

Fig. 5(a) shows how to find the distance between the instrument and the object (BC) and the object height (DC) when the object is smaller than the laser meter or measuring, adjacent side/ distance through the object and instrument. Angles were measured using a servo with a laser beam (elevation and depression). The rise of depression in the figure is 45°, and the opposite side's height (AB) is 10 units or the height of the instrument is known. Consequently, the need to determine the adjacent side's length is BC. The object's height will be calculated after receiving the value of BC, which is 10 units on the adjacent side.

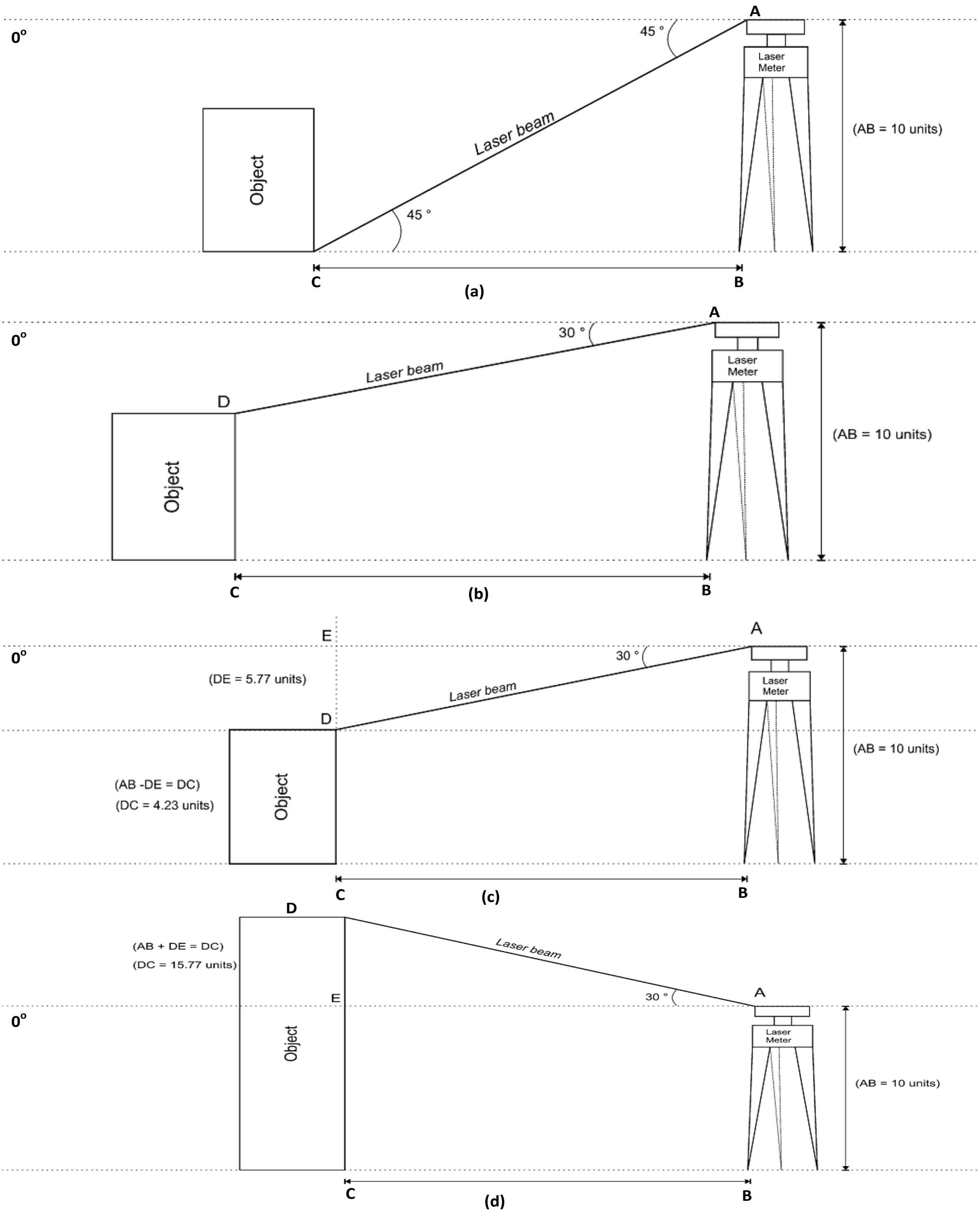

Fig. 5. Experimental measurement of object height and distance: a) finding distance b/w object and laser meter; b) finding height of object (object is smaller than laser meter); c) finding height of object (object is smaller than laser meter); d) finding height of object (object is taller than laser meter).

The angle of depression in Fig. 5(b) is 30°, and the length of the adjacent side is 10 units. DC is to be calculated and the laser beam must be focused towards the object top, as shown in Fig. 5(b).

The determination of the object's height, requires a prior evaluation of DE (distance between the top of the instrument and the top of the object), which is 5.77 units

(10 - 5.77 = 4.23). Consequently, the residual distance, which is 4.23 units, equals the object height (both having the same base)—getting the value of DC on the opposite side, which is 4.23 units. All of the values are obtained in Fig. 5(c), and the object's height is 4.23 units, and BC is 10 units as in Fig. 5(c).

Fig. 5(d) shows how to find an object's height when it is taller than the laser meter, considering that the adjacent side's length (BC) is 10 m and its elevation angle (AE) is 30°. Consequently, the length of the opposite side (ED) is 5.77 m, and the object's total length is 10 + 5.77 m.

3.2. Error and Precision Analysis - The Magnitude of Distance Measurement

The horizontal distance measured was 284 m at a maximum angle of 89.80°, with an opposite side of 1 m serving as the standard instrument height. For vertical distance/height measurements, the maximum distance may be measured at an angle of 89.80°. This condition is inversely correlated with the object's proximity to the laser meter; the closer an object is, the less accurately it can be measured vertically, and vice versa.

$$tan\theta = \frac{p}{b}$$

The servo angle resolution is 0.2°; therefore, if the servo turns the servomotor beyond 89.8°, the following angle is tan 90°, which is undefined. Additionally, an imaginary line divides the servo's domain of 0° to 180° into -90° to 0° to +90°. As a result, that angle has the most significance.

3.3. Linear Fitting / Residual Curve

Fig. 6 shows the linear fitting model that was used to find the correlation between the reference devices measured data (M.H) and the Instrument's distance and height. The accuracy and error values were validated using the linear fit and residual fit of Y and independent variables with substantial R^2 values of -0.94 and 0.5 m.

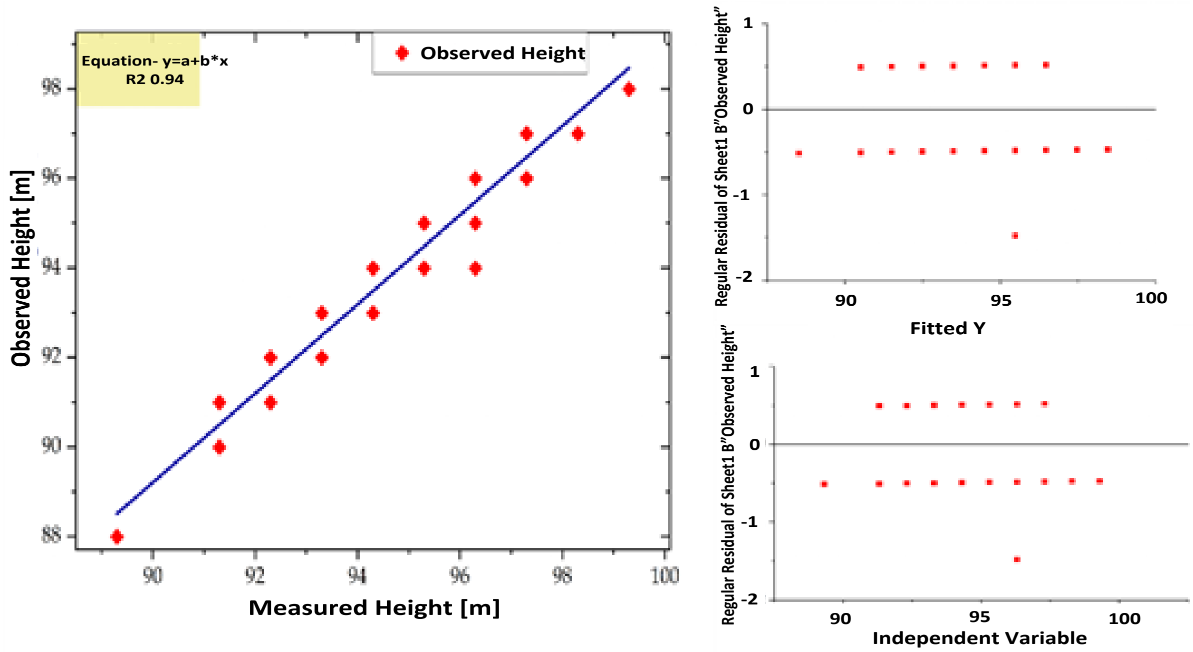

Fig. 6. Linear fitting and residual curve.

4. CONCLUSIONS

The current investigation presented breakthrough height and distance measurement device that considers using a fundamental trigonometric principle (tan function). Contrary to its rivals, this approach maintains measurement efficiency and does not rely on a feedback signal to determine length, which is an astounding feature. In order for it to be semi-automatic, the operator must offer feedback. Additionally, it is user-friendly and requires no special training or prior knowledge due to its straightforward handheld form and operational procedure. None of costly components and receivers are used; so it becomes cost-effective too. However, the current device cannot replace any other modern measurement equipment and method nor could it be used in susceptible areas since many extra factors - like visibility, leveling and geodesic curvatures - affect the accuracy and precision of the measurement. However, there must be a higher demand for taking regular rough estimates and educational purposes and so on. In this instrumentation study, two measurement cases were studied and validated: i) when the object was smaller than the laser meter and ii) when the object greater than the laser meter. In both instances, the algorithm calculates height using the reference of the instrument's height. Subsequently, the measurement of horizontal distance from the current instrument is limited due to the fixed instrument length (1 m) and, similarly, the measurement of horizontal height is fixed. Under ideal circumstances, the device could measure 284 m with a maximum of the possible angle of 89.80^{o} with the used servo motor. The proposed method was tested in every scenario and found to be accurate enough.

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